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Guidelines for Environmental Risk Assessment and Management

Revised Departmental Guidance

ENVIRONMENT AGENCY

Institute for Environment and Health

July 2000

London: The Stationery Office

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Eland House
Bressenden House
London SW1E 5DU
Telephone 020 7944 3000
Internet service http://www.detr.gov.uk/

Further copies of this report are available from:

The Stationery Office, PO Box 29, Norwich NR3 1GN
0870 600 5522

ISBN 0 11 753551 6

Printed in Great Britain on material containing 00% pre-consumer waste,
75% post-consumer waste and 25% ECF pulp.
TJ001713 C5 7/00 519869 19585

Acknowledgements

The Guidelines document was written by Emma Green, Simon Short and Mark Taylor (Institute for Environment and Health (IEH)) with assistance from Peter Hinchcliffe (DETR), Gareth Llewellyn, Simon Pollard, Andrew Brookes and Jimi Irwin (Environment Agency), Paul Harrison and Linda Shuker (IEH) and other colleagues from DETR and the Environment Agency. Case studies were provided by DETR and the Environment Agency.

We would also like to acknowledge the contributions of participants in the 1997 Workshop on Guidance for Environmental Risk Assessment and Management held in London, 28 November 1997, and the members of the Task Force on Risk Assessment who met in Leicester, 6 March 1998.

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FOREWORDS FROM THE DEPARTMENT OF THE ENVIRONMENT, TRANSPORT AND THE REGIONS AND THE ENVIRONMENT AGENCY

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When the Department of the Environment published *A Guide to Risk Assessment and Risk Management for Environmental Protection* in 1995, it represented one of the first attempts to explore some of the underlying principles of assessing environmental risk.

Five years later, publication of this revised guidance emphasises the establishment of risk assessment and risk management — along with risk communication — as essential elements of structured decision-making processes across Government.

The predecessor Departments of the Department of the Environment, Transport and the Regions have long been at the forefront of developments across the whole area of risk assessment. DETR's central role in environmental safety and chemicals management was strengthened with the transfer of the Health and Safety Executive to the Department in 1997 and the addition of responsibility for road, aviation and marine safety after the Departments of the Environment and Transport merged in 1997. So we have been happy to collaborate with the Environment Agency and the Institute for Environment and Health in preparing this revised and improved guidance.

The revisions have been made for several reasons, but principally to incorporate new thinking on the communication of risk and public involvement in decision-making processes. Through media coverage and advances in communication technology, in particular the World Wide Web, we are all being made increasingly aware of information about potential environmental hazards in our everyday lives — often as soon as new information emerges and before scientific research can fully illuminate problems. With this increased awareness comes growing public sensitivity to the emergence of new risks, growing public interest in the way in which science policy is formulated and a growing desire to become involved in that process. The guidance underlines our commitment to effective risk communication and stakeholder participation in the risk management process.

This document provides a framework for the development of functional risk assessment guidance by the regulators, which will inevitably be geared towards specific issues such as contaminated land, waste management, major accident hazards, *etc.* Importantly, however, this guidance will serve as the 'first port of call' for many Agency officers before they tackle the detail. We hope it will serve a similar role for everyone interested in risk-based decision-making in Government.

Henry Derwent
Director, Environment: Risks and Atmosphere Directorate
Department of the Environment, Transport and the Regions

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Risk assessment has established itself as an essential tool for the management of environmental risk and has been widely adopted by business, regulators and the financial sector.

The assessment of environmental risk is central to the Environment Agency's environmental vision and operational activity. At a strategic level, the consideration of environmental risks within the context of societal values assists in the prioritisation of our corporate activity. Across our regulatory remit, we increasingly require risk assessments to be conducted in support of authorisations to abstract from, or discharge to, the environment. Such assessments now employ a wide range of tools and techniques at various levels of sophistication and the need for consistency of approach is well-recognised. In response, and to provide the Environment Agency's corporate lead in the field of risk assessment and integrated decision-making, we established the National Centre for Risk Analysis and Options Appraisal in 1997.

This update of the Department's 1995 *Guide to Risk Assessment and Risk Management for Environmental Protection* provides a key opportunity to establish a set of common high level principles to which public-domain environmental risk assessments can refer. Developments in the field of risk assessment, especially with respect to the need for greater transparency, the consideration of the wider social context within which such assessments are discussed, and the recognition of a broader range of tools for screening and prioritisation are all reflected in this revision.

Whilst the specific requirements of individual legislation will take precedence over this guidance, I trust you will find it a valuable document and useful starting point for your work in this field.

Dr Jan Pentreath
Chief Scientist and Director of Environmental Strategy
Environment Agency

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CHAPTER 1
Introduction to the guidelines

1.1 Background

Society is increasingly conscious of the harm that its activities can cause to the environment, and the harm to people or the loss of quality of life that can result from environmental degradation. We recognise the need to manage our activities in a way that minimises the risks of environmental damage, while at the same time ensuring economic growth and social progress. The interaction between human activity and the environment is complicated and difficult to quantify, and it is not easy to judge where the balance should lie between environmental protection and economic and technological progress. Environmental risk assessment is a key element in the appraisal of these complex problems, and for formulating and communicating the issues so that transparent and equitable policy, regulatory or other decisions can be taken.

The proactive application of risk assessment

In recent years, there has been a shift from reactive measures to protect the environment to more proactive approaches aimed at preventing or minimising (rather than remediating) environmental damage and loss. This change in emphasis has been reflected in the use of risk assessment at the outset as part of the package of tools for making decisions about environmental management, particularly in the context of sustainable development. This document encourages the use of formal risk assessments as part of a proactive approach to environmental protection. While such an approach should be the norm, risk assessments may sometimes usefully be applied retrospectively if previously unidentified risks come to light. Environmental surveillance and monitoring to collect information over a long period of time can help to detect previously unidentified risks as well as provide a basis for forecasting future impacts.

1.2 Purpose

The guidelines presented in this document provide a common framework for risk assessment as a key part of the process of appraisal for environmental decision-making. They build on the UK Department of the Environment's 1995 publication A *Guide to Risk Assessment and Risk Management for Environmental Protection*. The guidelines set out some basic principles which the Department of the Environment, Transport and the Regions (DETR) and the Environment Agency would normally intend to use in the assessment and management of environmental risks and which are recommended for all public-domain risk assessments. The guidelines provide decision-makers, practitioners and the public with a consistent language and approach for environmental risk assessment and management.

The need for and conduct of risk assessment must be seen in the broader context of the proper appraisal of projects, programmes and policies. For central Government this is nested with HM Treasury's 'Green Book', *Appraisal and Evaluation in Central Government*, and in guidance from the Regulatory Impact Unit. More specifically, in 1998, DETR issued summary guidance on environmental appraisal: *Policy Appraisal and the Environment: Policy Guidance.* This explicitly places risk assessment as a key part of a proper environmental appraisal (see paragraph 6.6 of the DETR document). And more recently, a Cabinet Office-led working group has produced a *Policy Makers Checklist*, which brings together all the available guidance on existing impact assessments and appraisals as a first stage in the creation of an integrated system in support of sustainable development. The checklist, part of the Government's *Modernising Government* agenda, is accessible via the Cabinet Office Regulatory Impact Unit's internet site (see Section 1.8).

For the Environment Agency, a broader policy context for risk assessment is provided by the Agency's general duties on sustainable development (see 1997's *Introductory Guidance on the Agency's Contribution to Sustainable Development*) and costs and benefits (see 1997's *Taking Account of Costs and Benefits*). From an operational perspective, the majority of the Agency's risk assessment activity takes place within the context of the specific statutory responsibilities administered by its individual regulatory functions. These may command more specific requirements with respect to risk assessment not covered by these general guidelines.

1.3 Scope

The guidelines describe general principles and provide case studies to demonstrate how environmental risk assessment and management processes can be applied across a diverse range of activities. The framework set out here can be applied to a wide range of hazardous activities and environmental systems, and across a diversity of spatial and temporal scales. The principles described can be applied at all levels of environmental protection, from broad policy development to site-specific risk management decisions.

These guidelines do not provide detailed prescriptive guidance, but aim to highlight basic concepts and point to more detailed information and other resources where relevant.

The target audience

The guidelines are intended to be used, in conjunction with existing appraisal and other relevant guidance, primarily by risk assessors and risk managers in DETR and the Environment Agency. They are also recommended to other Government departments, agencies and organisations to meet the Government's commitment to place the environment at the heart of all policy-making. Because Government policy covers a very wide range of activities, establishing a set of common principles for environmental risk assessment and management is essential. In addition, these guidelines are relevant to other public or private sector organisations involved in making decisions that may have an impact on the environment. It is, therefore, the aim that the principles set down here should be adopted in all routine decisions concerning environmental policy, management and protection.

What is 'the environment'?

In general, the term *environment* covers the physical surroundings that are common to everybody including air, water, land, plants and wildlife. This document adopts the definition used in the Environmental Protection Act 1990 that the environment '... consists of all, or any, of the following media, namely the air, water and land'. These guidelines focus on the application of risk assessment and management for the protection of the whole or part of our general surroundings and also for the protection of human health through exposure to our general surroundings. They do not apply to the protection of individuals or of the larger public body, as in consumer or public health protection.

Hazard and risk: problems with terminology One of the difficulties with the concept of risk is that it relates to common experiences for which a language has been developed across a diverse range of disciplines and activities. This language often lacks precision, and its ambiguity can lead to confusion. It is not the intention of these guidelines to be prescriptive about terminology, but it is important to set out clearly the way that the terms *hazard* and *risk* are used here:

> *hazard* — a property or situation that in particular circumstances could lead to harm.
>
> *risk* — a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.

A complicating issue for environmental risk assessment is the lack of an easily defined measure of what constitutes *harm* to the environment. In some cases definitions of environmental damage are laid down in statute, but in others appropriate criteria will need to be selected on the basis of scientific and social judgements. These issues are discussed throughout the guidelines.

1.4 The framework

These guidelines propose a framework which consists of parallel, interlinked and complementary processes — science-based risk assessment, stakeholder involvement and risk management — which should be seen as fitting within the general options appraisal perspective described above.

Risk assessment Guidance on the scientific aspects of risk assessment is based on that provided in the Department of the Environment's 1995 guidance document, brought up to date where necessary. Ways of estimating the probability of harm being caused to the environment and of evaluating the severity of that harm are described. The guidelines show how to base an assessment of risk on these two measures. They also deal with the considerable uncertainty that is likely to exist in the quantification of both the probability and the consequences of any hazard.

Stakeholder involvement Stakeholders are those parties concerned with, or affected by, risk and may include Government, regulatory authorities and other agencies, professional and industrial bodies, environmental and local interest groups and individual members of the public. All activities involve a certain level of risk and it is the role of risk assessment to inform decisions about accepting, managing or removing those risks. The objectives, interests and responsibilities of stakeholders may be varied and contradictory.

The guidelines emphasise the importance not only of communicating the scientific aspects of risk assessment in a coherent and transparent way, but also of understanding underlying concerns, particularly those of the general public who may be affected by decisions based on risk assessments.

During the risk assessment and stakeholder dialogue, the broader significance of a risk is evaluated as a basis for risk management decision-making. This process essentially determines the acceptability of a risk. Having evaluated the significance of a risk, a decision must be made as to whether the risk is acceptable as it stands, whether it should be modified, or whether it should be removed altogether. This process involves consideration of the various options available to manage a risk, deciding which of these is the preferred option and communicating the basis for any decisions taken.

The final decision on how best to manage environmental risks should, therefore, always be informed both by science and by stakeholder concerns, and will often be a political decision.

Structure of the guidelines

This document promotes a tiered approach to environmental risk assessment, together with pointers to useful sources of advice and information. This tiered approach has a broad international consensus. A comprehensive bibliography is provided at the end of the document, as are case studies to illustrate the processes of risk assessment and management. This approach is reflected in the structure of the guidelines as follows:

- *A framework for environmental risk assessment and management* (Chapter 2)
- *The social aspects of risk* (Chapter 3)
- *Problem formulation* (Chapter 4)
- *Risk screening and prioritisation* (Chapter 5)
- *Quantification and dealing with uncertainty* (Chapter 6)
- *Evaluating the significance of a risk* (Chapter 7)
- *Options appraisal and decision-making* (Chapter 8)
- *Monitoring* (Chapter 9)

These guidelines are intended to be read and used within this tiered approach. While they follow a logical progression, each chapter covers a distinct element of the risk assessment and management process and can, therefore, be used independently.

1.5 Environmental risk management and sustainable development

Sustainable development aims to achieve a better quality of life for everyone now and for generations to come. The needs of the present should not compromise the ability of future generations to meet their own needs (intergenerational equity). Sustainable development is concerned with achieving economic development in the form of higher living standards while protecting and enhancing the environment. The overall aim is to ensure that these economic and environmental benefits are available to everybody.

The Government's vision of sustainable development is based on four broad objectives:

- social progress which recognises the needs of everyone;
- effective protection of the environment;
- prudent use of natural resources; and
- maintenance of high and stable levels of economic growth and employment.

The achievement of sustainable development requires collective partnership approaches to decision-making for environmental protection. It is about integrating economic demands and social needs with the capacity of the environment to cope with discharges, pollution and other perturbations, and to support human and other life. Decisions based on environmental risk assessments must therefore also take account of the likely economic and social impacts of the options under consideration.

1.6 Risk management and the precautionary principle

In the Rio Declaration adopted by governments at the United Nations Conference on Environment and Development in 1992, the precautionary principle was interpreted as follows:

> 'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.'

The UK Government's interpretation, which is set out in Chapter 4 of its sustainable development strategy, *A Better Quality of Life,* is based on the Rio definition. It states that precautionary action requires assessment of the costs and benefits of action and transparency in decision-making.

The precautionary principle means that it is not acceptable just to say 'we can't be sure that serious damage will happen, so we'll do nothing to prevent it'. Precaution is not just relevant to environmental damage — for example, chemicals which may affect wildlife may also affect human health.

At the same time, precautionary action must be based on objective assessments of the costs and benefits of action. The principle does not mean that we only permit activities if we are sure that serious harm will not arise, or there is proof that the benefits outweigh all possible risks. That would severely hinder progress towards improvements in the quality of life.

There are no hard and fast rules on when to take action: each case has to be considered carefully. We may decide that a particular risk is so serious that it is not worth living with. In other cases society will be prepared to live with a risk because of other benefits it brings. Transparency is essential: difficult decisions on precautionary action are most likely where there is reason to think there may be a significant threat, but evidence for its existence is as yet lacking or inconclusive. Decisions should be reviewed to reflect better understanding of risk as more evidence becomes available.

The extent to which precautionary action is necessary should be given careful thought for three reasons. First, action that is taken to protect one aspect of the environment can sometimes cause damage elsewhere (unintended consequences). Second, it may be better in certain circumstances not to take action if the consequences of doing so are irreversible (reversibility). Third, a decision on whether to take precautionary action should take account of the potential benefits forgone as a result of such action.

Because of the general lack of consensus over practical application of the precautionary approach, the use of risk assessment to inform decisions about environmental protection has sometimes been presented as being in conflict with the precautionary principle. In reality, risk assessment is often employed where issues are not clear and can be used to identify effects considered serious enough to warrant precautionary action. Risk assessments can sometimes point to the possibility of significant environmental damage, albeit in the presence of large uncertainties, and it is in such cases that precautionary action is particularly valid.

Dealing with uncertainty

Uncertainty can affect all stages of risk assessment and management processes. Analysing the sources and magnitudes of uncertainties can help to focus discussion, identify knowledge gaps and feed into decisions about the most appropriate risk management options, including whether or not precautionary action is necessary. Uncertainties generally fall into the following categories:

- *model* — where models provide only an approximation of the real environment;
- *sample* — where uncertainties arise from the accuracy of measurements or validity of the sample;
- *data* — where data are interpolated or extrapolated from other sources;
- *knowledge* — where the scientific base does not provide sufficient understanding; and
- *environmental* — where the inherent variability of the environment leads to errors in our approximations.

To evaluate and use risk assessments effectively as a credible basis for decision-making, it is important to understand how different sources of uncertainty contribute to the overall variability of the final risk estimates. Sensitivity analysis is an important part of this process and is a method used to examine the behaviour of a model by measuring the variation in outputs resulting from changes to its inputs.

Uncertainty analysis and evaluation are concepts which run throughout the risk assessment and management processes and discussions about them arise throughout these guidelines.

Time-scales

Because of the complexity of the natural environment, conducting a full risk assessment can in some cases be very time-consuming. Sometimes, it will therefore be necessary to consider precautionary action on the basis of hazard or initial risk assessments. In so doing, it is always necessary to account for the possible social and economic implications of any such action, in line with the requirements of sustainable development.

1.7 Justifying an intention

The previous edition of these guidelines used the terms 'intended course of action' or 'intention' to cover a wide range of possible actions which may prompt the need for a risk assessment. For the purposes of these guidelines, an *intention* is taken to mean 'any course of action, intentional or otherwise, which by its nature may pose a risk to the environment (natural or built), and the life it sustains' (Chapter 4).

In addition to demonstrating a clear understanding of the intention and its impacts, there is a further question, which research on risk perception shows is probably the most important of all — *is there a justifiable need for this activity?*

When proposed and existing projects are reviewed, normally the importance of quantified risk estimates, costs and benefits are all covered. However, the social justification of the activity is rarely included as an explicit consideration. Very often it is this social dimension that colours the whole dialogue (are we imposing a risk on the community which has no particular justification?). Perhaps there are perfectly good alternatives, for example, in the scale, location and management of an intended activity. Or perhaps apparently unreasonable opposition to a small risk is a consequence of not making the socio-economic benefits of the activity clear. It should be noted, however, that in some regulatory regimes related to safety, socio-economic factors are not legally considered grounds for withholding approval — the decision must be made on a scientific evaluation of risk alone.

1.8 Further information

Key references

Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science
A comprehensive treatment of the basic principles of environmental risk assessment and management. The publication consists of authored chapters which address the scientific principles of risk assessment ranging from industrial chemicals to genetically modified organisms (GMOs), and which also discuss the way in which risk assessment is used in decision-making for risk management.

Department of the Environment (1995) *A Guide to Risk Assessment and Risk Management for Environmental Protection*, London, UK, HMSO
The guide explores the underlying principles of systematic risk assessment and management as a contribution to the UK's Sustainable Development Strategy.

Department of the Environment (1991) *Policy Appraisal and the Environment*, London, UK, HMSO
DETR (1998) *Policy Appraisal and the Environment: Policy Guidance*, London, UK, DETR
The 1991 document highlights the need to examine environmental impacts within policy decision analyses. The 1998 guidance does not replace the previous document, but presents a more focused guide for the non-specialist.

DETR (1998) *Opportunities for Change. Consultation Paper on a Revised UK Strategy for Sustainable Development* (Document reference 97EP0277), London, UK, DETR
A consultation document on a new sustainable development strategy for the UK; see resulting strategy at UK Government (1999).

DETR (1998) *Sustainable Production and Use of Chemicals. Consultation Paper on Chemicals in the Environment* (Document reference 98EP0058), London, UK, DETR
This consultation document sought views on ways in which a more precautionary approach to chemicals in the environment could be adopted and helped in the preparation of a new and coherent strategic policy on chemicals in the environment (see next entry).

DETR (1999) *Sustainable Production and Use of Chemicals — A strategic approach. The Government's Chemicals Strategy*, London, UK, DETR
The Strategy sets out Government policies to avoid harm to the environment or to human health through environmental exposure to chemicals. It covers chemicals entering the environment through commercial production and use. New policies described include a voluntary scheme for assessments and risk reduction strategies by industry, and a Stakeholder Forum.

Douben PET, ed (1998) *Pollution Risk Assessment and Management*, Chichester, UK, Wiley & Sons Ltd.
Provides an extensive discussion of the basic principles of integrated pollution control and risk management.

Environment Agency (1997) *Introductory Guidance on the Agency's Contribution to Sustainable Development*, Bristol, UK, Environment Agency
Provides initial guidance on how the Agency will contribute to sustainable development. It explores the background to the Agency's sustainable development duty, the legislative and policy context and briefly describes the wider concept of sustainable development.

Environment Agency (1997) *Taking Account of Costs and Benefits*, Bristol, UK, Environment Agency
Provides guidance for Environment Agency staff on how the 'Cost and benefits' duty in Section 39 of the Environment Act 1995 may be carried out.

Environment Agency (1998) *Consensus Building for Sustainable Development*, Bristol, UK, Environment Agency
This document sets out the Environment Agency's agenda for building collective partnership approaches for decision-making as a contribution to achieving sustainable development. It provides some useful and practical illustrations of models for consensus building.

Health and Safety Executive (1999) *Reducing Risks, Protecting People*, Sudbury, UK, HSE Books
A discussion document on the framework of risk-based health and safety regulation in the UK with a valuable review of recent developments in risk-based decision-making.

HM Treasury (1997) *Appraisal and Evaluation in Central Government: Treasury Guidance*, London, UK, TSO
This document deals with risk and environmental impacts as aspects of the general appraisal framework for projects, programmes and policies.

ILGRA (1996) *Use of Risk Assessment Within Government Departments: Report prepared by the Interdepartmental Liaison Group on Risk Assessment*, Sudbury, UK, HSE Books
This reviews the principles and practices used in Government for risk assessment with a view to identifying best practice and encouraging common approaches.

ILGRA (1998) *Risk Assessment and Risk Management: Improving Policy and Practice within Government Departments*, Sudbury, UK, HSE Books
The second report to Ministers deals with regulatory frameworks for regulating risk, risk communication and the use of experts in decision-making.

Lees N, Woolson H, O'Hara J & Wynne B (1997) *Environmental Information: A Guide to Sources* (Second edition), London, UK, The British Library Science Reference and Information Service
An easy-to-use and comprehensive directory of where to go for information and help on environmental issues.

Royal Commission on Environmental Pollution (1998) *Setting Environmental Standards*, Twenty-first Report, London, UK, TSO
A comprehensive review of the process of establishing standards for environmental protection with recommendations for a more participatory approach to their development.

Spackman M (NERA) (1998) *Developing a Common UK Approach to Negotiations on Risk Assessment at International Level*, London, UK, Health and Safety Executive
This document reviews various aspects of approaches to risk assessment and compares UK and European perspectives.

UK Government (1994) *Sustainable Development: The UK Strategy* (Cm 2426), London, UK, HMSO
This document sets out the UK strategy for sustainable development in the light of the United Nations Conference on Environment and Development held in 1992. It highlights key areas for future action to achieve sustainable development and seeks to set this information in the context of the UK's international role and in response to Agenda 21.

UK Government (1999) *Sustainable Development:* A *Better Quality of Life.* A *strategy for sustainable development for the* UK (Cm 4345), London, UK, TSO
The UK Government's revised sustainable development strategy.

US EPA (1998) *Guidelines for Ecological Risk Assessment* (EPA/630/R-95/002F), Washington DC, USA, US Environmental Protection Agency
These guidelines were written to improve the quality and consistency of ecological risk assessments. They should be of particular interest to risk assessors and risk managers, highlighting and discussing important principles and terminologies for the ecological risk assessment process.

Electronic information sources

Cabinet Office Regulatory Impact Unit internet site —
http://www.cabinet-office.gov.uk/regulation/index.htm

DETR internet site — http://www.detr.gov.uk

Environment Agency internet site — http://www.environment-agency.gov.uk

Green Channel internet site — http://www.greenchannel.com — *a web-site which promotes communication of environmental information. It provides a forum for professional, public interest and commercial organisations.*

US Environmental Protection Agency internet site — http://www.epa.gov —
this web-site hosts a variety of pages on environmental risk assessment and internal links to supporting information.

CHAPTER 2
A framework for environmental risk assessment and management

2.1 An overall framework

A pragmatic approach to environmental risk assessment can transform what may sometimes appear to be an extremely detailed, complex and resource-intensive process into a practical aid to decision-making. Figure 2.1 provides a framework for a tiered approach to environmental risk assessment and management where the level of effort put into assessing each risk is proportionate to its priority (in relation to other risks) and its complexity (in relation to an understanding of the likely impacts). This framework, the principal elements of which are described in more detail in Chapters 4 to 8, also illustrates:

- the importance of correctly defining the actual problem at hand;
- the need to screen and prioritise all risks before quantification;
- the need to consider all risks in the options appraisal stage; and
- the iterative nature of the process.

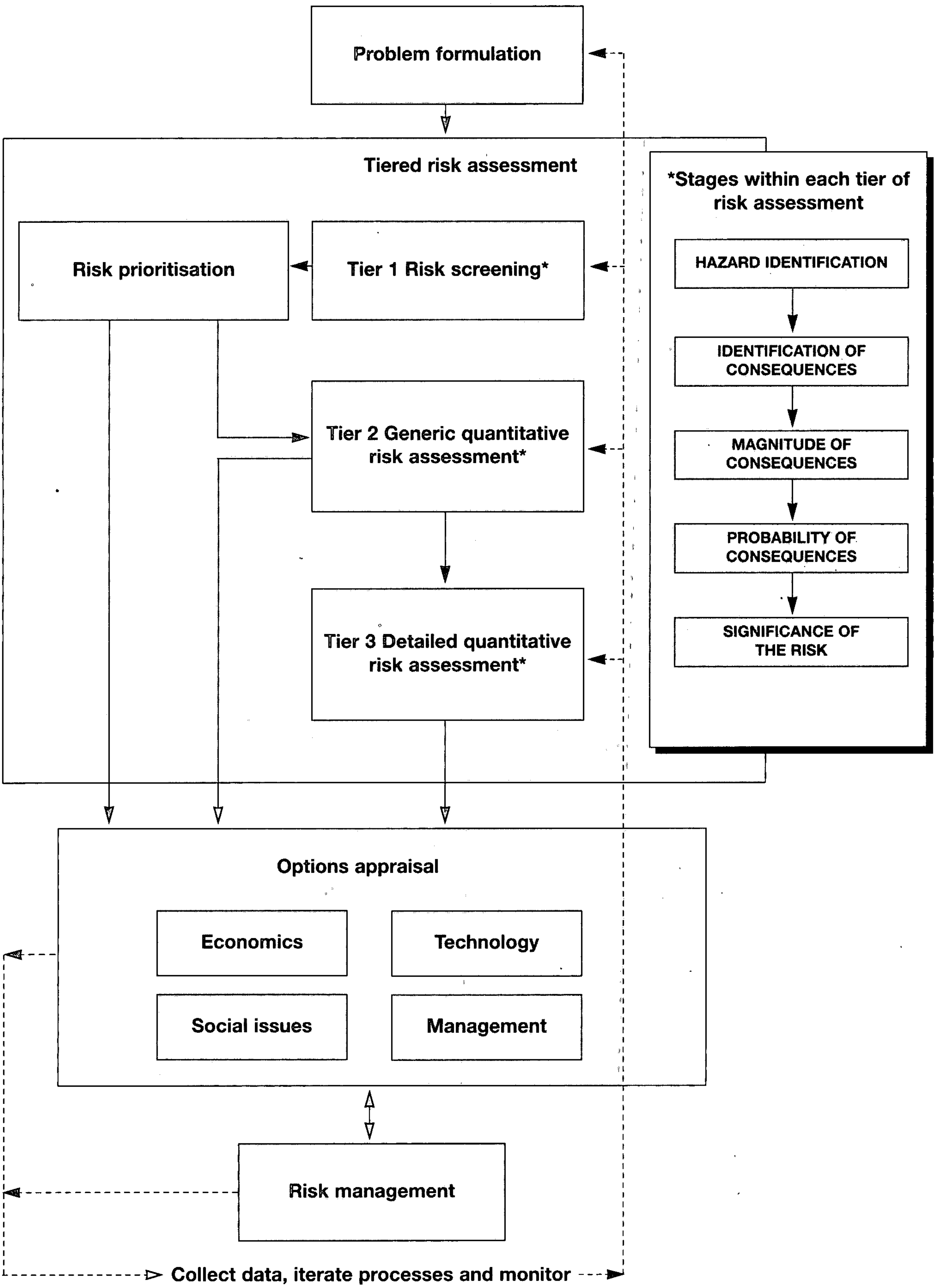
The remainder of this chapter sets out some of the generic aspects of this framework, and in particular those elements which need to be considered at a number of points in the risk assessment process, albeit at differing levels of detail.

2.2 Key stages in each tier of environmental risk assessment

Stage 1: Hazard identification

These guidelines define *hazard* as a property or situation that in particular circumstances could lead to harm. This may be determined by properties or circumstances and could include, for example, the release of chlorofluorocarbons (CFCs), a tidal surge along a stretch of the coast, a dry summer leading to low river flows, or the planting of a genetically modified crop. Where risk assessment is to be applied at the policy level, the hazard may be as broad as the adverse impacts of road transport on the environment, or the adverse impacts of induced climate change from the contribution of fossil fuel-derived carbon dioxide emissions.

Figure 2.1 A framework for environmental risk assessment and management



The identification of hazards, both in the problem formulation stage (Chapter 4), and in subsequent tiers in the process, will have an important bearing on the breadth of the overall assessment and the credibility of the final output.

One common pitfall in establishing the hazard is to overlook secondary hazards that may arise. For example, during a river flood, sediments may be deposited on agricultural land in the flood plain. If these sediments were to be contaminated, they might pose an additional hazard.

Stage 2: Identification of consequences

The potential consequences that may arise from any given hazard are inherent to that hazard. Although the full range of potential consequences must be considered at this stage, no account is taken of likely exposure and therefore likely consequences. For example, while the potential consequences of a discharge of toxic metals to a watercourse may be self-evident, a flood may have additional, non-obvious consequences such as pollution arising from an over-stretched sewerage system, or loss of habitats due to river scouring.

These examples serve to highlight why it is necessary to take a broad look at the potential environmental damage that may occur, if only to be clear why some potential consequences are rejected for further assessment.

Stage 3: Estimation of the magnitude of consequences

The consequences of a particular hazard may be actual or potential harm to human health, property or the natural environment (the issue of probability of occurrence is covered below). The magnitude of such consequences can be determined in different ways depending on whether they are being considered as part of a risk screening process, or as part of a more detailed quantification of risk. At all stages of risk assessment several key features need to be considered, as described below.

The spatial scale of the consequences

The geographical scale of harm resulting from an environmental impact will often extend considerably beyond the boundaries of the source of the hazard. Failure to consider this at an early stage may result in the scope of the risk assessment being too limited. For example, a major accident in a chemical plant is likely to have significant effects on the environment well beyond the perimeter of the site.

The temporal scale of the consequences

The duration of the harm that results may raise issues of intergenerational equity (see Section 1.5), or may be so prolonged that the damage can be assumed to be permanent and the environment beyond recovery. For example, should the release of a genetically modified crop result in extensive cross-breeding with adjacent indigenous flora, any harmful environmental impacts could extend far into the future.

The time to onset of the consequences

A further factor to consider is how quickly harmful effects might be seen. Standard economic techniques tend to discount impacts that will happen in the future but sustainable development emphasises the need to protect the interests of future generations. Risk assessment and management must therefore pay as much attention to long-term problems as to the more immediate risks. For example, the spillage of a solvent on porous ground may not result in an impact on the underlying aquifer for decades. Once realised, however, the duration of the harm is likely to be of the order of decades and will compromise the value of that aquifer as a source of water for future generations.

The ability to forecast the time-scale and magnitude of the environmental impact through robust and long-term modelling is therefore valuable, particularly at the quantifiable end of the risk spectrum.

Stage 4: Estimation of the probability of the consequences

All stages to this point have assumed that realisation of the hazard will lead to environmental harm. However, the probability of the consequences occurring must also be taken into account. This has three components:

The probability of the hazard occurring

The probability of the receptors being exposed to the hazard

The probability of harm resulting from exposure to the hazard

The probability of the hazard occurring

Depending on the circumstances, assigning probabilities may be quite straightforward or may require some sophistication in approach. For example, at a screening level, it might be as simple as stating, on the basis of experience, that on a scale of 1 (low) to 5 (high) a pin-hole leak in a particular pipe in a chemical plant has a probability of, say, 4. Floods can be categorised by their return period (eg one in a hundred years) based on historical records. On the other hand, there will be situations in which it is necessary to assign a probability distribution to the likelihood of the event occurring — for example, that a non-genetically modified crop will be widely pollinated by a genetically modified crop. In many instances this information can be obtained from monitoring data, or based on 'worst-case' or 'reasonable worst-case' scenario estimates.

The probability of the receptors being exposed to the hazard

It is important to establish, at an early stage in the process, whether or not a pathway exists between the hazard and the receptor. If it can be shown that no actual or potential connection exists, then the risk requires no further attention. For example, soil contamination will not pose a risk to farm animals if the land is not used for agricultural purposes. But care is needed not to overlook less obvious pathways, or changes in future circumstances.

Having established one or more pathways, the degree of exposure via those pathways should be quantified. A range of factors will affect the probability and degree of exposure. For example, the exposure of a receptor to an atmospheric emission of sulphur dioxide will depend on the direction and strength of the prevailing wind at the time of release. The impact of a coastal flood in a tourist area may be dictated by the time of the year at which the flood occurs; the loss of property may be greater in summer when caravan parks are occupied than during the winter season when occupancy is likely to be low.

The probability of harm resulting from exposure to the hazard

Even following exposure, the likelihood of harm resulting is probabilistic and will depend on the likely susceptibility of an individual receptor to the hazard and the amount and duration of exposure. This is often simplified in terms of a dose–response relationship, which directly relates exposure to the magnitude of harm for certain receptor types. Such relationships frequently embody 'safety' or uncertainty factors to account for the extrapolation of data from experimental or generalised studies. In flood damage assessment, for example, standard depth–damage curves are used to relate the depth of flood waters to the amount of damage sustained by a building or its contents, again according to the duration of exposure to the flood waters. These relationships simplify the probabilistic nature of harm, because for any exposure, the likelihood of harm at a certain magnitude will be dependent on many individual factors. Few risk assessments allow for this level of sophistication, and the magnitude of harm is usually taken as a direct result of exposure.

Stage 5: Evaluating the significance of a risk

This stage is often referred to as risk characterisation, although this terminology tends to hide the true goal of the activities involved. Having determined the probability and magnitude of the consequences that may arise as a result of the hazard, it is important to place them in some sort of context. It is at this point, therefore, that some value judgements are made, either through reference to some pre-existing measure, such as a toxicological threshold, environmental quality standard or flood defence standard, or by reference to social, ethical, or political standards. In some circumstances, a formalised quantitative approach to determining significance may be possible, for example the tolerability of risk (TOR) framework developed by the Health and Safety Executive. In other instances, the risks of various options might be compared against one another.

2.3 Options appraisal

Having estimated the magnitude and the significance of the risks posed by the hazard(s), the options for risk management are identified and evaluated. It is important to carry out this procedure as a distinct preliminary step because ill-considered risk management strategies may otherwise result in wasted effort and expenditure on the part of the decision-maker. Options appraisal provides a framework for doing this (Chapter 8). The options that will usually be available are:

- exploring with society the acceptability, or otherwise, of the risk — this can include rejecting unacceptable risks altogether or accepting the risk being imposed;
- reducing the hazard through new technology, procedures or investment; and
- mitigating the effects, through improved environmental management techniques.

The decision on precisely which option or combination of options to choose will involve a balance of risk reduction, costs, benefits and social considerations. These issues are discussed in greater detail in Chapters 7 and 8.

CHAPTER 3
The social aspects of risk

3.1 Background

Economic, political, legal and social concerns play important roles throughout the assessment, evaluation and decision-making stages of risk management. Ensuring dialogue between interested parties at all stages requires an understanding of the social aspects of risk along with an appreciation of the mechanisms by which stakeholders can be actively engaged in the process.

The evaluation of risk entails a judgement about how significant the risk is to the receiving environment and to those concerned with, or affected by, the decision. It is, therefore, a process which necessarily involves the question of risk acceptability. In conjunction with formal scientific input, this requires the examination of public and political judgements about risks alongside the measurable costs and benefits of the activity in question. The precise knowledge required for an objective evaluation is often lacking for environmental risk assessment and an element of judgement is often needed. Furthermore, environmental quality involves both scientific elements and social elements. There is, therefore, a need to consider carefully the social dimensions of a risk as a part of the decision-making process.

The sections below highlight some of the factors that should be considered when evaluating risks and making decisions about environmental protection. These include some of the key elements which shape individual and social responses to risk.

3.2 Why consider the social dimensions of risk?

Society is increasingly conscious of the harm that its activities can cause to the environment, and the harm to people or the loss of quality of life that can result from environmental degradation. Recent experiences such as the BSE crisis and the Brent Spar controversy have led to a decline in public confidence in conventional risk assessment and management processes. Decisions about environmental risks should take account of social issues because:

- general awareness of environmental risks has increased and this is often associated with heightened levels of concern;
- recent experience has shown how essential it is to have in place a framework which ensures transparency in decision-making and which forms a justifiable basis for policies on environmental protection;

- calls have been made for a greater degree of public involvement in decision-making processes for environmental protection; and
- there is increasing pressure on those who create and regulate risk to inform the public about the risks to which they and their environment are exposed.

In conjunction with the assessment of a risk, the decision-maker should ask whether the risk is likely to be acceptable to those concerned with, or affected by, the risk or consequent management decision. Evaluating the social significance of a risk can guide decision-making and help towards communicating about the risk to interested parties. It is, therefore, essential that the decision-maker considers social dimensions as part of the processes to identify, assess, evaluate and manage risks to the environment. Key objectives of doing so are to:

- *engage* all stakeholders in issues that affect them and their communities to ensure that policies reflect the values of the society to which they are directed;
- ensure that decisions about the acceptability of environmental risks *recognise* that environmental protection is part of the wider context of sustainable development — this includes objectives of economic growth, social progress and prudent resource management as well as environmental protection and enhancement;
- help to *identify difficult cases* in advance by highlighting what types of risk are likely to be seen as unacceptable; and
- aid the *communication* of risk messages to encourage desired actions and behaviour, or to meet statutory requirements.

3.3 Risk perceptions

It is now well-established that lay reactions to risk can differ considerably from judgements that are based on scientific probability estimates. Since the 1960s, a large body of research on reactions to risk has developed. Much of this work has demonstrated that differences between lay and expert judgements on risk can be attributed to the complex concepts of risk that lay people and scientists apply.

Counter to traditionally held views, these reactions can often be predictable, and are frequently rational. It is, therefore, important to understand how and why particular reactions to risk arise.

Perceived risk is driven by a complex mixture of factors, including individual attitudes and beliefs as well as wider social and cultural values. Risk perceptions may be based on accurate or inaccurate information, and the existence of uncertainties in the evaluation of hazards can also be important. Thus, risk judgements not only depend on the physical characteristics of the hazard itself but are also determined by broader psychological and sociological considerations.

Questions about the role and credibility of institutions charged with the management and communication of risk also constitute a significant factor in shaping perceptions. Furthermore, the perception of risk is multi-dimensional, with particular hazards meaning different things to different people depending on underlying values and the context of the risk.

Consideration of what factors may cause (or fail to cause) anxiety and alarm about a particular risk at an individual level is important. This can help the decision-maker to identify (in advance) the types of risk that are likely to cause general concern. Risk perception research has also explored the cultural dimensions that shape individual and group responses to risk. Beliefs, attitudes, values and behaviour can all affect perceptions of hazard and risk. Risks that pose a threat to social group values are likely to lead to heightened risk perceptions.

Important factors (sometimes termed *fright* or *outrage factors*) which may cause a risk to create anxiety or be less acceptable are summarised in Box 3.1.

Box 3.1 Factors which can influence risk perceptions

Risks which are *involuntarily* imposed (eg pollution from an incinerator) tend to be seen as less acceptable than voluntary ones (eg driving a car or undertaking dangerous sports).

Unfamiliar risks (eg genetically modified organisms) tend to cause greater concern, particularly if they are considered to be poorly understood by science.

Activities which pose a threat of a *dreaded* form of death, injury or illness (eg cancer) are viewed with alarm and are less acceptable.

Man-made or '*technological risks*' (eg pesticides, nuclear power stations) are less acceptable than natural ones (eg floods and radon).

A risk which may cause a single *large-scale* consequence (eg civil aviation accident) causes more concern than risks which result in numerous small-scale consequences (eg car accidents).

Alarm may be caused by risks when the consequences of exposure are *delayed* and cause *hidden* or *irreversible* damage (eg exposure to ionising radiation).

Inequitable distribution of risks and benefits as a result of a particular activity is likely to make a risk less acceptable.

Activities which pose a risk to certain groups such as *children* and *future generations* are generally more worrying.

Risks which are the subject of *controversy* and *contradictory* information generally cause concern.

Adapted from Department of Health (1998) and summarising key findings from risk perception research

Whether a risk is acceptable or not depends on broad societal issues and scientific assessments. At a general level, the issues raised above can help to guide decision-making by highlighting likely responses to different types of risks. The main issues are summarised below.

- While risk perceptions sometimes differ considerably from scientific probability estimates, individual and social responses to risk often represent *rational and defensible judgements*. While decisions about environmental risks should have a sound scientific basis it is also important to give explicit consideration to social dimensions.

- Risk is *multi-dimensional and context-driven* and it is over-simplistic to represent risk as a single-scale concept such as probability estimates.

- *Fright factors* may highlight the types of risk that are likely to cause concern. They may also be used to identify particular cases where the risk is perceived to be lower than suggested by probability estimates, and may explain why such patterns exist.

- Risk perceptions and responses are linked to *wider attitudes, beliefs and behaviour* and, therefore, have a strong social as well as individual dimension.

- Perceptions can be distorted through *social amplification*. The role and likely reactions of the media therefore need to be anticipated.

3.4 Trust and credibility

Conflict and controversy have characterised some recent risk debates, and distrust in the risk assessment and management process plays a central role in these cases.

Trust and credibility are frequently identified as important determinants of risk perception. It is important to be open and accountable, and to take differing views into account rather than disregarding them as 'emotive' or 'irrational'. While such a climate may help to build confidence, it should be stressed that trust is eroded very easily and once lost is difficult to restore.

3.5 Equity

Inequity in the distribution of risks and benefits is an important factor influencing attitudes to risk. It can result, for example, in a particular community having to bear the disadvantages of a facility or development while not necessarily gaining the benefits. Examples may include the siting of a waste incineration plant or a disposal facility for low-level radioactive wastes or a major road transport route. The community perceives that it will suffer from the consequences of such activities through both environmental degradation and stigmatisation of the locality, which in turn may have broader economic impacts such as loss of tourism or lowering property prices. Although sometimes dismissed as expressions of self-interest (the *Not In My Back Yard* — NIMBY — response), recent challenges about the distribution of risk have raised not only questions of location and scale but also the fundamental issue of necessity.

3.6 Responses to risk and the role of the media

It is commonly held that 'the media' tend to portray environmental risks as more serious than estimated by scientific risk assessments, although in reality the role of the media in generating responses to risk is not clear-cut. Because it is likely that public and media interest reinforce each other (rather than the media generating initial interest), it is useful for the decision-maker to consider factors which may amplify media interest in a particular issue. This can help to identify environmental risks which may be controversial and may also help in developing a strategy for dealing with the media on a particular issue.

Factors which play a role in generating media interest have been summarised in the Department of Health's 1998 publication *Communicating About Risks to Public Health* and are listed below:

- the risk is characterised by fright factors described above (Box 3.1);
- the risk or management decision is associated with questions of blame, trust or credibility;
- conflict and uncertainty exist between scientists and regulators;
- human interest, particularly with identifiable victims, is important;
- the risk or management decision may be viewed as a first sign of future problems;
- the presence of strong visual impact; and
- widespread exposure to risk, even if at low level.

3.7 Risk communication

Communication about environmental risks serves many important purposes. Communication can be used either as a tool to provide information, explain and warn, or to encourage collective partnership approaches to decision-making through greater public participation in the risk management process.

The various functions of risk communication are to:

- ensure compliance with *statutory requirements to warn or inform* individuals about certain risks — this may include requirements to inform the public of the correct behaviour to adopt in the event of a major industrial accident under the 'Seveso II' (Control of Major Accident Hazards) Directive, and requirements to inform the public of an intention to carry out a deliberate release of genetically modified organisms under the Environmental Protection Act 1990;
- encourage desired *changes* in knowledge, attitudes, opinions and/or behaviours;
- ensure that *information* aimed at encouraging desired risk reducing behaviour is available — this may include, for example, the provision of information about air quality and measures which may be taken to reduce certain polluting activities;
- create *trust* and *confidence* in risk decision-making processes and in risk management institutions;
- ensure that experts and regulators *discuss* all issues relevant to the decision-making process for a particular risk to the environment; and

- *engage* stakeholders in two-way communication, thereby ensuring that decision-making reflects broad social values.

Risk communication to inform and explain

Risk communication can be implemented in many different ways. Successful risk communication is difficult to achieve and it will frequently be necessary to engage diverse audiences. These audiences may hold different values and have different levels of understanding, and the interpretation of a message can be dependent on a variety of social factors. Provided these complexities are borne in mind, and the objectives are clearly defined, communication can achieve its desired outcome.

Many of the points made earlier about risk perceptions are salient to the development of risk communication. Efforts simply aimed at the provision of quantitative risk estimates are likely to be of limited value because of the complex nature of risk judgements. Communication should be sensitive to a broad concept of risk, encompassing not only quantitative information, but also other dimensions such as individual attitudes and issues of trust and credibility.

Describing risk

Risk comparisons

Risk communication efforts have frequently used a wide range of hazards to place a particular risk in perspective. While this approach may help individuals to envisage very small or very large probabilities, their use as a more sophisticated communication tool requires caution. Individuals distinguish between hazards along a range of qualitative dimensions, and risk comparisons must take this into account wherever possible. For example, making a comparison between two activities that have similar statistical probabilities and similar outcomes but are not comparable with regard to whether they are taken voluntarily or not, is likely to be viewed with scepticism.

A common language

Recent efforts by the UK Department of Health have focused on the development of a *common language* for the communication of risks. For example, the use of comparisons based on familiar scenarios such as 'roughly one person in a small town' for '1 in 10,000' may help to give a feel for the magnitude of a particular risk.

A risk spectrum

A *risk spectrum* can provide a useful means for describing risk. This approach has been used in flood alert warnings, whereby the likely impact from flooding is communicated via a scale of:

- yellow (a warning of flooding to low-lying farmland and minor roads near rivers or the sea, but flooding of property is not expected);
- amber (flooding of isolated high risk properties, roads and large areas of farmland near rivers or the sea); and
- red (a warning of serious flooding to a significant number of residential and commercial properties, roads and large areas of farmland).

3.8 Stakeholder participation

What is stakeholder participation?

An important objective of sustainable development is the adoption of collective partnership approaches to decision-making for environmental protection. Experience suggests that risk management decisions made in collaboration with stakeholders tend to be more effective and durable. Stakeholders are parties concerned about, or affected by, a risk management problem (Section 1.4). The use of participatory approaches in the development of risk management strategies is important for many reasons.

- Public involvement is an essential part of a sustainable development strategy (Section 1.5).
- Risk management is often implemented outside traditional government arenas, for example by individual citizens, industry and workers. This has led to calls for greater involvement in the decision-making process of those affected by risk problems.
- While decisions may largely be based on the best available scientific and technical information, their success is also dependent on sensitivity to a range of social, economic and political considerations.
- Environmental protection is a societal goal and there is a need to engage the public in issues which affect individuals and their communities.
- Participatory approaches provide a process by which *expert* and *lay* perspectives can inform each other. By clarifying the nature of disagreements about risk they may help to resolve conflicts over controversial issues (consensus building).
- Participation can help people to make a more informed decision and help to reduce resentment from individuals or groups who feel they are excluded from decisions which directly affect them.

Stakeholders may include a wide range of Government departments and other agencies, individuals, interest groups and other institutions who have an interest in the decision-making process. Since Government, the public, industry, environmental and consumer groups, *etc*., often have different views about what constitutes an acceptable risk, it is important to explore possibilities for engaging these stakeholder groups at all points in the risk management processes. At the same time it is necessary to recognise that the nature and extent of stakeholder involvement must reflect the scope and impact of the particular risk in question.

Identifying stakeholders

If a decision has been made to involve stakeholder participation in the decision-making process, it is important to identify at an early point which stakeholders should be involved. To aid this process the following questions may be asked:

- Who will potentially be affected by the risk and the consequences of any management decision?
- Which parties or individuals have knowledge and expertise which may be useful to inform any discussion or decision?
- Which parties or individuals have expressed an interest in this particular, or a similar type of, risk management problem?
- Which stakeholders will be prepared to listen, respect diverse viewpoints and be prepared to negotiate?

Participatory approaches Participation can take many forms, including collaboration between Government, industry and interested parties to identify common goals and mutually acceptable solutions, stakeholder-based decision-making committees, focus groups, consensus building conferences (round-table process) and citizens' juries. In a publication entitled *Consensus Building for Sustainable Development*, the Environment Agency provides several case studies to illustrate the use of different participatory initiatives in environmental protection. The choice of approach should be guided by a number of key considerations, as highlighted in the following terms by the US Presidential/Congressional Commission on Risk Assessment and Risk Management:

- The decision-makers should make explicit the extent to which they are prepared to respond to stakeholder involvement.
- The aims of stakeholder participation must be clearly stated and stakeholders should be involved as early in the process as possible. If a decision is non-negotiable, stakeholder involvement should not be considered.
- The nature and extent of stakeholder involvement must reflect the scope and impact of the risk management decision.
- Participation should aim to confront the key issues of a risk management problem rather than confronting individuals or stakeholder groups.

The selection of a particular participatory approach requires creative and constructive thinking about the various aims of the process and the decision options available. The techniques that may facilitate open discussion about contradictory objectives, responsibilities and interests in relation to the particular environmental risk in question must also be considered.

The concept of a participatory approach is primarily *bottom-up*, whereby stakeholders are engaged in the processes of problem formulation, appraising the preferred management options and proposing solutions to a particular risk problem. It relies on communication as a two-way process to exchange information and opinions between various institutions, groups and individuals.

Stakeholder involvement brings together diverse viewpoints and may help to resolve existing or potential problems by ensuring that stakeholders are involved in the development of the solutions. It can, therefore, bring long-term gains. However, it requires careful planning, large amounts of time and other resources, and cannot be expected to guarantee the resolution of conflict or controversy.

3.9 Further information

Key references

Baines J (1995) *Beyond Compromise: Building Consensus in Environmental Planning and Decision-making,* London, UK, The Environment Council
A very helpful introduction to consensus building covering the basic principles and providing illustrative case studies and sources for further information and help.

Department of Health (1998) *Communicating About Risks to Public Health — Pointers to Good Practice,* London, UK, TSO
This document offers insights from well-established material and provides pointers to good practice for communicating effectively about risks.

Environment Agency (1998) *Consensus Building for Sustainable Development,* Bristol, UK, Environment Agency
This document sets out the Environment Agency's agenda for building collective partnership approaches for decision-making as a contribution to achieving sustainable development. It provides some useful and practical illustrations of models for consensus building.

Environment Council (1995) *Who's Who in the Environment — England,* London, UK, The Environment Council
A comprehensive directory of organisations in England which are concerned with some aspect of the environment (natural and built). It lists the areas of interest and services provided by each organisation and may be helpful in identifying important stakeholders. Separate directories exist for Scotland, Wales and Northern Ireland. A single and more up-to-date directory is available in electronic format.

Health and Safety Executive (1992) *The Tolerability of Risk from Nuclear Power Stations,* Sudbury, UK, HSE Books
Report produced following a recommendation from the report of the Sizewell B Public Inquiry in 1986 that the HSE should formulate and publish guidelines on the tolerable levels of individual and social risk to workers and the public from nuclear power stations. The document discusses risk and the tolerability of risk, the regulation of industrial risk and broad principles of risk assessment, as well as specific topics concerning the risks associated with the operation of nuclear installations.

Health and Safety Executive (1999) *Reducing Risks, Protecting People,* Sudbury, UK, HSE Books
A discussion document on the framework of risk-based health and safety regulation in the UK with a valuable review of recent developments in risk-based decision-making.

ILGRA (1998) *Risk Communication: A Guide to Regulatory Practice,* Sudbury, UK, HSE Books
Guidance, illustrations and assistance to regulators in developing good practice on the principles of risk communication.

Lees N, Woolson H, O'Hara J & Wynne B (1997) *Environmental Information: A Guide to Sources* (Second edition), London, UK, The British Library Science Reference and Information Service
An easy-to-use and comprehensive directory of where to go for information and help on environmental issues. It includes a useful compendium of organisations which may be helpful in identifying important stakeholders.

Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Framework for Environmental Health Risk Management* (Final Report), Vol. 1, Washington DC, USA, Presidential/Congressional Commission on Risk Assessment and Risk Management
Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Risk Assessment and Risk Management in Regulatory Decision Making* (Final Report), Vol. 2, Washington DC, USA, Presidential/Congressional Commission on Risk Assessment and Risk Management
A particularly useful reference in discussing the role and involvement of stakeholders.

Royal Society (1992) *Risk: Analysis, Perception and Management* (Second edition), London, UK, The Royal Society
Includes an introductory discussion on risk perception and provides an overview of the different approaches to understanding the social aspects of risk.

Slovic P (1992) Perception of risk: reflections on the psychometric paradigm. In: Krimsky S & Golding D, eds, *Social Theories of Risk*, London, UK, Praeger
A useful review by a key researcher in the field of psychometric investigations into risk perceptions, highlighting key findings and implications for the management and communication of risk.

SNIFFER *et al.* (1999) *Communicating Understanding of Contaminated Land Risks*, Stirling, UK, Scotland and Northern Ireland Forum for Environmental Research
This report provides a basic step-by-step guide to risk communication and relationship building in the context of contaminated land management, primarily aimed at regulatory officers.

Electronic information sources

Environment Council — *Who's Who in the Environment: UK computer database*

Green Channel internet site — http://www.greenchannel.com — *a web-site which promotes positive environmental change through better communication of environmental information. It provides a forum for professional, public interest and commercial organisations.*

Key periodicals

Journal of Risk Research

Risk Analysis

Risk: Health, Safety and Environment

CHAPTER 4
Problem formulation

4.1 Introduction

Clearly setting out the problem at hand and the boundaries within which any decisions are to be applied is important in risk assessment. Risk assessments are generally employed where the outcome of a given activity is uncertain. It is often tempting to omit any formal documented definition of the problem, particularly where there is pressure to complete the risk assessment quickly. However, failure to define the problem clearly is to lose the focus of the assessment itself, and may even result in an inappropriate output.

Stakeholders have an important role to play in problem formulation and their early involvement will tend to make risk management decisions more effective and durable (Section 3.8).

Describing the problem in clear and unambiguous terms will assist in selecting the level and type of assessment methodology used, and improve the risk management decision. It will also provide an important baseline should the process or eventual decision be challenged or audited. A range of issues pertinent to problem formulation which should be considered before undertaking any risk assessment is set out below.

4.2 Defining the intention

An important prerequisite to formulating the problem is a complete definition of the intention (Section 1.7). The intention will often be to carry out an activity which may add to existing risks. Sometimes the intention may be to act in order to reduce risks. This in itself does not alter either the need for, or the nature of, the risk assessment.

For risk assessors intimately concerned with a particular intention, it is easy to make implicit assumptions when defining the intention or take account of knowledge that will not be known to anyone who uses the risk assessment later. Consequently, recording the definition of the intention from the outset provides significant benefits by making clear to anyone using the assessment exactly what was taken into account. A good statement of the intention will also facilitate monitoring and feedback and help to determine whether discrepancies between forecasts and outcomes were caused by poor judgement, lack of knowledge or other factors.

To assist in defining the intention, it is helpful to consider the following four facets.

- What was the situation before the intention — the *baseline*?
- What are the characteristics of each contributing element of the intention — the *components*?
- How are the components related and what steps or processes are involved in the intention — the *process*?
- What will be the situation after the intention — the *forecast*?

Baseline The *baseline* refers to the state of the environment both in the locale of the hazards arising from the intention, and over the area where harm may be expected. Whereas the temporal and spatial boundaries of a hazard may be easily defined, the effects can be far more wide-ranging; the risk assessment should reflect this. The baseline will also include a record of all other relevant pre-existing hazards that may affect the outcome of the risk assessment. For example, if the intention is a new water abstraction from a river, there might be a risk of low water flows affecting aquatic plants. Existing abstraction levels would therefore be an important piece of baseline information.

Components A unifying principle to bear in mind during problem formulation and throughout risk assessment is the connection between the *source (of the hazard)*, the *pathway*, the *receptor*, and the *impact.* It is important that connectivity, or potential connectivity between these four components can be shown. If any of these components is missing then the risk assessment need go no further. Each of the risk *components* will have characteristics that may affect the consequences of an intention. For example, the chemical composition and combustion products of diesel fuel differ from unleaded petrol. To assess the risks associated with a road building programme, it will be necessary to estimate the relative numbers of diesel and petrol vehicles, and, thereby, their relative effects on air quality. A traffic flow dominated by diesel vehicles will have different effects from a flow dominated by petrol vehicles.

Process Each component of the intention can relate to other components as part of an overall *process*. For instance, the risk that a pollutant will reach an aquifer depends on the relationship between such things as groundwater flow, rainfall and geological conditions. In bringing together each of the components, further factors will be brought in to play which may affect the risk. For example, in establishing a new chemical plant there are important factors to consider before, during and after the project. Some of these factors include:

- *before* — clearing the site before construction starts;
- *during* — water and energy consumption, processes, emissions, wastes and materials transported to and from the site in both the construction and operational phases; and
- *after* — the final decommissioning and demolition of the site.

Forecast The *forecast* reflects the need to be able to define what may happen as a consequence of the intention. This is clearly very difficult, but some of the most important consequences may be determined here. For instance, the situation after a flood may be very similar to the situation before the flood. After decommissioning a nuclear power station, however, the adjacent land and the waste disposal site taking the redundant materials may be contaminated with radioactive material for a long time.

4.3 Justifying an intention

Chapter 3 provided a broad overview of the social aspects of risk, stressing that such issues should be considered at all stages of the risk assessment process. Having defined the overall intention and the problem facing the decision-maker, it should then be possible to address the benefits to society from the intention, for comparison with the risks which society is being asked to accept, in order to judge whether society is prepared to tolerate the risk or not.

The assessment of both proposed and existing risks includes economic factors (costs and benefits). Increasingly, socio-economic analysis is used for this purpose.

4.4 Setting the boundaries

An important requirement for any risk assessment is ensuring that its boundaries are clearly and logically selected. The boundaries can relate to factors such as:

- the spatial extent and time-scales over which the intention and any consequences may be considered;
- when the output from the risk assessment is required;
- the resources that can be assigned to the risk assessment;
- the purpose for which the output from the assessment is required; and
- the weight of decision to which the risk assessment will contribute.

It is important to document the grounds for selecting these boundaries.

4.5 The controlling factors

It is rare for hazardous events to occur without one or more factors controlling their timing, intensity and duration. While this may appear self-evident, it is important for the selection of risk reduction options. If controlling factors are not considered in the problem formulation stage, difficulties may arise when choosing the most appropriate risk reduction options. In relation to flooding, for example, factors such as the prevailing meteorological conditions, state of any flood defences, soil moisture deficit, and hydraulic capacity of the flood channel will all control the hazard to some extent. Equally, plant operator performance, levels of investment, training and even staff morale can be important factors in controlling risks from a chemical plant.

Some of the factors that control policy may initially be difficult to identify, but they are as important in their link to the hazard itself as are the more specific risks mentioned above. The policy options to reduce the environmental impact of power generation may be influenced by the degree of society's reliance upon electricity and, therefore, future population growth may well be one of the controlling factors.

In carrying out a policy-level or project-level risk assessment (Section 1.3), the factors controlling the hazards need to be clearly defined in the problem formulation stage. Modifying these factors will often be a key consideration in the options appraisal stage (Chapter 8).

4.6 Developing a conceptual model

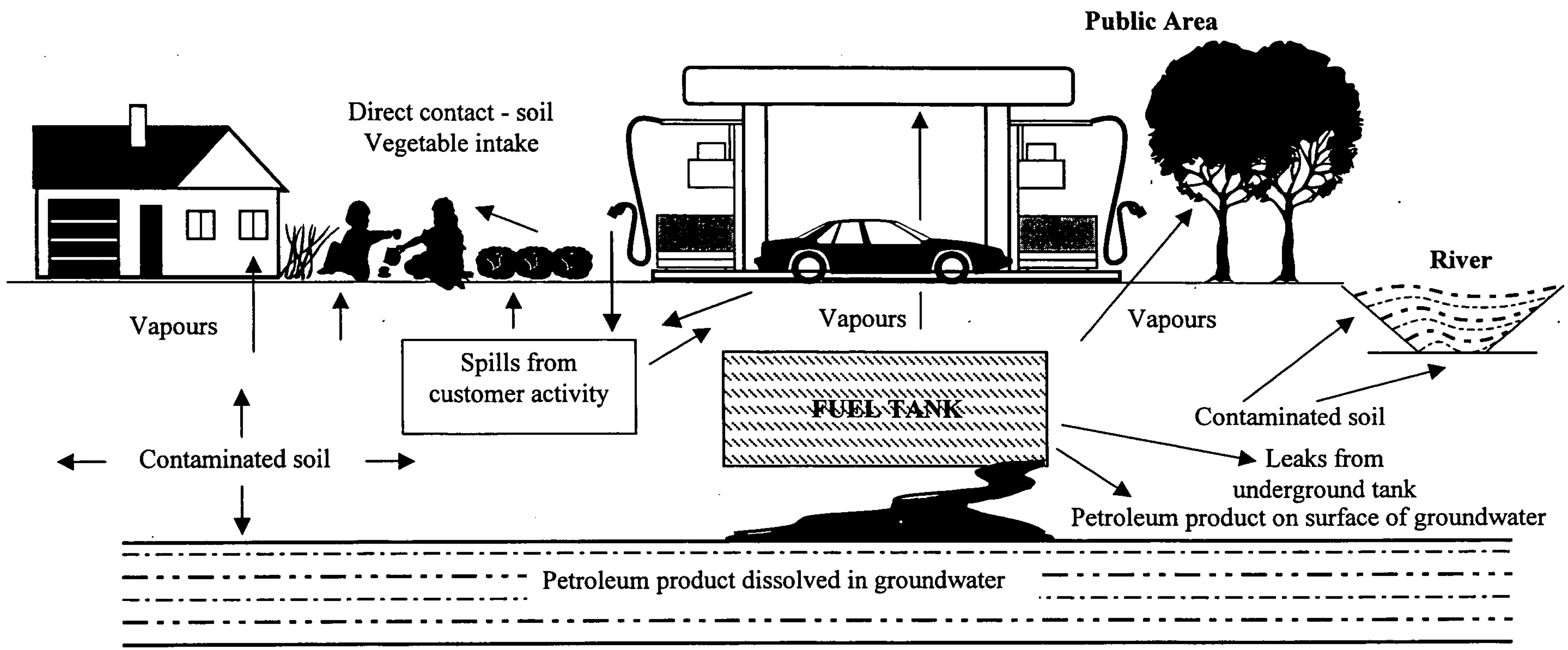
Conceptual models are useful tools in problem formulation. They present in both visual and written form the hypothesised relationships between sources, pathways and receptors. For example, Table 4.1 and Figure 4.1 present hypotheses of the source–pathway–receptor relationship for petroleum retail sites where historic or ongoing contamination is an issue.

Table 4.1 Simplified, illustrative conceptual model for exposure to hydrocarbon fuels at petroleum retail sites

Primary source	Secondary source	Hazard	Transport mechanism	Pathway	Medium of exposure	Receptor
Fuel tank	None	Dizziness, CNS depression, potential carcinogenicity	Vapour transport through air	Inhalation of vapours	Air	Humans (forecourt users)
Fuel tank	None	Vegetative die back, damage to leaf function	Vapour transport through unsaturated zone	Absorption of vapours	Air	Adjacent vegetation (trees)
Fuel tank	None	Derogation of groundwater quality	Product loss and vertical migration to water-table	Dissolution in groundwater	Water	Groundwater aquifer
Fuel tank	None	Derogation of surface water quality	Product loss and dissolution in groundwater	Base flow and discharge to adjacent surface water body	Water	Adjacent river
Fuel tank	Contaminated soils	Dizziness, CNS depression	Vapour transport through unsaturated zone	Inhalation of vapours	Air	Humans (recreational users)
Fuel tank	Contaminated soils	Skin irritation, contact dermatitis in extreme	Direct contact with contaminated soil	Dermal contact at surface	Soil	Humans (recreational users)
Fuel tank	Contaminated soils	Flammability	Vapour transport through unsaturated zone	Vapour build-up in basement void	Air	Humans (residential)
Fuel tank	Contaminated soils	Flammability	Vapour transport through unsaturated zone	Vapour build-up in basement void	Air	Property
Fuel tank	Contaminated soils	CNS depression, asphyxiation	Vapour transport through unsaturated zone	Vapour build-up in basement void	Air	Humans (residential)
Fuel tank	Contaminated soils	Derogation of surface water quality	Bulk fluid transport through unsaturated zone	Free product flow to adjacent river	Water	Adjacent river
Fuel tank	Free product on water-table	Derogation of soil quality	Evaporation to overlying soils	Vapour phase	Soil vapour	Soil
Fuel dispenser	None	Derogation of soil quality	Spillage and percolation through cracked hardstanding	Leaching	Soil	Soil
Fuel dispenser	None	Various, potential carcinogenicity	Vapour transport through air	Inhalation	Air	Humans (forecourt users)
Spills from customer activity	None	Vegetative die back	Vapour transport through unsaturated zone	Absorption of vapours	Soil gases	Adjacent vegetation (home grown produce)
Spills from customer activity	None	Various, potential carcinogenicity	Vapour transport through unsaturated zone	Consumption of contaminated produce	Vegetable produce	Humans (residential consumers of home grown produce)
Spills from customer activity	None	Various, potential carcinogenicity	Vapour transport through air	Inhalation	Air	Humans (forecourt users)
Spills from customer activity	Contaminated soils	Dizziness, CNS depression	Vapour transport through unsaturated zone	Inhalation of vapours	Air	Humans (forecourt users)

CNS, central nervous system

Figure 4.1 Simplified, illustrative conceptual model for exposure to hydrocarbon fuels at petroleum retail sites



Adapted from Institute of Petroleum (1998)

To ensure risk assessments focus on the most important hazards, conceptual models should be flexible and integrate all available information and expert opinion on a given set of hazards.

The level of detail required in the conceptual model will differ depending on the complexity of the risk assessment. A conceptual model can be highly specific and concentrate on just one facet of a large project, or it may be possible to embody the entire intention in one model. For a single chemical affecting a single receptor the conceptual model will probably be simple; in the case of multiple sources and multiple receptors the model will be more complex.

Uncertainty in conceptual models

Uncertainty in developing conceptual models arises from a lack of knowledge, failure to identify hazards, failure to consider the boundaries of the risk assessment correctly, or failure to consider direct or indirect effects. These factors become increasingly important when dealing with multiple stressors in complex situations. It may be appropriate to work with two or more conceptual models where there are alternative hypotheses.

Uncertainty cannot be completely eliminated but should be acknowledged wherever it arises.

Iteration and refinement

It is important to revisit, and where necessary revise, the conceptual model to ensure the underlying rationale is correct. The breadth of the conceptual model is likely to narrow during the risk assessment process. Initial models are often wide-ranging but as further information is accrued certain hypotheses may be discarded. The result is a risk assessment focusing on only the most significant hazards.

4.7 Further information

Key references

Baird DJ, Maltby L, Greig-Smith PW & Douben PET (1996) *ECOtoxicology: Ecological Dimensions,* London, UK, Chapman & Hall
An interesting collection of papers addressing the importance of ecological issues within ecotoxicology, with a particularly relevant contribution on the evaluation of the importance of indirect effects.

Calow P, ed (1993/1994) *Handbook of Ecotoxicology,* Vols. 1 and 2, London, UK, Blackwell Scientific Publications
A comprehensive and accessible collection of information on toxicity tests, how they are carried out, problems associated with them and their interpretation. Volume 1 concentrates on tests used for prediction while Volume 2 complements Volume 1 by covering how to deal with test results.

Calow P (1998) *Handbook of Environmental Risk Assessment and Management,* Oxford, UK, Blackwell Science
A comprehensive treatment of the basic principles of environmental risk assessment and management. Chapters discuss hazard identification, problem formulation and conceptual model development. Of particular interest are chapters 3 (Smrchek & Zeeman), 5 (Seidler et al.) and 7 (Suter).

Department of the Environment/Advisory Committee on Releases to the Environment (1993) *The Regulation and Control of the Deliberate Release of Genetically Modified Organisms,* London, UK, Department of the Environment
Guidance for interpreting the legislation on the release of genetically modified organisms to the environment.

Department of the Environment/Advisory Committee on Releases to the Environment (1995) *Guidance to the Genetically Modified Organisms (Deliberate Release) Regulations 1995,* London, UK, Department of the Environment
As above.

DETR/Environment Agency (2000) *Model Procedures for the Management of Contaminated Land,* CLR 11, London, UK, DETR (in preparation)
The report provides a generic framework for the management of contaminated land and is aimed at a broad audience. It includes a phased approach to risk assessment dealing with the qualitative and numerical aspects of risk assessment in this context with clear links to risk management.

European and Mediterranean Plant Protection Organisation (1994) Decision-making scheme for the environmental risk assessment of plant protection products; Terrestrial vertebrates. *EPPO Bull, 24,* 37–87
An example of the guidelines produced by the European and Mediterranean Plant Protection Organisation for the ecotoxicological risk assessment of plant protection products.

Institute of Petroleum (1998) *Guidelines for the investigation and remediation of contaminated retail sites,* Colchester, UK, Portland Press
Guidelines identifying the stages of a site investigation and appropriate remediation techniques.

Paustenbach DJ (1989) *The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies,* New York, USA, John Wiley & Sons
A useful collection of case studies that concentrate mainly on human health risk assessment. There are also some case studies looking at risks to wildlife.

Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Framework for Environmental Health Risk Management* (Final Report), Vol. 1, Washington DC, USA, Presidential/Congressional Commission on Risk Assessment and Risk Management
Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Risk Assessment and Risk Management in Regulatory Decision Making* (Final Report), Vol. 2, Washington DC, USA, Presidential/Congressional Commission on Risk Assessment and Risk Management
A particularly useful reference in discussing the role and involvement of stakeholders.

US EPA (1998) *Guidelines for Ecological Risk Assessment* (EPA/630/R-95/002F), Washington DC, USA, US Environmental Protection Agency
A recently published document giving useful information on problem formulation and risk assessment planning from an ecological viewpoint.

Walker CH, Hopkin SP, Sibly RM & Peakall DB (1996) *Principles of Ecotoxicology,* London, UK, Taylor & Francis
An excellent textbook covering the fundamentals of ecotoxicology, including fate and behaviour of chemicals, use of biomarkers, toxicity testing and discussions on ecotoxicological impacts from the level of the individual through to the ecosystem, including case studies.

Electronic information sources

DETR internet site — http://www.detr.gov.uk

Environment Agency internet site — http://www.environment-agency.gov.uk

Health and Safety Executive internet site — http://www.hse.gov.uk/hsehome.htm

Organisation for Economic Co-operation and Development (OECD) internet site — http://www.oecd.org/

Society of Environmental Toxicology and Chemistry (SETAC) internet site — http://www.setac.org/

United Nations Environment Programme, Chemicals Programme internet site — http://irptc.unep.ch/irptc/

Key periodicals

Aquatic Toxicology

Archives of Environmental Contamination and Toxicology

Atmospheric Environment

Chemosphere

Conservation Biology

ENDS Report

Environmental Pollution

Environmental Science and Technology

Ground Water

Journal of Environmental Management

Journal of Environmental Quality

Journal of Toxicology and Environmental Health

Risk Analysis

Water Environment Research

CHAPTER 5
Risk screening and prioritisation

5.1 Background

Setting priorities is important for decision-making. In environmental risk assessment and management, prioritisation may be undertaken at several stages. In the initial stages, hazards may have to be scored and ranked to prioritise those that are of most concern. Later, risks and risk management options may be scored and ranked to identify priorities for further risk assessments and for risk management decisions.

Screening and prioritisation can be applied at all levels of risk assessment and management, and across a diverse range of activities which may impact on the environment. Given the wide variety of uses, there is no single ranking or prioritisation system appropriate to all applications in environmental risk management. Nevertheless, these guidelines aim to promote consistency across a broad range of activities by highlighting the common principles of priority-setting. Priority-setting can help to promote transparency in decision-making by ensuring an explicit and justifiable basis for those decisions.

5.2 Why screen and prioritise?

In general, screening will be used to determine which hazards or risks should be investigated in more detail. Ranking each of these, based on their screening scores, will provide a priority list for further action.

In the past there has been a tendency to apply quantitative methods at the outset of a risk assessment, and thereby miss issues that are difficult to quantify. The ability to consistently screen all risks for a given problem is therefore vitally important. Risk screening (Tier 1 of the framework for environmental risk assessment in Figure 2.1) to identify and subsequently prioritise relevant risks helps to minimise unnecessary effort and reduces the chance of potentially important risks being overlooked. It also provides an auditable trail to support or explain the omission of certain risks from further consideration.

5.3 Key criteria for risk screening

Various approaches to risk screening have been developed both in the health and safety field and for environmental risk. Although they differ in their structure and the measures used to determine the priority of any risk, the key elements of the screening process reflect the framework for a full risk assessment as described in Chapter 2, but are quantified in much less detail.

Identification and magnitude of consequences

Characterising the nature of the hazard requires a consistent measure to be used and usually reflects the importance of the hazard in relation to others. For example, where the hazard is a chemical, its relative toxicity to the likely receptor organisms might be an appropriate measure. A very swift inundation by flood waters may rank higher than a gradual rise in water levels.

Exposure may not always follow on from a hazard. Screening and prioritisation can be based on an initial evaluation of likely pathways between source and effect. Factors such as the strength and direction of the wind in relation to an atmospheric release, the ability to evacuate homes in advance of flooding, and the ability of fish to move away from zones of polluted water will all affect the probability of exposure.

Probability of consequences

The likelihood of the hazard being realised can be roughly estimated using coarse indicators. For instance, the effectiveness of existing flood defences and typical meteorological conditions could be used to predict the probability of a flood.

Significance of the risk

This reflects the harm that may result if exposure to the hazard actually occurs. The screening of impacts or consequences should take account of their nature, geographical extent, timing and duration and their likely importance. Likely public concern (Section 3.3) should also be considered.

5.4 Methods for risk screening and prioritising

Depending on the risks in question, different methods for screening and prioritisation can be applied. The key to effective screening and prioritisation is consistency and transparency of approach.

Numerical approaches

Scoring systems and scales (eg low (1) to high (5)) should be designed with reference to the factors outlined in Section 5.3 and must be appropriate and meaningful to the application under study. The overall score for the risk is the product of each criterion score. The data and information used to assign scores can come from a variety of sources:

- experience of the same issue;
- experience of similar issues;
- experience elsewhere in the world (eg generic information); and
- worst-case scenario estimates.

Qualitative approaches

For some environmental problems, the complexity of the issues to be addressed may be considerable. This is particularly true when risk assessment is employed to assess policy-level issues or where the sources of risk are diverse. Sometimes there may be no prior experience on which to base risk judgements and worst-case assumptions have to be made. In such cases, it may be difficult to determine the scores that should be assigned to each of the criteria listed in Section 5.3, and another approach needs to be adopted.

Expert judgement and preference elicitation have been used by many organisations as a way of screening risks and prioritising future work. The Warwick Risk Initiative has developed techniques which have subsequently been employed by the Environment Agency in screening risks to the environment from road transport. The technique involves a panel of people scoring each risk through a structured discussion. Expert groups, such as the Advisory Committee on Releases to the Environment (ACRE), are regularly used by Government to advise on the priority that should be assigned to particular risks.

5.5 Prioritising effort

Risk screening and subsequent prioritisation has a number of benefits:

- it clearly identifies why some risks will not be investigated further;
- it identifies some risks where action, as opposed to any further investigation, may be preferable; and
- it prioritises resources for the subsequent stages of risk assessment.

It is important that risks identified through screening processes as being of low priority are not discarded entirely from the remainder of the process. For instance, a future risk management option targeted at a high priority risk may also reduce risks of lesser priority. The value of this option would therefore be increased. Equally, some risk management options may worsen low priority risks.

There may be situations in which the cost of carrying out the required risk assessment would exceed the expected benefits of the intention. If this is still the case after taking all reasonable steps to reduce the costs of the risk assessment to a minimum, and taking account of the full socio-economic value of the intention, then the sensible course of action would be to decide not to proceed with the intention.

5.6 Further information

Key references

Health and Safety Executive (1997) *Risk Ranking* (Contract Research Report 131/1997), Sudbury, UK, HSE Books
Presents a review of methods available for comparing and ranking risks for priority setting in decision-making.

Swanson MB & Socha AC (1997) *Chemical Ranking and Scoring: Guidelines for Relative Assessment of Chemicals,* Pensacola FL, USA, Society of Environmental Toxicology and Chemistry
Summarises the discussions of a workshop which focused on the science of chemical ranking. The publication focuses on measures of exposure, ecological effects, human health effects and other chemical characteristics to consider in ranking and scoring.

Electronic information sources

Warwick Risk Initiative internet site —
http://www.warwick.ac.uk/statsdept/risk/index.html

Key periodicals

Risk Analysis

CHAPTER 6
Quantification and dealing with uncertainty

6.1 Introduction

Risk assessments for complex, high priority risks can be time-consuming and expensive. In Chapter 2, the principle was introduced that the amount of effort put into the risk assessment should be proportional to the severity of the problem. The tiered approach shown in Figure 2.1 is intended to help match effort to severity by providing a series of clear stages, after each of which decisions are taken about whether or not further effort would be justified. If an initial assessment of risk based on a reasonable 'worst-case' scenario indicates little cause for concern then there is little point in moving on to more sophisticated analyses. Alternatively, cause for concern may become apparent at an early stage and there would then be little point delaying the identification of risk management options in order to complete the risk assessment. More detailed data and sophisticated analysis may be required where initial estimates indicate the need for further refinement of the estimation.

Previous and ongoing monitoring programmes are important information sources and modelling and simulation are useful techniques for analysing information. Tools and techniques for risk assessment are being developed all the time. The RiskWorld internet site provides some useful pointers to models for quantifying the probability of release, estimating the consequences and dealing with uncertainty (Section 6.4).

Where information is limited, informed decisions can be based on assumptions or extrapolations. It is important, though, that data gaps or assumptions are acknowledged. Sensitivity analysis offers a useful approach to dealing with such uncertainties. It provides a means to examine the behaviour of a model by measuring the variation in outputs resulting from changes to its inputs.

6.2 Types of quantification

Estimating the probability of events

In environmental risk assessment, there can be situations in which the probability of an event is 1 (ie it will happen). For example, once the decision to build a dam has been taken, its construction will certainly lead to the loss of habitats, landscape features and structures in the flooded area. In this case, the important parameters to consider are the probability and magnitude of consequences arising from the construction rather than the probability of the event (construction) itself. Another example of such a situation would be the release of planned, routine emissions. In situations outside the system design (ie accidents or malicious releases) the initiating event probability becomes more important. More usually, the event has a probability less than 1, and an estimate of its probability will be required. There are various techniques available to do this, some of which are briefly outlined below.

Actuarial or historical information

This involves looking at the reliability of components or other factors within a system based on past experience or data. To be useful there has to be a statistically significant number of data points. If the event relates to a novel process or is very rare (such as a major industrial accident), then it will not be possible to gather sufficient data for a probability estimate. Other circumstances lend themselves more easily to the use of historical data. For example, the frequency of collisions involving road tankers that can then lead to environmental pollution might be estimated from direct data on past road tanker accidents.

Synthesised analysis

Many processes, industries or sectors do not have sufficient data on which to base such estimates and other techniques involving synthesised analysis are needed. Two of the most widely used and well-known techniques to deal with operation or process failures are fault tree analysis and event tree analysis. These are similar in that logic diagrams are employed to represent the propagation of events or faults through a system.

Fault tree analysis

Fault tree analysis can be used to assess the probability of a system failure in the absence of actual data. The technique requires information on the failure rates of components within a system. Combining such data can provide an estimate of the probability of system failure over time or of failure on demand (eg failure of a safety system to operate). The aim is to take an undesired event (system failure) and describe how it might occur.

Event tree analysis

Event tree analysis operates in the opposite way to fault tree analysis by taking a situation and asking to what system states it might lead. A simple example would be considering how a release of chlorine could affect the local environment and population around a plant. The probabilities would depend on the operation of safety systems, size of release, wind direction, distance from source to receptor, and so on.

Estimating the magnitude of consequences

In some cases there will be a high level of uncertainty in the estimation of the magnitude of consequences, and making some judgement on the possible consequences may be the best option. For example, there is often great uncertainty in ecological risk assessment, and it becomes very difficult to predict the extent to which a target population may decline and the degree of seriousness of the subsequent effects on community and ecosystem function that may result. In such cases cost-effective measures to avoid serious or irreversible harm must be adopted, even in the face of uncertainty.

In most cases, however, it will be possible to quantify the magnitude of the consequences, and possibly even to place a monetary value on them (which will facilitate socio-economic analysis). The significance of the magnitude of a consequence, at least to a certain extent, is a matter of judgement. Where no guidance exists regarding the significance, a rough, *ad hoc* scale can be developed. An example is presented below ranging from negligible to extremely severe effects. Approaches using coarse scales of this sort have proved useful in risk assessment related to a range of environmental problems, for example assessing suitable clean-up standards for contaminated land.

- *Negligible* — Sub-lethal effects in individuals that do not cause a change in population structure or size.

- *Mild–Moderate* — Effects occurring at the population level. Effects on ecosystems that are not regarded as being of high value for whatever reason.

- *Severe* — Local extinctions (depending on the species) and local dysfunction of communities and ecosystems.
- *Very severe* — Global extinctions (depending on species) and widespread effects on the functioning of communities and ecosystems.
- *Extremely severe* — Impacts on the functioning of global ecosystems.

Estimating the probability of consequences

Estimating the probability of consequences is likely to be at best semi-quantitative. There are three primary factors to consider when estimating the probability of consequences (Section 2.2) — whether the event will be initiated; whether exposure to the hazard will occur; and whether harm will result following exposure.

For example, there are well-developed techniques for estimating the probability that a chemical released to the environment will lead to harm to organisms. These are based on comparing a known concentration at which effects occur with a predicted or measured concentration in the environment.

In some cases it might be possible to base exposure predictions on measured levels in environmental compartments. There will be uncertainty in these measurements and, where this uncertainty is unacceptable or data are unavailable, the use of surrogates, models and assumptions will usually be of value. For example, physico-chemical properties of a substance and details of the amounts released into the environment can be used to predict its environmental partitioning and environmental concentrations. Mass–balance models are then used to quantify the amounts of a chemical expected to be present in different compartments within a particular environment.

Where strict quantitative analysis is not possible, expert opinion may be needed. For example, it is often less feasible to carry out a detailed quantification when the risk being considered is from living organisms (genetically modified organisms or alien species, for example). Hence in such cases regulatory decisions are usually based on the opinion of an expert advisory committee.

6.3 Dealing with uncertainty

Sources of uncertainty

Analysing the sources and magnitudes of uncertainty can help determine how much confidence can be placed in the risk assessment as a basis for decision-making. Uncertainties can arise from several sources, including natural or inherent variability over space and time, variability in the accuracy of measurements and data manipulation, and knowledge gaps due to lack of data. They can also arise when models and test systems do not accurately reflect the environment or exposed population of concern.

Analysing uncertainty

Methods for analysing and describing uncertainty may be simple or complex. Where significant knowledge gaps exist a useful approach is to estimate consequences based on alternative scenarios, presented as a series of estimates with different assumptions and descriptions of uncertainty. A common approach to dealing with uncertainty is to adopt a worst-case scenario which assumes that the consequences will definitely occur, or to assign given magnitudes to the consequences. Uncertainty can, in many cases, be reduced by collecting more information (ie increasing the sample size). On the other hand natural variability (eg chemical sensitivities within and between species) cannot usually be reduced by further measurement and must be expressed through the use of statistical descriptions such as probability and frequency distributions. Sensitivity analysis should always be carried out where the degree of uncertainty is critical.

Because many risk estimates will be subject to uncertainty from various sources, 'safety' factors (sometimes called 'protection' or 'uncertainty' factors) are often applied, especially in standard-setting and decision-making. Safety factors are typically applied when extrapolating from animal data to humans, from data derived from a small number of individuals to a population, or from a species to a mixed ecosystem.

The decision process for developing safety factors can involve scientific judgements on a wide range of quantitative and qualitative information to produce a single number expressing those judgements and uncertainties. Safety factors can take account of scientific uncertainties in available data and allow, for example, for the protection of the more susceptible parts of the environment. Determining an appropriate safety factor requires a combination of experience and judgement. Recording the rationale behind such judgements is important.

6.4 Further information

Key references

Baird DJ, Maltby L, Greig-Smith PW & Douben PET (1996) *ECOtoxicology: Ecological Dimensions*, London, UK, Chapman & Hall
An interesting collection of papers addressing the importance of ecological issues within ecotoxicology, with a particularly relevant contribution on the evaluation of the importance of indirect effects.

Begon M, Harper JL & Townsend CR (1990) *Ecology: Individuals, Populations* and *Communities* (Second edition), Oxford, UK, Blackwell Scientific Publications
As above.

Calow P (1997) *Controlling Environmental Risks from Chemicals: Principles and Practice*, Chichester, UK, John Wiley & Sons
A concise but informative textbook dealing with the basic principles of the environmental risk assessment of chemicals, including sections on European and North American legislation.

Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science
A comprehensive treatment of the basic principles of environmental risk assessment and management.

Department of the Environment/Advisory Committee on Releases to the Environment (1993) *The Regulation and Control of the Deliberate Release of Genetically Modified Organisms*, London, UK, Department of the Environment
Guidance for interpreting the legislation on the release of genetically modified organisms to the environment.

Department of the Environment/Advisory Committee on Releases to the Environment (1995) *Guidance to the Genetically Modified Organisms (Deliberate Release) Regulations 1995*, London, UK, Department of the Environment
As above.

European and Mediterranean Plant Protection Organisation (1994) Decision-making scheme for the environmental risk assessment of plant production products; Terrestrial vertebrates. ***EPPO Bull, 24,*** **37–87**
An example of the guidelines produced by the European and Mediterranean Plant Protection Organisation for the ecotoxicological risk assessment of plant protection products.

Paustenbach DJ (1989) ***The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies,*** **New York, USA, John Wiley & Sons**
A useful collection of case studies concentrating mainly on human health risk assessment with some ecotoxicological case studies.

Royal Society (1992) ***Risk: Analysis, Perception and Management*** **(Second edition), London, UK, The Royal Society**
A comprehensive study of risk assessment, management and perception from a variety of viewpoints.

Schnoor JL (1996) ***Environmental Modeling: Fate and Transport of Pollutants in Water, Air and Soil,*** **New York, USA, John Wiley & Sons**
Addresses key questions about fate, transport and long-term effects of chemical pollutants in the environment.

Walker CH, Hopkin SP, Sibly RM & Peakall DB (1996) ***Principles of Ecotoxicology,*** **London, UK, Taylor & Francis**
An excellent textbook on the fundamentals of ecotoxicology, including chemical fate and behaviour, biomarkers, toxicity testing and discussions on ecotoxicological impacts from the individual through to the ecosystem, including case studies.

Electronic information sources

RiskWorld internet site — http://www.riskworld.com/

Key periodicals

Archives of Environmental Contamination and Toxicology
Atmospheric Environment
Chemosphere
Conservation Biology
Environmental Pollution
Environmental Science and Technology
Environmental Toxicology and Chemistry
Ground Water
Journal of Environmental Quality
Journal of Toxicology and Environmental Health
Nature
Toxicology

CHAPTER 7
Evaluating the significance of a risk

7.1 Introduction

Along with the formal scientific assessment of the probability and magnitude of adverse impacts on the environment, the broader significance of an identified risk needs to be established as a basis for decision-making. To ensure that the outputs from a risk assessment help in decision-making a number of questions should already have been addressed (see US EPA, 1998; and Chapters 4, 5 and 6 of these guidelines).

- What impacts to the environment may occur?
- How harmful are these impacts to the environment?
- How likely is it that these impacts will occur?
- How frequently and where will these impacts occur?
- How much confidence can be placed in the results of the risk assessment?
- What are the critical data gaps and can these gaps be filled?
- Are further iterations to the risk assessment needed?

Evaluating the significance of a risk also involves determining the broader implications of the risk problem including social, political and economic considerations. Once these judgements are made about a risk's acceptability, decisions can be taken about how to reduce or manage the risk (Chapter 8).

7.2 Risk estimation as a basis for risk management decisions

For most activities it is likely that more than one hazard will be identified. For each separate hazard, combining the probability of the consequences and the magnitude of those consequences yields an estimation of risk. Both components are likely to be at best semi-quantitative and so each component will to some extent represent judgements on the basis of the knowledge and experience available. Issues relating to the probability of environmental consequences and how to deal with uncertainty are discussed in Chapter 6.

A simple matrix (Figure 7.1) can provide a consistent basis for decision-making. It should of course be used with caution, recognising the over-simplification that it will normally represent. The probability and consequences are defined according to parameters relevant to the situation; the boundaries of risk acceptability (and tolerability, where relevant) indicated on the matrix can be tailored to the factors influencing the significance of the risk (Section 7.3). Individual situations are mapped onto the matrix to provide a ready and consistent indication of their acceptability or tolerability.

Figure 7.1 Estimation of risk from consideration of magnitude, consequences and probabilities

Increasing acceptability ↘	Consequences			
	Severe	**Moderate**	**Mild**	**Negligible**
Probability				
High	high	high	medium/low	near zero
Medium	high	medium	low	near zero
Low	high/medium	medium/low	low	near zero
Negligible	high/medium/low	medium/low	low	near zero

7.3 Factors influencing the significance of a risk

Statutory and policy requirements

A wide range of standards for pollution control exist in the UK including exposure standards, environmental quality standards, emission standards, process or operating standards and product standards. Clearly if these are legally mandatory and a risk assessment demonstrates that an intended activity is likely to breach them, the risk is unacceptable and measures to reduce it to acceptable levels should be adopted.

There is a substantial amount of legislation and numerous policy objectives that may affect the significance of a risk. Information sources are available which provide overviews and guidance on statutory requirements (Section 7.5).

In situations not covered by legislation, or where policy is to seek environmental improvements beyond those aspired to by statute, targets should be set through socio-economic analysis and expert judgement, taking account of the societal pressures which lead to policy or political decisions.

Value judgements

Defining what constitutes unacceptable harm to an ecosystem is a difficult task and ultimately depends on what values society places on ecosystems. Some hold the opinion that maintenance of ecosystem function is the main objective and that the loss of individual species may not be of consequence with respect to this. Maintaining ecosystem integrity, at local and global scales, is clearly important to the maintenance of an environment which provides the resources and conditions required for man's survival and development. The preservation of biodiversity in its own right has received much attention in recent years and many arguments have been put forward in support of this. Some habitats and species are considered to be of particularly high value for conservation, as a result of value judgements made on the basis of rarity, attractiveness, fragility and so on. The UK Government has set out priorities and strategies for biodiversity conservation in the UK Biodiversity Action Plan. These are reinforced by national statute implementing the EC Wild Birds Directive and the EC Habitats Directive.

Social aspects of risk

The acceptability of a risk can be significantly influenced by a range of psycho-social and political factors. These may include individual risk perceptions and attitudes, cultural values, questions of trust and credibility about risk proponents and managers, and questions of equity in risk distribution (Chapter 3). While risk management decisions should be based on the best scientific information available, these factors should also be considered when evaluating the significance of a risk. An important step is the creation of a constructive dialogue between stakeholders affected by or interested in risk problems (Section 3.8).

Economic considerations

Economic factors can have a significant influence on the decision-making process and may affect the acceptability of a given option. An example could be a town's flood defence. There are construction and maintenance costs associated with any flood protection scheme; there may also be costs in terms of damage to the environment by habitat removal or alteration. Various options to control the flood risk might be open to the Environment Agency. While it might technically be feasible to construct a flood defence scheme that protects against a one in fifty year flood event, the construction and maintenance costs of such a scheme are likely to be high. The Agency could, therefore, consider a scheme to protect against a more frequent but less harmful event, say a one in ten year flood. While the construction and maintenance costs of such a scheme would be lower, the costs in terms of damage to property from more severe but less frequent flood events might outweigh the financial savings in construction and maintenance costs.

The best option is likely to be the one with the greatest excess of benefits over costs, where the benefits are those accruing from protection (eg the damage or loss of property, materials, crops, human health and environmental assets that is avoided) and the costs are those social and private costs of the control options, including construction, maintenance and environmental damage. This should include both those benefits and costs that can be monetised and those that cannot (or for which robust monetary valuations are not readily available) — the latter need to be assessed in physical and qualitative terms. Because monetary values can more readily be assigned to some impacts than others, care is needed to ensure that adequate consideration is given in any decision-making to all non-monetised items that may be thought significant, relative to the monetised elements.

The changing environment and changing baselines

Baselines against which alternative risk assessment scenarios can be compared are likely to change over time. Changing baselines may be the result of a diverse set of factors including, for example, climate change, increasing urbanisation, demographic changes, changes in social attitudes towards risk acceptability and advances in technologies available to reduce risk. This can result in a new set of conditions against which existing risks and management options should be compared and altered if necessary. Clearly the possibility of such changes can have an impact on risk significance and should always be borne in mind.

7.4 Other significant factors

According to circumstances, UK statute or policy may subject an activity to requirements or principles to limit risk, as listed below:

ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
BATNEEC	best available technique not entailing excessive cost
BPEO	best practicable environmental option
BPM	best practicable means

None of these terms is exactly equivalent to another. Generally they are used within a strict legal context, and consequently the use of one criterion rather than another needs to be considered carefully in each situation.

'As low as reasonably practicable' is a wide statement of principles and forms the cornerstone of nuclear plant safety. A risk that has been reduced to ALARP corresponds to the concept of tolerable risk. This implies that any further reduction in the risk can be achieved only at grossly disproportionate cost and that the benefits afforded by the risk are judged to outweigh the costs.

Other criteria commonly used in environmental risk assessment are described as BPEO and BATNEEC. Both these criteria involve balancing the reduction in risk with the practicability and cost of reducing that risk.

The application of BATNEEC normally means that the additional costs of avoiding environmental damage are justified by the benefits. Therefore, BATNEEC would not require the reduction of risk from 'low' to 'negligible' if that would require very expensive techniques. Under the Environmental Protection Act 1990, the BATNEEC criterion is applied in integrated pollution control (IPC) and in the management of risks from the release of genetically modified organisms to the environment.

Importantly, the application of BATNEEC means that the estimation of the risk associated with a particular activity can change over time as new techniques and technologies are developed, and the costs of existing techniques vary. Such changes may warrant another iteration of the whole risk assessment process. The BATNEEC criterion relies not only on technological solutions, but includes other approaches such as environmental management systems and staff training.

The BPEO is a term of policy guidance. It is the option which provides the most benefit or least damage to the environment as a whole, at an acceptable cost in both the long and short term. The BPEO, as a concept with legal basis, was introduced with IPC under Part I of the Environmental Protection Act 1990. Operators of prescribed industrial processes which produce releases to more than one environmental medium must ensure that BATNEEC is used to minimise pollution to the environment as a whole, having regard to BPEO. Again, an element of cost versus environmental benefit/risk is brought into play in deciding which process option constitutes BPEO. A key feature of the BPEO approach is that decision-making is transparent and that an audit trail exists so that all stages in the choice of the BPEO can be scrutinised.

7.5 Further information

Key references

For key references relating to the social aspects of risk see Chapter 3.

Biodiversity: The UK Steering Group (1995) *Biodiversity: The UK Steering Group Report, Volume 1: Meeting the Rio Challenge,* London, UK, HMSO
An account of the UK strategy for protecting biodiversity following the Biodiversity Convention at the Earth Summit in Rio de Janeiro in June 1992. This volume sets out the basic action plan and includes the targets for key species and habitats and the process of information gathering with respect to UK biodiversity.

Biodiversity: The UK Steering Group (1995) *Biodiversity: The UK Steering Group Report, Volume 2: Action Plans,* London, UK, HMSO
Following on from Volume 1, this gives more detailed information on the species and habitats considered as priorities for conservation. Action plans for the protection of a number of species/habitats are also presented.

Calow P (1992) Can ecosystems be healthy? Critical consideration of concepts. *J Aquatic Ecosystem Health,* 1, 1–5
An interesting discussion paper addressing the difficulties in identifying the properties of undisturbed ecosystems and the whole concept of the existence of 'healthy ecosystems'.

Calow P (1998) *Handbook of Environmental Risk Assessment and Management,* Oxford, UK, Blackwell Science
A comprehensive treatment of the basic principles of environmental risk assessment and management. Chapters discuss the way in which risk assessment is used in decision-making for risk management for different applications, highlighting important factors which may influence the significance of a risk.

Douben PET, ed (1998) *Pollution Risk Assessment and Management,* Chichester, UK, Wiley & Sons Ltd.
Provides an extensive discussion of the basic principles of integrated pollution control and risk management.

Haigh N, ed (1992) *Manual of Environmental Policy: The EC and Britain,* London, UK, Cartermill Publishing
This manual provides a complete account of EC environmental policy and a comprehensive treatment of British policy that is relevant to the implementation of EC legislation. First published in 1992, the manual is regularly updated and two comprehensive releases are issued in May and November.

HM Treasury (1997) *Appraisal and Evaluation in Central Government: Treasury Guidance,* London, UK, TSO
This document deals with risk and environmental impacts as aspects of the general appraisal framework for projects, programmes and policies.

Pearce DW & Turner RK (1990) *Economics of Natural Resources and the Environment,* London, UK, Harvester Wheatsheaf
A book that provides background discussion of the economic principles and practice relating to environmental resources and impacts.

Perrings C, Mäler K-G, Folke C, Holling CS & Jansson B-O, eds (1997) *Biodiversity Loss: Economic and Ecological Issues,* Cambridge, UK, Cambridge University Press
Contains useful discussions on the concepts of diversity, the implications of biodiversity loss for ecosystem functioning, the driving forces behind biodiversity loss, and the options for promoting biodiversity and conservation.

Royal Commission on Environmental Pollution (1998) *Setting Environmental Standards,* Twenty-first Report, London, UK, TSO
A comprehensive review of the process of establishing standards for environmental protection with recommendations for a more participatory approach to their development.

US EPA (1998) *Guidelines for Ecological Risk Assessment* (EPA/630/R-95/002F), Washington DC, USA, US Environmental Protection Agency
These guidelines were written to improve the quality and consistency of ecological risk assessments. They should be of particular interest to risk assessors and risk managers, highlighting and discussing important principles and terminologies for the ecological risk assessment process.

Electronic information sources

CEDREC — *A comprehensive computer database of UK and EC environmental legislation with easy-to-use cross-referencing and expert interpretation. Updated quarterly.*

DETR internet site — http://www.detr.gov.uk

Environment Agency internet site — http://www.environment-agency.gov.uk

Environment Plus CD-ROM — *Provides a wide range of information on the environment, including the full text of relevant EC and UK legislation plus the DETR's bibliographic database. Updated quarterly.*

World Conservation Monitoring Centre internet site — http://www.wcmc.org.uk

Key periodicals

Atmospheric Environment
Conservation Biology
Environment
Environmental Science and Technology
Journal of Environmental Management
Journal of Risk Research
Marine Pollution Environment
Risk Analysis
Risk, Decision and Policy

CHAPTER 8
Options appraisal and decision-making

8.1 Introduction

Options appraisal is the process of identifying the 'best' risk management technique. This may involve scoring, weighting and reporting different risk management options. Various criteria are used for identifying the 'best' option, according to context, but a common framework is to seek to maximise some long-term definition of human well-being such as sustainability, net social benefit or value for money. Key inputs for this process are the controlling factors for each risk identified during the problem formulation stage (Chapter 4). For instance, if a controlling factor is the level of investment in monitoring and control equipment, then options appraisal can focus on those issues immediately.

An appraisal process normally involves identifying and reporting the benefits and costs of options, and then ranking those options with regard to the appropriate criteria, and risk management is no different. Relevant options may include emerging technologies and management techniques which reduce a risk's frequency or consequences. Social issues and the perceptions and aspirations of the public should also be considered as part of the process (Chapter 7). Combining all of these elements permits a systematic comparison of options for risk management. The process may be iterative, with options appraisal feeding back to the various tiers of risk assessment (Figure 2.1 and Section 8.4).

General risk management options

There are three main options available to the risk manager when presented with a risk problem. The options are to: reject the intention altogether because it poses unacceptable risks; accept whatever risk is imposed; or reduce the risk in some way, by doing one or more of the following: modifying the receiving environment or hazard; modifying or avoiding exposure; or modifying the effects or consequences of a risk.

8.2 Trade-off analysis: methods for decision-making

This section outlines some of the systematic methods that can be used for comparing and evaluating (or trading off) alternative risk management options. There is no universal decision-focused method suitable for all circumstances, rather, selection or adaptation of an existing methodology or development of a new methodology will be necessary.

All good policy decisions rely on the effective analysis of alternative options. Therefore, a systematic appraisal is important to ensure that the decision-maker is clear about the objectives and how to decide where the balance lies between the benefits from the reduction of the risk and the implications for society of introducing potential control measures. A systematic appraisal of the options will be the process of identifying, quantifying and weighting the costs and benefits of the measures which have been identified as means of implementation. This process must include all implications of the potential options, and not just those that can be quantified.

All appraisals should involve a systematic approach. This is generally best achieved through a step-by-step process to help guide the decision-maker through the development of the strategy in a structured way. Each appraisal will require varying degrees of emphasis at different stages depending on the individual circumstances, but a common framework can be envisaged consisting of the following steps:

- Identification of the objective, ensuring a clear and common understanding of what is the desired outcome.
- Identification of the options. In most cases there will be options that are obvious to the decision-maker. Some will be less applicable than others and it will be necessary to identify those that have the potential, either in whole or part, to meet the objective.
- The options identified will need to be implemented using various tools, such as policy instruments, economic measures or regulations. Consideration should be given to the selection of those most appropriate while recognising that they will not be mutually exclusive and a combination of one or more may be appropriate for one or more options.
- Identification of the impacts of the options. This will require collection of data from those stakeholders that will be affected by potential measures. Close consideration should be given to the implications of changes in working methods (good and bad) to meet the objective.
- Clarify the decision criteria such as the economic costs, the implications of change, and the human health and environmental benefits.
- Compare the advantages and drawbacks for each option including the trade-off between quantified and qualitative data to draw conclusions.

Some of the techniques for taking forward such a systematic appraisal are summarised below.

Environmental impact assessment

Environmental impact assessment (EIA) is a widely used procedure for systematically assessing the environmental impacts of proposed projects. It is a legal requirement for certain projects likely to have significant effects on the environment. Information on the environmental effects of a project, and the main alternatives, is documented in a form which provides a focus for public scrutiny of the project. It enables the importance of the predicted effects, and the scope for mitigating them, to be evaluated before a decision is made as to whether the project can proceed. Under EIA there is no requirement to produce monetary evaluations of environmental impacts and no requirement to consider formally the costs of risk management options.

Strategic environmental assessment Strategic environmental assessment (SEA) is closely allied to EIA but focuses on the potential environmental effects of policies, plans or programmes (PPPs) as opposed to individual projects or developments. PPPs may be concerned with programmes of development (eg transport or power networks), geographical areas (eg local authority areas, regions or countries), types of area (eg cities or shorelines), or economic sectors (eg mining or agriculture). SEA uses a range of techniques to predict both the direct effects of PPPs and their interaction with other PPPs and activities.

The Government requires environmental effects to be considered in decision-making at all levels and SEA is widely undertaken in this context and as part of the assessment framework for sustainable development. The European Commission has proposed a directive requiring SEA of a range of plans and programmes which are likely to have significant effects on the environment. The Directive is expected to be adopted around the end of 2000, with Member States then having three years to incorporate it into national law.

Cost–benefit analysis Cost–benefit analysis (CBA) involves expressing as many costs and benefits as possible in terms of the monetary or other value placed on them by society, and deriving the net benefit. This is a very general technique, but it has stringent information requirements. A particular area of difficulty is choice of a discount rate which may discriminate unduly against long-term options.

In many CBAs there will be effects that cannot be given a monetary value and there will sometimes be key environmental assets which cannot readily be valued. Where there is no market for an environmental good, techniques for monetary valuation exist that measure people's preferences. These techniques need to be used with caution, as the values they produce may not always be robust for their intended (or unintended) uses. There is always a danger with valuation techniques of placing too much emphasis on those attributes that can be measured at the expense of those that cannot. Such approaches to trade-off often require the specialist advice of environmental economists. They are summarised in HM Treasury's 'Green Book', *Appraisal and Evaluation in Central Government.*

Environmental capital Consideration of environmental capital is a more recent and unique approach. It rests on the idea that the environment consists of assets which can provide a stream of benefits or services as long as care is taken not to damage them. A distinction is often made between 'critical', 'constant' and 'tradable' environmental capital.

Ranking, rating and weighting Further methods have been developed involving ranking, rating or scaling and weighting to compare alternative options. These involve summarising both quantitative and qualitative information on alternative options using the assignment of a rank, rating or scale value relative to each of a number of decision factors or criteria. These decision factors can include the economic costs and benefits of the intention, social and political perspectives, and so on. Ranking involves placing options from best to worst; scaling refers to the assignment of algebraic or letter scales; and rating employs a pre-defined range. The rank, rating or scale value is then presented in a matrix to aid decision-making.

A trade-off analysis using a weighting approach involves weighting the relative importance of each decision factor. Such an approach will always be open to criticism because the weights may be seen as arbitrary or biased. Although some methods are available, experience indicates that it may be difficult to reach a consensus about the appropriate weights to be allocated. It is desirable to undertake sensitivity analysis on the scores and weights attached to different criteria (Section 6.3).

Multi-criteria analysis The techniques summarised above can be incorporated into what is termed multi-criteria, or multi-attribute, analysis. This approach involves multiplying the weighting for each decision factor by the rank, rating or scale value of each option. The resulting products are then totalled to arrive at an overall score for each option.

8.3 Which technique?

Any particular technique selected for trade-off analysis will have inherent assumptions and limitations and these should be stated for the purposes of openness and transparency. The results of a particular analysis should be seen as an aid to decision-making, rather than providing a definitive answer on the preferred option.

8.4 Iteration

Unless the intention is very simple it will be necessary to revisit some or all stages in the risk assessment process. Certainly, the decision-making process may highlight significant information gaps not identified at an earlier stage. The problem is in balancing an understandable desire to gather ever more information before choosing a course of action with the need to make a timely decision. Lack of information should not be used as an excuse for postponing or avoiding decision-making. Significant information gaps may be cause to invoke the precautionary principle (Section 1.6).

If the risks associated with an intention are acceptable then the intention can go ahead. If an intention presents unacceptably high risks, however, then mitigatory options will be required. This can include not undertaking the intention and thereby completely avoiding the risk (but also forfeiting any benefits that might have resulted). Each risk management option should be reassessed through the risk assessment process to determine whether it reduces the risks to an acceptable level. Each option may introduce new risks and the reassessment should not just be a review of what has already been considered.

8.5 Risk communication and decision-making

During options appraisal it will normally be necessary, as in all preceding stages, to engage in dialogue with relevant stakeholders. The guidance provided in Chapter 3 is as relevant to the risk management process as it is to risk assessment.

The case studies in Annex I provide examples of how decisions were reached in some particular instances.

8.6 Further information

Key references

Department of the Environment (1991) *Policy Appraisal and the Environment*, London, UK, HMSO
This document highlights the need to examine environmental impacts within policy decision analyses.

EFTEC for DETR (1998) *Review of the Technical Guidance on Environmental Appraisal, London, UK, DETR*

Environment Agency (1997) *Taking Account of Costs and Benefits*, Bristol, UK, Environment Agency
Provides guidance for Environment Agency staff on how the 'Cost and benefits' duty in Section 39 of the Environment Act 1995 may be carried out.

HM Treasury (1997) *Appraisal and Evaluation in Central Government: Treasury Guidance, London, UK*, TSO
This document deals with risk and environmental impacts as aspects of the general appraisal framework for projects, programmes and policies.

Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Framework for Environmental Health Risk Management* (Final Report), Vol. 1, Washington DC, USA, Presidential/Congressional Commission on Risk Assessment and Risk Management
Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Risk Assessment and Risk Management in Regulatory Decision Making* (Final Report), Vol. 2, Washington DC, USA, Presidential/Congressional Commission on Risk Assessment and Risk Management
A particularly useful reference in discussing the role and involvement of stakeholders.

Key periodicals

Journal of Environmental Assessment Policy and Management

Journal of Environmental Management

Project Appraisal

Risk Analysis

Sustainable Development

CHAPTER 9
Monitoring

9.1 Introduction

This chapter outlines the main points to consider in monitoring, but it is not the purpose of these guidelines to provide detailed advice. Monitoring plays a central role in environmental risk assessment and management and is undertaken to gain continuous or periodic information about aspects of an intention before it starts, during its lifetime and after its completion. Information from monitoring programmes is integrated into environmental risk assessment and management in various ways:

- as the baseline against which to compare actual and predicted impacts;
- as an input to models, forecasts and quantification stages;
- to provide information to feed back into the risk assessment in an iterative process;
- to confirm that risk assessments and management options are meeting their desired aims; and
- as an alert mechanism if adverse impacts are found.

Baseline information

Describing the situation before the intention is one of the first steps in the problem formulation stage (Chapter 4). Where possible, this baseline should be derived from sampling and monitoring in the immediate vicinity of the intention. Where this is not possible (for example, where the operation being assessed has already commenced) the baseline can be derived from a reference area unaffected by the intention. In this case, the reference area should be similar in physical, environmental and ecological character. In some situations it may be useful to use such a reference area as a control, in which case baseline monitoring will be needed both at the reference area and in the immediate vicinity of the intention.

The baseline is not static and may change over time within a given area. Impacts that may appear at first to be attributable to the intention may in fact be the result of natural variation or other indirect changes (Section 7.3). It is also important to consider the effect that socio-demographic changes can have on the significance of a risk.

A related issue is distinguishing effects of previous or nearby activities from effects stemming from the intention. Only with a well-defined baseline can such a distinction be made. For instance, the death of vegetation near a newly built factory on a former gas works site could not easily be attributable to either the new factory or the previous site use without baseline monitoring.

Models and forecasts Monitoring programmes can provide valuable data for modelling and forecasting the environmental effects of an intention. The information need not be new (ie gathered specifically for the purpose). For example, actuarial data are used to help predict when components in a system will fail (Section 6.2). The more specific the information is to the intention, the more certainty can be placed in predictions or models based on it.

While monitoring can help predict trends, it is less useful where events are rare or where an event is not easily distinguishable from the baseline.

Audit and alert Because of the inherent uncertainty in environmental risk assessment, some forecasts may not be on target. Monitoring thus becomes a useful tool for either confirming or contradicting forecasts. For example, a risk assessment of a new shopping centre may predict no significant adverse effects on local air quality from changes in traffic patterns, but monitoring may show air quality impacts of more significance than predicted. There are two courses of action to take when this happens: first, to instigate management options to address the impacts, and second, to use the findings to modify and improve current and subsequent risk assessments. This highlights the iterative nature of the risk assessment framework described in Chapter 2.

Monitoring can also play a role in retrospective assessment. This approach is similar to human epidemiology and is sometimes termed ecoepidemiology. For example, the cause of a decline in a lake's fish stocks may not immediately be apparent. Using ecoepidemiology, the reproductive success, contaminant levels, fry survival and other parameters might be used to infer that the decline was caused by contamination.

9.2 What to monitor

It is rare to be able to monitor every parameter relating to the intention. It is therefore important to tailor a monitoring programme to the particular situation; it should be designed with specific goals and questions in mind in order to increase its usefulness and cost-effectiveness.

Problem formulation Deciding what to monitor will to a great extent depend on the intention in question and on the outcome of the problem formulation stage (Chapter 4). The problem formulation should have identified the most important risk components associated with a given intention and it is these components that require monitoring. The problem formulation will also define the temporal and spatial scale of the risk assessment and thereby define the monitoring boundaries.

Controlling factors Hazardous events are often subject to factors controlling their timing, intensity and duration (Section 4.5). These factors are an ideal focus for a monitoring programme. For example, it will be difficult to predict a flood without monitoring rainfall and river flows.

Expertise and knowledge A prerequisite for the design of an effective environmental monitoring programme is a good understanding of the local ecosystem and the possible effects of the intention. This understanding underlies the identification of the possible risks of the intention. In addition, projects or policies can have effects that extend beyond local ecosystems and have regional, national or even global significance, such as acid rain or global warming.

Two key considerations to note when choosing measurement parameters are natural variability and sensitivity to risk exposures. For instance, a simple approach in ecosystem monitoring is observing changes in population levels of important, relevant species. If there is no change in population then there is deemed to be no significant effect. Such an approach is not sufficiently refined, however, to detect sub-lethal effects, and for this purpose, more descriptive measures of status of the environment are employed, such as reproductive rates and bioconcentration levels.

9.3 Designing the monitoring programme

Having decided what information is needed for assessing and managing the risk, and from this deciding what to monitor, the next stage is to design the monitoring programme. Normally, specialist advice will be needed in order to ensure that the appropriate parts of the environment (air, water, soil, biota) are monitored and that the programme delivers the information required at an optimum cost. Preliminary surveys to obtain data on which to base the design may be needed. A poorly designed monitoring programme will almost certainly result in considerable waste of time and effort and, worse, fail to produce the information required to assess or manage the risk.

Where to sample

Sampling locations will normally be located either close to the risk being assessed, or in an appropriate reference area (Section 9.1). The precise location of the sampling point within that area can be of critical importance. For example, when sampling a river for water quality measurements, it is important to know whether or not water quality is homogeneous across the river at the sampling point. If it is not, a decision will need to be made about where within the cross-section of the river the best information about environmental impact will be obtained.

When to sample

Sampling frequency will depend on the precision with which information is required, the natural variability of the receiving environment and the nature of the hazard. Statistical analysis of these factors will indicate the minimum sampling frequency necessary to deliver the required information. A lower sampling frequency will reduce the monitoring programme costs, but at the expense of reduced precision. A judgement will often be needed about the costs and benefits of improved precision.

Sampling pattern

If the feature being monitored is intermittent (for example, a non-continuous discharge to air) it will be necessary to determine the most useful sampling pattern. This will not always be a regular pattern. For example, sampling air quality at the same time of day, on the same day each week will only provide limited information on general air quality. If this happens to coincide with a regular discharge then the monitoring programme will provide information about the instantaneous effect of the discharge on air quality. If the long-term or average impact of the discharge on air quality is required, then a different sampling pattern will be necessary (for example, a randomised or regularly rotating programme).

Sampling technique

The way in which the sample is taken, the type of material in which it is collected and stored, and the length of time between sampling and any further investigation (for example chemical analysis) can all substantially influence the validity of the derived data. Factors to be considered include the dangers of cross-contamination from the sampling container, disturbance of the sample by inappropriate handling or storage, and, when sampling birds, fish or mammals, the need to avoid inflicting unnecessary suffering.

9.4 Interpreting and dealing with monitoring data

Even simple monitoring and sampling programmes produce large amounts of raw data that, to be of most value to risk assessment and management, must be interpreted and processed appropriately. The methods used for this will depend on the type of data gathered and their proposed use. Data presentation can range from simple graphs, figures or tables, to more complex methods using mapping techniques or Geographic Information Systems.

The various parameters in a monitoring programme are sometimes aggregated or represented as an index (such as 'ecosystem health'), or expressed in terms of one parameter that integrates other factors. For example, the parameter 'species abundance' can reflect anthropogenic factors such as chemical contamination, physical disturbance and harvesting rates as well as natural variables. However, indices such as ecosystem health may not be transparent or comprehensible to either the public or decision-makers.

Wherever possible, the key stakeholders and the general public should have access to both the raw and the processed data, making sure that the key uncertainties and assumptions made are duly described.

9.5 Further information

Key references

Calow P, ed (1993/1994) *Handbook of Ecotoxicology*, Vols. 1 and 2, London, UK, Blackwell Scientific Publications
This is a well-structured and clear account of ecotoxicology; of particular interest is Chapter 20 in Volume 1 (Hopkin) focusing on monitoring, its driving forces, the main approaches, and recommendations on how to ensure it meets the needs of risk management and decision-making.

Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science
A comprehensive treatment of the basic principles of environmental risk assessment and management. Various chapters discuss monitoring, auditing and surveillance.

Keith LH (1991) *Environmental Sampling and Analysis: a practical guide*, Michigan, USA, Lewis Publishers
Covers the planning, sampling, analysis and reporting of environmental monitoring programmes.

Lave LB & Upton AC, eds (1987) *Toxic Chemicals, Health and the Environment*, Baltimore, USA, Johns Hopkins University Press
A useful collection of papers on environmental monitoring, from measuring chemicals in the environment to the clean-up of contaminated sites.

Peakall D (1992) *Animal Biomarkers as Pollution Indicators*, London, UK, Chapman & Hall
A thorough review and discussion of the use of biomarkers (particularly animals) in ecotoxicology and pollution monitoring, including their role in studies at the individual level to the level of the ecosystem.

Schnoor JL (1996) *Environmental Modeling: Fate and Transport of Pollutants in Water, Air and Soil*, New York, USA, John Wiley & Sons
Addresses key questions about fate, transport and long-term effects of chemical pollutants in the environment.

Walker CH, Hopkin SP, Sibly RM & Peakall DB (1996) *Principles of Ecotoxicology*, London, UK, Taylor & Francis
An excellent textbook covering the fundamentals of ecotoxicology, including fate and behaviour of chemicals, use of biomarkers, toxicity testing and discussions on ecotoxicological impacts from the level of the individual through to the ecosystem, including case studies.

Electronic information sources

Bath Information Data Services internet site — http://www.bids.ac.uk/

British Geological Survey internet site — http://www.bgs.ac.uk/

Centre for Ecology and Hydrology internet site — http://www.ceh-nerc.ac.uk/

Countryside Agency internet site — http://www.countryside.gov.uk/

DETR Environmental Protection internet site — http://www.environment.detr.gov.uk/

English Nature internet site — http://www.english-nature.org.uk/

Manchester Metropolitan University Atmospheric Research and Information Centre internet site — http://www.doc.mmu.ac.uk/aric/arichome.html

Natural Environment Research Council internet site — http://www.nerc.ac.uk/

UK National Air Quality Information Archive internet site — http://www.aeat.co.uk/netcen/airqual/

World Conservation Monitoring Centre internet site — http://www.wcmc.org.uk/

WRc (Water Research Centre) internet site — http://www.wrcplc.co.uk/

Key periodicals

Agriculture, Ecosystems and the Environment

Clean Air

Conservation Biology

Environmental Pollution

Environmental Science and Technology

Environmental Toxicology and Chemistry

Global Climate Change Digest

Ground Water Monitoring and Remediation

Haznews

Journal of the Air and Waste Management Association

Journal of the Chartered Institution of Water and Environmental Management

Marine Pollution Bulletin

Water Environment Research

Water Research

ANNEX I
Case studies

A1.1 Risk assessment for the release of genetically modified sugar beet

This annex is adapted from an application for consent to release genetically modified (GM) sugar beet submitted under the *Genetically Modified Organisms (Deliberate Release) Regulations 1992* (as amended 1995 and 1997).

The release is for research purposes only and relates to a small-scale trial to assess the field performance of GM sugar beet modified for tolerance to the herbicide glufosinate ammonium.

The GM sugar beet has two inserted genes: a bacterial gene (*pat*) which encodes the enzyme phosphinothricin-N-acetyltransferase enabling the sugar beet to withstand applications of the herbicide glufosinate ammonium; and a bacterial gene (*neo*) which encodes the enzyme neomycin phosphotransferase which confers resistance to the antibiotic kanamycin.

The GM sugar beet seeds were sown in March 1997 in a sugar beet growing area and were monitored at weekly intervals during the release to ensure that any bolting plants (plants which enter their reproductive phase) were removed and destroyed before the onset of flowering. At harvest, in October 1997, the beets were collected and any remaining plant material pulverised and ploughed into the soil. After harvest, the release site was planted with a cereal crop and monitored for one year to ensure any regrowth of the sugar beet (volunteers) was destroyed.

The risk assessment described below indicates that the release of this genetically modified organism (GMO) may pose a low risk to the environment because of the likelihood of gene transfer to wild relatives or sugar beet crops, and/or survival of the GMO. Any risk from these hazards is reduced to near zero by destroying bolters during the release and any volunteers during post-release monitoring.

Hazard identification

Capacity to survive, establish and disseminate in the environment

The GM sugar beet may have a greater tendency to overwinter, establish and invade habitats that are normally beyond sugar beet's range. It may also become an agricultural pest, ie a weed.

Potential for gene transfer between the GM sugar beet and other organisms

Three scenarios are envisaged:

- GM sugar beet cross-pollinates commercial sugar beet crops;
- GM sugar beet cross-pollinates a wild relative — *B. maritima* — to produce kanamycin-resistant glufosinate-tolerant hybrids; and

- the glufosinate gene and kanamycin gene in GM sugar beet are transferred to micro-organisms resident in the gut of humans and animals during ingestion.

Products of expression of inserted genes

The GM sugar beet produces two novel enzymes: phosphinothricin acetyltransferase that confers herbicide tolerance and neomycin phosphotransferase that confers tolerance to the antibiotic kanamycin. Both gene products are non-toxic to plants, animals or man, but the allergenic properties of these proteins are unknown, as are the indirect effects of the expression of these foreign proteins in sugar beet.

Phenotypic and genetic instability

The loss of kanamycin resistance and herbicide tolerance would make these plants sensitive to kanamycin and glufosinate ammonium. This in itself does not represent a hazard but re-integration at a different site in the sugar beet genome could inactivate the expression of other genes and this might be harmful.

Pathogenicity to other organisms

Neither gene (*neo* and *pat*) are associated with pathogenic traits in bacteria. Neither strain of the donor organisms — *Escherichia coli* K12 and *Streptomyces viridiochromogenes* — are associated with pathogenicity. No hazard is identified.

Identification of consequences

Survival, establishment and dissemination

- The invasion of natural and semi-natural habitats and the erosion of species diversity; and
- A significant agricultural weed.

Potential for gene transfer between the GM sugar beet and other organisms

- *B. maritima* hybrids with glufosinate and kanamycin tolerance — the ecological consequences of this are uncertain. The traits might confer a selective advantage to these plants increasing their weediness that might result in habitat invasion.
- *B. maritima* hybrids may become an agricultural weed.
- Cross-pollination of sugar beet crops to yield seed that could lie dormant in locations at some distance from the release site. Resulting hybrids may be more resistant to weed management programmes to control volunteer beet in following crops.
- The transfer of the kanamycin resistance gene from sugar beet to micro-organisms which reside in the human or animal gut might reduce the effectiveness of treating bacterial infections with kanamycin.

Products of expression of inserted genes

- Neomycin phosphotransferase and phosphinothricin-N-acetyltransferase may cause an allergenic response in some people exposed to pollen expressing these two proteins.
- Interaction of these proteins with the metabolic pathways of sugar beet may give rise to toxic compounds.

Phenotypic and genetic instability

The loss of kanamycin resistance and herbicide tolerance would make these plants sensitive to kanamycin and glufosinate ammonium. This in itself does not represent a hazard but, the genes may integrate at a different genetic location disabling the expression of genes which may lead to harmful consequences.

Estimation of the magnitude of the consequences

Survival, establishment and dissemination

The proposed field trial with GM sugar beet is a small-scale test (less than 50 m^2) of limited duration (one growing season). It will take place within an agricultural environment where sugar beet is regularly grown. *The magnitude of the consequences for the agricultural and natural environment is estimated as: Mild.*

Gene transfer between the GM sugar beet and other organisms

B. maritima hybrids and sugar beet crops with kanamycin and glufosinate tolerance:

The scale of any impact on the surrounding countryside would be limited to a maximum distance of two miles initially. If a selective advantage is conferred by these genes they will be perpetuated and their gene frequency in the B. maritima population will rise. The time taken to see an environmental effect may take several years. If they become troublesome weeds in the agricultural environment then the time to see an effect will probably be shorter. *The magnitude of consequences is estimated as: Mild.*

Transfer of antibiotic resistance:

The scale of the impact would be restricted to animals fed the sugar beet as fodder and humans ingesting the sugar. Kanamycin is not important in clinical and veterinary medicine. The treatment of infections by pathogenic bacteria would not be compromised by the uptake of the kanamycin resistance trait. *The magnitude of consequences is estimated as: Mild.*

Products of expression of inserted genes

Toxicity:

Birds and animals that visit the site will be exposed. Any sugar harvested from the trial (50 m^2) will be mixed with sugar from conventional sugar beet crops thereby reducing any toxicity to people. *The magnitude of consequences is estimated as: Mild.*

Allergenicity:

The frequency of bolter formation is variable but normally less than 5% of the crop. Pollen production will therefore be limited, but any pollen produced can disperse significant distances and Peterborough is located 2 miles away so these people may be exposed for two months in the year. *The magnitude of consequences is estimated as: Mild.*

Phenotypic and genetic instability

Effects are likely to be of limited scale and duration. *The magnitude of consequences is estimated as: Mild.*

Probability of the consequences

Survival, establishment and dissemination

The recipient:

Sugar beet root fragments not destroyed at harvest can survive through mild winters and sprout to form volunteer plants the following year. Sugar beet is, however, a very uncompetitive plant in agricultural, natural and semi-natural habitats. It is non-invasive by nature and self-sustaining populations of sugar beet have never been reported in any habitat.

The genes inserted:

Tolerance to kanamycin and glufosinate are traits that are unlikely to increase the capacity of the GM sugar beet to survive, establish and invade natural or semi-natural habitats. Kanamycin and glufosinate are not factors which influence plant competitiveness in nature.

The GM beet:

Laboratory studies indicate that the parent and GM sugar beet are very similar in several characters including frost tolerance. Therefore, considering the characteristics of the parent, the properties of the genes inserted and preliminary data on the characteristics of the GM beet, *the probability that GM sugar beet will have a greater capacity to survive, establish and invade natural habitats is estimated as: Negligible.*

Survival of the GM sugar beet after the trial may allow limited survival and establishment in the agricultural environment where it may become a weed. Tolerance to glufosinate will give the GM sugar beet a selectable advantage when this herbicide is applied in weed management programmes. However, the GM sugar beet is sensitive to other herbicides used to control sugar beet volunteers and so its establishment is likely to be transient. *Therefore, the probability of the modified sugar beet becoming an agricultural pest is estimated as: Low.*

Gene transfer

Sugar beet is a biennial, growing vegetatively in the first year and flowering in the second; sugar beet is harvested at the end of the first year. However, a minority of individuals (2–5%) flower in the first year, produce pollen and set seed. Pollen is wind rather than insect dispersed and can travel in excess of 2 miles. The transfer of the transgenes to sugar beet crops which are located 100 metres away from the site and to *B. maritima* which grows at this location is therefore likely.

Beta maritima:

Glufosinate- and kanamycin-tolerant *B. maritima* are unlikely to become more competitive and invade other habitats including the agricultural environment as a result of inheriting these traits. *Therefore, the probability of B. maritima hybrids invading new habitats and becoming an agricultural pest is estimated as: Low.*

Sugar beet crops:

Hybrid sugar beet seed which emerge in following crops will be susceptible to normal agricultural practices of weed control and will not persist. *Therefore, the probability of sugar beet hybrids becoming an agricultural pest is estimated as: Low.*

Bacteria:

High levels of the kanamycin resistance already exist in bacterial populations. Transfer of this gene from plants to bacteria (from where it was derived) would **not** lead to a significant increase in background levels. Also, the frequency of horizontal gene transfer from plants to bacteria is very small. *Therefore, the probability of GM sugar beet compromising the therapeutic use of kanamycin in people which consume the sugar is estimated as: Negligible.*

Products of expression of inserted genes

Toxic effects:

Toxicity due to the insertion of these non-toxic genes into sugar beet is unlikely. Furthermore, the mixing of sugar derived from this small plot with sugar derived from conventional crops will dilute any toxins produced. *Therefore, the probability of toxic effects is estimated as: Low.*

Allergenic effects:

These are not expected because the proteins do not resemble known allergenic proteins. Also the production of pollen from the plot will be small (bolter frequency × plot size). However, people in Peterborough could be exposed for two months. *Therefore, the probability of allergenicity is estimated as: Low.*

Phenotypic and genetic instability

Observations from successive generations show stable transgene insertion and expression. *Therefore, the probability of gene instability is estimated as: Negligible.*

Evaluation of the significance of the risk

The overall risk of damage to human health and the environment is *low to effectively zero* as the following components of risk have been assessed as:

Survival, establishment and dissemination	Low
Gene transfer to sugar beet crops	Low
Gene transfer to *B. maritima*	Low
Horizontal gene transfer to bacteria	Near Zero
Phenotypic and genetic instability	Near Zero
Toxicity and allergenicity of gene products	Low
Pathogenicity to other organisms	Near Zero

Risk management

Survival, establishment and dissemination

At harvest the GM sugar beet material will be pulverised and ploughed into the soil. Therefore, the risk of survival, establishment and dissemination is reduced from low to near zero.

Toxicity:

No GM sugar beet will be permitted to enter the human food or animal feed chain. Therefore, the risk of toxic effects is reduced from low to near zero.

Allergenicity:

Bolters will be removed from the GM sugar beet before the onset of flowering to prevent pollen dispersal. Therefore the risk of pollen-mediated allergenic effects is reduced from low to near zero.

Gene transfer to crops and *B. maritima*:

Bolters will be removed from the GM sugar beet plants before the onset of flowering to ensure gene transfer to neighbouring sugar beet crops and *B. maritima* is prevented. Therefore the risk of habitat invasion from *B. maritima* hybrids is reduced from low to near zero.

Monitoring

During the trial

The GM sugar beet will be monitored at weekly intervals during the release to ensure that any bolting plants (plants which enter their reproductive phase) are destroyed before the onset of flowering.

Post trial

The release site will be inspected twice in the year following the trial for the effective control and destruction of any GM sugar beet.

A1.2 Risk assessment for road transport: a semi-quantitative methodology

This case study was undertaken at both a screening level (Tier 1) to identify the primary areas of concern, and a generic level (Tier 2) to quantify some of the risks facing the environment. The risk assessment was undertaken by the Environment Agency which, although not having a formal remit in relation to road transport, needed to take a holistic long-term view of the associated issues since they have a bearing on its ability to regulate and manage the environment effectively. The Agency also needed to be informed in discussions with Government and other organisations. A risk-based framework was imposed on the information available for a wide range of issues. At such a strategic level, it is necessary to make and record broad assumptions and understand how uncertainties in information affect the final outcome.

TIER 1 — RISK SCREENING

Hazard identification

Many authoritative studies have highlighted the severe and widespread environmental impacts of road transport. From discussions with experts in the field, the Environment Agency determined the following environmental consequences to be of particular concern:

- Raw materials
- Road construction
- Road maintenance
- Road run-off
- Accidents and spillages
- Exhaust emissions
- Waste and tyre disposal

Identification of consequences

The full range of consequences arising from road transport has yet to be fully established. From discussions with experts in the field, the following consequences were determined to be of concern:

- Climate change
- Poor air quality
- Poor soil quality
- Poor water quality
- Flooding
- Impact on water resources
- Ecological damage
- Landscape
- Property
- Human health
- Quality of life

Estimation of the magnitude of the consequences

An expert elicitation exercise was carried out to determine the priorities with respect to the consequences. This was based on three key factors: the significance of the consequences, whether the Environment Agency has a policy or formal remit in the area, and whether there is capacity to mitigate the effects.

The following consequences were deemed to be important for certain hazards: water quality, flooding and water resources, ecological quality, soil quality, air quality and climate change. Many other issues were considered to be as important but too far outside the Agency's remit.

Probability of the consequences

At the screening level, the probability was determined to be unity, as the activities were known to occur, and the consequences had been linked by scientific knowledge and professional experience to the hazards.

Evaluation of the significance of the risk

The expert elicitation process enabled the consequences for each hazard to be prioritised. As a result the following consequences for each hazard were determined to be of sufficient concern to warrant further investigation at Tier 2.

Road construction and maintenance

Ecological quality, water quality, flooding and water resources, ecological quality and/or habitat loss.

Road use

Water quality, climate change, air quality, soil quality.

TIER 2 — GENERIC QUANTITATIVE RISK ASSESSMENT

Hazard identification

The primary focus for hazard identification at this stage was the Tier 1 risk screening described above. A wide range of risks was identified and the example given here for illustration is that of road construction giving rise to water quality problems.

A range of scenarios was discussed by an expert group, and the following hazard scenario was specifically chosen for further assessment:

- The transport of sediment into watercourses during the construction of roads.

Identification of consequences

Suspended solids are responsible for the siltation of spawning grounds for migratory fish such as salmon, and for harm to habitats and aquatic macrophytes. The first of these consequences can lead to significant declines in populations of key fish species.

Estimation of the magnitude of the consequences

The magnitude of the consequences was determined through the use of event trees containing information derived from scientific literature, monitoring programmes, and expert opinion.

The consequences were deemed to be high when intense storms coincide with lower river flows in summer.

Probability of the consequences

The contribution to suspended sediment concentrations from road construction was represented in an event tree. Under average conditions most sediment (0.89) is incorporated into the ground works of the road. Around 0.02 of the sediment is removed in control structures and less than 0.05 is transported into surface water. The remainder is deposited elsewhere in the catchment from dirty vehicles or by wind erosion and deposition.

Evaluation of the significance of the risk

The risk was determined to be significant for this impact. Discharges from road construction sites may be up to 14 times greater than the Environmental Quality Standard (EQS) for suspended solids in surface waters taken for potable supply.

Risk management

The sediment trapping efficiency of control structures has been taken into account in determining the probability of the consequences. Clearly further efficiency improvements in this area would be useful. In addition, the timing of construction is important, and could contribute to risk management planning. In particular, construction during times of lower river flow may be inappropriate.

Monitoring

The Environment Agency will detect the consequences of such activities through its General Quality Assessment scheme for surface waters. The monitoring of sediment erosion by those responsible for construction will greatly assist early remediation of the hazard.

A1.3 Risk assessment of coastal flooding: a semi-quantitative methodology

This risk assessment provides an indication of the relative level of risk for various sections of developed land behind a coastal defence. The risk relates to flooding with consequential damage to property, and harm to humans, including injury and potential loss of life.

This case study was undertaken at a Tier 1 screening level to assess coastal flood risks to different types and mixes of development from a well-characterised flood hazard. Its principal use was in combining what was known quantitatively about the flood hazard with qualitative information that could reasonably be inferred regarding community vulnerability and response, to provide an overall risk screening of the area behind the existing sea defences.

TIER 1 – RISK SCREENING AND RISK PRIORITISATION

Hazard identification

Flood waters

The principal hazard is:

- a threat to human life and property from saline water overtopping or percolating through a coastal defence structure.

The hazard is initiated by a combination of wind, waves, storm surges and astronomical tides which exceed the strength of the coastal defences and lead to flooding of the land area behind. The volume, depth and velocity of flood waters are important in determining the consequential harm.

Secondary hazards

The force of water can introduce further hazards, the adverse impacts of which can be significant:

- debris including beach shingle, cars and skips may be picked up and carried by the flood waters and may also cause injury and structural damage.

Identification of consequences

Flood waters

The overriding consequence of such an event is that flood waters inundate a land area behind the coast. In the context of this study, the principal resulting consequences of this event were considered to be:

- injury to humans including potential loss of life from debris, flowing and ponded water;
- structural damage to residential and commercial properties due to debris and flowing water; and
- water damage to residential and commercial properties due to ponded water.

Importantly, the presence of flood waters can also lead to:

- restricted access to roads, disruption to travel, and delayed access by emergency services.

For this case study, the flood hazard had been previously characterised from specialist studies and the severity of various flood events assessed by considering:

- the mechanism of flooding (overtopping or percolation);

- the flood volume;
- the mode of action for moving water (direct wave impact, surging water flow, secondary impact of moving water, steady water flow or ponded water); and
- the presence of debris in areas of land behind the coast.

Flood volumes and water velocities for each land section were estimated. This assessment provided an inventory of potential consequences by land section according to whether the flood event was initiated by overtopping of, or percolation through, the coastal defence and the amount of water involved in each case.

Estimation of the magnitude of consequences

The nature of harm posed by the flood hazard and the vulnerability of receptors determine the magnitude of the consequences. Here, each land section was assessed by considering the severity of the flood event, the nature of harm that could result and the vulnerability of the development in each case; the latter with reference to the development 'mix' of each land section. The principal consequences were weighted (in *italics*) according to the nature of harm posed within the context of this study:

- no significant damage (*1*)
- minor water damage to properties (*10*)
- minor structural damage (*50*)
- major structural damage or injury (*500*)
- loss of life (*2000*)

The vulnerability of the development type in each section of land to these consequences was assigned an indicative 'value', from 1 (for low value structures) to 5 (for developments with a high residential mix).

For each land section, a product of the exceedance probability referred to below (eg 0.02) and the principal consequence type (eg 500) for each land section, weighted according to its vulnerability (eg 4), provided a relative assessment of the magnitude of the consequences. Damage scores were aggregated for floods of selected exceedance probability (and severity).

Probability of the consequences

Flooding is a natural and episodic risk. It is important to identify the consequences that may occur for any given probability (and severity) of the hazard. In this regard, flood risk is inherently distinct from most chemical risk assessments.

In this case study, the magnitude of the consequences was estimated for floods with annual exceedance probabilities of 0.1, 0.02 and 0.005 (ie with mean return intervals of 10, 50, and 200 years) as described above.

The resulting damage assessment or '*damage profile*' (Table A1.1 below) represents the relative probability and magnitude of the consequences for each section of land. The higher the ranking, the higher the estimated damage. It assumes, however, that the damage sustained is independent of community response in each land section and one of the aims of the study was to factor this in accordingly. For example, the probability of harm to humans is dependent on their ability to respond to the flood in advance and whilst it occurs, and also to the ability of emergency services to respond to their needs.

To account for these issues, the generalised sections of land behind the existing defences were each scored according to their reliance on various community response factors. The main factors controlling the probability of harm being sustained were deemed to be (weighting according to relative importance in *italics*):

- the availability of access by emergency vehicles (*5*);
- the availability of easy routes of evacuation to shelters (*5*);
- the amount of advanced warning available (*5*);
- a prior knowledge of evacuation procedures (*3*);
- the availability of access to shelter within the property (*2*); and
- the existence of protection for properties (drop boards, *etc.*) (*2*).

The extent to which these factors were likely to influence community response in each land section following the issue of a red flood warning was accounted for by scoring them on a 1 (low influence) to 5 (high influence) basis. Local flood defence staff with knowledge and experience of procedure and likely response were used to elicit individual scores, the means of which were summed and taken to represent a '*response profile*'.

Evaluation of the significance of the risk

Table A1.1 shows damage, response and risk (sum of damage and response) profiles for the land sections studied. To avoid over-attribution to the scores, sections were banded and assigned a qualitative risk designation. In a relative risk context, the *very high* designation represents a risk of substantial damage with little ability to respond on receipt of a red warning. *High* represents substantial or moderate damage with possible access to escape routes. *Medium* represents lower damage with reasonable ability to respond due to the level of emergency access, *etc.* These designations were interpreted in the context of flood probability that was well-characterised, assessed in detail and had accounted for storm severity, probability and sea defence performance.

Risk management

The principal risk management action determined from this assessment and other supporting data is a recommendation that development or re-development be steered away from areas where the risk is deemed to be high or very high.

In general, the case study has shown the need to consider community response factors and strengthen the public awareness of how to respond to flood hazards. It has highlighted the importance of emergency planning and the ability to provide the necessary resources including people, equipment and materials for dealing with flooding.

Monitoring

The monitoring of the risk will be undertaken within an overall flood monitoring and warning framework. In addition, it will be necessary to monitor the development of properties within the flood plain, in areas that are deemed to be at greatest risk from coastal flooding.

Table A1.1 **Damage, response and risk 'profiles' and designations for sections of land behind a coastal defence scheme**

Land section	Damage profile	Response profile	Risk profile	Designation
1	350	102	452	Very High
2	125	102	227	High
3	125	97	222	High
4	100	98	198	High
5	105	87	192	High
6	100	92	192	High
7	105	84	189	High
8	105	69	174	High
9	48	53	101	Medium
10	14	84	98	Medium
11	3	87	90	Medium
12	1	79	80	Medium

ANNEX II
Bibliography

Adams J (1995) *Risk*, London, UK, UCL Press

Baines J (1995) *Beyond Compromise: Building Consensus in Environmental Planning and Decision-making*, London, UK, The Environment Council

Baird DJ, Maltby L, Greig-Smith PW & Douben PET (1996) *ECOtoxicology: Ecological Dimensions*, London, UK, Chapman & Hall

Begon M, Harper JL & Townsend CR (1990) *Ecology: Individuals, Populations and Communities* (Second edition), Oxford, UK, Blackwell Scientific Publications

Bell S (1997) *Ball and Bell on Environmental Law: The Law and Policy Relating to the Protection of the Environment* (Fourth edition), London, UK, Blackstone Press

Biodiversity: The UK Steering Group (1995) *Biodiversity: The UK Steering Group Report, Volume 1: Meeting the Rio Challenge*, London, UK, HMSO

Biodiversity: The UK Steering Group (1995) *Biodiversity: The UK Steering Group Report, Volume 2: Action Plans*, London, UK, HMSO

Blake ER (1995) Understanding outrage: how scientists can help bridge the risk perception gap. *Environ Health Perspect, 103* (suppl 6), 123–125

Blowers A, ed (1993) *Planning for a Sustainable Environment*, London, UK, Earthscan Publications

Bowers JK (1997) *Sustainability and Environmental Economics*, Harlow, UK, Earthscan

Brookes A (1999) *Road Transport and the Environment: Risk Assessment*, Final Report, London, UK, National Centre for Risk Analysis and Options Appraisal, Environment Agency

Calow P (1992) Can ecosystems be healthy? Critical consideration of concepts. *J Aquatic Ecosystem Health, 1*, 1–5

Calow P, ed (1993/1994) *Handbook of Ecotoxicology*, Vols. 1 and 2, London, UK, Blackwell Scientific Publications

Calow P (1997) *Controlling Environmental Risks from Chemicals: Principles and Practice*, Chichester, UK, John Wiley & Sons

Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science

Campbell LH & Cooke AS (1997) *The Indirect Effect of Pesticides on Birds*, Peterborough, UK, Joint Nature Conservation Committee

CEC (1979) Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds; OJ L103 25.04.79

CEC (1982) Council Directive 82/501/EC of 24 June 1982 on the major-accident hazards of certain industrial activities; OJ L230 05.08.82

CEC (1991) Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market; OJ L230 19.08.91

CEC (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora; OJ L206 22.07.92

CEC (1996) Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances; OJ L10 14.01.97

Covello VT & Allen F (1988) *Seven Cardinal Rules of Risk Communication*, Washington DC, USA, US Environmental Protection Agency

Covello VT & Merkhofer MW (1993) *Risk Assessment Methods: Approaches for Assessing Health and Environmental Risks*, New York NY, USA, Plenum Press

Crossland B, Bennet PA, Ellis AF, Farmer FR, Gittus J, Godfrey PS, Hambly EC, Kletz TA & Lees FP (1992) Estimating engineering risk. In: Royal Society (1992) *Risk: Analysis, Perception and Management* (Second edition), London, UK, The Royal Society

DeAngelis DL (1996) Indirect effects: concepts and approaches from ecological theory. In: Baird DJ, Maltby L, Greig-Smith PW & Douben PET (1996) *ECOtoxicology: Ecological Dimensions*, London, UK, Chapman & Hall, pp 25–41

Department of Health (1991) *Guidelines for the Evaluation of Chemicals for Carcinogenicity* (Report on Health and Social Subjects 42), London, UK, HMSO

Department of Health (1998) *Communicating About Risks to Public Health — Pointers to Good Practice*, London, UK, TSO

Department of the Environment (1991) *Policy Appraisal and the Environment*, London, UK, HMSO

Department of the Environment (1995) *A Guide to Risk Assessment and Risk Management for Environmental Protection*, London, UK, HMSO

Department of the Environment/Advisory Committee on Releases to the Environment (1993) *The Regulation and Control of the Deliberate Release of Genetically Modified Organisms*, London, UK, Department of the Environment

Department of the Environment/Advisory Committee on Releases to the Environment (1995) *Guidance to the Genetically Modified Organisms (Deliberate Release) Regulations 1995*, London, UK, Department of the Environment

Derby SL & Keeney RL (1990) Risk Analysis: Understanding 'How Safe is Safe Enough?'. In: Glickman TS & Gough M (1990) *Readings in Risk*, Washington DC, USA, Resources for the Future

DETR (1998) *Policy Appraisal and the Environment: Policy Guidance*, London, UK, DETR

DETR (1998) *Opportunities for Change. Consultation Paper on a Revised UK Strategy for Sustainable Development* (Document reference 97EP0277), London, UK, DETR

DETR (1998) *Sustainable Production and Use of Chemicals. Consultation Paper on Chemicals in the Environment* (Document reference 98EP0058), London, UK, DETR

DETR (1999) *Sustainable Production and Use of Chemicals – A strategic approach. The Government's Chemicals Strategy*, London, UK, DETR

DETR/Environment Agency (2000) *Model Procedures for the Management of Contaminated Land*, CLR 11, London, UK, DETR (in preparation)

Douben PET, ed (1998) *Pollution Risk Assessment and Management*, Chichester, UK, Wiley & Sons Ltd.

EFTEC for DETR (1998) *Review of the Technical Guidance on Environmental Appraisal*, London, UK, DETR

Environment Agency (1997) *Introductory Guidance on the Agency's Contribution to Sustainable Development*, Bristol, UK, Environment Agency

Environment Agency (1997) *Taking Account of Costs and Benefits*, Bristol, UK, Environment Agency

Environment Agency (1998) *Consensus Building for Sustainable Development*, Bristol, UK, Environment Agency

Environment Council (1995) *Who's Who in the Environment — England*, London, UK, The Environment Council

European and Mediterranean Plant Protection Organisation (1994) Decision-making scheme for the environmental risk assessment of plant protection products; Terrestrial vertebrates. *EPPO Bull, 24*, 37–87

Felter SP, Dourson ML & Patterson J (1998) Assessing risks to human health from chemicals in the environment. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 9–23

Fite E (1998) ECOFRAM (a workgroup on probabilistic risk assessment for pesticides): Terrestrial progress report. In: *Interfaces in Environmental Chemistry and Toxicology: From the Global to the Molecular Level, 8th Annual Meeting of SETAC-Europe, 14–18 April 1998, Bordeaux, France*, Belgium, Society of Environmental Toxicology and Chemistry (SETAC)

Fort D, Hansen B, Irwin F, Jones S, Jones B, Socha A, Wilson R, Haaf B, Gray G & Hoffman B (1997) Framework for Chemical Ranking and Scoring Systems. In: Swanson MB & Socha AC (1997) *Chemical Ranking and Scoring: Guidelines for Relative Assessment of Chemicals*, Pensacola FL, USA, SETAC

Gardner GT & Gould LC (1989) Public perceptions of the risks and benefits of technology. *Risk Anal*, 9, 225–242

Giddings J (1998) ECOFRAM (a workgroup on probabilistic risk assessment for pesticides): Overview and aquatic progress report. In: *Interfaces in Environmental Chemistry and Toxicology: From the Global to the Molecular Level, 8th Annual Meeting of SETAC-Europe, 14–18 April 1998, Bordeaux, France*, Belgium, SETAC

Gould JH (1998) Evaluation of the likelihood of major accidents in industrial processes. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science

Haigh N, ed (1992) *Manual of Environmental Policy: The EC and Britain*, London, UK, Cartermill Publishing

Health and Safety Executive (1992) *The Tolerability of Risk from Nuclear Power Stations*, Sudbury, UK, HSE Books

Health and Safety Executive (1997) *Risk Ranking* (Contract Research Report 131/1997), Sudbury, UK, HSE Books

Health and Safety Executive (1999) *Reducing Risks, Protecting People*, Sudbury, UK, HSE Books

Health Council of the Netherlands: Committee on Risk Measures and Risk Assessment (1995) *Not All Risks are Equal* (Publication No. 1995/06E), The Hague, Netherlands, Health Council of the Netherlands

Health Council of the Netherlands: Committee on Risk Measures and Risk Assessment (1996) *Risk is More than Just a Number* (Publication No. 1996/03E), The Hague, Netherlands, Health Council of the Netherlands

Hedgecott S & Dobbs TJ (1998) Risk assessment and management for inland waters. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 475–505

HM Treasury (1997) *Appraisal and Evaluation in Central Government: Treasury Guidance*, London, UK, TSO

HMSO (1990) *Environmental Protection Act 1990* (c.43), London, UK

Hopkin SP (1994) *In situ* biological monitoring of pollution in terrestrial and aquatic ecosystems. In: Calow P (1994) *Handbook of Ecotoxicology,* Volume 2, London, UK, Blackwell Scientific Publications, pp 397–427

ILGRA (1996) *Use of Risk Assessment Within Government Departments: Report prepared by the Interdepartmental Liaison Group on Risk Assessment*, Sudbury, UK, HSE Books

ILGRA (1998) *Risk Assessment and Risk Management: Improving Policy and Practice within Government Departments*, Sudbury, UK, HSE Books

ILGRA (1998) *Risk Communication: A Guide to Regulatory Practice*, Sudbury, UK, HSE Books

Institute of Petroleum (1998) *Guidelines for the investigation and remediation of contaminated retail sites*, Colchester, UK, Portland Press

Kasperson RE, Renn O, Slovic P, Brown HS, Emel J, Goble R, Kasperson JX & Ratick S (1988) The social amplification of risk: A conceptual framework. *Risk Anal*, 8, 177–187

Keith LH (1991) *Environmental Sampling and Analysis: a practical guide*, Michigan, USA, Lewis Publishers

King NJ (1998) Application of risk assessment in policy and legislation in the European Union and in the United Kingdom. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 249–260

Kjørven O (1998) Environmental risk assessment in development programmes: the experience of the World Bank. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 506–519

Lave LB & Upton AC, eds (1987) *Toxic Chemicals, Health and the Environment*, Baltimore, USA, Johns Hopkins University Press

Lees N, Woolson H, O'Hara J & Wynne B (1997) *Environmental Information: A Guide to Sources* (Second edition), London, UK, The British Library Science Reference and Information Service

Mackay D (1994) Fate models. In: Calow P (1994) *Handbook of Ecotoxicology,* Volume 2, London, UK, Blackwell Scientific Publications, pp 348–367

Mackay D & Paterson S (1982) Fugacity revisited: the fugacity approach to environmental transport. *Environ Sci Technol*, *16*, 654A–660A

Marris C, Langford I & O'Riordan T (1996) *Integrating Sociological and Psychological Approaches to Public Perceptions of Environmental Risks: Detailed Results from a Questionnaire Survey*, Norwich, UK, Centre for Social and Economic Research on the Global Environment

May H & Burger J (1996) Fishing in a polluted estuary: fishing behaviour, fish consumption and potential risk. *Risk Anal*, *16*, 459–471

Newbold C (1975) Herbicides in aquatic systems. *Biol Conserv*, *7*, 97–118

Parliamentary Office of Science and Technology (1996) *Safety in Numbers? — Risk Assessment in Environmental Protection*, London, UK, Parliamentary Office of Science and Technology

Paustenbach DJ (1989) *The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies*, New York, USA, John Wiley & Sons

Peakall D (1992) *Animal Biomarkers as Pollution Indicators*, London, UK, Chapman & Hall

Pearce D (1998) Valuing risks. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 345–378

Pearce DW & Turner RK (1990) *Economics of Natural Resources and the Environment*, London, UK, Harvester Wheatsheaf

Pearce D, Markandya A & Barbier E (1994) *Blueprint for a Green Economy*, London, UK, Earthscan Publications

Perrings C, Mäler K-G, Folke C, Holling CS & Jansson B-O, eds (1997) *Biodiversity Loss: Economic and Ecological Issues*, Cambridge, UK, Cambridge University Press

Pitcher TJ & Hart PJB (1982) *Fisheries Ecology*, London, UK, Chapman & Hall

Pollard SJT, Harrop DO, Crowcroft P, Mallett SH, Jeffries SR and Young P (1995) Risk Assessment for Environmental Management. *Journal Chartered Institute of Water and Environmental Management*, 9, 621-628

Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Framework for Environmental Health Risk Management* (Final Report), Vol. 1, Washington DC, USA, Presidential/Congressional Commission on Risk Assessment and Risk Management

Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Risk Assessment and Risk Management in Regulatory Decision Making* (Final Report), Vol. 2, Washington DC, USA, Presidential/Congressional Commission on Risk Assessment and Risk Management

Rasmussen NC (1990) The application of probabilistic risk assessment techniques to energy technologies. In: Glickman TS & Gough M (1990) *Readings in Risk*, Washington DC, USA, Resources for the Future, pp 195–205

Renn O & Levine D (1991) Credibility and trust in risk communication. In: Kasperson RE & Stallen PJM (1991) *Communicating Risks to the Public*, The Netherlands, Kluwer Academic Publications, pp 175–218

Royal Commission on Environmental Pollution (1998) *Setting Environmental Standards*, Twenty-first Report, London, UK, TSO

Royal Society (1992) *Risk: Analysis, Perception and Management* (Second edition), London, UK, The Royal Society

Schnoor JL (1996) *Environmental Modeling: Fate and Transport of Pollutants in Water, Air and Soil*, New York, USA, John Wiley & Sons

Seidler RJ, Watrud LS & George SE (1998) Assessing risks to ecosystems and human health from genetically modified organisms. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 110–146

Simberloff D & Alexander M (1998) Assessing risks to ecological systems from biological introductions (excluding genetically modified organisms). In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 147–176

Slovic P (1992) Perception of risk: reflections on the psychometric paradigm. In: Krimsky S & Golding D, eds, *Social Theories of Risk*, London, UK, Praeger

Slovic P (1993) Perceived risk, trust and democracy. *Risk Anal*, *13*, 675–682

Slovic P (1996) Perception of risk from radiation. *Radiat Protect Dosim*, 68, 165–180

Smrchek JC & Zeeman MG (1998) Assessing risks to ecological systems from chemicals. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 24–90

SNIFFER *et al.* (1999) *Communicating Understanding of Contaminated Land Risks*, Stirling, UK, Scotland and Northern Ireland Forum for Environmental Research

Spackman M (NERA) (1998) *Developing a Common UK Approach to Negotiations on Risk Assessment at International Level*, London, UK, Health and Safety Executive

Stern PC & Fineberg HV, eds (1996) *Understanding Risk. Informing Decisions in a Democratic Society*, Washington DC, USA, National Research Council, National Academy Press

Suter GW II (1998) Retrospective assessment, ecoepidemiology and ecological monitoring. In: Calow P (1998) *Handbook of Environmental Risk Assessment and Management*, Oxford, UK, Blackwell Science, pp 177–217

Swanson MB & Socha AC (1997) *Chemical Ranking and Scoring: Guidelines for Relative Assessment of Chemicals*, Pensacola FL, USA, Society of Environmental Toxicology and Chemistry

Traas TP, Luttik R & Jongbloed RH (1996) A probabilistic model for deriving soil quality criteria based on secondary poisoning of top predators: I: Model description and uncertainty analysis. *Ecotoxicol Environ Saf*, *34*, 264–278

Tversky A & Kahneman D (1981) The framing of decisions and the psychology of choice. *Science, 211*, 453–458

UK Government (1994) *Sustainable Development: The UK Strategy* (Cm 2426), London, UK, HMSO

UK Government (1999) *Sustainable Development: A Better Quality of Life. A strategy for sustainable development for the UK* (Cm 4345), London, UK, TSO

US EPA (1998) *Guidelines for Ecological Risk Assessment* (EPA/630/R-95/002F), Washington DC, USA, US Environmental Protection Agency

Vari A, Kemp R & Mumpower JL (1991) Public concerns about LLRW facility siting — a comparative study. *J Cross-Cultural Psychol*, *22*, 83–102

Walker CH, Hopkin SP, Sibly RM & Peakall DB (1996) *Principles of Ecotoxicology*, London, UK, Taylor & Francis

Weinstein CE (1996) Ecotoxicology: environmental fate and ecosystem impact. In: de Serres FJ & Blood AJ (1996) *Ecotoxicity and Human Health: A Biological Approach to Environmental Remediation*, London, UK, Lewis Publishers, pp 63–85

Widdows J (1994) Marine and estuarine invertebrate toxicity tests. In: Calow P (1994) *Handbook of Ecotoxicology*, Volume 2, London, UK, Blackwell Scientific Publications, pp 145–166

World Commission on Environment and Development (1987) *Our Common Future*, Oxford, UK, Oxford University Press

Yoon KP & Hwang C-L (1995) *Multiple Attribute Decision Making: An Introduction*, Thousand Oaks CA, USA, Sage Publications

ANNEX III
Sources of further information

Government departments, agencies and committees

Advisory Committee on Hazardous Substances
Chemicals and Biotechnology Division
Department of the Environment, Transport and the Regions
Ashdown House
123 Victoria Street
LONDON SW1E 6DE
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Advisory Committee on Releases to the Environment
Chemicals and Biotechnology Division
Department of the Environment, Transport and the Regions
Ashdown House
123 Victoria Street
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http://www.environment.detr.gov.uk/acre/index.htm

Central Science Laboratory
Sand Hutton
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http://www.csl.gov.uk

Centre for Environment, Fisheries and Aquaculture Science
Pakefield Road
LOWESTOFT
Suffolk NR33 0HT
Tel: 01502 562244
Fax: 01502 513865
http://www.cefas.co.uk

Department of the Environment — Northern Ireland
Clarence Court
10–18 Adelaide Street
BELFAST BT1 2GB
Tel: 028 9054 0540
http://www.nics.gov.uk/env.htm

Department of the Environment, Transport and the Regions
Environmental Protection Group
Ashdown House
123 Victoria Street
LONDON SW1E 6DE
Tel: 020 7944 3000
http://www.detr.gov.uk

Department of Health
Richmond House
79 Whitehall
LONDON SW1A 2NL
Tel: 020 7210 4850
http://www.doh.gov.uk/

Environment Agency
National Centre for Risk Analysis and Options Appraisal
Steel House
11 Tothill Street
LONDON SW1H 9NF
Tel: 020 7664 6811
Fax: 020 7664 6911
http://www.environment-agency.gov.uk

Health and Safety Executive
Research Strategy Unit
PO Box 1064
SHEFFIELD S3 7YB
Tel: 0114 289 2365
Fax: 0114 289 2400
http://www.hse.gov.uk/hsehome.htm

Health and Safety Executive
Risk Assessment Policy Unit
Rose Court
2 Southwark Bridge
LONDON SE1 9HS
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Fax: 020 7717 6955
http://www.hse.gov.uk/hsehome.htm

HM Treasury
Treasury Chambers
Parliament Street
LONDON SW1P 3AG
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Fax: 020 7270 5244
http://www.hm-treasury.gov.uk

Ministry of Agriculture, Fisheries and Food
3–8 Whitehall Place
LONDON SW1A 2HH
Tel: 0645 335577
Fax: 020 7270 8419
http://www.maff.gov.uk

The National Assembly for Wales
Cardiff Bay
CARDIFF CF99 1NA
Tel: 029 2089 8200
http://www.wales.org.uk/index_e.html

Pesticides Safety Directorate (PSD)
Mallard House
King's Pool
3 Peasholme Green
YORK YO1 2PX
Tel: 01904 455775
Fax: 01904 455733
http://www.maff.gov.uk/aboutmaf/agency/psd/psdhome.htm

Scottish Environment Protection Agency (SEPA)
Erskine Court
Castle Business Park
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Tel: 01786 457700
Fax: 01786 446885
http://www.sepa.org.uk

Scottish Executive
Victoria Quay
EDINBURGH EH6 6QQ
Tel: 0131 556 8400
http://www.scotland.gov.uk

Non-departmental public bodies

British Geological Survey
Kingsley Dunham Centre
Keyworth
NOTTINGHAM NG12 5GG
Tel: 0115 936 3100
Fax: 0115 936 3200
http://www.bgs.ac.uk

Centre for Ecology and Hydrology
CEH-Directorate
Monks Wood
ABBOTS RIPTON
Cambridgeshire PE28 2LS
Tel: 01487 772400
Fax: 01487 773590
http://www.ceh-nerc.ac.uk/

Countryside Agency
John Dower House
Crescent Place
CHELTENHAM
Gloucestershire GL50 3RA
Tel: 01242 521381
Fax: 01242 584270
http://www.countryside.gov.uk

Countryside Council for Wales
Plas Penrhos
Ffordd Penrhos
BANGOR
Gwynedd LL57 2LQ
Tel: 01248 385500
Fax: 01248 355782
http://www.ccw.gov.uk

English Nature
Northminster House
PETERBOROUGH
Cambridgeshire PE1 1UA
Tel: 01733 455000
Fax: 01733 568834
http://www.english-nature.org.uk

Forestry Commission
231 Corstorphine Road
EDINBURGH EH12 7AT
Tel: 0131 334 0303
Fax: 0131 334 4473
http://www.forestry.gov.uk

Joint Nature Conservation Committee
Monkstone House
City Road
PETERBOROUGH
Cambridgeshire PE1 1JY
Tel: 01733 562626
Fax: 01733 555948
http://www.jncc.gov.uk

MRC Institute for Environment and Health
University of Leicester
94 Regent Road
LEICESTER LE1 7DD
Tel: 0116 223 1600
Fax: 0116 223 1601
http://www.le.ac.uk/ieh

National Radiological Protection Board
Chilton
DIDCOT
Oxfordshire OX11 0RQ
Tel: 01235 831600
Fax: 01235 833891
http://www.nrpb.org.uk

Royal Commission on Environmental Pollution
Steel House
11 Tothill Street
LONDON SW1H 9RE
Tel: 020 7273 6635
Fax: 020 7273 6640
http://www.rcep.org.uk

Scottish Natural Heritage
12 Hope Terrace
EDINBURGH EH9 2AS
Tel: 0131 447 4784
Fax: 0131 446 2277
http://www.snh.org.uk

Academic institutions

Centre for Analysis of Safety Policy and Attitudes to Risk (CASPAR)
University of Newcastle
Claremont Road
NEWCASTLE UPON TYNE NE1 7RU
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Fax: 0191 222 5780

Centre for Coastal and Marine Sciences
Plymouth Marine Laboratory
Prospect Place
West Hoe
PLYMOUTH PL1 3DH
Tel: 01752 633100
Fax: 01752 633101
http://www.npm.ac.uk

Centre for Environmental Strategy
University of Surrey
GUILDFORD
Surrey GU2 5XH
Tel: 01483 300800
Fax: 01483 876671
http://www.surrey.ac.uk/CES/

Centre for Hazard and Risk Management (CHaRM)
Loughborough University
LOUGHBOROUGH
Leicestershire LE11 3TU
Tel: 01509 222161
Fax: 01509 223991
http://www.lboro.ac.uk/departments/charm/excharm.html

Centre for Social and Economic Research on the Global Environment (CSERGE)
School of Environmental Sciences
University of East Anglia
NORWICH NR4 7TJ
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Fax: 01603 593739
http://www.uea.ac.uk/env/all/resgroup/cserge/

Non-government organisations

Chemical Industries Association (CIA)
Kings Buildings
Smith Square
LONDON SW1P 3JJ
Tel: 020 7834 3399
Fax: 020 7834 4469

Confederation of British Industry (CBI)
Centre Point
103 New Oxford Street
LONDON WC1A 1DU
Tel: 020 7395 8247
Fax: 020 7240 1578
http://www.cbi.org.uk

Council for the Protection of Rural England
Warwick House
25 Buckingham Palace Road
LONDON SW1W 0PP
Tel: 020 7976 6433
Fax: 020 7976 6373
http://www.greenchannel.com/cpre/

The Environment Council
212 High Holborn
LONDON WC1V 7VW
Tel: 020 7836 2626
Fax: 020 7242 1180
http://www.the-environment-council.org.uk

Environmental Data Services Limited
40 Bowling Green Lane
LONDON EC1R 0NE
Tel: 020 7814 5300
Fax: 020 7415 0106
http://www.ends.co.uk

Friends of the Earth
26-28 Underwood Street
LONDON N1 7JQ
Tel: 020 7490 1555
Fax: 020 7490 0881
http://www.foe.org.uk

Green Alliance
40 Buckingham Palace Road
LONDON SW1W 0RE
Tel: 020 7233 7433
Fax: 020 7233 9033
http://www.green-alliance.demon.co.uk/

Greenpeace
Canonbury Villas
LONDON N1 2PN
Tel: 020 7865 8100
Fax: 020 7865 8200
http://www.greenpeace.org.uk

Royal Society for the Protection of Birds (RSPB)
The Lodge
SANDY
Bedfordshire SG19 2DL
Tel: 01767 680551
http://www.rspb.org.uk/

World Conservation Monitoring Centre
219 Huntingdon Road
CAMBRIDGE CB3 0DL
Tel: 01223 277314
Fax: 01223 277136
http://www.wcmc.org.uk

World Wide Fund for Nature (WWF-UK)
Panda House
Weyside Park
GODALMING
Surrey GU7 1XR
Tel: 01483 426444
http://www.wwf-uk.org

European institutions and other international organisations

European Chemicals Bureau
Joint Research Centre
Via E. Fermi 1
TP 582
JRC Ispra
I-21020 (VA)
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Fax: +39 332 785631
http://ecb.ei.jrc.it/

European Documentation and Information Centres — for details of these centres see Lees N, Woolson H, O'Hara J & Wynne B (1997) *Environmental Information: A Guide to Sources* (Second edition), London, UK, The British Library Science Reference and Information Service

Office for Official Publications of the European Communities
2 Rue Mercier
2985 Luxembourg
http://eur-op.eu.int/general/en/index.htm

Organisation for Economic Co-operation and Development
2 rue André Pascal
75775 Paris
CEDEX 16
France
http://www.oecd.org

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