DETR
ENVIRONMENT
TRANSPORT
REGIONS

Management of Harm to the Environment:

Criteria for the Management of Unplanned Releases

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The contents of this final report reflect the views of the project team based on a wide range of discussions and do not necessarily reflect the views of individual Steering Group members.

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Executive Summary

The use of risk assessments to facilitate the management of risks from industrial or other activities is now common practice. Whereas a number of different techniques are employed, they have the common attribute of systematically examining a process so as to identify hazards and to then predict the consequences and likelihood of those hazards occurring. Risk criterion schemes are often used to assist in examining the results from such risk assessments so as to indicate the significance of the risks. The focus of attention to-date has been on the development of risk management techniques, including risk criteria, for the protection of human health. There are now various initiatives underway to widen the use of such techniques to protection of the environment.

The processes followed within a risk assessment are broadly similar no matter what the 'target' at risk being assessed. However, the criteria used to indicate the significance of the results are, of necessity, target specific. A programme of research has therefore been undertaken to stimulate consideration of environmental risk criteria and to explore the feasibility of the development of such criteria to assist in the management of risks to the environment. The most recent phase of this research is described in this report.

The objectives of the research were to develop an approach which may assist operators and regulators in screening/prioritising the management of risks to the natural environment by, for example, identifying areas where further work was required, and to widen the debate on the issues associated with assessing harm. The focus of the earlier work was the aquatic environment; this has also been the main area of research in this study. The majority of this report is thus concerned with how risks from accidental releases of hazardous substances to the aquatic environment might be assessed and their significance evaluated. An Environmental Harm Index (EHI) is developed to assist in this process. A risk criterion framework has also been proposed, using the EHI, to assist in screening risks of minimal concern from those which warrant further consideration.

The EHI is a refinement of a similar parameter developed in an earlier study. It is founded on the philosophy that there are three factors associated with the consequences of an accident which determine the harm from that event. Thus, it includes parameters relating to:

- severity, ie, the degree of harm;
- size, ie, the extent of the harm; and
- time, ie, the timescale associated with the harm.

These parameters are normalised and then multiplied together to produce the EHI. Equal weight is applied to the parameters.

Although the principal focus of attention has been the aquatic environment, adaptation of the EHI to the terrestrial environment has also been explored. It was concluded that the scientific basis was not sufficiently well developed to support a practicable approach at present. Nonetheless, risks to the environment from accidental releases to all environmental media should be considered within the risk management process; it is recognised that the extent to which it is possible to quantify/ these risks on a comparable basis is restricted.

Case studies using data from accidents and predicted events have been conducted. Thus, data from real incidents were used, supplemented where necessary by modelling, to explore the hypothesis that there is a correspondence between the value of the EHI and harm to the environment. This hypothesis was upheld. There was also a link between the magnitude of the EHI and the financial penalties (fines, court costs and restocking/cleanup costs) of the incidents.

The predicted events were for accidents at several industrial sites located next to rivers and an estuary. The accident scenarios ranged from process deviations and storage tank failures to transport accidents; each scenario had an associated predicted frequency of occurrence based on generic failure rate data. The sensitivity of the EHI to the choice of river flow data was explored.

The link between the magnitude of the EHI and harm to the environment was further considered by reference to a qualitative accident severity model used within some industries. It was shown that the two schemes, though different in their basic approach and flexibility, were consistent in their relative rankings of incidents.

The case studies have been of considerable assistance in demonstrating the use of the EHI and its applicability to a range of scenarios within both the riverine and estuarine environments. It is recommended that the result from any EHI calculation is accompanied by a commentary which explains the rationale behind the data used, the contribution of the various terms to the overall value, and a description of the harm.

The case studies were used to assist in development of a risk criterion scheme. This scheme embodies the concept that risk is a function of consequence (in this case, EHI) and frequency, and that priorities for further attention can be ascribed on the basis of risk levels. Such further attention might include:

- ensuring that risks do not increase;
- reviewing/revising the risk assessment;
- identifying potential risk reduction measures; and
- introducing risk reduction measures.

The action chosen will be influenced by the magnitude of the risk but will also depend on a range of other factors. The proposed risk criterion scheme is a framework which assists the management process, and it is emphasised that the criteria on their own are neither the final nor the only input in any decision-making process. It is not appropriate to accept any implied acceptability or otherwise of risk purely on the basis of a comparison of assessed risks with risk criteria. The criteria are a tool to assist in decision-making.

The proposed criteria divide the spectrum of possible risks into three regions. This is to facilitate their practical application. The boundaries between the regions are not intended to be used as threshold, above and below which fundamentally different types of risk management actions would be taken. They are presented as indicators differentiating between degrees of concern and hence the need for attention/action. It is also important to recognise that any predicted risk has some uncertainty associated with it which must be taken into account when considering any further action. The proposed scheme contains the following three regions of risk:

- an upper level of risk above which risks are priorities for further attention;
- a lower level of risk beneath which risks are of minimal concern and do not warrant the attention of regulators, but require continued monitoring to ensure they remain low; and,
- an intermediate region between these two limits within which risks require some further consideration but which do not necessarily require the instigation of risk reduction measures provided that risk management action has been taken to ensure that risks are As Low As Reasonably Practicable (ALARP).

The concept of a major accident was used to assist in calibrating the criteria. Such an event was considered to be one lying on the boundary between the upper two risk regions. From the case studies it appeared that an EHI of at least 100 would be appropriate for this type of accident. The frequency associated with such an event is less easy to determine since historical data on major accident rates are not available. Guidance from the Health and Safety Commission's Advisory Committee on Major Hazards was used to influence the decision to adopt a frequency of 10.4 per year per site to accompany the EHI of 100 in defining one point on the upper boundary. Further information or experience in using the proposed framework could indicate that this definition should be changed.

As a first step in gaining experience in using the proposed criteria, the predicted risk levels for five of the sites used as case studies have been plotted in the same format as the criteria. These risk levels are known to be conservative. The results indicate how the criteria may be used as part of the risk management process.

Throughout the project the aim has been to seek to provide a practical risk management tool to assist in the screening of urgent risks from those of lesser significance. It is recognised that this involves achieving a balance between practicability and scientific rigour. The proposed tool is not intended to be prescriptive but rather to provide a framework which assists in discussions between interested parties on the management of risks to the environment. Whereas it does not represent the policy of any regulatory body, it is perceived that it has some merit in assisting in the dialogue between regulators and industry concerning levels of risk and associated management decisions.

In summary, the research has produced a practical tool which may be used to assist in the management of risks to the aquatic environment, particularly estuaries and rivers, from accidental releases. Experience may indicate that the criteria should be revised. Some suggestions for further work to explore additional issues which could not be addressed as part of this research are also outlined.

CHAPTER 1

Introduction

The use of risk assessments to facilitate the management of risks from industrial or other activities is now common practice. Whereas a number of different techniques are employed, they have the common attribute of systematically examining a process so as to identify hazards and to then predict the consequences and likelihood of those hazards occurring. Risk criterion schemes are often used to assist in examining the results from such risk assessments so as to indicate the significance of the risks. Over the past few decades various risk criterion schemes have been developed and are now applied to risk management and land-use planning decisions in a number of countries throughout the world. This development has been driven by the need for standards in the management of hazardous industrial activities in modern society; however, there is a need to balance risks against benefits and hence any such standards, or criteria, are only one of the very many factors used in the risk management decision-making process.

The focus of attention to-date has been on the development of risk management techniques, including risk criteria, for the protection of human health. There are now various initiatives underway to widen the use of such techniques to protection of the environment. The regulatory framework in the UK has promoted these initiatives and has recently been strengthened by the adoption within the European Communities of two important council directives relating to the regulation of the more hazardous installations. Thus, the directive dealing with the control of major-accident hazards involving dangerous substances (96/82/EC) places a requirement on operators *'to take all measures necessary to prevent major accidents and to limit their consequences for men and the environment*', whilst that concerning integrated pollution prevention and control (96/61/EC) requires that emissions are prevented, wherever practicable, and, where that is not possible, minimised *'in order to achieve a high level of protection for the environment as a whole*'.

The processes followed within a risk assessment are broadly similar no matter what the 'target' at risk being assessed. However, the criteria used to indicate the significance of the results are, of necessity, target specific. A programme of research has therefore been undertaken to stimulate consideration of environmental risk criteria and to explore the feasibility of the development of such criteria to assist in the management of risks to the environment. The most recent phase of this research is described in this report. However, it is appropriate to acknowledge that the work builds upon an earlier study sponsored by DGXII of the European Commission, UK regulatory bodies and industry. A brief history of this earlier work is included in section two of this report.

The objectives of the research were to develop an approach which may assist operators and regulators in screening/prioritising the management of risks to the natural environment by, for example, identifying areas where further work was required, and to widen the debate on the issues associated with assessing harm. The focus of the earlier work was the aquatic environment; this has also been the main area of research in this study. The majority of this report is thus concerned with how risks from accidental releases of hazardous substances to the aquatic environment might be assessed and their significance evaluated. Case studies have been used to demonstrate the proposed approach and to assist in its development. However, some investigations into the extension and application of the work to the terrestrial environment have also been undertaken.

Throughout the project the aim has been to seek to provide a practical risk management tool to assist in the screening of urgent risks from those of lesser significance. It is recognised that this involves achieving a balance between practicability and scientific rigour. The proposed tool is not intended to be prescriptive but rather to provide a framework which assists in discussions between interested parties on the management of risks to the environment. Whereas it does not represent the policy of any regulatory body, it is perceived that it has some merit in assisting in the dialogue between regulators and industry concerning levels of risk and associated management decisions. The following sections of this report describe the proposed framework, its derivation and use.

CHAPTER 2

Project Framework

2.1 Project direction

This research has been sponsored by the Department of the Environment and directed by a Steering Group chaired by the Environment Agency and consisting of representatives from UK regulators and industry. Three Task Groups were set up to allow more detailed investigation and debate of some issues than was possible in the main Steering Group meetings. Delegates to these Task Groups were, in the main, drawn from Steering Group members. A full list of participating organisations and the terms of reference for the Task Groups are provided in Appendices 3 and 4, respectively.

In addition to the discussions engendered as a result of the various Group meetings, several presentations on the work were made at meetings of other organisations. These presentations were used both to promote awareness of the research and to stimulate debate. The views of a range of technical experts were also specifically sought at a seminar held in March 1997; this was hosted by AEA Technology and consisted of two sessions addressing issues associated with the formulation and use of a measure of harm for aquatic and terrestrial ecosystems. A list of organisations to which presentations have been made and those represented at the seminar is provided in Appendix 3.

All the meetings referred to above provided valuable guidance to the research team during the development of the risk criterion scheme described in this report.

2.2 Previous research work

The current research has extended some earlier work undertaken by AEA Technology in collaboration with VROM/RIZA in the Netherlands and AGEL-CBI in Hungary. That work, as stated previously, was sponsored by the EU, UK regulators and industry.

The earlier work focused on three particular ecosystems, namely, rivers, estuaries, and lakes. It culminated in the development of three sets of criteria, one from each participating organisation, to measure the harm from an accidental release of hazardous substances. Although there were differences of approach between the organisations, there was a large degree of common ground. It was agreed that an Environmental Harm index (EHI) could be developed which had the following common features:

- a measure of the severity of an accident based on use of lethality data;
- a measure of the size of the ecosystem damaged using a 'dangerous concentration' as a threshold value to define the extent of the damage.

The magnitude of the EHI was then considered to reflect the degree of harm to the environment. The scheme suggested by AEA Technology also included consideration of the predicted frequencies of different EHI values. The combination of frequency and EHI was used as a measure of risk to the environment and suggestions were made concerning levels of risk which might be, in some sense, acceptable or tolerable. This risk criterion scheme was the starting point for the current research project.

2.3 Case studies

A limited number of case studies were performed in the previous study, mainly to show that it was practicable to perform the various calculations. The present study has included many more case studies to assist in providing guidance on matters such as the influence of data choices on EHI values and the levels of concern associated with different risk values, the latter being based on EHI values and their associated frequency of occurrence. These case studies comprise data from actual incidents as well as predicted events.

CHAPTER 3

Environmental Risk Management

The main objective of a risk management strategy is to judge the acceptability or otherwise of an activity, reflecting a balance between the risks, costs and benefits. Thus, it is necessary to define the associated risk and the framework whereby its significance may be assessed.

3.1 General concepts of risk management

The environmental risk associated with a particular hazard is defined in terms of its potential adverse effects on the environment and the likelihood of those effects occurring. That is, the risk is a combination of a consequence and the frequency of occurrence of that consequence. In determining the significance of a particular risk, factors not explicitly included in the risk assessment may be included, for example, perception of society's views on the level of risk.

The practicalities of any risk management strategy require that attention is focused on those risks of greatest concern. This usually means that some initial screen is placed on results from a risk assessment so that low frequency and/or low consequence events are deemed of low priority for management action; in some risk criterion schemes such events are termed 'acceptable' or 'of minimal regulatory concern'. Higher priorities are ascribed to risks with larger frequencies and/or consequences. The risk criterion scheme discussed below places further structure on the risk management process by dividing the spectrum of risks into three regions for the purposes of risk-based decision-making. However, the basic philosophy on setting priorities remains the same.

The risk assessment activity is linked to risk management and is generally an iterative process, starting with simple methods and pessimistic assumptions, and only proceeding to more complex methods and less pessimistic assumptions where these are needed to meet the objectives of the assessment; such objectives might typically be to show that the risks are acceptable or to prioritise risk reduction measures.

Cost-benefit considerations are important in deciding upon the merit of potential risk reduction measures and, in particular, in demonstrating that risks are as low as is reasonably practicable. In addition to the actual costs of any proposed measure, the associated benefits need to be judged in terms of both the relative reduction in risks and the resultant residual risk. The merit of allowing for cost benefit arguments in determining actions to reduce risks has been recognised within the Environment Act 1995, which requires that the Environment Agency (and its equivalents in Scotland and Northern Ireland) must take into account the likely costs and benefits of exercising, or not, their powers.

3.2 Form of criteria

The use of risk criteria to assist the decision-making process associated with management of environmental risks has been referred to above. Any such criteria are only one of the factors used in this process.

Quantitative risk criteria define, for the purposes of risk-based decision-making, levels of risk which are of minimal concern and those which require at least some further action. The form of criteria suitable for management of risks to the environment has been much discussed during the course of this research project. There is agreement on the following issues:

- risk should be measured in terms of effects (consequences) and frequency;
- high consequence and high frequency events are high priorities for further attention/action;
- low consequence and low frequency events are of minimal concern to both regulators and industry;
- between the above there should be some gradation of levels of concern and priorities for further attention/action, and
- case studies and experience of risk levels of concern elsewhere are of value in informing the meaning of the terms 'high- and 'low'.

Figure 3.1 Example criteria

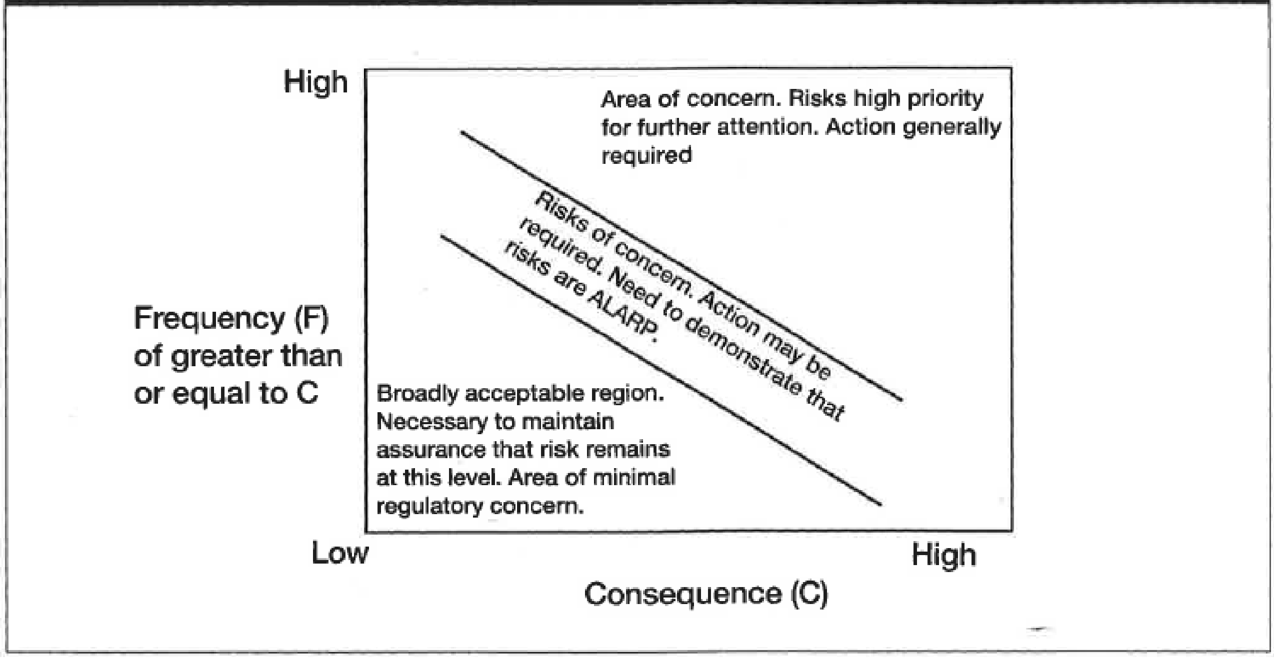

Figure 3.1 shows a criterion scheme meeting the above requirements. The intermediate band between 'high' and 'low' risks is present to facilitate the practical application of the tool; risks in that region are of concern but actions further to reduce them would not be required provided that they could be shown to be As Low As Reasonably Practicable (ALARP). This format is analogous to that used elsewhere in the management of risks to people. It is not suggested that the boundaries between the three regions be regarded as strictly implemented thresholds

which determine precisely what action needs to be taken. They should be viewed as assisting in the risk management process by indicating the degree of concern and the corresponding need for action. Initially, at least, the action required would probably be a review of the risk assessment itself.

In summary the proposed scheme contains the following three regions of risk:

- an upper level of risk above which risks are priorities for further attention – this attention might involve reviewing the assumptions and modelling used in the assessment, in order to be satisfied with the level of conservatism within the results, or it might involve the instigation of some risk reduction measures, and the action adopted will depend on factors such as the relative costs, benefits and level of residual risk of the different approaches;
- a lower level of risk beneath which risks are of minimal concern and do not warrant the attention of regulators, but require continued monitoring to ensure they remain low; and,
- an intermediate region between these two limits within which risks require some further consideration but which do not necessarily require the instigation of risk reduction measures provided that risk management action has been taken to ensure that risks are As Low As Reasonably Practicable (ALARP).

This general structure has proved to be quite effective as a tool for managing risks elsewhere. In some cases, the term ALARP is replaced by ALARA, with the word Practicable replaced by Achievable, but the concept remains essentially the same. The framework clearly provides a mechanism for focusing attention on the most urgent areas of risk.

3.3 Philosophy on the use of risk criteria

A risk criterion scheme provides a framework to assist in risk management decision-making. Thus, the criteria on their own are neither the final nor the only input in any decision-making situation and it is not appropriate to accept any implied acceptability or otherwise of risks just on the basis of comparison of assessed risks with risk criteria. For example, it must be recognised that there are various levels of complexity which can be invoked when performing risk assessments, each with an associated level of cost. Thus, in the early stages of any assessment, a relatively inexpensive, conservative (ie, pessimistic) calculation may be performed. If comparison of the resultant risk with the risk criteria shows that they are of very minimal concern, then it is likely that no further action needs to be taken. However, if this is not the case then more detailed, less conservative assessments may be performed. Thus, it can be seen that criteria may be used as part of a stepwise, cost-efficient assessment scheme whereby increasing levels of complexity (and cost) are only embarked upon, where shown to be necessary. Such an approach has the value of helping to ensure that the more costly assessments are performed in those situations posing the greatest risks; conversely, those posing minimal risk may be screened out using simple inexpensive techniques.

It must also be recognised that there is always some uncertainty associated with any evaluation of risk. This may derive from uncertainties in the parameters used in the assessment model or as a consequence of the model not properly accounting for certain phenomena. For example, in the case of models for the aquatic environment, some models have limited ability to deal with the interaction between pollutants and sediments. These various sources of uncertainty need to be recognised when using criteria to make judgements on the importance or otherwise of assessment results.

In summary risk criteria represent a tool to assist in decision-making. They are a very valuable component of any decision-making process involving judgements on risk. They are a key element of goal-based (as opposed to prescriptive) approaches to regulation and can form part of a cost-effective approach to risk assessment. In the regulatory context, criteria may be viewed as facilitating discussion between the regulator and the regulated. The nature of such a discussion will depend on where the assessed risk lies in relation to the criteria. Thus, if viewed from a philosophical stance, criteria represent a central feature of a systematic risk management strategy, which gives rise to a clear understanding of the factors giving rise to risk and, thereby, allows better informed decision-making concerning management of risks.

The above points were endorsed by delegates to the seminar held as part of this study. They expressed the view that there were particular advantages in adopting an approach to risk management which allowed:

- a simple screening of risks to identify those requiring some further consideration;
- provided a transparent assessment method for prioritising actions; and, as a corollary;
- an audit trail for management actions.

Such a system was perceived to offer benefits to all parties involved in the management of environmental risks.

CHAPTER 4

Assessing Environmental Harm

The environment is such a complex entity that it is not practicable, nor necessarily desirable, to consider all aspects within a risk assessment. Thus, a major feature of the present research project involved determining which constituents of the environment should be considered when assessing environmental harm. Official guidance on what constitutes the environment has been limited and, when available, is specified in general terms. For example, for the purposes of the CIMAH regulations the environment has been broadly defined as ‘both the natural and man-made environment'[1].

This section describes a proposed methodology whereby harm to the environment, resulting from industrial accidents, can be assessed within a simple and practicable scheme.

4.1 The natural environment

The natural environment is far too complex and diverse a collation of inter-dependent flora, fauna, and habitat types to enable it to be considered as one entity. For the purpose of this study the natural environment has been sub-divided into **aquatic** and **terrestrial** environments, and each considered in detail separately (see chapters 5 and 6). Despite this sub-division, there is common ground between the two. Classic ecological theory divides the environment into three levels: **individual** organisms, groups of individuals or **populations**, and populations of several organisms or species living together in **communities**. At this level the community, along with its physical setting or habitat, is seen as a single interacting unit or **ecosystem**[2]. Consequently, every ecosystem, whatever the environmental media involved, can be viewed as a collection of interacting populations of species which depend on their habitat and each other for survival. Given this common ground it was considered feasible to develop a methodology for assessing harm to the environment which is generally applicable to a range of ecosystems. This idea is built upon in the following two sub-sections.

4.1.1 Harm to the Natural Environment

Harm to the natural environment can be defined in a variety of ways. Definitions could include loss of 'value' in financial, recreational and aesthetic terms as well as ecological impacts.

Adverse effects on the financial value of the environment may include such things as the loss of crops, harm to natural resources and subsequent loss of income (for example, from fishing), or a reduction in water, land or air quality which requires remediation. Although

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[1] Interpretation of Major Accident to the Environment for the Purposes of the CIMAH Regulations. A Guidance Note by the Department of the Environment, June 1991

[2] Brewer R. 'The Science of Ecology' Second Edition 1994, Saunders College Publishing

methods are available to estimate the more obvious (direct) financial impacts of accidental releases, they will almost certainly not reflect the full extent of any environmental harm. For example, estimation of the economic value of unexploited individuals, populations of species and habitats is a very complex exercise. Such environmental economics is time consuming, costly, subjective and outside the experience of the majority of risk assessors; for these reasons, financial loss was not considered viable as a measure for environmental damage within the context of the present work. However, the direct costs associated with historical events were considered in the case studies (chapter 7), so that a comparison could be made with the chosen measure of environmental harm to ensure that increasing costs are properly reflected in the proposed scheme.

Recreational value may be lowered in a variety of ways. For example, a reduction in water quality might result in the loss of opportunity for activities such as swimming and boating, whereas land contamination might mean a loss of recreational areas. However, limited areas of the environment are used for recreational purposes and not all environmental damage would have an effect on recreational use. Similar comments may also be made with respect to aesthetic value.

Thus, it is considered that financial, recreational, and aesthetic damage to the natural environment are all subsets of the total ecological harm resulting from an unplanned release. Whereas each component would give some measure of the damage inflicted on the environment, none could give a complete picture of the extent of the harm. For this study, it was therefore agreed that harm should be measured by focusing on ecological impacts, since this afforded the best opportunity to encapsulate the full extent of harm. Nonetheless, it is recognised that other measures of harm, including financial considerations, are of value in any risk management system.

Ecological harm to the natural environment may be direct or indirect, immediate, or delayed, temporary, or persistent. Any attempt to predict the effects of unplanned releases on the environment must ideally take account of the various types of disruption that can occur to ecosystems. Harm and disruption to the ecology may include:

- direct abiotic effects:
  - disturbing the equilibrium of nutrient and oxygen cycles;
  - physical destruction of habitat;
  - smothering effects eg, due to oil spills;
- direct biotic effects, inducing adverse acute or chronic effects to one or more species, for example,
  - changes in behaviour;
  - changes in growth rates;
  - changes in reproduction rates;
  - changes in longevity;
  - promotion of tumour growth;
  - increased mortality rates;
- indirect biotic affects:
  - accumulation in the food chain;
  - changes in ecosystem diversity;
  - changes in community structure and function.

Bringing all this together, irrespective of the manner in which the environment is affected or harmed, and however that harm manifests itself, there are three main components to any measure of harm:

- **severity**, ie, how badly is it affected?
- **size**, ie, how much is affected?
- **time**, ie, how long is it affected for and when?

4.1.2 Assessing Harm to the Environment

All the above aspects are important and relevant when discussing harm to the natural environment; however, it is necessary to identify a parameter (or parameters) which can best be used to measure levels of harm so that objective criteria can be established. In addition, when deciding on the most relevant measure it is necessary to consider whether that **measure** is representative of the general state of the environment, can be modelled and has sufficient, reliable data to support decisions about the level of risk posed by a particular chemical.

In an ideal situation, in order to protect the natural environment, the stability and integrity, structure and function of each ecosystem (biotic and abiotic components) should be maintained. Therefore, harm to the environment should be measured in terms of any adverse change in ecosystem function, thus including potential impacts from all the direct and indirect biotic and abiotic effects mentioned above. However, assessing the status of an ecosystem or community is a complex and time-consuming task because each system is unique. Ideally any environmental risk assessment would be based on site-specific descriptions with comparisons made pre- and post-incidents to determine the impact particular sets of circumstances have on particular ecosystems. However, even with considerable effort and research work, it is not possible to describe fully an ecosystem and therefore it is not practicable to protect all species individually.

A number of methods and data types have been considered within the project for classifying environmental harm and have subsequently been discounted. These have included:

- quality standard data such as Environmental Quality Standards (EQS) or Suggested No Adverse Response Levels (SNARLS);
- no effect levels, such as No Observed Effect Concentrations (NOECs);
- methods for predicting optimum ecosystem community structure and composition; or
- (for the aquatic environment) riverine and estuarine water quality classification systems.

EQS values and no effect levels are not considered appropriate for the management of accidental releases since they were primarily developed for protecting ecosystems over long time periods from continuous releases. The concept of the SNARL was developed for accidental situations; however, data are only available for a relatively small number of chemicals, and the concept is designed for the protection of human health from contaminated drinking water. Models aimed at predicting optimum community structure and composition for habitat types could potentially have a role to play. Such approaches are, however, relatively complicated, and very data intensive and, certainly at the present time, not considered appropriate for a risk management protocol which may be widely used by industry and regulators, over a wide range of ecosystem types. Finally, water quality classification systems would be difficult to use as a predictor of environmental harm, since they are primarily designed to determine quality using direct measurements for a water body. Moreover, such systems are based on limited criteria, centred around the dissolved oxygen levels within the water column, and as such have limited general applicability to include, for example, the adverse effects caused by highly toxic releases.

In view of the above, a more pragmatic approach is adopted in the present work which takes account of practical requirements such as data availability. Consequently, for the purposes of the derivation of objective criteria, simplified generic descriptions of ecosystems have been devised based on a limited number of trophic levels. Harm to the environment can then be measured by assessing the potential impact of an unplanned release on a representative sensitive species chosen from the generic ecosystem. Harm to a sensitive species is used as a surrogate measure for the potential impact on the ecosystem as a whole. The generic ecosystems are discussed further in chapters 5 and 6 for the aquatic and terrestrial environments respectively.

There is no one 'most sensitive species'[3] which could always be selected to represent each trophic level of a generic ecosystem, since species have varying sensitivities to different groups of substances. Therefore, representative species must be identified to be ecologically important but also generally applicable (eg, to UK rivers) with widely available data on the effects associated with different contaminant levels. The main reasons for developing a generic ecosystem approach include the lack of data available for the majority of native species, and also the desire to standardise and simplify the data collection exercise of any proposed criterion scheme. By using a prescribed generic set of species, consistency can be achieved between assessments whilst retaining sufficient flexibility to allow for rare or migratory species to be chosen if the data are available.

Having decided to use a single species to represent harm to the environment, it is necessary to decide on the type of effect on that species to be used as a measure of the severity of the damage. When assessing the effect of exposure to hazardous chemicals on populations of species, it is the percentage of the population affected and the ages of the individuals affected, which best describes the damage sustained by the species. Unfortunately, the data which are widely available rarely allow calculations of percentage mortality, nor estimations of the age ranges most affected. Even the probability that any given level of chemical in the environment presents a hazard to an exposed population of one species, whether humans, birds, fish or other species, can be extremely difficult to determine. In many cases the available data are not robust enough to make precise predictions possible.

Toxicological testing attempts to determine the dose-effect relationship of single substances by associating an exposure concentration with a certain effect, usually mortality or some sub-lethal effect such as immobilisation. The most reliable and extensively available toxicity data are those for concentrations and, to a lesser extent, doses, which result in the death of

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[3] Cairns J Jnr. and Niederlehner B R. Problems with selecting the most sensitive species for toxicity testing. Hydrobiologia 153:87-94, .1987

50% of an exposed species. These data are generally referred to as LC_{50}s and LD_{50}s; the two parameters are related since any dose is a function of the concentration and corresponding exposure time.

In the case of effects associated with factors such as changes in pH or dissolved oxygen levels, then effects tend to occur when these parameters fall outside of 'tolerable' bands. The extent of these bands depends on a host of environmental conditions, such as temperature, as well as the species and contaminant involved.

Information on the concentration of a contaminant in the environment and the species which is most sensitive to the chemical(s) in question enables some deductions to be made. For example, for toxic substances, death of a significant proportion of a fish population is damaging in both ecological and societal terms and can be estimated by comparing the exposure concentration with an LC_{50} value. However, if the level of concern is physiological impairment, for example, growth reduction or reduction in reproduction rates, which can affect the long-term viability of the ecosystem, then this can be determined by an 'effect concentration' or EC_{50} (which is measured in a manner similar to the LD_{50}).

4.2 Environmental harm index

Taking into account the advantages and disadvantages of various measures of environmental damage discussed above, the Environmental Harm Index (EHI) was developed to assist in quantifying the potential for damage from any accident. The features of the EHI are:

- a measure of the **severity** of the accident using toxicity data for the most sensitive of the species from the generic ecosystem described above;
- a measure of the **size** of the ecosystem damaged using the concept of a 'dangerous concentration' (DC); and
- a measure of the **time** for which the ecosystem is adversely affected before recovering to a state close to the original.

In general terms the EHI may be represented by the following expression:

$$\text{EHI} = \frac{\text{Severity of effect in ecosystem}}{\text{Reference severity}} \times \frac{\text{Size of the ecosystem affected}}{\text{Reference size}} \times \frac{\text{Time for which ecosystem is affected}}{\text{Reference time}}$$

It is proposed, therefore that the EHI is defined as the product of the predicted severity of the accidental release, the predicted size of the ecosystem affected and the predicted time for which the ecosystem is affected, divided by the equivalent product for a **reference** accident. In this formulation the three terms are assumed to be equally important. Many alternative formulations might be envisaged in which the same terms were weighted or capped in some way; however, there does not currently seem to be any alternative method which would be both of more value and generally accepted. The **reference** and **potential** accidents used within the EHI should be defined in similar terms to allow the meaningful comparison of the predicted effects.

Some general features of each of the terms in the EHI are presented below; detailed consideration is presented later.

4.2.1 Reference Accident

The values for the parameters which make up the reference accident are chosen to reflect an unplanned release which would result in a **significant impact** on the environment. Therefore, a potential accident calculated to have an EHI of 1 would be expected to result in some significant impact. The term 'significant impact' may assist with, for example, the identification of acceptable/tolerable frequencies, since the term implies a large and measurable consequence and there has been some discussion of acceptability of such levels of incident. This is considered further in Chapter 8.

Consideration of the concept of a **major** accident to the environment was presented by the Department of the Environment[4]. By reference to the views expressed by various interested parties, harm to a range of ecosystem types was described and various levels classified as major. Harm was variously described with reference to the proportion of species of any system affected, the size of the ecosystem impacted or the timescales over which the damage persisted. The nature of the information presented does not permit rigorous analysis, however this study took guidance from the document when deriving parameter values to define the reference accident for various ecosystems.

4.2.2 Severity

The maximum concentration of any pollutant released into the environment can help provide a measure of the severity of the damage inflicted on the exposed ecosystem. Comparison of the peak concentration with the reference value, known to result in a significant impact, gives some indication of the type of harm inflicted. For example, if the maximum concentration in a river exceeds the reference value, such as the LC_{50} for a sensitive trout species, the severity term of the EHI formula would be greater than 1. This would indicate that some trout mortality would be expected.

It is important that the location in the environment at which to measure the maximum concentration is clearly defined in order to ensure consistency between assessments. However, this definition will necessary be different between environment types.

4.2.3 Size

If any part of an ecosystem is exposed to a pollutant concentration greater than a 'dangerous concentration' (DC) it is expected that the environment will be damaged in some way. It is proposed that the DC is defined by the lowest available sub-lethal toxicity data for a species representative of the exposed ecosystem. Defining the DC in this way will give an indication that, for concentrations above this value, some level of damage has been done and will enable the size of ecosystem affected to be estimated. Thus, the size of ecosystem exposed

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[4] Interpretation of Major Accident to the Environment for the Purposes of the CIMAH Regulations, A Guidance Note by the Department of the Environment, June 1991.

to a concentration greater than the DC provides a measure of the extent of harm caused by the unplanned release.

Although the DC must always be defined in the same way to ensure consistency between assessments, the value chosen to represent the DC will vary with ecosystem type and chemical released.

4.2.4 Recovery Time

The ability of an ecosystem to return from a damaged state will be dependent on a number of factors. The time taken to return to a state close to its original state is termed 'the recovery time'. Different ecosystems may demonstrate different recovery times when exposed to the same input of pollutant. Recovery time will depend on the type, susceptibility, diversity, abundance, colonising ability, and population processes of the species involved. There will also be some dependence on the rate at which material is flushed from the system as well as on the rate of remobilisation of residual material (a consequence of biological uptake or adsorption to soils and sediments) present after the main body of pollutant has passed through the system.

Accurate prediction of these effects is difficult due to the complex nature of the phenomena involved. There is some literature on the recovery of terrestrial systems from physical disturbances, such as logging and farming, but very little on the recovery of aquatic systems. Some attempts have been made to develop models of recovery[5]; however, the utility of those models for the purposes of the current work is questionable due to their complexity.

Given these difficulties, the following simple approach has been adopted. It is considered possible to classify any ecosystem's recovery time into a series of categories based on expert judgement. Recovery time might thus be classified as being a few days, a few weeks, or a few years, based on an understanding of the nature of the system. Representative recovery times can be devised for each recovery time category ie, the recovery time corresponding to the accidental spill, T_{acc}, which should be used in the specification of the EHI. Thus, the final term in the earlier expression for EHI is simply replaced by the ratio T_{acc}/T_{ref}, with T_{ref} defined by a significant accident, and T_{acc} obtained by estimating the recovery rime category and using the appropriate representative value.

It is recognised that there will be some uncertainty associated with this relatively simple approach. However, it is essential that recovery time is accounted for in the EHI. At this point it is worth noting that consideration was given to using weighting factors to represent recovery time categories (rather than years) and producing a range of weighting factors to represent the recovery times of differing environments. However, these more complicated

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[5] Cairns J Jr, Dickson K L and Herricks E (Eds) Recovery and Restoration of Damaged Ecosystems, University Press of Virginia, Charlottesville 1977,

Cairns J Jr. The Recovery Process in Damaged Ecosystems, Ann Arbor Science, Ann Arbor, Michigan, 1980.

Jordan W R, Gilpin M E and Aber J D. Restoration Ecology, Cambridge University Press, UK, 1987

Yount J D and Niemi G J (Eds). Recovery of Lotic Communities and Ecosystems Following Disturbance: Theory and Application. Environmental Management 14 (5), 1990.

Detenbeck N E, DeVore P W, Niemi G J and Lima A (1992) Recovery of Temperate-stream Fish Communities from Disturbance: A Review of Case Studies and Synthesis of Theory. Environmental Management 16:33-53.

procedures are not considered tenable. Moreover, the comments made in Chapter 3, concerning the underlying philosophy on the use of criteria must be borne in mind. Uncertainty surrounding the use of this method needs to be accounted for in the decision-making process, particularly when comparing assessed risks with criteria.

4.2.5 Important Issues

It is vital, if the EHI concept is to prove to be of value, that EHI values predicted for unplanned release scenarios can be demonstrated to relate to the potential environmental consequences. That is, that the predicted EHI value does not grossly over- or underestimate the damage potentially sustained by the environment. The relationship between EHI values and environmental consequences for the aquatic environment has been investigated within the case studies undertaken as part of this project. EHI values have been calculated for real accidents, for which information on actual consequences was available, and for hypothetical releases, for which a general statement on the extent of the consequences could be made. The details of these case studies and the results are discussed in Chapter 7.

The proposed EHI concept and formulation is a simple approach to managing a complex problem. As discussed in earlier sections, a variety of alternative methodologies for assessing harm to the environment were investigated but dismissed on the grounds of excessive data and/or expertise requirements. It has been the desire throughout this project to develop an approach which is scientifically defensible but simple enough to allow its application by nonexperts.

It is important that the risk management process focuses attention and costs on those risks of greatest concern. A common approach to this issue is, in the first instance, to undertake relatively simple assessments using conservative assumptions, modelling and data. If the resultant risk is not of concern, then no further action may be warranted. However, if this is not the case, then it is generally useful to adopt an iterative approach in which the assessor considers the simplest way of refining the risk assessment to the point at which either the risk is considered of no concern, or it is clear that some risk reduction measures should be introduced. The proposed EHI concept may be used as part of this iterative approach.

It must also be stressed that the EHI concept is intended as an aid to the identification and prioritisation of risk management actions and, as such, to provide sufficient information to assist in the dialogue between industry and regulator. The process of undertaking a risk assessment, identifying relevant input data, and deriving the EHI, is in itself a valuable exercise. The generated EHI value will always be just one input to the discussion between regulators and industry. All parties involved in the management of risks must appreciate the underlying basis of the EHI. Consequently, it is strongly suggested that any EHI calculation carries with it a commentary. This commentary will be of considerable value in any discussions. It should include information on the source and relevance of the input data, any relevant site-specific information, a brief description of the three factors which make up the EHI and an indication of the predicted level of harm.

The results from any risk assessment will have some degree of uncertainty associated with them. The principal sources of these are uncertainties in the data and the accuracy/validity of the models. It is important to recognise and appreciate the extent of such uncertainties when decisions are made which are influenced by the results from a risk assessment.

CHAPTER 5

The Aquatic Environment

5.1 Description of Aquatic Ecosystems

An understanding of aquatic ecosystems is necessary at a sufficient the level of detail to enable exact nature and extent of the system which needs to be protected to be determined. One of the major concerns is whether protection of an ecosystem as a whole can be achieved by protecting single species. Consequently, the role of species and groups of species in the ecosystems of interest are investigated in this section. The aim is to derive a set of 'key-players' (species or groups of species) which represent the whole aquatic ecosystem, since it is recognised that it is not possible to protect all organisms individually. A number of factors will influence the choice of key-players, in particular biological and societal relevance and data availability. In addition, it is necessary to examine the inter-relationships which occur within rivers, estuaries, and lakes, represented primarily by the different categories within food-webs known as trophic levels. The aim is to identify an ‘end-point of concern’ which can realistically be protected and which represents the whole aquatic ecosystem.

Surface water ecosystems can be divided into rivers, estuaries, coastal waters, and lakes. Their similarities and differences will be discussed below. The case studies discussed in Chapter 7 are based on releases to rivers and hence the main focus of the following sections is the riverine ecosystem.

5.1.1 Physical Characteristics

The harm caused by an accidental release will differ depending upon the characteristics of the ecosystem. If a chemical enters the water, then the concentration will depend upon the properties of the water system as well as those of the chemical involved. For example, the physico-chemical characteristics of the surface water and the properties of the chemical will influence the distribution of the chemical in the water and hence the amount of chemical to which the biota will be exposed. This exposure concentration can be calculated by a range of modelling methods (including PRAIRIE™[6]).

The physico-chemical characteristics of aquatic ecosystems can be summarised as:

- volumetric flow;
- velocity or current;
- geomorphology of the watercourse, riverbanks and the sediment;
- turbulence;

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[6] PRAIRIE™ Pollution risk from Accidental Influxes into Rivers and Estuaries is a risk assessment tool developed by AEA Technology

- turbidity;
- tidal flow;
- residence time(s);
- stratification;
- pH, temperature, dissolved oxygen content, organic matter content and water hardness.

Flow and velocity influence the rate at which the pollutant is removed from the aquatic system. For example, in large, fast flowing rivers the pollutant will be dispersed within the water much more rapidly than from lakes. Dispersion is also influenced by the geomorphology of the water course; a high degree of turbulence caused by fast flows and rocky riverbanks will assist in the mixing and distribution of the pollutant. In the case of estuaries, this dispersion of pollution is influenced by tidal flow as well as the influx of fresh water. Pollutants are removed by chemical and physical processes such as degradation, sedimentation, and evaporation.

Stratification within estuaries and lakes influences the concentration profile of the pollutant. Stratification in estuaries is caused by salinity distributions, whilst in lakes the major influence is temperature cycling. These parameters are extremely difficult to model and can only be done for specific lakes and estuaries and not in a generic system.

Residence times in lakes and estuaries can vary from as little as days to as long as years. This will have a major effect on the impact which a polluting accident has on the ecosystem. When pollutants are removed quickly from the water system, they have less time to adsorb to sediments or enter the food chain and the exposure times for flora and fauna within the water system are short.

The pH, hardness, temperature, oxygen, organic matter content, and other similar parameters varies considerably between aquatic systems. However resident organisms are acclimatised to their surroundings and any alterations caused by pollutants may result in damage to the ecosystem.

This brief description of the physical characteristics of aquatic ecosystems serves to illustrate their complex nature and the various parameters which affect the distribution, retention, and effects of pollutants. Ideally, the modelling of the concentration of the pollutant within the water would take account of all these parameters, but it is recognised that this is possible in only a few limited circumstances.

5.1.2 Biological Characteristics

The different physical characteristics of rivers, lakes and estuaries influence the biological component of the ecosystems. For example, the salinity distributions in estuaries influence the distribution of species so that there are, in effect, several different ecosystems with some degree of overlap between them. In addition, the environment within each compartment of an estuary is constantly changing due to the tidal patterns. Consequently, the organisms which live in these conditions have specifically evolved to tolerate them.

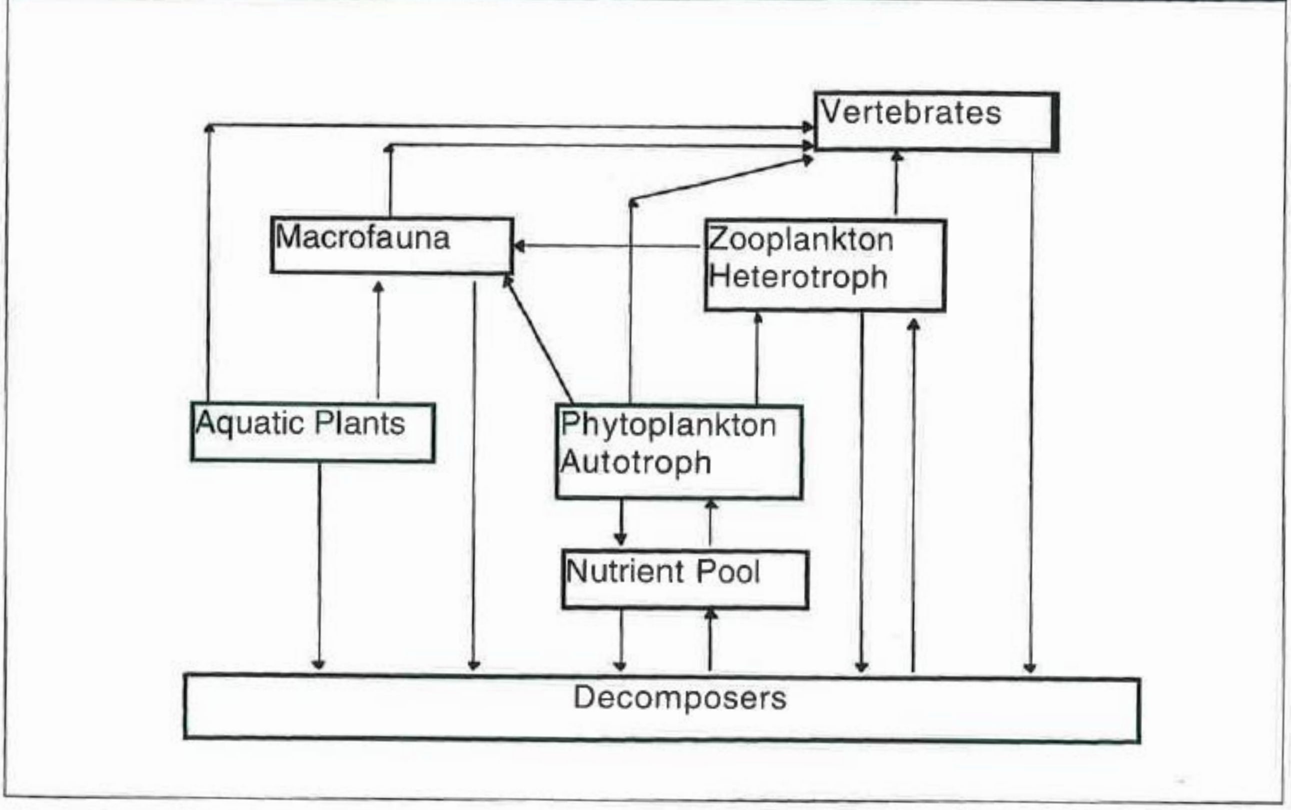
Despite the differences in the type and distribution of species in aquatic ecosystems it is possible to use their similarities to describe the aquatic ecosystem in a generic way. At the most basic level the ecosystem can be subdivided into flora and fauna. The flora (including algae, blue-green algae and higher plants) are the primary producers; they convert energy from the sun, CO_2 and other nutrients into carbohydrates and proteins. The carbohydrates and proteins are then available to the fauna; firstly, to primary consumers, such as zooplankton, and then, through their consumption, to secondary consumers such as fish and birds. A review of the literature indicates that at least six important groups can be identified. These are listed below, together with associated examples of species in each group.

Phytoplankton	Single celled diatoms
	Single celled and filamentous algae and blue-green algae
Higher Plants	Rooted vascular plants eg, pond weeds and grasses
	Water crowfoot (*Ranunculus pseudofluitans*)
	Lesser water parsnip (*Sium erectum*)
	Marestail (*Hippuris vulgaris*)
	Simple bur-weed (*Sparganium simplex*)
	Startwort (*Callitriche stagnalis*)
	Curly pondweed (*Potamogetan crispus*)
Zooplankton	eg, protozoa and water fleas
	Water- fleas (*Cladocera*)
	Fish louse (*Copepods*)
	Rotifera
	Protozoa
	Macroinvertebrates
	Freshwater shrimp (*Gammarus*)
	Stoneflies (*Plecoptera*)
	Mayflies (*Ephemeroptera*)
	Dragonflies (*Odonata*)
	Caddisflies (*Trichoptera*)
	Flies (*Diptera*)
	Mosquitoes (*Culicidae*)
	Biting and Non-biting Midges (*Chironomidae*)
Benthos	Snails (*Neritidae*)
	Bivalves eg, Mussel (*Mytilus edulis*)
	Worms (*Annelida*)
Fish	Salmon (*Salmo salar*)
	Rainbow Trout (*Salmo gairdneri*)
	Eel (*Anguilla anguilla*)

5.1.3 Generic Ecosystem

Although there can be significant differences in the type and distribution of species in rivers, estuaries and lakes, the groups listed above are representative of organisms in any aquatic ecosystem. In addition, these groups can be allocated to those elements which can manufacture their own food (autotrophs or primary producers) and those which cannot (heterotrophs). To survive, heterotrophs must directly or indirectly harvest the food made by autotrophs. The heterotrophs can in turn be subdivided into two groups: those that feed solely on autotrophs (primary consumers) and those which feed on other heterotrophs (secondary consumers). Another useful classification tool is the division of heterotrophs into vertebrates and invertebrates (that is, those with and without backbones respectively). One other component completes this functional description of an ecosystem, that is, decomposers. These live on dead and decaying organic matter and in the process return organic nutrients to the ecosystem. This simple model of an ecosystem can be displayed in diagrammatic form as shown in Figure 5.1 which also shows the interrelationships between these component groups, expressed as a simple food web.

Figure 5.1 Simplified Energy Cycle within a Freshwater Ecosystem



The descriptions of the riverine, estuarine and lake ecosystems can all be simplified using the analysis described above. Thus, aquatic ecosystems can be represented by a 'generic ecosystem' containing organisms from five trophic levels:

Phytoplankton	Primary producers (autotrophs)
Zooplankton	Primary Consumers (heterotrophs)
Benthos	Decomposers
Vertebrates	Secondary Consumers
Higher vertebrates	Tertiary Consumers

These five trophic levels summarise the main route of energy flow through the ecosystem and include representatives of the major inter-relationships between organisms at all different levels. By choosing suitable representatives of these five trophic levels a set of data can be constructed which is sufficient to describe the estuarine, riverine and lake ecosystems.

This generic system is consistent with the guidelines recommended by other European organisations. For example, the OECD suggests the use of a set of standardised toxicological tests based on algae, crustaceans, and fish. The CEC and the International Rhine Commission (IRC) recommend the use of the same groups of species plus a fourth level. The organisms chosen to represent the fourth level will depend upon the exact nature of the habitat under consideration and the chemical characteristics of the pollutant. For example, if the chemical adsorbs to sediments, then appropriate organisms for the fourth level would be benthic or sediment dwelling organisms.

As mentioned above, there are many aspects of the aquatic environment which may require protection. These include flora, fauna, use for potable water abstraction and recreational activities and aesthetic appeal. These aspects can in turn be related to the properties of the chemical in question, including toxicity, biological oxygen demand, taste, odour, colour, ability to form floating layers etc.

Ideally a risk assessment of an aquatic ecosystem would be based on a site-specific description with comparisons made pre- and post- incident to determine the degree of impact particular sets of circumstances have on that ecosystem. However, even with considerable effort and research work it is not always possible to arrive at a complete list of the organisms present. The alternative is to arrive at a more pragmatic approach which will take account of practical requirements for the choice of species and also data requirements. This will involve the use of the generic ecosystem as described above.

When using the proposed risk criterion scheme, it is suggested that effect data (on, for example, toxicity) are obtained for representatives of the trophic levels described above and the most sensitive species of these is chosen as the assessment endpoint. The main reasons for using a generic system include the lack of data for a large number of species and the necessity to simplify' and standardise the data collection exercise. By using a prescribed set of species, consistency can be achieved between assessments whilst still retaining sufficient flexibility to allow for rare or migratory species to be chosen (providing data are available).

For many chemicals only a few items of data will be available. In addition, the organisms for which data are available may not be representatives of the habitat in question. In such situations the data which are available can be considered as an indication of the actual harmful effect of the substance.

Ideally, because the risk-criteria are attempting to be protective of the ecosystem, data should be obtained for the range of organisms present in the environment under consideration. However, there will be some situations where this is either not practicable or it would mean using data of poor quality. The best way of proceeding in, these situations will depend on the particular circumstances and should form part of the discussion/commentary accompanying the presentation of results. However, where the problem is that good quality data are not available for at least four trophic levels, which is the minimum generally accepted as necessary, then in some countries (eg, the Netherlands) the data are divided by 10 to allow for by interspecies variation. Such an approach is one way of overcoming the lack of a comprehensive data set but has the drawback of making the calculations much more conservative. It may be appropriate to supplement a data set by using information for an organism from the generic ecosystem, even if that species is not actually known to be present in the environment, provided that the data are of good quality and the organism is representative of that type of environment.

5.2 Choice of parameters for proposed EHI

The measure of harm needs to be related to the characteristics of the chemical involved and the endpoint of concern. The question of how harm to the natural environment may be measured was discussed in Chapter 4. It was concluded there that three components needed to be considered, namely:

- an indication of the **severity** of the incident;
- an estimate of the **size** of the ecosystem contaminated; and
- an estimate of the **time** taken for the ecosystem to recover from the effects of the incident.

Each of these factors will be discussed below with special reference to the aquatic environment.

5.2.1 Severity of the Incident

A measure of the severity of the incident is dependent upon the nature (toxic or non-toxic) of the substance in question. For toxic chemicals the severity of the incident can be estimated by comparing the predicted environmental concentration (PEC) with a suitable toxicity measure for the most sensitive organism (non-toxic effects are considered separately below).

TOXICITY DATA

The most widely available toxicity data are in the form of effect concentrations, such as LC_{50}s, rather than dose-response relationships. The severity of an incident involving toxic chemicals is therefore most readily estimated by comparing the initial concentration of the substance in the environment with the LC_{50}s for the most sensitive organism from the generic ecosystem. The initial concentration is taken to be that which is calculated at the edge of the mixing zone.

The value of the environmental harm index will depend upon the toxicity data chosen for comparison with the PEC. If the PEC is equal to the LC_{50} then in the vicinity of the release approximately 50% of the most sensitive species will be expected to die and fewer than 50% of the less sensitive species will be expected to die. As the plug of pollutant moves downstream it becomes diluted and, in those regions, it is expected than that there will be less 50% mortality of all species. If an LC_{50} was used as the reference value for toxicity the calculations would be much more conservative. If the LC_{50} data were chosen for species which are not the most sensitive, then the calculations would be less conservative.

When the risk assessment is conducted the effect of the choice of data needs to be considered and discussed in the commentary that is attached to the EHI value.

EXPOSURE TIME

At this point, it is worth commenting further on the use of LC_{50} and EC_{50} data values of these parameters are derived from experiments in which particular species are exposed to particular concentrations over a defined time period, typically between 24 and 96 hours. Thus, any measured LC_{50} value has associated with it a test exposure time. Different exposure times will lead to different LC_{50} values, since the actual toxic dose is dependent on both concentration and time; in general, longer exposure times should be associated with smaller LC_{50} values.

Thus, when calculating EHIs, it is appropriate to consider whether or not the toxicity data used should be either selected to that they are from tests with time periods comparable to the exposure period of the accident, which are often shorter than those in test conditions. This raises a further question concerning the need to modify measured data to account for differences between test and actual exposure times; methods exist which allow these effects to be accounted[7] for, although there is clearly some uncertainty associated with their use. However, a brief review of available toxicological data indicates wide variation, in, for example, LC_{50} values. In some cases, data for one chemical could cover an order of magnitude or more. Moreover, higher LC_{50} values may be found for 96-hour test exposures compared to 24 hours (contrary to what might be expected). This variation is a reflection of differences in the various test conditions, ie, differences in test species and test conditions (flowing or static water, temperature etc.).

In view of the above, and considering the complexity of an actual aquatic system relative to test conditions, it is considered appropriate to err on the conservative side and always use the minimum available LC_{50} and EC_{50} values for any particular species, irrespective of the test exposure time. Any alternative approach would need to be justified by the assessor. No matter what data are used their choice should be discussed in the commentary accompanying the results.

It is also worth noting that the above specification for the EHI has not utilised other possible data and methods which could have been used to classify environmental harm. This issue

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[7] Suter G. W. (1993) “Ecological Risk Assessment” Lewis.

was addressed in Chapter 4; the reasons for rejecting the various alternatives will not be repeated here.

The severity term for the aquatic EHI is therefore:

$$\frac{\text{PEC}}{\text{LC}_{50} \text{ (minimum for generic ecosystem)}}$$

5.2.2 Size of the affected area

As stated above it is important to consider the size of the ecosystem which has been affected. This is necessary as the degree of harm to the environment increases as the size contaminated increases. The minimum degree of contamination which is considered in the calculation of the environmental harm index is represented by the "dangerous concentration", DC. Where the data are available the DC is given by the LC_{50} for the most sensitive organism in the generic ecosystem. If these data are not available, then it is suggested that the DC is the $LC_{50}/10$. Since the application factors generally available to extrapolate from LC_{50}s to NOECs (No Observed Effect Concentrations) are typically of the order of 1000, as suggested in the EPA method quoted in USES[8], and factors of 10 are also typically applied to LC_{50} data to account for interspecies variation, then the proposed approach seems reasonable.

The size of the affected area is therefore determined by the area which is contaminated to a level above the DC between the release point and the point where the concentration falls below the DC. Models are available to allow this calculation. The size contaminated is then compared with a reference size (S_{ref}). Values for S_{ref} have been taken from the guidance document produced by the Department of the Environment[9]. The values are given based on the assumption that if such a size is contaminated (above a certain level) then a significant effect can be said to have occurred. Values for S_{ref} are given below in Table 5.1 for the three aquatic ecosystems under consideration. Where the size denoted by S_{ref} is only a small part of a larger, similar, ecosystem it may be appropriate to consider using a higher value than suggested in the table; for example, for a spill into a very large estuary it may be justifiable to use a much larger value for S_{ref} than 2 ha. This is one of many site-specific issues which need to be considered in the assessment and form part of the discussion/commentary accompanying the results.

Table 5.1 Values for S_{ref}	
River	10 km
Estuary	2 ha
Lake	1 ha

The size term for the aquatic EHI is therefore:

$$\frac{S \text{ (contaminated above DC)}}{S_{ref}}$$

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[8] RIVM, VROM, WVC (1994) Uniform System for the Evaluation of Substances (USES) version 1.0

[9] Interpretation of Major Accident to the Environment for the Purposes of the CIMAH Regulations. A guidance note by Department of the Environment June 1991

5.2.3 Recovery Time

As stated above it is important to consider the length of damaged; time for which the ecosystem is this equates to the time taken for the ecosystem to recover back to a state similar to its condition prior to the accident. Accurate prediction of this period is extremely difficult due to the complex nature of the phenomenon involved and, in some cases, an ecosystem may never recover to a state near to its original. It might thus be argued that a time parameter should not be included in the EHI; however, failure to do so would mean that an important parameter, possibly even the most important parameter from a public perception point of view, was excluded. It is therefore proposed to include this parameter within the EHI and to adopt a simple approach in which expert judgement is used to assign an ecosystem's recovery time to one of a series of categories.

The suggested categorisation of recovery times is shown in the left-hand column of Table 5.2. The right-hand column shows representative recovery time for each category, that is, the recovery time corresponding to the accidental spill, T_{acc}, which should be used in the calculation of the environmental harm index.

Table 5.2 Categorisation of Recovery Times

Recovery Time Category	**T_{acc} (years)**
Permanent	50
5-20 years	20
1-5 years	5
Weeks – 1 year	1
Days	0.1

Use of the proposed T_{acc} values will introduce a degree of conservatism into the results. This is particularly so when the predicted recovery time is at low end of the proposed categories, in which case the T_{acc} value may be between 4 and 20 times greater than the actual recovery period. One approach to overcome this difficulty would be to use a larger number of categories; this would be justified if there were sufficient confidence in the predicted values. Alternatives to the above T_{acc} values may be used if they can be justified.

Again, the recovery time parameter is compared with a reference value (T_{ref}), which has been taken from the DoE guidance as representing the time taken for an aquatic ecosystem to recover after a significant effect. T_{ref} for all aquatic habitats is therefore taken as five years. Information from real accidents to rivers which resulted in prosecution and large values of EHI has indicated that a recovery time of five years is not unreasonable.

The recovery time term for the aquatic EHI is therefore: $\frac{T_{acc}}{T_{ref}}$

5.2.4 Changes in pH, Temperature and Dissolved Oxygen

The above section discusses the choice of parameters for the risk assessment of a toxic substance. Consideration has been given to extending the EHI to apply to the following:

- reduction in dissolved oxygen (DO) in the water column, as a consequence of increased biochemical oxygen demand, BOD, or the presence of surface layers which limit re-aeration;
- changes in the pH such that the water becomes too acidic or alkaline and impacts upon particular species; and
- changes in water temperature.

Effects on ecosystems resulting from the above are not reported in a comparative fashion to toxic effects. Essentially a range of 'threshold' values have been identified, above or below which harm to the system might be expected. This threshold value equates to the dangerous concentration (DC). For example, in the case of dissolved oxygen, a concentration can be identified beneath which, in the particular conditions pertaining to the experiment or test, harm to a particular species was observed. For chemicals which alter the pH of the aquatic environment, data exist which identify threshold pH values above or below which, harm to a particular species was observed.

To utilise the available information, an EHI has been developed which assumes those effects to be categorised by a threshold value, beyond which harm has occurred and cannot be further characterised in terms of severity. Thus, the 'severity of harm' term in the generic EHI presented above simply reduces to unity once the threshold has been reached or exceeded. The EHI then becomes:

$$\mathrm{EHI} = \frac{S(>DC)}{S_{ref}} \times \frac{T_{acc}}{T_{ref}}$$

where S_{ref}, T_{acc} and T_{ref} are as specified above. S(>DC) is the size of ecosystem (ie, length of river area of estuary, etc.) that is contaminated above the threshold value.

The calculation of the above EHI for non-toxic substances has two major requirements. Firstly, models are required which allow the distribution of DO, pH and temperature to be estimated as part of the risk assessment process. Although not always widely available such models do exist. Secondly, data are required which indicate when harm might be expected to occur due to specific changes in pH, temperature or DO. Literature reviews[10] have shown that threshold values for each of the effects do exist. It is the responsibility of the assessor to obtain appropriate data for the situation and justify their use in the assessment.

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[10] See, for example,
Alabaster and Lloyd (1982) "Water quality criteria for freshwater fish".
CEC (1978) "Directive on the quality of freshwaters needing protection or improvement in order to support fish life". 78/659/EEC Official Journal L222, 14 August 1978.
Hughman S,J., O'Donell A.R., Mance G.(1984) "A survey of estuarine oxygen concentrations in relation to the passage of migratory salmonids" WRc report ER 745-M.

5.2.5 Other Factors influencing the EHI

Basic specifications for various EHIs have been presented above, reflecting consideration of a range of issues. The calculation of the EHIs are based on acute effects from releases over a short period of time. However, there is a range of other factors which need to be considered, which might influence specific EHI calculations in particular circumstances. These factors include those which are likely to give rise to long term effects and the means by which such effects could be accounted for. These factors include:

- bioaccumulation;
- attachment of chemicals to sediments;
- chronic effects.

Each of these will be discussed in turn below.

BIOACCUMULATION

some pollutants have the potential to bioaccumulate in the tissues of exposed organisms. Chemicals may bioaccumulate in tissues because of direct exposure to contaminated or through water the ingestion of contaminated food. This may not only prolong the residence time of the chemical within the ecosystem, but also result in the indirect exposure of higher organisms to the contamination via their food intake.

Bioaccumulation is an effect most likely to occur as a result of continuous or chronic exposure to contamination; see the discussion on chronic effects below. Where bioaccumulation is suspected to be an additional route of exposure in the ecosystem then expert judgement is required to assess the likely impact on the aquatic ecosystem.

Simplifying assumptions can be made to identify chemicals with the potential to bioaccumulate[4] ie, those chemicals with a log Kow ≥ 3.0. In addition, estimates can be made of the resulting tissue concentrations following exposure[3]. However, these models rely on the assumption of equilibrium conditions and their use in simulating environmental exposures is subject to uncertainty[11].

ATTACHMENT OF CHEMICALS TO SEDIMENTS

A pollutant released to an aquatic system may attach to sediments, resulting in a lowering of the concentration in the water column, with a corresponding increase in sediment concentrations and, potentially, a longer residence time in the system.

Where this is expected to occur, benthic organisms may be particularly at risk. It is therefore, considered appropriate (where possible) to ensure that sediment dwelling organisms are included in the generic species list from which the minimum LC_{50}/EC_{50} is selected, so that these organisms are accounted for in the overall protection of the ecosystem.

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[11] Calow (1993) Handbook of ecotoxicology, Vol 1, Blackwell

Attachment to sediments could, of course, give rise to chronic exposure; methods for dealing with such effects are presented below.

CHRONIC EFFECTS

The need to take chronic effects into account will depend upon the characteristics of the chemical. The EHI for toxic effects, as specified above, does not necessarily account for these impacts, since it is (initially at least) focused on acute timescales. However chronic effects will be accounted for, at least to some extent, when acute effects are also predicted to occur, ie, when some part of the environment is contaminated above the 'dangerous concentration' so that there will be a non-zero value for the EHI. An appropriate selection of the recovery time value, T_{acc}, will assist in refining this further so as to account for the longer time scale that the ecosystem may take to recover in such situations. In addition to the above methods for accounting for chronic effects when there is a non-zero value for the toxic EHI, it may be necessary to account for chronic effects when the toxic EHI is zero. This represents the situation where no part of the environment is exposed above the DC. It is still possible for long-term, low-level exposure to impact on the ecosystem and it may be necessary in the future to develop a method to assess this harm. In the absence of such a method the possibility of chronic effects should be noted in any discussions concerning future actions as a result of use of the proposed risk criterion scheme.

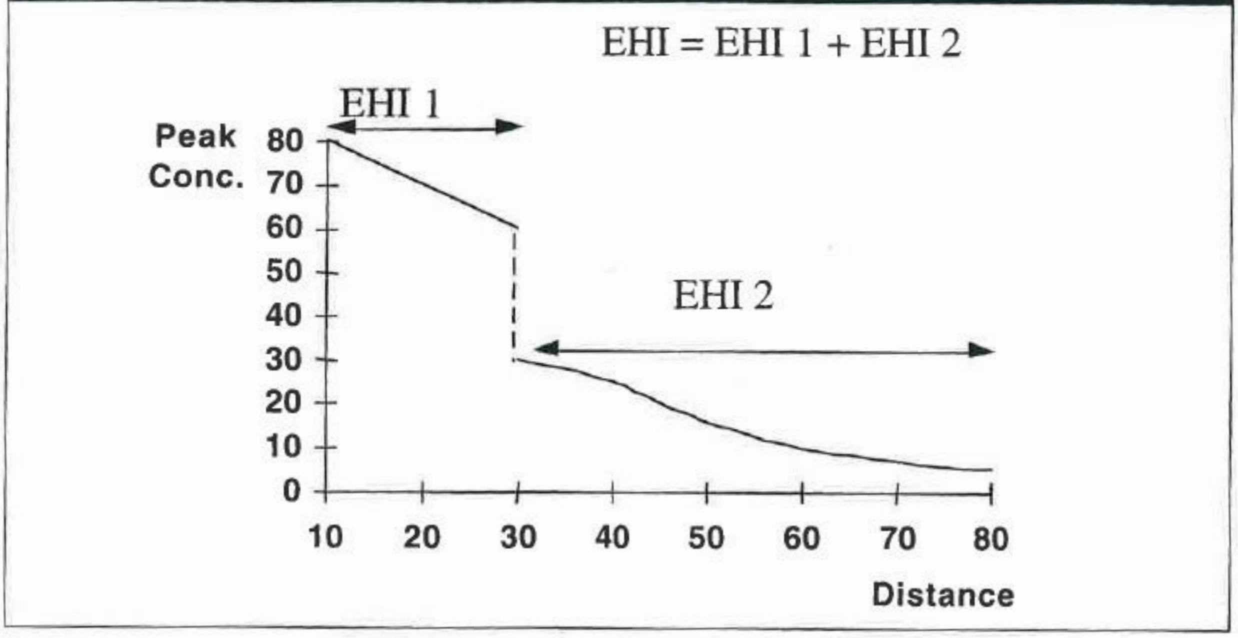
5.3 Calculating the EHI for Aquatic Ecosystems

The first step in calculating the EHI is to determine the predicted environmental concentration (PEC) of the pollutant in the water. This can be done using modelling techniques such as those used in PRAIRIE^{TM} or by applying a suitable dilution factor. It is recommended that the concentration is taken at the edge of the 'mixing zone'. This concentration is then divided by the LC_{50} for the most sensitive species from the generic ecosystem. The aim is to be conservative in the first instance, so the choice of toxicity data is, ideally, taken from a suite of organisms which represent the generic ecosystem. If fewer data are available, then the LC_{50} for the most sensitive organism of those available should be chosen. The reasons for this are given above.

Once the quotient for the PEC/LC_{50} has been obtained then the size contaminated needs to be determined. This is obtained using the methods described above and a quotient obtained for $Size/S_{ref}$. The final parameter in the calculation of the EHI is that for recovery time. Again, a quotient is obtained for T_{acc}/T_{ref} as described in the relevant section above.

For a single river the EHI is calculated by multiplying together the values for all three quotients. For a river system where a series of rivers and tributaries are contaminated by one spill, then the EHI needs to be calculated for each section of river and then summed together. This is illustrated in Figure 5.2.

Figure 5.2: **Illustration of method for calculating the EHI along a river/tributary system**



The descriptions of the process for calculating each of the three terms in the EHI includes a requirement for the choice of data to be justified by the assessor. The risk assessment and the process of obtaining the data required to calculate the EHI is as important as the final EHI value. Consequently, it is recommended that a 'commentary' accompany the EHI value. This commentary should include an audit trail demonstrating the source of the data used and justifications for its use, plus relevant site-specific data. The aim is to provide sufficient information to assist in any decision-making process.

5.4 Groundwater

The above discussions have considered the assessment of harm to surface waters from the accidental release of harmful chemicals from industrial sites. The impact of such accidental releases on groundwater is also an important issue and needs to be included in any assessment of the risks to the environment from accidental releases of harmful chemicals. The Environment Agency's document 'Policy and practice for the protection of groundwater' does not cover this issue. Consequently, the process for the assessment of harm, described above, needs to be extended to include groundwater and would need to be consistent with the policy document on groundwater. This is considered further in Chapter 11 on Future Work.

CHAPTER 6

The Terrestrial Environment

Although the generic issues associated with the assessment of harm to the terrestrial environment are similar to those already discussed above for aquatic ecosystems, the diversity of terrestrial ecosystems means that the prediction of environmental effects is much more complex. Terrestrial organisms are not only exposed to pollutants in the air, but also from contaminated porewaters, surface and groundwaters, from pollutants in soil and contaminants transferred via the food chain. Calculation of exposure levels is not, therefore, a simple matter of an equilibrium partitioning process, and as such terrestrial environmental exposure models and datasets are not as well developed as their aquatic counterparts. Although interest in terrestrial ecotoxicity has increased over the past few years, with an ever-increasing range of toxicity tests and models, the literature is still focused on the aquatic environment. Nevertheless, the options for assessing harm to the terrestrial environment from industrial accidents have been considered, and the conclusions formed in consultation with the members of the terrestrial task group and the experts attending the seminar held in March 1997.

A wide range of industrial accidents may result in harm to the terrestrial environment, from process failures releasing toxic gases/aerosols to atmosphere, to storage or transfer accidents involving spills contaminating the surrounding land. Any terrestrial exposure model has therefore to consider both air and land as possible routes to exposure. The discussions with the terrestrial task group emphasised that separate approaches should be taken for the air and land pathways since the likely chemicals involved, the species affected and the timescales for recovery will be distinctly different. In fact, releases to air were given the highest priority for criteria development. Furthermore, the view was expressed that significant environmental damage is not normally associated with accidents directly contaminating land; more often it is associated with chronic exposure following long-term contamination.

6.1 Terrestrial targets of concern

In order to assess the likely impact on species inhabiting the terrestrial environment, a general framework has first to be established in which several potential targets are identified[12]. Pathways to exposure, ecological functions, and morphological and physiological structures need to be considered in identifying suitable indicator species to be considered in any environmental assessment. Broad target categories for the terrestrial environment may be assigned as:

- man;
- flora;

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[12] Richardson (ed) 1988, Risk Assessment of chemicals in the Environment

- fauna;
- soil/surface layers;
- geological formations/man-made structures.

In fact, the OECD workshop on ecological effects assessment[13] suggested that the elements essential for inclusion within a terrestrial effects assessment are: soil microflora, terrestrial plants, soil dwelling invertebrates, pollinators, birds and mammals.

Although the effects on particular species should be considered within an assessment, more importantly the functional integrity of the whole ecosystem should also be assessed. Assessing functional integrity relies on a knowledge of the interrelation between the various components of the ecosystem - the most difficult aspect to address in any exposure model. Therefore, the lethal or sub-lethal effects on *particular species* are often used as *surrogate indicators* of ecosystem degradation since these endpoints are much easier to determine. For example, although soil function is routinely monitored when assessing soil degradation, it is not normally incorporated into predictive effects modelling; instead, the toxicity to earthworms and other soil biota are more commonly used parameters.

The various components and targets within the terrestrial environment are explored in more detail below.

6.1.1 Air

Despite being a major pathway for pollutant transport, air is a major factor to sustaining life in the terrestrial environment. Air is the source of oxygen for man, other mammals and birds to breathe and it supports the carbon dioxide vital to plant life. These species, as primary targets, would therefore be most affected by a loss of air quality through atmospheric pollution. Indirect exposure to soil-dwelling species (secondary targets) would also occur following deposition of pollutants from the atmosphere to the surface canopy during transport. Air is therefore both a direct and indirect route for environmental exposure, and is often considered separately from the more complex effects on the land.

6.1.2 Soil

The soil is the important medium within which plants grow. As primary producers, plants are an integral part of the foodwebs of the terrestrial environment, and therefore impacts on the soil may have a direct impact on the functions of these plants and hence on the entire ecosystem.

Water is also a vital constituent of soil as it supports life and acts as a transport medium throughout the soil structure. In particular, water aids pollutant transport through the soil layers following initial deposition to the soil surface, thus increasing the likelihood of exposure of soil-dwelling organisms.

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[13] OECD workshop on Ecological Effects Assessment, OECD Environment Monographs, No 26, May 1989

Soil is the loose surface material of land and is a complex mixture of chemicals and physical components which nor only supports the growth of plants and but also provides a habitat for marly types of animals. Soil formation is dependent upon some of the organisms which live on and within the soil. They contribute to the formation of the organic components, ie, leaf litter and humus, and also to the physical processes of breaking up the soil particles by the action of roots and burrowing organisms. Impacts on the organisms within the soil would therefore affect soil formation, again possibly disrupting the whole ecosystem function.

The size and constituents of each of the soil horizons vary considerably between the distinct soil types associated with different climates. For example, deserts, grassland, broad leafed forest, and conifer forest present different soil profiles and a corresponding variety of flora and fauna. Such variations impact on the choice of appropriate indicator species for use in effects assessment, and should also be taken into account when making comparisons between types of environment.

Soil textures also vary and are classified according to the sizes of the mineral particles present as gravel, sand, silt, and clay. Soils made up of mainly small particles are heavy soils such as clay and have the advantages of retaining water well and being fertile. In contrast light, sandy soils allow the free movement of roots, but do not retain water efficiently and are less fertile. The recovery time of particular ecosystems will therefore vary considerably with soil type, given the variation in chemical persistence and the variations in ecological diversity.

The difference in soil fertility between light and heavy soils also results from the way in which minerals are retained. Minerals such as calcium and magnesium are cations and are stored on the surface of particles, whereas anions dissolve in water. Plants remove cations and replace them with hydrogen ions during growth, and therefore the potential fertility of soil depends primarily on cation exchange capacity. It can be seen therefore that pollution of the soil resulting in any changes to the cation exchange capacity will affect the fertility, productivity and ultimately the types of plant that will grow in the soil.

6.1.3 Flora

The most important factor for the survival of any ecosystem is the source of energy or food for the organisms within it. As primary producers, converting energy from sunlight into carbohydrates and proteins for consumption by primary consumers, the flora of the terrestrial environment are a vital link in the chain. They rely on water, carbon dioxide and selected minerals to carry out this process. Green plants, in particular, trees, contribute to the production of oxygen from carbon dioxide, thus assisting in the cycle to support man and other oxygen breathing species inhabiting the environment.

A common categorisation of the flora is given as:

- trees
    - coniferous
    - deciduous
- shrubs

- herbs
- grasses
- mosses
- liverworts
- ferns

with agricultural crops generally being a subset of herbs and grasses. Although the major classification of flora is as primary producers, some plants are classified as parasites or saprobes. This smaller group of plants are not primary producers, but consumers and as such rely on the survival of the ecosystems within which they live.

Plants in general are habitats for many of the fauna of the terrestrial environment. In a forest ecosystem, for example, the humid, dimly illuminated environment covered by a thick canopy is suitable for mosses, lichens and ferns and their associated fauna. Impacts on the canopy itself would not only have implications for the food chain, but also for the basic survival of the species for which they provide a home.

6.1.4 Fauna

The fauna inhabiting the terrestrial environment are as varied as the flora on which they rely. Herbivores obtain their food directly by eating plants and are the primary target following contamination of the environmental flora. In turn, herbivores are preyed on by carnivores, who may also be the source of food for other carnivores. Animal and plant waste is decomposed by microorganisms (bacteria, fungi) within the habitat, which return the raw materials to the environment, thus finally establishing the cycle. These complex patterns of food chains are what makes exposure assessment within the terrestrial environment most complex. Hence, modellers will often stop at the primary producers, or take the first primary consumer as an indicator species for harm.

The major categories of terrestrial fauna are:

- mammals, including man;
- birds;
- amphibians;
- reptiles;
- insects;
- invertebrates;
- protozoa.

6.1.5 Rock Formations and Man-Made Structures

The impact of pollutants on more permanent features such as surface rock formations or man-made structures is complex and difficult to assess. Rare geological features such as limestone pavement have become increasingly scarce as the rocks are removed for landscape gardening, and such sites, along with other rare habitats, are now designated to be SSSIs (Sites of Special Scientific Interest) requiring particular protection. The assessed impact on such habitats would have to consider not only the geological feature itself bur also the possible harm to the rare species that tend to inhabit these areas for which derailed toxicity data may not be available. Man-made structures are often geared around public use, and therefore contamination of these sites, thus increasing the hazards associated with public access, is a particular issue to be considered in environmental assessments.

6.2 Assessing Harm

Most natural ecosystems are in a state of equilibrium or balance so that few major changes occur in the natural {lora and fauna. Adaptations to natural changes, such as the slow change of climate, tend to be gradual. Man, however, often induces more sudden changes following direct removal of the habitat, eg, forest clearance, or by polluting the environment in which the ecosystems exist. The difficult aspect of assessing environmental harm, therefore, is to be able to quantify the damage to particular terrestrial targets.

Terrestrial organisms are exposed by air, water, soil and food. Such combinations of these media mean that there is no single predicted environmental concentration which may be used as an indicator for the terrestrial environment. As has already been suggested, knowledge of exposure and ecological effects in the terrestrial environment is limited compared to the aquatic environment. As such terrestrial exposure models are not well developed, and hence, there is no generally applicable methodology for use in effects assessments.

The approaches to predictive modelling of the impacts of pollutants on the terrestrial environment often involve comparisons between specific predicted environmental concentrations (PECs) and measured or derived toxicity levels for particular species, chosen to indicate conservative the likely macro-effect. Simple hazard ranking schemes are also used, often dividing chemicals into broad categories or priority classes based on their relative toxicity.

The toxicity data available range from experimentally determined LC_{50}s and EC_{50}s to No-Observable Effect Concentrations NOECs) and No-Effect Levels (NELs). Although the assessment endpoints are well defined, the range of test data available is limited. Due to the lack of information available, these toxicity data are often extrapolated to other species, situations, or environments. In particular the use of site-specific or medium-dependent parameters in generic effects modelling needs to be handled with care. Such extrapolation brings with it obvious uncertainties and an apparent lack of scientific evidence to support the predictive calculations.

As a result, the scope of data collation and derivation has routinely been driven by the requirements of regulation. For example, the standards associated with land remediation and site-cleanup[14] are focused on a limited number of chemicals and options for future land use. They are derived specifically for the purpose of relating levels of risk from existing contaminated sites to intended land-use, identifying trigger levels above which specific actions may be required if the land is used for the specified purpose.

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[14] DoE, consultation on Draft Statutory Guidance on contaminated Land, September 1999, ICRCL, Guidance on the assessment and redevelopment of contaminated land, ICRCL Guidance note 59/83, July 1987

The environmental assessment levels developed for routine releases by the Environment Agency[15] take account of human toxicity for releases to atmosphere, for which man has been generally accepted to be the major target. Limited data are available for releases to other environments, where flora and fauna toxicity levels are more commonly used.

There is a wealth of information available for pesticides following the changes in regulation and agricultural management over the last decades. As a result, the impact of these substances on terrestrial species is relatively well understood. For more commonly used industrial chemicals, however the situation is less certain.

Although the Dutch have presented eco-toxicity data for a substantial number of industrial chemicals[16], they have often been drawn from parallels in the aquatic environment, by assuming equilibrium partitioning between soil and water and scaling the aquatic data for use in the terrestrial environment. This is a common approach where datasets are limited, bringing with it increased levels of uncertainty in the assessments. Such uncertainties can force the assessor into a series of conservative choices which may be defensible individually, but collectively can be widely implausible.

Various suggestions for the development of an environmental harm index applicable to the terrestrial environment have been discussed within this project. It was felt[17] that the field was not sufficiently well developed to support such an approach at this stage, and that it was more important to demonstrate the value of the EHI for the aquatic environment where the datasets are more extensive, and the environment less complex.

6.3 Conclusions

In summary, the complexity of terrestrial environment in comparison to that of the aquatic environment brings associated problems in modelling environmental consequences. Although the development of approaches to environmental risk assessment were encouraged by all involved in the debate, it was agreed that the selection of appropriate parameters to represent the severity of harm for the terrestrial environment was not straightforward. None of the available approaches were considered entirely satisfactory. It was therefore agreed that the work on the terrestrial environment should not be pursued further until the aquatic environment had been fully explored, and the benefits of the EHI approach demonstrated there first.

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[15] HMIP, Environmental, Economic and BPEO Assessment Principles for Integrated Pollution Control, Environmental Protection Act 1990, Technical Guidance Note E1

[16] Denneman, CAJ, and van Gestel, CAM, Soil Contamination and Soil Ecosystems: proposals for ecotoxicological C-values, RIVM report 7Z5201001, RIVM, Bilthoven

[17] Expert Seminar Management of Harm project, March 1997

CHAPTER 7

Aquatic Case Studies

The case studies considered within this project have been invaluable in helping to demonstrate the use of the EHI, and in particular, illustrate its adaptability to a range of scenarios within both the riverine and estuarine environments. The sensitivities to the choice of the individual parameters have been explored, together with the ways in which parallels can be drawn between the calculated EHI values and the likely consequences using the associated commentaries and the individual components of the EHI (ie, severity, size, time). In fact, demonstrating the link between EHI and consequence is key to the future use of the methodology and in providing a framework on which to make consistent judgements. To support this endeavour, therefore, some of the accident scenarios have also been assessed using a more generalised *qualitative* accident severity model taken from industry[18], as explored in more detail below.

The first group of case studies comprise historical events for which data have either been provided by the Environment Agency from their records or taken directly from the literature. In most cases the releases have occurred into UK rivers, and together with information on the measured concentrations and the actual observed consequences, comparisons have been made between the predicted EHI and accident severity. Furthermore, since the ecosystem recovery times were not always known in these real cases, the sensitivity of the EHI values to the choice of recovery time has also been considered.

The second group of case studies fall into the category of predicted accident scenarios, for which a range of information was available. The first data set has been based on several industrial activities located close to a large river in UK. These accident scenarios range from process deviations and storage tank failures to transport accidents, for which associated generic frequencies of release have been assessed. The results have provided a range of releases for each of several sites along the river and its tributaries, and have not only enabled the range of EHI values to be estimated but have also allowed overall site risks to be presented (ie, frequency vs EHI). In addition, for several of the sites considered the likely severity of the releases has been explored, together with the sensitivities of the results to the choice of river flow data and release magnitude.

The second set of data was kindly provided by a large chemical company, based on the assessments they have carried out for one of their sites in the UK. These releases occur within an estuarine environment for which a specific dispersion model had previously been developed. The results of the EHI assessment have been compared to the company's perceptions of accident severity, thus further exploring the link between EHI and consequence.

Each of these groups of case studies are considered in turn below.

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[18] SIESO, Private Communication 1997

The conclusions presented here were further supported by a range of hypothetical assessments which were used to explore the sensitivities of the EHI evaluation to individual parameter assumptions. To maximise the clarity of presentation, any detailed information on these case studies has been omitted from this report.

7.1 Historical Events

These case studies are a key component of the project, demonstrating the usefulness of the EHI concept and providing a benchmark on which to judge any future developments. They are also important in demonstrating the link between the magnitude of the EHI and the likely accident severity. The proposition explored below is that an increase in EHI is associated with an increase in accident severity, hence the higher the value of the EHI the greater the possible consequences.

As already suggested the historical cases were either based on information provided by the Environment Agency or on data taken from the literature and comprise the following where RC denotes the river case number:

Table 7.1 Historical Case Studies

Historical Case Number	Chemical Released	Released quantity	Measured incident data or Modelled PRAIRIE data
RC1	Paraformaldehyde	130 kg	modelled
RC2	Kymene	1000 kg	modelled
RC3	Kymene	1000 kg	measured
RC4	LT31	not known	measured
RC5	"Freon"	not known	measured
RC6	Lindane	not known	measured
RC7	TBTO[19]	not known	measured
RC8	Sandoz, Disulfoton	estimated between 3000 and 8900 kg	measured
RC9	Diquat	not known	measured

In cases RCI and RC2 where the released quantity was known, together with information about the river flow state in which the release occurred, the EHI values have been predicted using the PRAIRIE^{TM} river dispersion model. In the remaining cases the value of the EHI has been calculated using measured concentration information taken at the time of the accident or as estimated following the release when the full impact of the event was known.

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[19] Same accident scenario as RC6

Table 7.2 EHI Values and Reported Accident Consequences for the Historical Case Studies

Case Number	Chemical Released	EHI formulation				Reported Accident Consequences	
		Severity	**Size**	**Time**	**EHI**	**Ecosystem**	**Financial**
RC1	Paraformaldehyde	2.6+	2.5+	1.0*	6.5	Invertebrates and 514 fish killed along 2 km stretch, concentrations modelled were above toxic levels to trout fingerlings beyond this distance	Fine £6000 Costs £3000
RC2	Kymene	110+	1.4+	1.0	150	100% mortality of salmonids over 14.5 km, 5-year recovery time	Fine £10,000 NRA Costs £2,500 Mitigation Costs £200K
RC3	Kymene	276	1.4	1.0	390	as for RC2 above	as for RC2 above
RC4	LT31**	408	0.4	1.0	160	Growth of mosses inhibited, large numbers of dead fish, 5-year recovery time	Not taken to court Costs to date £4,500 Estimate of fish costs £17,000
RC5	"Freon"	34	0.14	1.0	4.7	Major fish kill of adult sea trout/brown trout, water quality poor / upstream good 5-year recovery time	Not taken to court Ex gratia payment of £3,500 based on value of fish stocks etc.
RC6	Lindane	1470	3	1.0	4400	Fish and biota severely affected, 15000 fish killed, 70-80% decline in population, 5 year recovery time	Total figures unknown NRA cleanup - £100K
RC7	TBTO	102	3	1.0	310	As RC6	As RC6
RC8	Sandoz, major component Disulfoton (Many other insecticides and pesticides released)	10	86#	1.0*	>>860	500,000 fish killed, inc. 150,000 eels.700 km downstream concentrations no longer toxic to fish, but still toxic to Daphnia. Recovery of benthic fauna after 3 years, eels took several years to repopulate	Costs of site clean-up £28M Compensation claims £35M Fund for ecological recovery of Rhine £3M
RC9	Diquat released into beck (a) and then feeding into river (b)	(a)	(a)	(a)	(a)	Pollution sensitive organisms had re-populated atter 5 years - could conclude that for 50 km (distance above toxic levels), many fish and insects would have been killed	No record of costs found but were quoted as 'significant'
		4760	0.85	1.0*	4050		
		(b)	(b)	(b)	(b)		
		22	4.2	1.0*	90		
					Total		
					4140		

Notes:

* estimated recovery time of 5 years

** using concentration 50 m downstream (32.6 mg/l)

difficulty in estimating final distance from information available

+ modelled using PRAIRIETM

Table 7.2 illustrates the calculated values of the environmental harm index for each of the historical cases, together with a brief description of the accident consequences. For each of the chemicals considered, data for a range of species has been collated and the EHI values represented in the table reflect those obtained for the most sensitive species across all trophic levels.

The reference size and time for the above calculations were taken to be 10 km and 5 years, respectively, as suggested above in Chapter 5. Releases RC1 and RC2 have assumed an approximate release duration of 30 minutes in order to model the dispersion, due to a lack of detailed information on the accident. The values of the EHI would increase if a shorter duration was assumed, which in the case of RC2 would bring the value closer to that estimated for the actual measured values for this accident in RC3. For release RC9 two separate components of the EHI are presented corresponding to the initial release into the local beck and the subsequent dispersion as it reaches the main river, denoted (a) and (b) in Table 7.2. This process of summing the individual components of the EHI was described in Chapter 4.

The severity, size and time terms are presented separately, which illustrates that for the cases considered the severity term is most dominant in the formulation. This not only reflects the use of the LC_{50} for the most sensitive species within this term, and its sensitivity to that value, but also the limited length of the rivers being considered over which the impact may be observed (thus limiting the size term). For the Sandoz case, the length of river affected above the DC (Dangerous Concentration) was difficult to estimate from the information available. Furthermore, the initial concentration is based on limited data, taken from reported levels of disulfoton in the Rhine. Therefore, the estimate given can only be an approximation to the actual value of the EHI, it which is believed should be much greater, as denoted in the table.

In those cases where information was forthcoming a minimum of a 5-year recovery time has been suggested, which has also been used for those cases in which the time taken for the recovery of the ecosystems was not known. Given the 5-year reference time assumed for rivers, this term has no overall impact on the magnitude of the EHI for these cases.

The reported accident consequences given in Table 7.2 illustrate the link between calculated values of EHI and accident severity, since the data suggests a general trend that an increase in the EHI correlates with an increase in numbers of fish killed and an increase in costs associated with the accident. This therefore supports the initial proposition that there is a correspondence between increased values of EHI and an increase in accident consequences.

The proposition has been explored further by re-assessing the historical accident information against a more qualitative accident severity model suggested by industry as illustrated in Table 7.3. Within this model severity is denoted by a range of consequence levels of increasing effect from 1 to 5. Three broad groups of issues are considered, from the basic definition of the magnitude of the consequence to any visible or toxicity effects. The complete range of effects observed, or likely to be observed, should be considered in estimating the overall impact, and hence the examples in the table are given for illustrative purposes only.

The assessment of accident severity for each of the real cases is compared to the predicted values of EHI below, and is illustrated in Figure 7.1. As already suggested, the value for the

Sandoz incident is known to be larger than the EHI value given in Table 7.2, and hence only an approximate estimate could be presented. This uncertainty is illustrated by an arrow above the associated EHI value in Figure 7.1.

Table 7.3 Suggested Qualitative Accident Severity Model

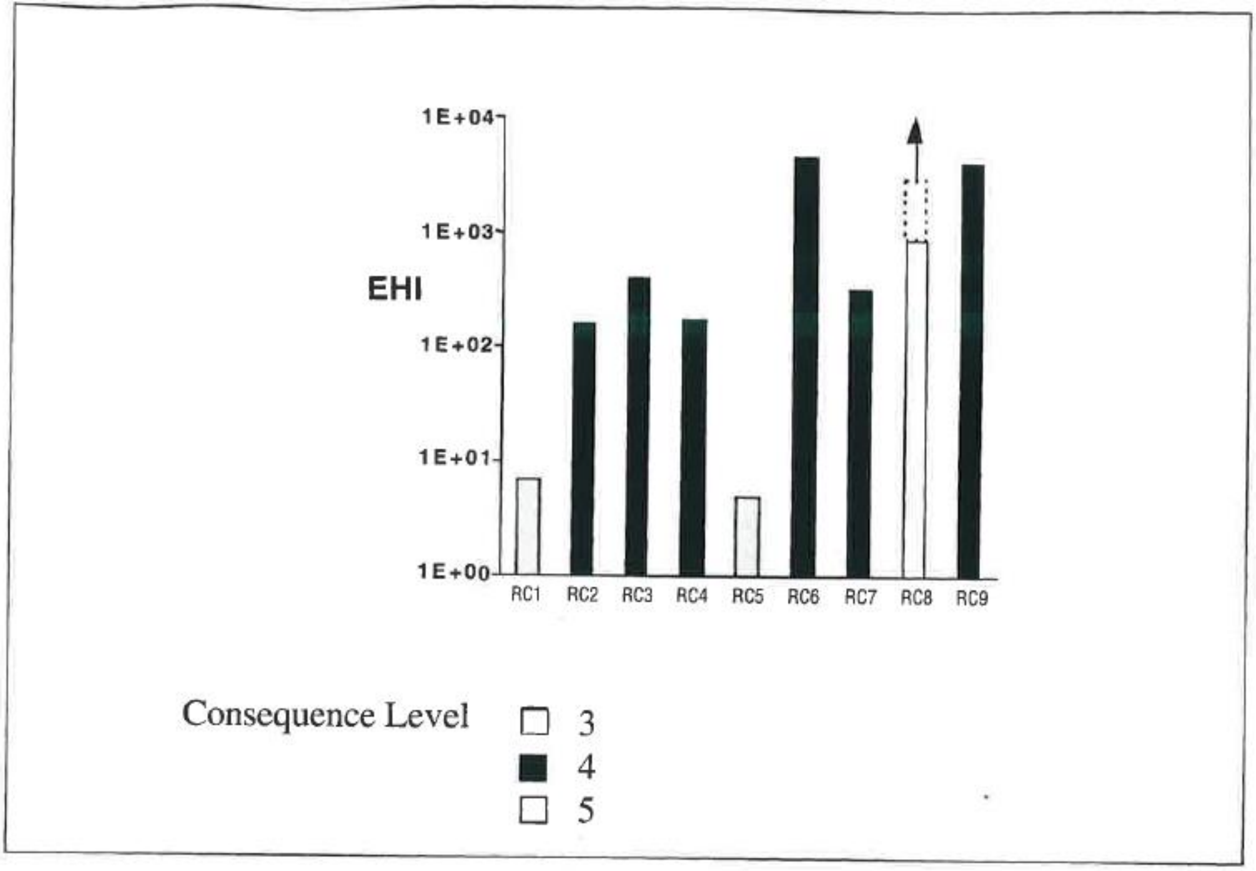
Consequence level	Low ← Consequence → High				
	Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Broad Definition of Effect	Minimal/ barely detectable	Observable but localised	Substantial, fairly widespread	Major	Catastrophic
Examples of Visible Effects	River slightly discoloured	River discoloured for significant length (hundreds of metres)	River discoloured for thousands of metres	Accidents meeting DOE threshold criteria	Accidents significantly more serious than DOE criteria
Examples of Effects on Biota	No/very few fish killed	Significant fish killed and other aquatic life affected	Large numbers of dead fish and aquatic life badly damaged		

Table 7.4 Comparison of EHI values with Accident Consequence Level

Case Number	EHI	Consequence level
RC1	6.5	3
RC2	150	4
RC3	390	4
RC4	160	4
RC5	4.7	3
RC6	4400	4
RC7	310	4
RC8	>>860	5
RC9	4140	4

The results are generally consistent, with the exception of the result for Sandoz, which is known to be an underestimate, and suggest that an increase in the value of the EHI can be associated with an increase in accident severity. Thus, again supporting the proposition declared earlier.

Figure 7.1



Determining the recovery time is particularly difficult for any accident scenario. Given the range of effects observed for those cases considered here, eg, the range of possible recovery times for each location and for each of the trophic levels, it was difficult to predict exactly what the overall recovery time will be. Furthermore, the sensitivity of the predicted values of the EHI to the reference recovery time of 5 years was also of interest. For each of the real cases, therefore, the sensitivities to the choice of recovery time has been explored, by varying the values of T_{acc} and T_{ref} over a likely range of between 2.5 to 10 years. Since the EHI scales directly with the time term, this obviously affects the overall values of the EHI. However, the variation is limited to the range of possible values of T_{acc} or T_{ref}, ie, in this case a factor of 4, as illustrated below in Table 7.5 for T_{ref}. More importantly the rank of each of the cases in increasing values of EHI remain the same. Therefore, if the EHI was used within a screening process the actual choice of recovery time becomes less critical.

7.2 Predicted Accident Scenarios

This group of case studies comprise releases to both rivers and estuaries. In the main, they have been based on locations and industrial operations in the UK using information supplied by industry. In some cases where detailed site-specific data was not forthcoming, more generic information has had to be used, for example in determining accident frequencies for the river cases.

Table 7.5 EHI Estimates for Real Cases with varying values of T_{ref}

Case Number	Chemical Released	T_{ref}		
		2.5	**5**	**10**
RC1	Paraformaldehyde	13	6.5	3
RC2	Kymene	300	150	75
RC3	Kymene	780	390	200
RC4	LT31	320	160	80
RC5	"Freon"	9.4	4.7	2.4
RC6	Lindane	8800	4400	2200
RC7	TBTO	620	310	160
RC8	Sandoz, Disulfoton	1700	860	430
RC9	Diquat	8300	4140	2100

7.2.1 River Cases

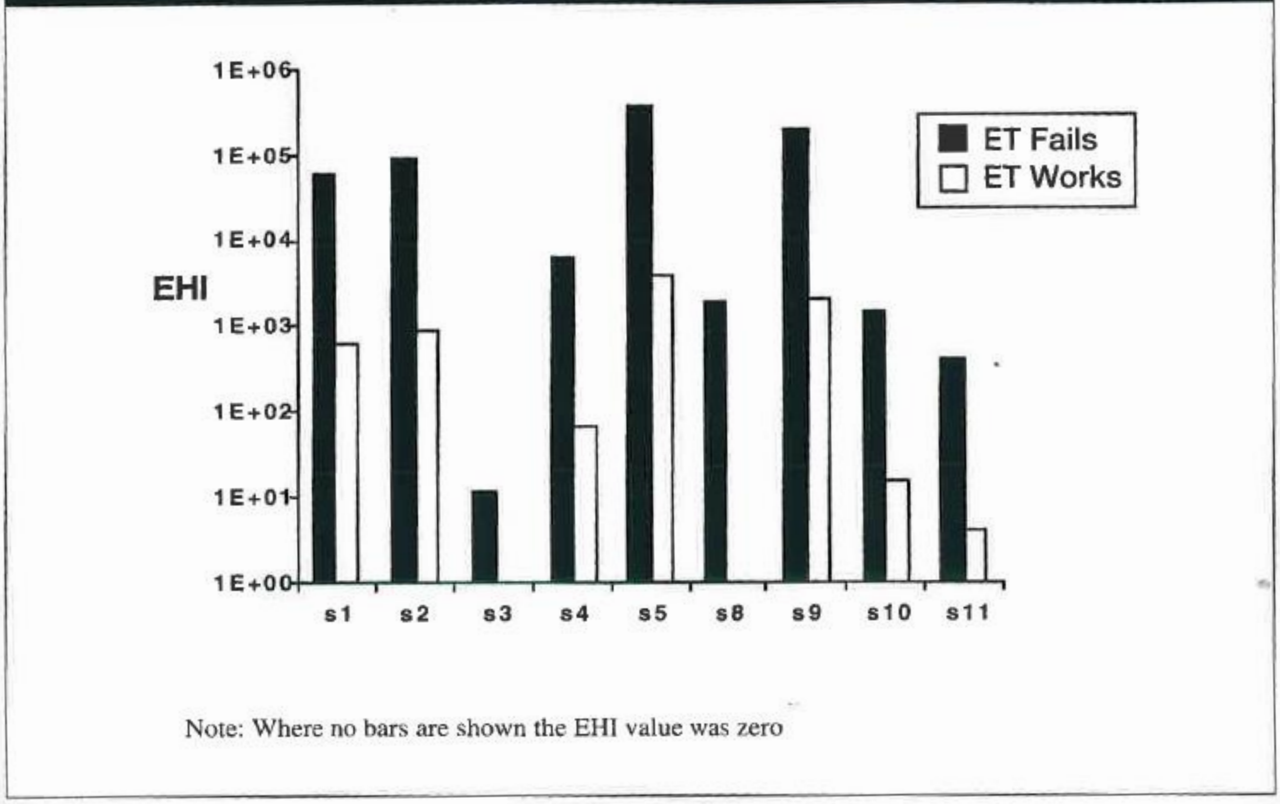
The risks posed by five industrial sites situated along a large river and its tributaries in the UK have been considered as a part of the aquatic accident case studies. These are based on an evaluation of the information supplied both by the operators themselves and the Environment Agency. The EHI values were calculated for a number of accident scenarios at each site and were assumed to be released to the river/tributary on which the site was situated. However, to explore the sensitivities of the EHI values to river sizes and flow rates, the same releases have also been assumed to occur within a range of rivers typical of the UK.

Site 1 is a relatively complex site on which several industrial processes are carried out and is located adjacent to the river. Sites 2 to 4 are smaller plants involving less complex activities, smaller storage facilities, and are situated along tributaries feeding into the river. Each of several possible accident scenarios for all five sites have been considered in the assessments, to which associated generic frequencies have been assigned and modified as far as possible to take account of site-specific data. Predicted concentrations in the water downstream of the release point were calculated using the PRAIRIE^{TM} model and using flow data appropriate to the river/tributaries under consideration. The assessments are however conservative, in that pessimistic assumptions have been made when estimating the likely releases to the aquatic environment, and pollutant losses during transport have been omitted from consideration. Although some chemical releases have been omitted from the assessment, where appropriate toxicity data was unavailable at this stage, those major events contributing greatest to the risks to the aquatic environment have in general been included, and can therefore illustrate the use of the EHI as a screening tool. A detailed description of the assessments for each of these case studies given in Appendix 1.

To illustrate the process, the EHI results for site 1 are presented here. The site is situated on River C, the largest of the rivers considered in the case studies. For this site eleven accident scenarios were determined, releasing a variety of chemicals from the storage tanks on site.

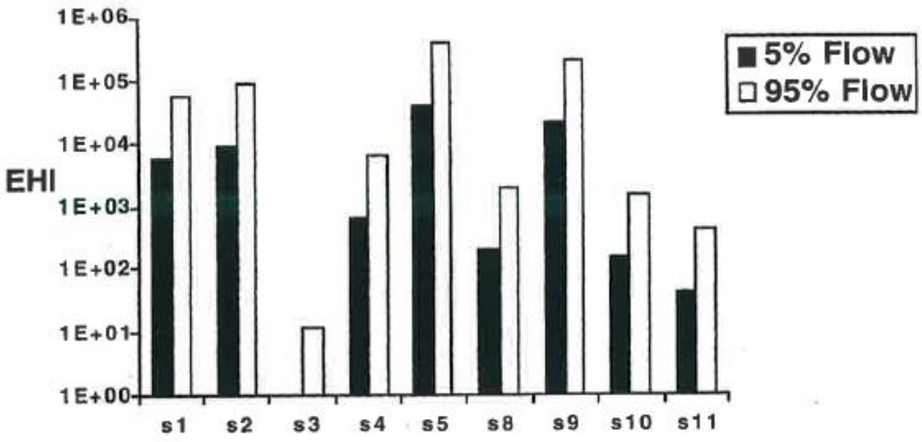
Each pollutant is then assumed to be channelled via an effluent treatment (ET) system, which either fails on demand or remains in full operation, each with associated probabilities of occurrence. Figure 7.2 illustrates the effect of the change in state of the effluent treatment system on the EHI estimates for each scenario, reflecting the change in the magnitude of the release. The results presented here are based on the 95th percentile flow rate for the river, which represents the lower end of the spectrum, thus maximising the estimate of the concentrations in the river. In order to establish the complete spectrum of risk for the site, a range of flow rates has been considered in the case studies. Figure 7.3 compares the results at low (95%) and high (5%) flow rates for each of the scenarios considered, where it can be seen that the increase in flow reduces the values of the EHI by up to an order of magnitude.

Figure 7.2 **EHI values for Site 1 Scenarios at 95% River C Flow Rate**



Note: Where no bars are shown the EHI value was zero

Figure 7.3 **Variation in EHI Values with River Flow Rate (Results for Site 1, River C – ET Fails)**



Note: Where no bars are shown the EHI value was zero

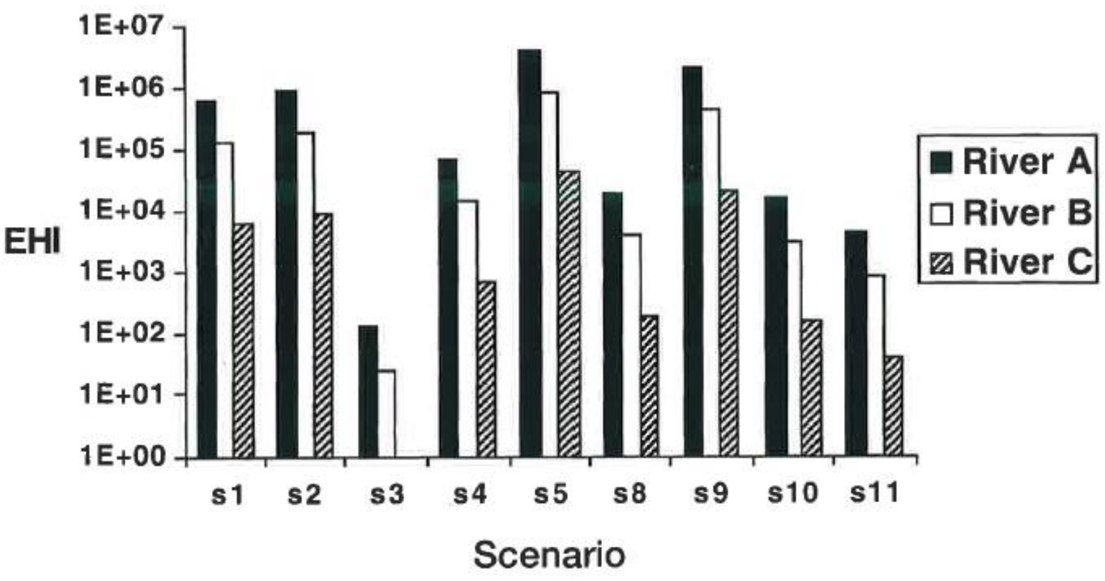
In order to relate these values of EHI predicted for site 1 to levels of consequence, each of the accident scenarios has been considered in terms of the qualitative categories described in Table 7.3 above. In order to categorise each release, the magnitude of the individual severity, size and time terms have been considered. For the case where the effluent treatment system remains operational, the following categorisation has been evaluated, where, again, an increase in consequence level with increasing values of EHI can be seen:

Table 7.6 comparison of EHI values for site 1 with Levels of consequence (Results for Site 1, River C - ET Works)

Scenario	**EHI values**		**Consequence level**			
			95% river flow		**5% river flow**	
	95% river flow	**5% river flow**	**Level**	**Comments** Size of initial concentration & distance above DC	**Level**	**Comments** Size of initial concentration & distance above DC
s1	620	62	2	>LC_{50} Salmon 24 hr, 100 km	3	=LC_{50} Salmon 24 hr, 100 km
s2	930	93	4	>>LC_{50} Daphnia Magna48 hr, 100 km	4	>LC_{50} Daphnia Magna 48 hr, 100 km
s3	0	0	1	DG not reached	1	DG not reached
s4	67	6.8	4	>LC_{50} Daphnia Magna 48 hr, 100 km	2	<LC_{50} Daphnia Magna 48 hr, 100 km
s5	4000	403	4	>>LC_{50} Rainbow Trout 96 hr, 100 km	4	>>LC_{50} Rainbow Trout 96 hr, 100 km
s6	0	0	1	DG not reached	1	DG not reached
s7	0	0	1	DG not reached	1	DG not reached
s8	0	0	1	DG not reached	1	DG not reached
s9	2100	210	4	>>LC_{50} Brook Trout 96 hr, 100 km	4	>>LC_{50} Brook Trout 96 hr, 100 km
s10	15	1.5	3	=LC_{50} Brook Trout 24 hr, 100 km	2	<LC_{50} Brook Trout 24 hr, 100 km
s11	4.1	0	2	<LC_{50} Dab 96 hr,100 km	1	DG not reached

Sensitivities to a change in the characteristics of the river in which the pollutant is released were also explored within a range of hypothetical scenarios, together with the predicted accident cases for UK sites. The figure below illustrates the impact that a change in river dimensions can have on the results of the assessment for site 1, taking a range of river characteristics increasing in size from Rivers A to C, with 'C' representing the larger end of the spectrum. The results illustrated below are for the 5th percentile flow rate appropriate to each river, ie, the high end of the spectrum, and as expected the EHI values increase with the reduction in river size and flow characteristics, corresponding to an increase in pollutant concentrations.

Figure 7.4 Comparison of EHI Values with Size of River Flow Rates (Data for Site 1, ET Fails)



Note: Where no bars are shown the EHI value was zero.

7.2.2 Estuary Cases

The estuary case studies considered in this project have been based on data for four hypothetical releases provided by an operator in the chemical industry. These data were for near instantaneous releases into a tidal river in the UK from 'Site 6', involving benzene, nitric acid, ammonia, and an amine.

All of the data to support the EHI calculations were provided by the operator. These data include toxicity data and concentrations at given distances from the release point. The data provided by the operator were obtained from their own site-specific data collection and modelling. This enabled it to be determined that the pollutants would remain in the upper stratified layer of the water. No impact on the benthic fauna would therefore be expected and hence there will be no impact on the food web. Many fish in the surface layers would be expected to take avoidance measures, although some deaths could occur. Recolonisation of the surface layers could be expected within days of the contamination leaving the estuary. Therefore, a value of 0.02 (equivalent to 7 days) was chosen for T_{acc}, instead of 0.1 as suggested in Chapter 5.

Initial modelling of the releases assumed very conservative conditions. In particular the following assumptions were made:

- a very low freshwater flow (93rd percentile);
- average tidal range;
- release at slack water prior to ebb tide (ie, high tide);
- all substances conserved (ie, no account taken of evaporation, degradation, etc.).

Each of the releases was modelled in two ways using data provided by the operator; first a simple screening method which compared the concentration at the edge of the mixing zone with the DC, followed by a second tier where the EHI was calculated. In addition, the EHI was calculated with and without the time factor to illustrate its effect. Table 7.7 below shows the EHI values for all cases, whilst Appendix 1 presents more detailed information on their calculation. For each of the cases for site 6, the operator has also estimated the likely accident severity based on the consequence levels for each event (as described above). These are illustrated below, showing an increase in severity with EHI from categories 1 to 2. The nitric acid release has been considered in two ways, with the EHI calculated in the first case using the suggested approach for pH, rather than that used in all other cases for toxicity.

Table 7.7 EHI values for Site 6 – The Estuary Cases (EC)

Case Number	Chemical Released	EHI with the time factor	EHI without the time factor	Accident severity category
EC1	Benzene	28	6890	2
EC2	Nitric acid ○ pH ○ toxic release	 0.11 12	 27 3060	 1 2
EC3	Ammonia	20	5030	2
EC4	An amine	0.83	207	2

Table 7.8 presents the least conservative EHI values chosen from Table 7.7 with the corresponding frequency values for each event as provided by the operator. It can be seen clearly, that unlike the historical case studies presented above, the inclusion of the time factor for these estuary cases has a significant impact on the value of the EHI. This results from the short recovery time in the estuary due to the fact that the pollutant does not have a significant effect on the food web and thus recolonisation is very quick (see Appendix A1.1 for further details).

Table 7.8 Point EHI Values for the Estuary Cases and Associated Frequencies

Case Number	EHI (with time factor)	Estimated Frequency (yr^{-1})
EC1	28	10^{-3}
EC2	12	10^{-2}
EC3	20	10^{-5}
EC4	0.83	10^{-5}

The above calculations represent only a first pass through the risk assessment process and additional stages of refinement can be conducted. For example, the concentration values from which the EHI values have been calculated assume that the chemical is conserved. This is likely to generate higher EHI values than would be the case if chemical transformations in the water column were taken into account. Therefore, it is likely that if additional calculations were performed using less conservative assumptions the EHI values would be lower than those shown in these calculations. The next step in a risk assessment would therefore be to re-examine the methodology and parameters used in the current assessment to identify any areas where an improvement might be made and to then repeat the above steps.

7.2.3 Summary of Case Studies

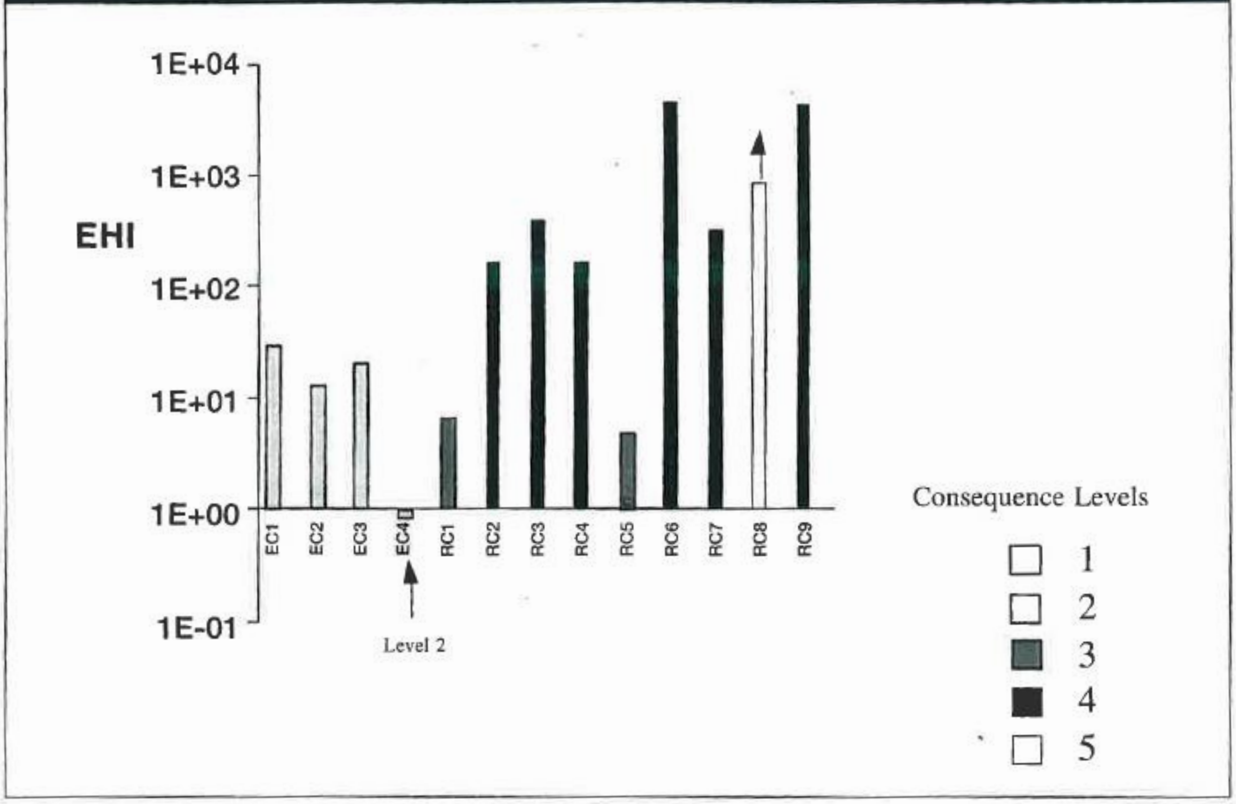
The case studies represented here, together with the many hypothetical cases considered within the project, have provided a valuable input to the process of development of the Environmental Harm Index. They have also assisted in the dialogue surrounding the development of environmental risk criteria as discussed further in Chapters 8 and 9 below.

Both the river and estuarine studies have helped to demonstrate the feasibility of the approach, whilst highlighting any limitations of the assessment. The experience of these and other case studies has been reviewed in detail by both the project team and the supporting task groups, and the overall conclusions are that the EHI concept may provide one of a number of useful inputs to a risk management decision-making framework.

The case studies considered have helped to demonstrate the link between the predicted EHI and the likely consequences in the aquatic environment. To support this endeavour, the predicted values of EHI were not only compared with real accident information, but also with the predictions of a more qualitative accident severity model suggested by industry. Overall, there appears to be a general trend for the river systems considered within this project, that an increase in the value of the EHI can be associated with an increase in likely accident consequences.

There has been some suggestion, however, that the relationship between the predicted values of EHI and the likely level of consequences may differ between the type of aquatic environment under consideration, eg, between rivers and estuaries. Figure 7.5 below illustrates that for the estuary considered in this study (site 6), the likely accident severity or predicted consequence level is somewhat lower than that predicted for the historical river cases for a similar level of EHI. For example, there is some degree of overlap in EHI values for the level 2 estuary cases (ECl - 4) and the level3 river cases (RC1, RC5). This situation is believed to result from the stratified nature of the estuary considered in this study, in that the pollutant remains in the upper layers of water, and although the concentrations may be relatively high in this upper layer (thus increasing the predicted value of the EHI), the estimated consequence level is low since the benthic organisms would not be affected. This situation may not be reproducible for other types of estuary where a greater degree of vertical mixing occurs. Estuaries within the UK are also, in general, inherently more variable in terms of their physical and hydrological properties than rivers. For these reasons, as well as the limited number of estuary case studies available to the project, a general conclusion may not be made at this stage.

Figure 7.5 Comparison of the EHI Values for the Real and Estuary Cases with Accident Severity



CHAPTER 8

Development of Criteria Framework to aid Risk Management

The general form proposed for the risk criteria has been discussed previously in Chapter 3. It was suggested that risk should be measured in terms of effects (consequences) and their associated frequency of occurrence. The spectrum of possible risks was divided into three regions with associated varying levels of concern. Several points were particularly emphasised, namely:

- the criteria were proposed to assist in the risk management decision-making process;
- criteria are only one of the factors used to influence any such decisions;
- the boundaries between the regions were not strictly implemented thresholds which precisely determined the actions to be taken.

The format previously suggested is built upon in this section, using the information generated from the case studies discussed in the previous section, so as to propose where the boundaries delineating the three regions might lie. It is emphasised at this point that the proposed criteria reflect the result of a research programme which has benefited from the advice of Steering Group members and testing via case studies. However, it is recognised that confidence in the validity of the criteria requires further experience of its use; this experience may suggest the need to reconsider and/or refine the proposed approach.

8.1 Proposed framework

The values of consequence and frequency which differentiate the three regions on the framework need to be defined before it can be used for practical risk management purposes. One concept which has been much discussed during the course of the research and which has been judged to have merit in assisting in this matter is that of 'a major or significant accident'. This is considered below in relation to the value of consequence and frequency associated with it. Risks associated with greater consequences and greater frequencies than such an event are considered to be priorities for further attention. As discussed in section three, such attention would probably, initially at least, involve a review of the risk assessment itself, but might, ultimately, require the implementation of some risk reduction measures. The consequence and frequency values for this accident thus lies upon the border between the ALARP and priority area for further attention in the framework described previously.

8.1.1 Consequence

It is proposed that the EHI, as described earlier, be used as a surrogate for the consequence parameter within the risk criterion scheme, particularly in the screening phase of the risk management process. The next consideration is the value of EHI corresponding to a major or significant accident. Since the denominator of the EHI includes parameter values taken from the definition of accidents of concern under the CIMAH regulations, it might be expected that an EHI of 1 would correspond to such an accident, since in that case the level of harm predicted from an actual accident would exactly equal that for the reference accident. However, this conclusion is misleading since it does not reflect three important considerations:

- The severity of effect term is based on an initial peak concentration which does not represent the exposure time of most species. The actual exposure time would be very difficult to predict and hence there is considerable merit in using the initial peak concentration to define severity; however, it is recognised that the result is an overestimate of the severity term.
- The case studies, particularly those based on real accident data, indicate that EHI values for major accidents (severity category 4) are typically at least 100.
- The case studies generating EHI values less than 10 are perceived by the Task Group on the aquatic environment to be associated with incidents much less severe than major accidents.

There is the further consideration that the accident at Sandoz, which is generally regarded as more severe than 'major', is estimated to have resulted in an EHI of at least 1000.

For the above reasons it is proposed than an EHI value of at least 100, calculated as described earlier is viewed as indicating the potential for a major or significant accident to rivers. There is insufficient evidence, at present, to suggest whether or not a similar statement may be made in respect of releases to estuaries.

8.1.2 Frequency

The next issue which requires consideration is the question of the frequency with which a major accident might be predicted to occur such that a higher value would suggest the risks are priorities for further attention. This matter has been the subject of discussion and correspondence throughout the research programme. The majority view was that this value should be no lower than 10^{-4} per site per year, with many suggestions that it should be higher. At this point it should be emphasised that the chosen frequency is that with which the consequences associated with an accident with an EHI of at least 100 is actually manifest in the environment. It is not the failure rate of the containment of hazardous material; this frequency will be greater than that required in this instance[20]. The relationship

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[20] A simple example may help to illustrate this point: Suppose a tank has a predicted failure rate frequency of F per year. Once the tank fails there are several barriers between the tank and the local river; these have a combined probability of failing on demand of P. Once it reaches the river the probability of the flow resulting in a major accident is R (in reality a range of flows would be considered, but this instance serves to illustrate the point in question). The predicted frequency of a major accident is then F x P x R per year. Since P and

between these two frequencies will depend on the accidents considered, the site and its location. However, experience suggest that there is generally at least a factor of ten between them, so that choosing a value of 10^{-4} per year for a major accident would imply a release frequency of 10^{-3} per year or more. It is therefore proposed, at this time, that the frequency ascribed to a major accident is 10^{-4} per year. Where an operator has information on the relationship pertinent to their situation between release frequency and consequence frequency it would be possible to modify the risk criterion so that this value of 10^{-4} per year is multiplied by the appropriate value; the resultant frequency would then be that of the release. (Care would be needed when considering implications of this approach on the full range of consequence frequencies.)

A frequency of 10^{-4} per year is consistent with that for a 'serious accident on a particular plant', as suggested by the Health and Safety Commission's Advisory Committee on Major Hazards[21] as being ‘just on the borderline of acceptability, bearing in mind the known background of risks faced every day by the general public'. That suggestion was made following the accident at Flixborough in which 28 people died. The relationship between this outcome and an event with an EHI of 100 is not certain, although it has been suggested by some members of the Steering Committee that Flixborough would be regarded as a more serious event.

Consideration of the historical frequency of events resulting in EHI values of around 100 would be of value in selection of an appropriate frequency. No one company is likely to have a sufficient number of major accidents per year to provide statistically robust data on the current level of such accidents per site per year. It is therefore necessary to consider the wider issue of the current level of major accidents in the UK per year and to then try to use this information to predict the average number of incidents per year per site. The two key inputs to this process are the number of accidents and the number of sites with the potential to cause such incidents. Unfortunately, neither of these is known. However, it seems probable that there are at least 100 to 1000 sites and hence choice of 10^{-4} per site per year implies a major accident being manifest 10^{-2} to 10^{-3} per year. Although the number of such incidents is not known some anecdotal data has been presented to suggest that currently major accidents are occurring about once per year. If this is actually the case, and if the estimated number of sites given above is correct, then it would suggest that a higher frequency should be chosen. Conversely, if the number of sites is actually larger than the value used above then a lower frequency would be appropriate.

At this stage it is not considered that there is sufficient robust evidence to make an unequivocal choice of a specific frequency value. Experience will inform this choice; however, as an initial step to help progress the selection of the most appropriate value, it is proposed that a value of 10^{-4} per year, as discussed above, is chosen for current purposes. It is acknowledged that this situation may change as further information is received or as perceptions change in the light of experience gained in use of the scheme. In any event, the selected point determines a line which is intended to assist in prioritising

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R are both less than one (and P is probably <0.1 on most sites), the frequency of a major accident is less than the frequency of the release from containment.

[21] Advisory Committee on Major Hazards, First report. 1976.

attention/actions, rather than as a boundary above and below which fundamentally different types of activities are undertaken.

8.1.3 ALARP region

The ALARP region represents risks of concern bur nor ones of the highest priority for attention. It is suggested that this region should be two orders of magnitude wide, with the result that an accident with an EHI of 100 would be considered to be of minimal regulatory concern if it was expected to occur with a frequency of 10^{-6} per year per site or less. It might be argued that an even broader band should be used; however, this would have the effect of including more risks within the region and it is considered that the resultant need for further risk management actions would not be warranted.

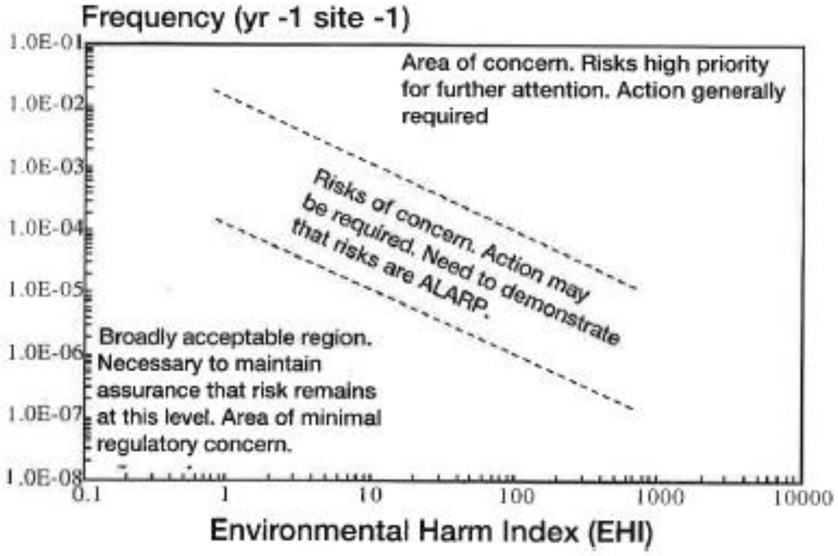
8.1.4 Overall framework

In the light of the above, the risk criterion scheme for a site, as currently proposed, is as shown on Figure 8.1.

The scheme, as shown, has regions delineated by lines with gradients of -1 (on the scale used). The choice of gradient reflects the suggestion that society's aversion grows as the magnitude of the consequence increases, but it is not the only value which could have been chosen to be consistent with this aversion. At this stage, it is considered to be a reasonable choice which is consistent with criteria used elsewhere to assist in the management of risks to people and which allows experience to be gained in use of the criteria. In the light of such experience, it may be appropriate to change the gradient.

It has been recognised throughout the study that translating the generally agreed concepts discussed in Chapter 3 into a quantitative risk criterion scheme is not a simple matter and that there will, of necessity, be some iteration before a widely accepted approach is achieved. Of particular difficulty is the question of where to set the 'boundaries' between the three regions of risk; although it must be remembered that these are intended to assist in indicating the degree of concern and the corresponding need for action, rather than being strictly implemented thresholds which determine precisely what actions need to be taken. It is therefore emphasised that the scheme shown in Figure 8.1 is one of several options which might be proposed in response to the factors identified above; for example, the frequency associated with a particular EHI value on the upper line could prove to be too large or too small for practicable risk management purposes. The figure, as shown, is therefore one possibility from amongst a range of options and it is to be expected that experience in use of the scheme will inform the choice of most appropriate option.

Figure 8.1 Proposed risk criteria



8.1.5 Semi-quantitative criteria

The risk criterion scheme presented above provides a basis on which to compare risks for particular accident scenarios to which specific levels of consequences and frequencies of occurrence may be associated. In some cases, only a conservative estimate of the consequences or frequencies may be made, due to for example a lack of detailed site-specific information and therefore the development of a more semi-quantitative scheme may be seen as desirable.

Chapter 7 (Table 7.3) introduced the idea of a *qualitative* accident severity model, using broad consequence levels and based on general descriptions of the likely accident consequences. Some degree of correlation has also been noted between an increase in these consequence levels and an increase in the value of the EHI. The development of a semiquantitative scheme may therefore use this information as a basis, by associating ranges of values of EHI with the likely accident severity categories, and associating them with appropriate ranges in frequency.

As suggested in the DoE guidance[22] on *Risk Assessment and Risk Management for Environmental Protection* a simple risk matrix may be a useful focus for such a scheme, for example:

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[22] A Guide to Risk Assessment and Risk Management for Environmental Protection, Department of the Environment, HMSO 1995.

Table 8.1 Risk Estimation Associated with General Levels of consequence and Frequency

Frequency	Consequence Level Severe	 Moderate	 Mild	 Negligible
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

In development of the semi-quantitative criteria, the consequence levels 'severe–negligible' may not only be associated with the consequence levels suggested above for the qualitative scheme, but ideally with ranges of values of EHI. However, as yet there is not sufficient data available from the case studies considered here to suggest what these ranges might be.

In terms of associating the frequency axis with levels of risk, guidance may be taken from both the DoE and the HSE risk management principles in which general criteria for assessing hazard tolerability could be associated with the following ranges of frequency:

Table 8.2 Ranges of Frequency Associated with Particular Levels of Consequence

Frequency	Consequence Level Severe	 Moderate	 Mild
High	$>10^{-4}$	$>10^{-2}$	>1
Medium	10^{-6} to 10^{-4}	10^{-4} to 10^{-2}	10^{-2} to 1
Low	$<10^{-6}$	$<10^{-4}$	$<10^{-2}$

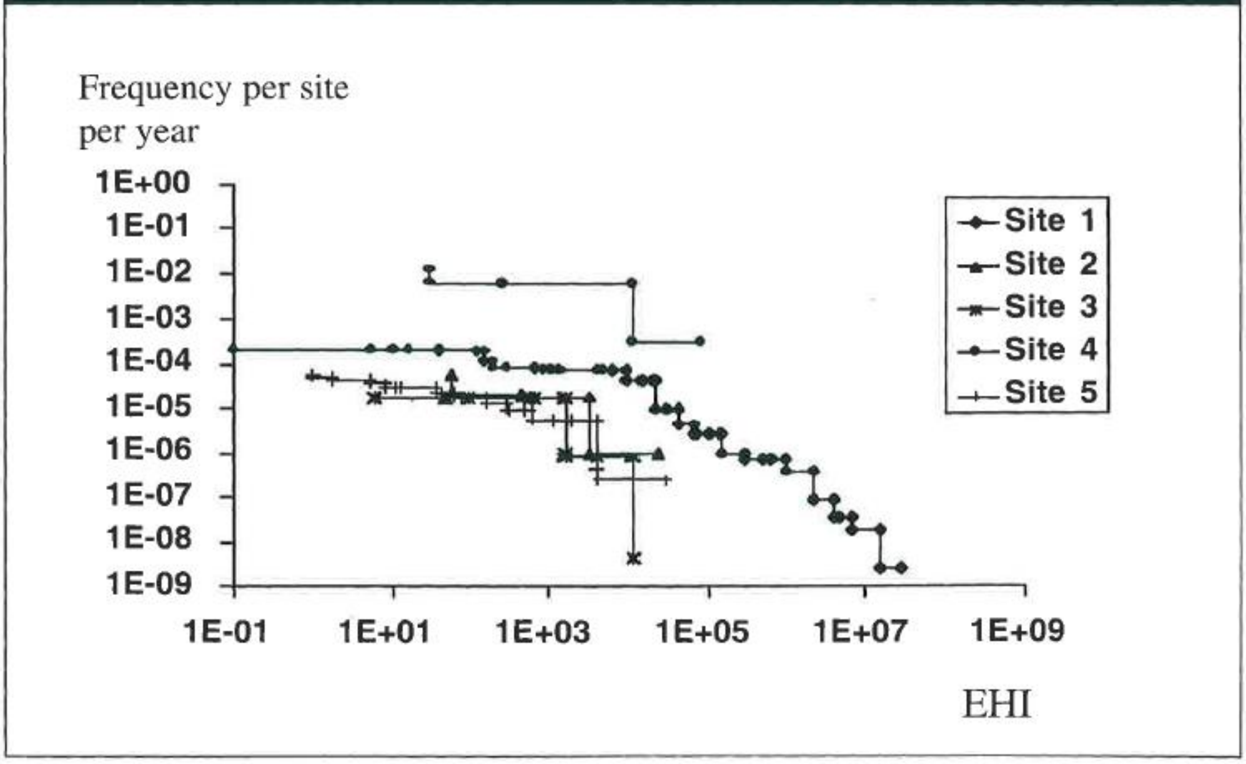
CHAPTER 9

Risk levels for Case Studies

The purpose of developing the proposed risk criterion scheme is to assist in the process of risk management. As already mentioned, the criteria on their own are only one element in this process and it is inappropriate to accept any implied acceptability or not, of risks on the basis of a comparison between assessed risks and criteria.

The criteria described in the preceding section may change in the light of experience in their use. However, as a first step in this process, the predicted risk levels from the case studies for sites 1 to 5 have been presented in the same format as the criteria; the results are shown on Figures 9.1-3. (N.B. The results for site 4 were calculated on a slightly different basis to the others, due to some data limitations; the effect of this is that these results are likely to overestimate this site's risks relative to those from the other sites.) The process of assessing the risks and developing these distributions for each site is described in detail in Appendix 1, section A1.2.

Figure 9.1 Risk levels for 5 sites on river A



The results show that sites 2, 3 and 5 are, in the main, within the intermediate (ALARP) region proposed criteria for all river sizes. Site 4 is always within the upper region (but see caveats noted earlier), whereas site 1 is in either the upper or intermediate region depending on the river size. It would be imprudent to make too many further observations since the risk assessment is known to be conservative. The next step in the risk management process would probably be to review the assumptions, data and modelling used so as to be able to revise the assessment. Such a process would be likely to reduce the predicted risks, bur the extent of this reduction cannot be commented on at this stage.

Figure 9.2 Risk levels for 5 sites on river B

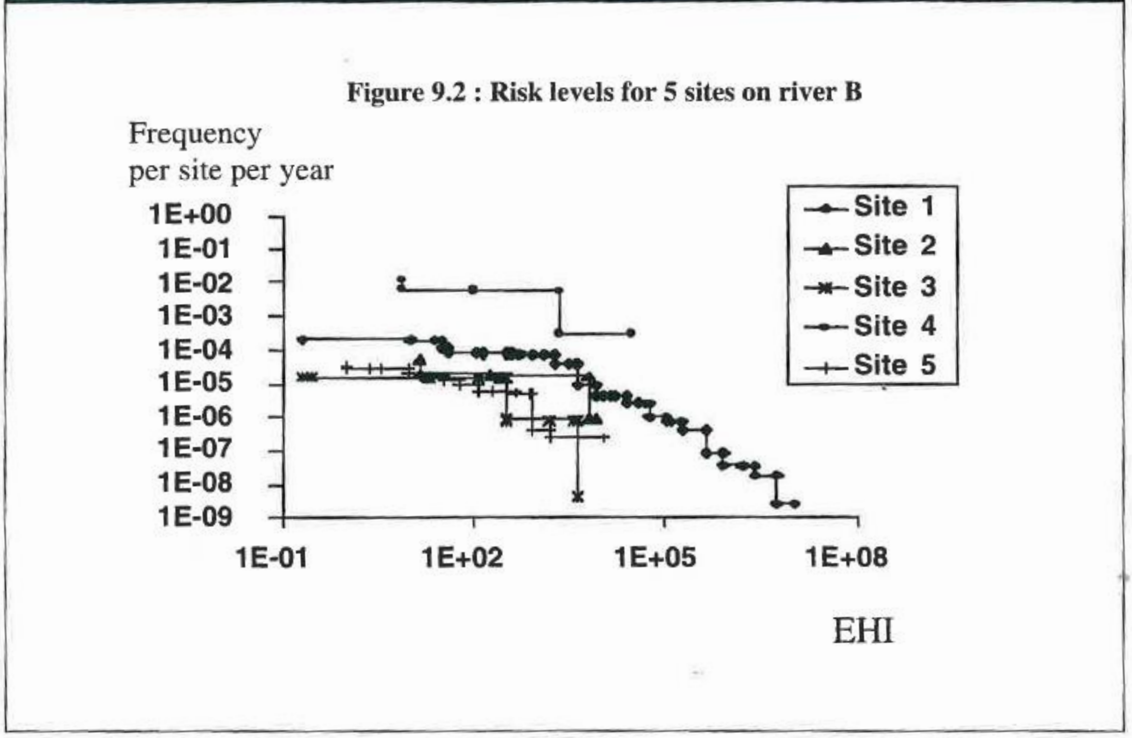
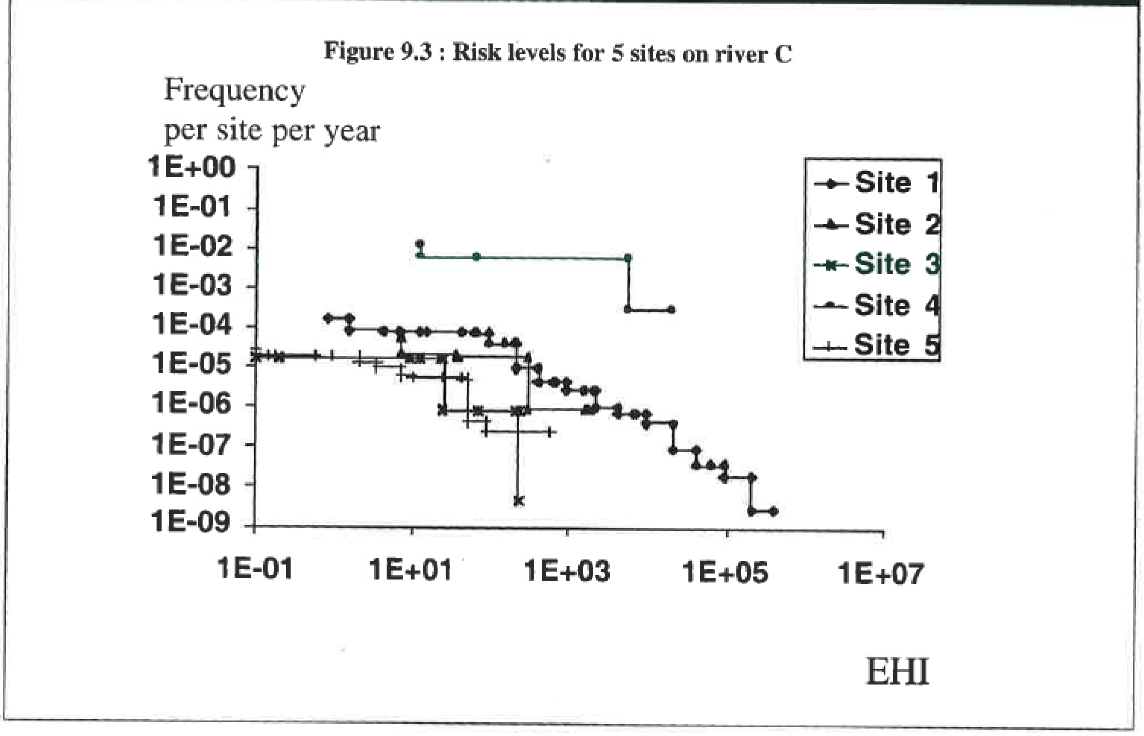


Figure 9.1 Risk levels for 5 sites on river C



CHAPTER 10

Commentary

The preceding sections of this report have described the development of an Environmental Harm Index (EHI) and its use within case studies. A risk criterion framework has also proposed, been using the EHI, to assist in screening risks of minimal concern from those which warrant further consideration. A summary and some additional comments on the research are provided below.

The principal focus of attention has been the aquatic environment. Adaptation of the EHI to the terrestrial environment has been explored, but it was concluded that the scientific basis was not sufficiently well-developed to support a practicable approach at present. Nonetheless, risks to the environment from accidental releases to all environmental media should be considered within the risk management process, although it is recognised that the extent to which it is possible to quantify these risks on a comparable basis is restricted.

Case studies using data from accidents and predicted events have been conducted. Thus, data from real incidents were used, supplemented where necessary by modelling, to explore the hypothesis that there is a correspondence between the value of the EHI and harm to the environment. This hypothesis was upheld. There was also a link between the magnitude of the EHI and the financial penalties (fines, court costs and restocking/cleanup costs) of the incidents. Further, it was shown that, within the constraints of the case studies considered, the relative ranking of the EHIs for the various accidents was not affected by the choice of reference time used in the normalisation of the EHI.

The predicted events were for accidents at several industrial sites located next to rivers. The accident scenarios ranged from process deviations and storage tank failure to transport accidents; each scenario had an associated predicted frequency of occurrence based on generic failure rate data. The sensitivity of the EHI, and it, predicted frequency, to the choice of river flow data was explored.

The link between the magnitude of the EHI and harm to the environment was further considered by reference to a qualitative accident severity model used within some industries. This model uses descriptors such as 'significant fish kill and other aquatic life affected’ to assist in categorising the predicted degree of harm and hence influence decisions concerning risk management actions. It was shown that the two schemes, though different in their basic approach and flexibility of use, were consistent in their relative rankings of incidents.

The case studies have been of considerable assistance in demonstrating the use of the EHI and its applicability to a range of scenarios within both the riverine and estuarine environments. It is recommended that the result from any EHI calculation is accompanied by a commentary which explains the rationale behind the data used, the contribution of the various terms to the overall value, and a description of the harm. This description of the harm might include reference to the expected degree of effects on biota (or not), seasonality issues, and any site-specific factors which would be expected to influence the magnitude of the harm. The purpose of this commentary is to facilitate understanding of the harm associated with a particular EHI value and to provide an audit trail which may be of value in understanding its 'quality'.

The case studies were used to assist in development of a risk criterion scheme. This scheme embodies the concept that risk is a function of consequence (in this case, EHI) and frequency, and that priorities for further attention can be ascribed on the basis of risk levels. Such further attention might include:

- ensuring that risks do not increase;
- reviewing/revising the risk assessment; and
- introducing risk reduction measures.

The action chosen will be influenced by the magnitude of the risk but will also depend on a range of other factors. The proposed risk criterion scheme is a framework which assists the management process, and it is emphasised that the criteria on their own are neither the final nor the only input in any decision-making process. It is not appropriate to accept any implied acceptability or otherwise of risk purely on the basis of a comparison of assessed risks with risk criteria. The criteria are a tool to assist in decision-making.

The proposed criteria divides the spectrum of possible risks into three regions. This is to facilitate their practical application. The boundaries between the regions are not intended to be used as thresholds above and below which fundamentally different types of risk management actions would be taken. They are presented as indicators differentiating between degrees of concern and hence the need for attention/action. It is also important to recognise that any predicted risk has some uncertainty associated with it which must be taken into account when considering any further action.

The concept of a major accident was used to assist in calibrating the criteria. Such an event was considered to be one lying on the boundary between the upper two risk regions. From the case studies it appeared that an EHI of at least 100 would be appropriate for this type of accident. The frequency associated with such an event is less easy to determine since historical data on major accident rates are not available. Guidance from the Health and Safety Commission's Advisory Committee on Major Hazards was used to influence the decision to adopt a frequency of 10^{-4} per year per site to accompany the EHI of 100 in defining one point on the upper boundary. Further information or experience in using the proposed framework could indicate that this definition should be changed.

As a first step in gaining experience in using the proposed criteria, the predicted risk levels for five of the sites used as case studies have been plotted in the same format as the criteria. These risk levels are known to be conservative. The results indicate how the criteria may be used as part of the risk management process.

In summary, the research has produced a practical tool which may be used to assist in the management of risks to the aquatic environment, particularly estuaries and rivers, from accidental releases. Experience may indicate that the criteria should be revised. Some suggestions for further work to explore additional issues which could not be addressed as part of this research are outlined in the next chapter.

CHAPTER 11

Future Work

This project has developed a methodology for assessing the risks to the environment from the accidental release of toxic chemicals to the aquatic environment. It has explored the possibility of adapting the methodology to the terrestrial environment and to non-toxic but harmful chemicals.

The aspects which would merit further study include:

- extension of the aquatic EHI and risk criteria to the terrestrial environment;
- extension of the EHI concept to include risks to groundwater;
- further consideration of non-toxic effects from accidental industrial releases, ie, pH, temperature, dissolved oxygen and suffocating layers either floating on the surface or covering the bed of the water course;
- exploration of the utility of applying weighting factors to the parameters in the EHI;
- further validation of the approach via case studies;
- establishment of current rate of occurrence of accidents of different magnitudes;
- review of guidance on what constitutes a major accident and its relationship to the chosen parameters for the reference accident.

Each of these is discussed briefly below.

TERRESTRTAL ENVIRONMENT

During this project investigations have been made into the possibilities of extending the aquatic EHI and risk criteria to the terrestrial environment. However, the terrestrial environment is much more complex than the aquatic environment and therefore the selection of parameters to represent the severity of harm is not straightforward. The development of approaches to environmental risk assessment was encouraged by all those involved in the debate. Further work is required to develop a method for assessing the risks to the terrestrial environment. It may not be possible to adapt the aquatic EHI concept, so a different approach may be necessary. This would involve the identification of parameters to represent the measure of harm and development of risk criteria.

GROUNDWATER

The Environment Agency's document "Policy and practice for the protection of groundwater" does not explicitly include measures to be taken to protect groundwater from the risks attributable to accidental releases. Consequently, it is important that a risk assessment method and suitable criteria are developed for the protection of groundwater. The possible adaptation of the aquatic EHI for this purpose would need to be investigated and additional parameters included where necessary.

NON-TOXIC EFFECTS

Options have been presented for adapting the EHI to account for effects such as pH, dissolved oxygen, and temperature changes. Further work is necessary to determine whether the same criteria (Figure 8.1) can be used for the EHI for non-toxic effects and for toxic effects. In addition, further case studies are required for releases involving non-toxic effects.

WEIGHTING OF PARAMETER VALUES

Discussions have been held during the project on the perceptions of different groups on the relative weighting to be attached to the terms within the EHI. Quite different views have been expressed. Further work is required to explore this issue and to seek to understand whether or not the perceptions of all interested parties have been properly reflected in the proposed scheme.

FURTHER VALIDATION WORK

Development of the proposed risk criterion has benefited greatly from the case studies. It is suggested that further such studies, particularly for incidents involving estuaries, would assist in validating the current scheme. It would also be of benefit to seek to validate further the relationship between EHI values and the magnitude of the environmental consequence.

EXISTING ACCIDENT RATES

Data on the current incidence of accidents, together with data permitting calculation of their associated EHI values and information on the actual levels of harm which occurred, would greatly facilitate calibration of the proposed risk criterion scheme. No such data currently exist in the public domain, although anecdotal evidence has been presented that significant accidents are occurring at a rate of once per year in the UK. Further studies to seek to establish the current incidence rate of larger accidents would be valuable in indicating whether or not the proposed attention/action levels on the proposed criterion are set appropriately.

As a corollary to the above, it would be of benefit to set up a system to collect relevant data from future incidents in a way which permitted calculation of the EHI and provided information on the harm suffered. Such data could be reviewed periodically and would also be of value in calibrating the proposed risk criteria.

MAJOR ACCIDENT

In 1991, the DoE published an interpretation of what would constitute a major accident to the environment to be used for the purposes of the CIMAH regulations[23]. In the light of more recent initiatives in assessing environmental harm, together with the impending developments of the regulatory framework following the COMAH directive, it would be timely to review the guidance on a major accident as presented in this earlier report.

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[23] Interpretation of Major Accident to the Environment for the Purposes of the CIMAH Regulations. A guidance note by Department of the Environment June 1991.

APPENDIX 1

Case Study Results

A1.1 Estuary Case Studies

Data for four hypothetical releases were provided from the chemical industry in the UK. These data were for near instantaneous releases of benzene, nitric acid, ammonia, and an amine into a tidal river.

Values for the EHI were calculated for each release using the data provided.

All of the data, except for the actual calculations, were provided by the chemical industry. These data include toxicity data and concentrations at given distances from the release point. The concentration data are given for each case in the form of a table. The data provided by the chemical industry were obtained using site specific data and modelling that enabled it to be determined that the pollutants remained in the upper stratified layer of the water. Therefore, no impact on the benthic fauna would be expected and hence there will be no impact on the food web. Many fish in the surface layers would be expected to take avoidance measures, although some deaths could occur. Recolonisation of the surface layers could be expected within days of the contamination leaving the estuary. Therefore, a value of 0.02 was chosen for T_{acc}.

Initial modelling assumed very conservative conditions. In particular:

- very low freshwater flow (93rd percentile);
- average tidal range;
- release at slack water prior to ebb tide (ie, high tide);
- all substances conserved (ie, no account taken of evaporation, degradation, etc.).

Each of the releases was modelled in two ways using data provided by the chemical industry; first a simple screening method which compared the concentration at the edge of the mixing zone with the DC, followed by a second tier where the EHI was calculated. In addition, EHI the was calculated with and without the time factor. This has been done so that a comparison can be made of the EHI with and without the time factor to assist in determining the potential utility of that factor.

Case One: Benzene

For this case the data provided were for a potential release of 18000 kg of benzene in 1700 m^3 effluent, over 20 minutes into the river. Evaporation and biodegradation effects have been ignored (in practice the half-life of benzene in sea water would be around 10 hrs[24] and the BOD_5 is 0.7 g/g (23% ThoD)). The biodegradation would lead to reduced levels of dissolved oxygen in the surface layers and produce a secondary impact.

The minimum of the two LC_{50} data values provided was 4.6 mg/l for salmon smolts, therefore the DC is taken to be 0.46 mg/l. The concentration at the edge of the mixing zone is 352 mg/l. This was calculated by applying a dilution factor of 30 x to the concentration resulting from 18000 kg in 1700 m^3 effluent [$(18000 \times 10^6)/(1700 \times 10^3 \times 30)$]. This concentration is higher than the DC and so the second tier of calculations was carried out to calculate the EHI.

DATA PROVIDED BY INDUSTRY

Table 1 Concentrations in water at given distances from the release point for Case One

Distance from release point	±0.2 km	±0.6 km	±1.2 km	±1.8 km
Concentration	20-25 mg/l	15-20 mg/l	5-15 mg/l	<0.5 mg/l

CALCULATING THE EHI

The concentration of benzene at a distance of 1.8 km from the release point is < 0.5 mg/l. As this is approximately the value of the DC the length of estuary contaminated is therefore 3.6 km. At this point the width of the estuary is 500 m, therefore the area contaminated above the DC is 180 ha [$0.5 \times 3.6 \times 10^2$]. The reference size for an estuary is 2 ha.

Therefore, the EHI calculation is:

$$\text{EHI} = \frac{352}{4.6} \times \frac{180}{2} \times \frac{0.02}{5}$$

EHI = 27.54

Without the time factor the value for the EHI is 6886.95

The estimated frequency for this release is approximately 10^{-3}/year.

Case Two: Nitric Acid

For this case the data provided were for a potential release of 18000 kg of nitric acid in 350m^3 of effluent into the river over period of 20 minutes. The EHI calculations can be done either by treating nitric acid as a toxin and using the concentration of nitric acid in the river or on the basis of an acid release which alters the pH. When calculating the EHI on the basis of changes in pH and using the protocol in the report, a parameter for severity is not used, ie, the first concentration value is nor compared with the LC_{50}. The EHI is calculated

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[24] K Verschueren, Handbook of Environmental Data on Organic Chemicals, Second Edition, 1983

from the area of the estuary contaminated above a threshold value. For nitric acid, the threshold pH is 3.7 which equates to a concentration of 12.6mg/l (data provided by industry).

The concentration at the edge of the mixing zone is 1028 mg/l. This was calculated by applying a dilution factor of 50 x to the concentration resulting from 18000 kg in 350m^3 effluent [(18000 x 10^6)/(350 x 10^3 x 50)]. This concentration is higher than the threshold and so the second tier of calculations was carried out to calculate the EHI.

DATA PROVIDED BY INDUSTRY

Table 2 Concentrations in water at given distances from the release point for Case Two

Distance from release point	±1.2 km	±1.6 km	±1.8 km	±2.0 km	±2.5 km
Concentration	50-250 mg/l	25-50 mg/l	12-25 mg/l	5-12 mg/l	<1 mg/l

CALCULATING THE EHI FOR AN ACID RELEASE

Data have been provided by industry which show the concentration profile down to 1 mg/l at a distance of 2.5 km from the release point (see table above). At a distance of 1.8 km downstream (and also upstream) from the release point the data indicates that the concentration is 12 mg/l. This equates to a pH of 3.7, the threshold pH. At this point the width of the estuary is given as 150m therefore the area above the threshold is 54 hectares [0.15 x 3.6 x 10^2].

The EHI can therefore be calculated as:

$$\text{EHI} = \frac{54}{2} \times \frac{0.02}{5}$$

EHI = 0.11

Without the time factor the EHI is 27

In practice there is substantial buffering capacity in the estuary due to the alkalinity in the freshwater flow (in addition, sea water has buffering capacity). This alkalinity is equivalent, on average to 80 mg/l HNO_3 (min25 mg/l). Thus, the impacted distance would, in practice be substantially less (typically about 1 km rather than 3.6 km).

CALCULATING THE EHI FOR NITRIC ACID AS A RELEASE OF TOXIN

For comparison purposes the EHI can be calculated by treating nitric acid as a toxin. The advantage of doing this is that the EHI will be correlated more effectively with the consequence of release. However, the practicalities of calculating the EHI on this basis needed to be tested. This calculation sets out to do this.

CALCULATING THE EHI

As shown above the concentration at the edge of the mixing zone is 1028 mg/l. If the DC is taken to be 1/10 of the LC_{50} it will be 1.26 mg/l. From the table above the distance contaminated above the DC can be seen to be 2.5 km downstream and the same upstream giving a total distance contaminated of 5 km. At this point the width of the estuary is 150 m. The area contaminated is therefore 75 ha [$0.15 \times 5 \times 10^2$].

The EHI can therefore be calculated as

$$\text{EHI} = \frac{1028}{12.6} \times \frac{75}{2} \times \frac{0.02}{5} = 12.23$$

EHI = 27.54

Without the time factor the EHI = 3059.52

The estimated frequency for this release is approximately 10^{-2} per year.

Case Three: Ammonia

For this case the data provided were for a potential release of 180000 kg of ammonia in $1180 m^3$ of effluent into the river. When a dilution factor of 50 is applied to this data the concentration at the edge of the mixing zone is 3050 mg/l [$(180000 \times 10^6)/(1180 \times 10^3 \times 50)$]. The toxic component of ammonia is the unionised ammonia. The LC_{50} data for unionised ammonia was provided by industry ie, 0.3 mg/l, so the DC is 0.03 mg/l. The EHI calculations are based on the assumption that 1% of the total ammonia is unionised. The value of 1% has been calculated for the site in question using the equation for calculating the concentration of unionised ammonia[25]. The percentage of unionised ammonia will vary from site to site depending upon the temperature and pH of the receiving water. For this case study 1% of the concentration at the edge of the mixing zone, ie, 30.5 mg/l is greater than the DC and therefore the EHI needs to be calculated.

DATA PROVIDED BY INDUSTRY

Table 3 Concentrations in water at given distances from the release point for Case Three

Distance from release point	±0.8 km	±1.5 km	±1.9 km	±2.1 km	±3.3 km
Concentration	>100 mg/l	>100 mg/l	>50 mg/l	>25 mg/l	>2 mg/l

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[25] NRA, 1994 Water Quality Objectives: Procedures used by the NRA for the Purpose of the Surface Waters (Rivers Ecosystem) (Classification) Regulations 1994

CALCULATING THE EHI

The lowest concentration value is >2 mg/l; 1% of this is 0.02 mg/l and will therefore be taken as being approximately equal to the DC. The distance downstream to this point is 3.3 km and therefore the total distance contaminated is 6.6 km. At this point the estuary is 150 m wide, therefore the area contaminated is 99 ha [$0.15 \times 6.6 \times 10^2$].

The EHI can therefore be calculated as:

$$\text{EHI} = \frac{30.5}{0.3} \times \frac{99}{2} \times \frac{0.02}{5} = 20.13$$

Without the time factor the EHI = 5032.5

The estimated frequency for this release is approximately 10^{-5} per year.

Case Four: An Amine

For this case the data provided were for a potential release of 75000 kg in 400 m^3 of effluent into the river. Conservation is assumed, although in practice the BOD_5 is about 0.9 g/g (39% ThoD). The biodegradation would lead to reduced levels of dissolved oxygen in the surface layers and produce a secondary impact. The toxicity datum provided was an EC_{50} for Daphnia of 163 mg/l. According to the protocol for calculating the EHI, EC_{50} values are taken to be the DC. For this release the concentration at the edge of the mixing zone is 3750 mg/l. This is above the DC and therefore the EHI needs to be calculated. In the absence of LC_{50} data, C_{ref} will be taken to be the EC_{50} for Daphnia of 163 mg/l.

DATA PROVIDED BY INDUSTRY

Table 4 Concentrations in water at given distances from the release point for Case Four

Distance from release point	±0.6 km	±1.2 km	±1.6 km	±1.8 km	±2.5 km
Concentration	>100 mg/l	>100 mg/l	>50 mg/l	>25 mg/l	>2 mg/l

CALCULATING THE EHI

At a distance of 0'6 km from the release point the concentration is given as > 100 mg/l. As this is approximately equal to the DC, the total distance contaminated is 1.2 km. At this point the width of the estuary is 150m, therefore the size of the estuary contaminated is 18 ha, [$0.15 \times 1.2 \times 10^2$].

The EHI can therefore be calculated as:

$$\text{EHI} = \frac{3750}{163} \times \frac{18}{2} \times \frac{0.02}{5}$$

EHI = 0.83

Without the time factor the value for the EHI = 207

The estimated frequency for this release is approximately 10^{-5}/year.

A1.2 River Case Studies

The risks posed by five industrial sites situated along a large river and its tributaries in the UK have been considered as a part of the aquatic accident case studies. These are based on an evaluation of the information supplied both by the operators themselves and the Environment Agency. The EHI values were calculated for a number of accident scenarios at each site and were assumed to be released to the river/tributary on which the site was situated. However, to explore the sensitivities of the EHI values to river sizes and flow rates, the same releases have also been assumed to occur within small and medium sized rivers typical of the UK.

Site 1 is a relatively complex site on which several industrial processes are carried out, and is located adjacent to the river. Sites 2 to 4 are smaller plants involving less complex activities, smaller storage facilities, and are situated along tributaries feeding into the river. Each of several possible accident scenarios for all five sites have been considered in the assessments, to which associated generic frequencies have been assigned. Predicted concentrations in the water downstream of the release point were calculated using the PRAIRIE^{TM} model and using flow data appropriate to the river under consideration. The assessments are however conservative, in that pessimistic assumptions have been made when estimating the likely releases to the aquatic environment, and pollutant losses during transport have been omitted from consideration. Although some chemical releases have been omitted from the assessment, where appropriate toxicity data was unavailable at this stage, those major events contributing greatest to the risks to the aquatic environment have in general been included, and can therefore illustrate the use of the EHI as a screening tool.

SITE 1

For this site eleven accident scenarios were considered from the range of possible storage failures/accidents occurring on site. These resulted in significant releases of the following chemicals to the river:

Scenario	Chemical Released
s1	Ammonia
s2	Aniline
s3	Butyl Alcohol
s4	Carbon Disulphide
s5	Chlorine
s6	Ethylene Glycol
s7	Isopropanol

Scenario	Chemical Released
s8	Phenol
s9	Sodium Cyanide
s10	Sodium Hydroxide
s11	Trichloroethylene

The site has an effluent treatment (ET) system which was assumed either to fail on demand, resulting in the total release of the chemical, or to remain intact, therefore reducing the overall release to the river. The dispersion of the material following release was calculated using the PRAIRIE river model, which estimated the concentrations at various distances downstream. Variations in the river flow rate were also taken into account, and the duration of the release was based on a minimum estimate of the time taken to discharge to the river. No loss of the pollutant, eg, by adsorption to sediments, was assumed to occur during transport. Both the initial concentration and the distance at which the concentration falls below the DC were then estimated for each release, based on the most restrictive toxicity data for each chemical considered. Given the magnitude of the releases involved the recovery lime was taken to be 5 years for all scenarios, resulting in the following range of EHI values for scenarios 1 to 11. Where the EHI is zero the initial concentration for the pollutant has not exceeded the DC for the chemical. It can be seen that the EHI values reduce dramatically with flow rate and as expected, with magnitude of release.

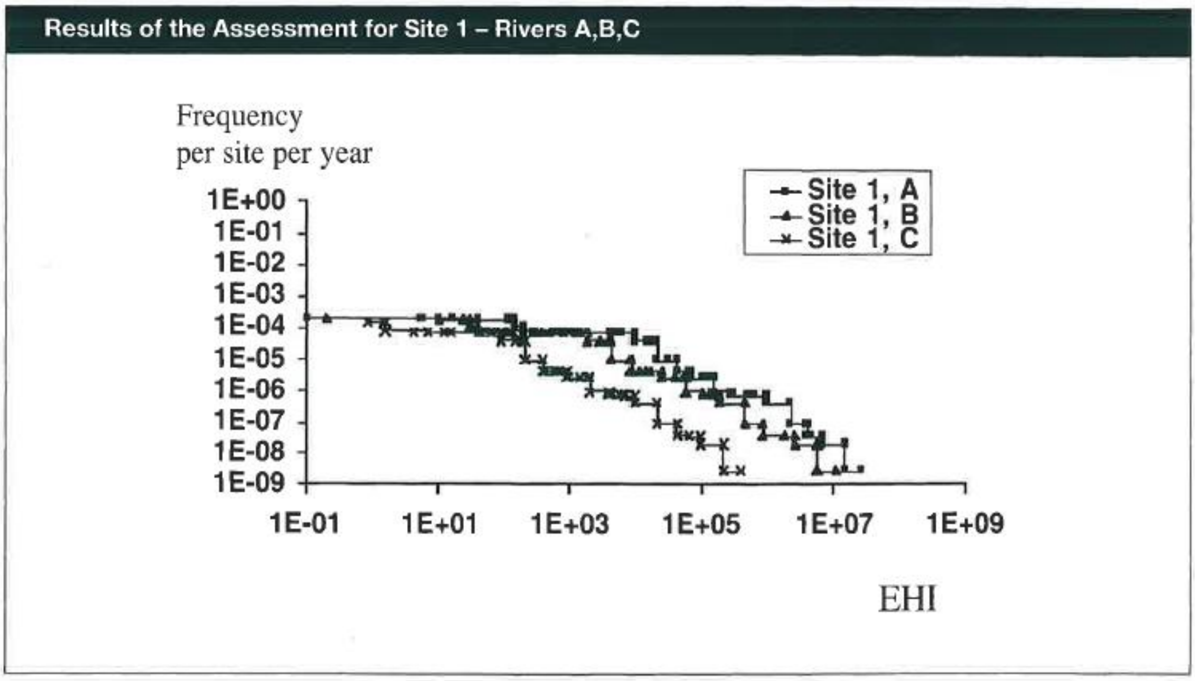
EHI Values for Site 1 Scenarios

Scenario	ET Fails		ET works	
	95% flow rate	5% flow rate	95% flow rate	5% flow rate
s1	62000	6300	620	62
s2	94000	9400	930	93
s3	12	0.79	0	0
s4	6800	690	67	6.8
s5	400000	40300	4000	403
s6	0	0	0	0
s7	0	0	0	0
s8	1970	198	0	0
s9	210000	21000	2100	210
s10	1500	150	15	1.5
s11	420	42	4.1	0

For each of the scenarios considered, an associated frequency of release was then estimated. These were based on generic failure rates for accidents involving storage, transport operations and industrial processes, but modified according to the number of tanks/drums on site and the number of operations being carried out per year at the site. Taking account of the probability of failure of the effluent treatment system, and the frequency with which particular flow states occur in the river, the following frequencies of release were then estimated for each scenario:

EHI Values for Site 1 Scenarios				
Scenario	**ET Fails**		**ET works**	
	95% flow rate	**5% flow rate**	**95% flow rate**	**5% flow rate**
s1	9E-10	1.7E-8	8.8E-8	1.7E-6
s2	1.7E-8	3.1E-7	1.6E-6	3.1E-5
s3	8E-9	1.5E-7	7.9E-7	1.5E-5
s4	9E-10	1.7E-8	8.9E-8	1.7E-6
s5	2.7E-9	5.1E-8	2.7E-7	5.1E-6
s6	5.5E-10	1.1E-8	5.5E-8	1.0E-6
s7	8E-11	1.5E-9	7.9E-9	1.5E-7
s8	1.7E-8	3.1E-7	1.6E-6	3.1E-5
s9	1.7E-8	3.1E-7	1.6E-6	3.1E-5
s10	4.1E-8	7.8E-7	4.1E-6	7.7E-5
s11	8E-9	1.5E-7	7.9E-7	1.5E-5

Finally, using the Frequency-EHI pairs for each of the scenarios, effluent treatment and river flow states, the overall frequency distribution was generated for the site, denoted as "Site 1, C" in the figure below. The process has also been repeated for a range of rivers representative of those typical to the UK, denoted A to C, and of increasing size and flow rate, C being the largest. The results are compared below, where the frequency axis denotes the frequency of exceeding a certain value of EHI per site per year of operation.



Results of the Assessment for Site 1 – Rivers A,B,C

SITES 2 TO 5

The remaining sites (2 to .5) are smaller operations than for site 1, with less processes being carried out; hence a smaller number of scenarios were identified in the assessments. These sites are situated on tributaries to river C, and this has been taken into account when carrying out the PRAIRIE runs. The same overall approach has been taken (as for site 1) and the results are presented here for comparison.

Site 2					
Scenarios	**Chemical released**	**95% River C flow rate**		**5% River C flow rate**	
		EHI	**Frequency**	**EHI**	**Frequency**
s1	Trichloroethylene	36	1.8E-6	6	3.4E-5
s2	Ammonia	1700	9E-7	300	1.7E-5
s3	Methanol	0	9E-7	0	1.7E-5

Site 3					
Scenarios	**Chemical released**	**95% River C flow rate**		**5% River C flow rate**	
		EHI	**Frequency**	**EHI**	**Frequency**
s1	Ammonia	230	4.5E-9	25	8.6E-8
s2	Sodium Hydroxide	210	4.0E-9	23	7.5E-8
s3	Acetic Acid	0.1	4.5E-9	0	8.6E-8
s4	Diethylene Glycol	0	4.5E-9	0	8.6E-8
s5	Ethylene Oxide	0.1	9.0E-9	0	1.7E-7
s6	Xylene	12	1.4E-8	0.2	2.6E-7
s7	Ferric Chloride	70	4.0E-9	9	7.5E-8
s8	Mixed Release	230	8.0E-7	25	1.5E-5

Site 4					
Scenarios	**Chemical released**	**95% River C flow rate**		**5% River C flow rate**	
		EHI	**Frequency**	**EHI**	**Frequency**
s1	Methanol	67	3E-4	12	5.7E-3
s2	Formalin	20000	3E-4	5000	5.7E-3

Site 5					
Scenarios	**Chemical released**	**95% River C flow rate**		**5% River C flow rate**	
		EHI	**Frequency**	**EHI**	**Frequency**
s1	Sodium Cyanide	580	2.5E-7	50	4.7E-6
s2	Sodium Hydroxide	10	2.5E-7	0.5	4.8E-6
s3	Trichloroethylene	25	2.5E-7	2.0	4.8E-6
s4	Cadmium Cyanide	90	1.8E-7	7.0	3.3E-6
s5	Cadmium Cyanide	43	1.8E-7	3.5	3.3E-6
s6	Cadmium Cyanide	0.9	3.5E-7	0.06	6.7E-6
s7	Cadmium Cyanide	0.2	3.5E-7	0	6.7E-6
s8	Sulphuric Acid	0.6	2.8E-7	0.03	5.3E-6
s9	Sulphuric Acid	0	2.8E-7	0	5.3E-6
s10	Sodium Dichromate	0.1	3.5E-7	0	6.7E-6

APPENDIX 2

Calculating the EHI: Worked Example

The following example demonstrates how the EHI can be calculated. This is done using data from a real incident which has been modelled using PRAIRIE^{TM}. The explanation of the parameters used, and the results would form the basis of the commentary which could be expanded as necessary.

GENERAL FORMULA FOR THE EHI

The formula for the EHI is:

$$\text{EHI} = \frac{C}{C_{ref}} \quad X \quad \frac{S}{S_{ref}} \quad X \quad \frac{T}{T_{ref}}$$

C = the concentration at the edge of the mixing zone
C_{ref} = the LC_{50} for the most sensitive organism
S = the size of the river or estuary contaminated at a level above the dangerous concentration (DC)
DC = suitable EC_{50} value or $LC_{50}/10$
S_{ref} = 10 km for a river, 2 hectares for an estuary
T_{acc} = value for recovery time in years
T_{ref} = 5 years

WORKED EXAMPLE INPUT DATA

This example will calculate the EHI for a spill of kymene into the rivers Ogmore and Llynfi in Wales. The data including toxicity data, river flow data and the estimate of the quantity spilled were provided by the Environment Agency. The toxicity data included a value from the manufacturer for a 96-hour LC_{50} of 0.7 mg/l and test values produced by the Environment Agency. These latter data are for a 6 hour and LC_{100}, both of which equalled 14.0 mg/l, and a 6-hour LC_{50} of 6 mg/l. All test data were for brown trout. (Ideally a range of data would be obtained and the LC_{50} for the most sensitive organism within all trophic levels used. Other data can be used by the assessor provided they are justified.) In this case the data used in the assessment was the 96-hour LC_{50} of 0.7 mg/l. No EC_{50} data were available and hence the DC has been set to equal the $LC_{50}/10$.

Worked example			
Pollutant	**Release (kg)**	**LC_{50} (mg/l)**	**Dangerous concentration, DC (mg/l)**
Kymene	1000	0.7	0.07

The site is 14.5 km upstream from the mouth of the River Ogmore; flow data were available and are given below. A dispersion coefficient of 10 m^2/s was used. It was assumed that the whole inventory was lost directly to the river over half an hour.

Worked example			
Upstream distance (m)	**95% flow (m^3/s)**	**Velocity (m/s)**	**Depth (m)**
14500	0.25	0.1	0.5
9225	0.5	0.07	1.0
3600	2.1	0.28	1.0

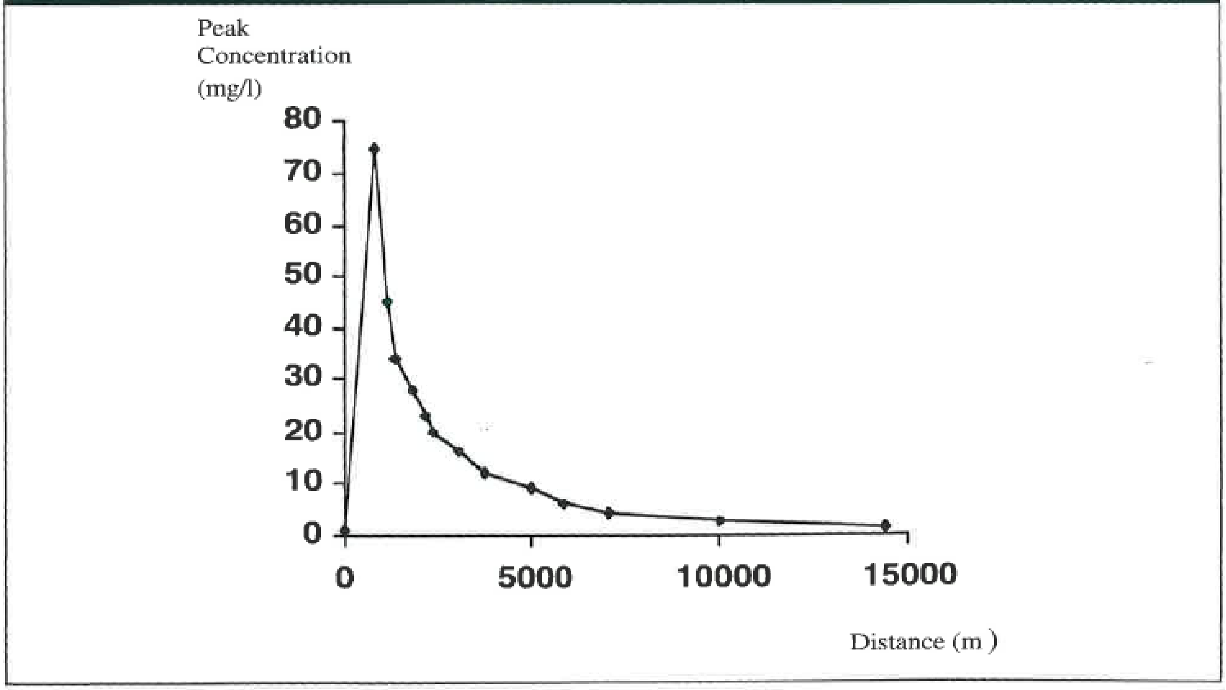
These data were input into PRAIRIE version 6.01 to calculate the initial concentration and the distance to the DC and the results are given in the table below.

SUMMARY OF RESULTS

The table below shows the parameters used to calculate the individual terms of the EHI and the final EHI. The initial concentration is taken to be the peak concentration at approximately 1 km from the release site which can be considered to be at the edge of the mixing zone. The graph below shows the peak concentration against distance from the release point.

Worked example			
Pollutant	**Initial concentration (mg/l)**	**Distance to DC (km)**	**EHI**
Kymene	75.6	14.4	156

Figure A2 Peak Concentration of Kymene against distance from release point



EXAMPLE CALCULATION

The EHI calculation for the kymene release using the data shown in the tables above, is as follows:

$$EHI = \frac{C}{C_{ref}} \times \frac{S}{S_{ref}} \times \frac{T}{T_{ref}}$$

$C = 75.6$ mg/l
$C_{ref} = 0.7$ mg/l
$S = 14.4$ km
$S_{ref} = 10$ km
$T_{acc} = 5$ years
$T_{ref} = 5$ years

Inserting these values into the equation gives the following:

$$EHI = \frac{75.6}{0.7} \times \frac{14.4}{10} \times \frac{5}{5} \quad 156$$

IMPACTS ON THE ENVIRONMENT

As this release was a real incident the actual harm to the environment can be compared with that predicted by the EHI value and the dispersion modelling illustrated by the graph above. Fish sampling by the Environment Agency post incident indicated that there had been a 100% mortality of salmonids between the release point and the estuary mouth 14.5 km downstream. From the graph above it can be seen that the concentration in the water did not drop below the LC_{50} for the whole length of the river. The dispersion modelling is therefore consistent with the result of the actual incident.

APPENDIX 3

Composition of Participating Groups

STEERING GROUP

Department of the Environment
Health and Safety Executive
Environment Agency
ICI
Zeneca
Bayer
Allied Colloids
SIESO
Ciba Geigy
BP International
CBI
Institute of Petroleum
AEA Technology

AQUATIC TASK GROUP

Environment Agency
ICI
Zeneca
AEA Technology

TERRESTRIAL TASK GROUP

Environment Agency
ICI
Zeneca
Institute of Petroleum
MAFF
Clayton Environmental
Nottingham Trent University
AEA Technology

FREQUENCY TASK GROUP

Health and Safety Executive
Environment Agency
ICI
SIESO
BP International
Zeneca

SEMINAR

University of Reading
Queen Mary and Westfield College
Huntingdon Life Sciences
University of Sheffield
Royal Holloway University of London
DNV Technica
Soil Survey and Land Research Centre
Eutech
Laporte
Zeneca
SEPA
Environment Agency
Institute of Terrestrial Ecology
AEA Technology

EXTERNAL ORGANISATIONS

Society of Chemical Industry (Delegates to 'Environmental Impact of Major Chemical Accidents')

Soil And Groundwater Technology Association

CBI Environment Protection Panel

IChemE (Delegates to 'Design for Safe Handling of Industrial Chemicals’)

Robens Institute of Industrial and Environmental Health & Safety (Delegates to ‘Principles of Toxicology and Risk Assessment')

APPENDIX4

Terms of Reference of Task Groups

TERMS OF REFERENCE FOR AQUATIC ENVIRONMENT TASK GROUP

1. To briefly examine the parameters within the EHI and factors not taken into account. This will set the context for the discussions on the case studies.
2. To assess the approach taken to the assessment of EHIs for example releases. This will involve the examination of case study results for past and hypothetical accidents.
3. To examine the proposed method for including factors not explicitly contained within the EHI.
4. To make proposals for the rest of the work programme, particularly in respect of further investigations or research needed to assist in clarifying uncertainties.
5. The findings of the Task Group will be reported to the main Steering Group for their consideration.

TERMS OF REFERENCE FOR TERRESTRIAL ENVIRONMENT TASK GROUP

1. To explore the methods currently available for measuring harm to the terrestrial environment and to examine the use of criteria in the assessment of that harm.
2. In the light of the above, to assess the approach taken in formulating the terrestrial EHI, examining the scope of its use, the parameters included, and any factors not taken into account. This will take account of the results of example case studies from hypothetical accidents.
3. To make proposals for the rest of the work programme, particularly in respect of further investigations or research needed to clarify the approach taken to date for the terrestrial environment.
4. To draw conclusions from the Task Group meeting which will be reported to the main Steering Group for their consideration.

TERMS OF REFERENCE FOR FREQUENCY TASK GROUP

1. To briefly examine the purpose and use of frequency criteria for harm to the environment from accidents. This will set the context for discussions on the nature and shape of criteria.
2. To agree broad principles for judging the tolerable frequency of accidents to the environment. This will include an examination of the general approach proposed by AEA Technology and an assessment of the possible alternatives.
3. To assess the information available on past hypothetical accidents and make proposals for individual criteria. This will involve the assessment of case study results and their implications or setting criteria.
4. To examine the setting of criteria for very small or very large accidents. This will include an assessment of whether the principles for setting criteria should differ in

any way for such accidents and review the assumptions proposed by AEA Technology.

5. To make proposals for the rest of the work programme on the development and validation of frequency criteria.
6. The findings of the Task Group will be reported to the main Steering Group for their consideration.