Risk Assessment Framework and Criteria for Major Accidental Release to the Environment in Malaysia

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Abstract

Events which could be considered a "major accident to the environment" are very diverse in nature. The UK Department of the Environment (DoE) has published a "Green Book" giving the definitions of such events. UK AEA Technology has attempted to define tolerability criteria for accidents to the environment in terms of an environmental severity index (ESI) which is the ratio of the severity of the accident to that of the most appropriate reference accident from the DoE Green Book. These criteria were proposed only for releases to rivers. This paper describes the development of risk assessment framework based on an environmental risk index (ERI) proposed (in tradition of the ICI Mond Index method for flammable hazards). The ERI is a measure of the total severity and probability of a wide range of possible environmental consequences which could result from any particular release. The tolerability criteria developed for the ESI method can also be used with the ERI. The ERI method is designed to facilitate rapid screening of the environmental risks from a variety of release scenarios. The effects of various methods for prevention and mitigation of the release can be taken into account. The framework will be described with reference to a hypothetical case study involving an accidental release of a pesticide into the River Don in Sheffield from a manufacturing plant. This has led to a number of improvements to the method, including a revision of the tolerability criteria proposed by AEA Technology. As for Malaysia, a similar approach could be proposed and adopted, as necessary.

INTRODUCTION

Under the Control of Industrial Major Accident Hazards (CIMAH) Regulations in the United Kingdom, an assessment of consequences of the potential major accident hazards either to humans or to the environment from eligible sites are required The forthcoming Control of Major Accident Hazards (COMAH) Regulations will increase the emphasis on major accident hazards to the environment. In Malaysia, CIMAH Regulations 1996 require the industries to provide information about their activities and for major hazards installation sites to prepare a safety report which include a risk assessment.

Risk assessment is a useful technique for setting priorities in the control of major accident hazards and for ensuring the adequacy of controls. The problem is that there is no clear methodology by which the risk from major accident hazards to the environment can be assessed or quantified. Therefore the main objective in this study was to develop such a method.

The scope of this work is to focus on the overall process of risk assessment, rather than the detail of methods for a particular consequence calculation. Consequence calculation methodologies do exist, and some methods for river dispersion calculations have been reviewed[1]. However, the authors found that risk assessment methodologies, which make use of the results of consequence calculations were largely missing. For example, although it is possible to use an existing river dispersion code and calculate the downstream concentration of a released chemical as a function of distance and time, there was no existing methodology for deciding whether the release would constitute a major accident nor whether the risk was acceptable or not.

This paper describes a framework of risk assessment for major accident hazards to the environment which has been developed. It is a "framework" rather than a complete methodology because it requires available consequence models to be used within it, as necessary.

DEFINITION OF "MAJOR ACCIDENT TO THE ENVIRONMENT"

The UK Department of the Environment (DoE) has issued guidance on the types of event which would constitute a major accident to the environment under the CIMAH Regulations (the so-called DoE Green book)[2]. The guidance is in terms of a number of examples of the types of events which would be a major accident, as listed below :

Criteria 5.2 - National Nature Reserves, Sites of Special Interest (SSSIs) and other Designated Areas

Permanent or long term damage to National Nature Reserves, Sites of Special Scientific Interest (SSSIs), a Marine Nature Reserve (statutory or voluntary), or an area protected by a limestone pavement order. Such damage, for example, is a loss of nature conservation value in one or more of the following :

- more than 10% or 0.5 hectares (whichever less) of the area of the site, or
- more than 10% of the area of a particular habitat, or
- more than 10% of a particular species associated with the site

Criteria 5.3 - The Wider Environment

Permanent or long term damage to wider environment such as area of scarce, intermediate or unclassified habitats, as follows :

- 2 or more hectares of scarce habitat. including vegetated shingle beaches, saline lagoons, dune slacks, unimproved neutral grassland (including seasonally flooded grassland), lowland limestone pavement or other lowland basic rock less than 300 metres in altitude. fens (including marsh and Phragmites reed beds), lowland raised bogs, lowland heathland of Southern Britain.
- 5 or more hectares of intermediate habitat. including heathland less than 300 metres in altitude. lowland limestone grassland less than 300 metres in latitude, salt marsh, sand dunes.
- 10 or more hectares of more widespread habitat, including farmland not otherwise classified.

Criteria 5.4 - Freshwater and Estuarine Habitat

Effects on a significant part of freshwater and estuarine habitat which may include stream, river, canal, reservoir, lake, pond or estuary according to the National River Authority (NRA) classification scheme. A "significant part" of a river, canal or stream is defined as 10 km stretch or a "reach", whichever is less. For a lake or pond a significant part is 1 hectare, and 2 hectares for an estuary.

Criteria 5.5 - Aquifers and Groundwater

Damage to aquifers and groundwater leading to contamination (or other effects) which would preclude its use for public domestic or agricultural water supply or have significant adverse impact on the surface waters and biotic system its supports.

Criteria 5.6 - The Marine Environment

Permanent or long term damage to the marine environment. The area of concern is damage to about 2 hectares or more of the littoral or sub-littoral zone or the benthic community adjacent to the coast or the benthic community of any fish spawning ground or to an area of about 250 hectares or more (approximately 1 square nautical mile) of the benthic community of the open sea, or a casualty count of about 100 sea birds (excluding the commoner species of gull), or 500 sea birds of any species, or 5 sea mammals of any species found dead or unable to reproduce as a result of the accident.

Criteria 5.7 - Particular Species

Death or inability to produce of a particular species in a significant percentage, whether caused directly or indirectly. Death or inability to reproduce of 1% of any species is considered significant, and for special protected or "high value" species the limit is lower.

Criteria 5.8 - Release of Persistent Toxic Substances

Release of persistent toxic substances into the environment of 10% or more of the "top-tier" threshold quantity of a persistent dangerous substance (according to CIMAH Regulation 6).

Criteria 6.2 - Built Heritage

Damage to a built heritage such as Grade 1 listed building (England and Wales) or a Category A building (Scotland) or a scheduled ancient monument such that it no longer possesses its architectural historic or archaeological importance and which would result in it being de-listed or de-scheduled if no remedial action is taken. Also damage to an area of archaelogical importance or to a conservation area resulting in loss of importance.

Criteria 6.3 - Recreational Facility

Damage to recreational facilities such as Long Distance Route (National Trail), Country Park such that it no longer possesses its aesthetic, cultural, amenity or public enjoyment value.

Criteria 7.2 - Crops, Domestic Animals and Other Foodstuff : Public Assess

Contamination of 10 hectares or more of land which, for one year or more, prevents the growing of crops or the grazing of domestic animals or renders the area inaccessible to public because of possible skin contact with dangerous substances, or contamination of a significant area of any aquatic habitat which prevents fishing or aquaculture or which similarly renders it inaccessible to public.

Criteria 7.3 - Water Sources and Supply

Contamination of water sources or supply such that the supply to 10,000 or more consumers is rendered unfit for human consumption and must be repaired.

Criteria 7.4 - Sewerage and Sewerage Treatment

Direct or indirect damage to a sewerage system or sewerage treatment works which results in a significant risk to public health by pollution of a water source used for water supply for 10,000 or more persons, or damage to a major sewerage system which results in an unacceptable and widespread hazard to public health or safety through flooding.

Criteria 7.5 - Socioeconomic Effects

Consideration of the socioeconomics effects which can result from a major accident, such as destruction of homes and industrial premises or loss of income from contaminated farmland or fisheries.

RISK CRITERIA FOR MAJOR ACCIDENTS TO THE ENVIRONMENT

A proposal for tolerability criteria for major accidents to the environment has been made as a result of a European collaborative project by AEA Technology and others[3]. The aim of that project was to develop a simple and reliable method of evaluating harm to the environment in order to make a judgement on the acceptability and tolerability of the risks. The project concentrated on releases into water, such as into rivers.

The development of risk criteria needs to consider the components of the ecosystems to be protected, a measurement of harm for that component and acceptable or tolerable frequencies associated with a range of harm indices. Risk criteria schemes displaying different regions of tolerable or intolerable risks at certain frequencies are already available in Europe for hazards to humans[4]. To be specific, in the UK, the as low as reasonably practicable (ALARP) framework is widely acceptable as a risk criteria scheme. In the Netherlands, they use an as low as reasonably acceptable (ALARA) approach which is a two region risk criteria scheme.

Use of a generic ecosystem consisting of five trophic levels was proposed. This summarises the main route of energy flow through the ecosystem and include representatives of the major interrelationships between organisms at different levels. The levels are shown below :

Phytoplankton	Primary producers
Zooplanton	Primary consumers
Bentos	Decomposers
Vertebrates	Secondary consumers
Higher vertebrates	Tertiary consumers

An Environmental Harm Index (EHI) was then proposed, which quantifies the potential for damage from any accident to that generic ecosystem. The main features of these EHIs are :

- A measure of the severity of the accident using measures of lethality and sub-lethal effects data (LC_{50}) for the most sensitive of the species from the generic ecosystem (see above).
- A measure of the size of the ecosystem damaged using the concept of a dangerous concentration (DC). The DC is a measure of the ecotoxicity of the chemicals involved in the accident. The volume of the polluted water or the length of a river containing concentrations above the DC is then one such measure of size.

There are two different options for calculating EHI :

i) ***The simple EHI option***

The simplest version is EHI defined as a ratio of the product of the maximum toxic effect and maximum size (for PEC geater than or equal to DC) to the reference accident as shown by the equation below :

$$EHI = \frac{PEC_{\max} \times S_{\max}}{\min LC_{50} \times S_{ref}} \qquad \text{Equation 1}$$

However, this definition may cause an overestimate of risks because the maximum concentration is used and no account is taken of the plume behaviour of the contaminant as it moves downstream in a river. But. this is a good screening method as it can save time.

ii) ***The step EHI option***

This could be more accurate as the ecosystem is divided into several segments at a particular distance downstream from the release point. The continuous decrease in maximum concentration over distance can be estimated by step-wise calculation.

$$EHI = \frac{\sum_{j=2}^{N} PEC_j (S_j - S_{j-1})}{\min LC_{50} \times S_{ref}} \qquad \text{Equation 2}$$

The value of PEC can be obtained from dispersion modeling software. For simplicity, all models assume that the pollutants are persistent, that is, they are not removed by processes such as volatilisation, degradation or adsorption to sediments.

After calculating the EHI. the next step is to assign tolerable frequencies of incidents to each EHI value. Because the DoE give the same status to risks to man as to the environment, the same value of tolerable risk was applied. i.e. 10^{-4} per year. It is suggested that for a value of EHI=1, i.e. for a major accident to the environemnt, a maximum tolerable frequency of 10^{-4} per year is assigned. It was suggested from historical data, that small accidents are currently tolerated at frequency of 10^{-2} per year and this has been used for an accident with an EHI of 0.01. In between EHIs of 0.01 and 10. it is proposed that the slope of the curve representing the maximum tolerable risk line is -1. When the EHI is greater or equal to 10. the accident must have frequency less than 10^{-5} per year to stay in the ALARP region, otherwise. it is intolerable. This is proposed in view of uncertainties associated with predictions at such levels. The resulting risk criteria are shown in figure 1.

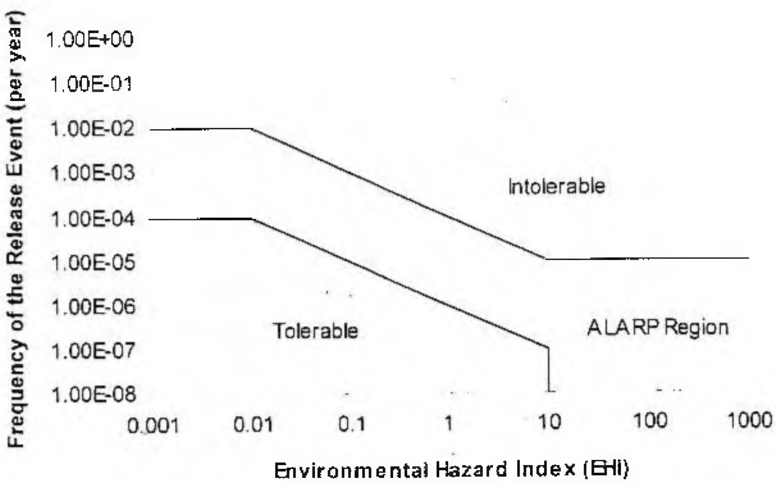

Figure 1 : AEA Technology EHI Criteria[3]

DISCUSSION

The DoE Green Book illustrates the wide variety of consequencies which can constitute a major accident to the environment. If risk assessment is to be performed for systems with a range of diverse consequences, then a risk ranking or risk index approach is often chosen. The EHI method developed by AEA Technology and their collaborators and described above is an example of a simple index method. After reviewing the method, few notes or criticisms are laid out below :

1) The EHI method was originally developed for water-bourne hazards only, in particular for releases into rivers. Analogous indices need to be developed for all other releases which can contribute to major accident hazards to the environment.

2) The calculation of EHI uses environmental concentration compared with the LC_{50}. However, it is well known that it is the dose (which is a combination of concentration and exposure time) and not the concentration which determines harm. This point is well supported by the HSE which has derived a series of dangerous dose criteria for many chemicals[5]. Another example is chlorine, where Lees derives chlorine probits in terms of dose[6]. The authors believe that dose is a better measure of toxicological effects than concentration for some accidents to the environment.

- The US EPA are moving towards a concentration quotient to characterise risk in an ecological risk assessment[7].

$$Risk \approx \frac{Exposure\ Concentration}{Effect\ Concentration} \qquad \text{Equation 3}$$

This equation applies to risk assessment in cases where permanent exposure occurs at very low concentrations. In an accident, exposure in a river will only last for a limited time, as the contaminated water moves past any given point and the concentration may be high compared with the LC_{50}. If a persistent chemical is released to land, the exposure could be so long-term that concentration ratio could be a better measure of risk than dose ratio, if toxicity data were available for very long-term exposures. However, LC_{50} or LD_{50} data are the most likely measure of toxicity to be found in the literature, and these are measured for short exposure times. The concentration will therefore not strictly apply to longer exposure times, although once an organism is dead it does not matter if the exposure lasts longer than the the time required to kill it. It is therefore proposed that a dose effect is used in cases when the exposure time is less than the measurement time for the LC_{50} (usually 96 hours). This will apply, for example, to short-term releases to flowing water or air, and to releases of non-persistent chemicals to any medium. Concentration effect should be used for exposures longer than the measurement time of the LC_{50} or LD_{50}. Concentration ratio should therefore be used for release of persistent chemicals to land or reasonably stagnant water such as lakes or ponds.

3) The EHI assumes that all chemicals causing environmental harm are non-persistent. The method needs further development to include the effects of persistent chemicals and the effects of bioaccumulation.

The authors decided to develop a risk index method for accidental releases to the environment. This method builds on the EHI method described above, but extends it to make it applicable to the full range of possible environmental consequences. The development of the method was also inspired by the Mond Index method by ICI[8] which allows account to be taken of a large number fo factors which affect the risk, and which has proved to be a useful and practical tool as either a paper-based or computerised method.

Many consequence models for different environmental hazards have been developed and continue to be developed by various workers. Several river dispersion models have been reviewed. Other workers have developed consequence models for hazards such as dispersion of toxic combustion products in air and dispersion of toxic liquids in the groundwater. Further development of consequence models is beyond the scope of this paper. Instead, the authors have concentrated on the development of a risk assessment framework which makes use of available consequence models. The aim is that the developed framework will describe the overall risk to the environment from an accident scenario, in such a way that the risk can be compared with tolerability criteria. This was considered to be the main gap in the currently available methodology for environmental risk assessment. Although a number of consequence models have been developed, the user is left uncertain about how to use the output which is in terms of concentration versus distance rather than effects or risk to the environment.

In order to develop the risk assessment framework, the authors have made use of the "major accident to the environment" definitions proposed in the DoE Guidance Note[2]. These definitions are currently the most definitive statement of how to interpret major accidents to the environment for the purpose of the CIMAH Regulations and so the authors consider that a risk assessment method based on them will be useful. However, the authors are aware that the DoE definitions can be criticised as suggested by Khayyat[9] and that the DoE intends to revise them. It is hoped that the developed framework is capable of modification for any change to be made to the definitions of major accidents to the environment.

PROPOSED ENVIRONMENTAL RISK INDEX METHODOLOGY

i) Overview

The flow diagram of the proposed risk assessment framework for major accident hazards to the environment is is shown in figure 2.

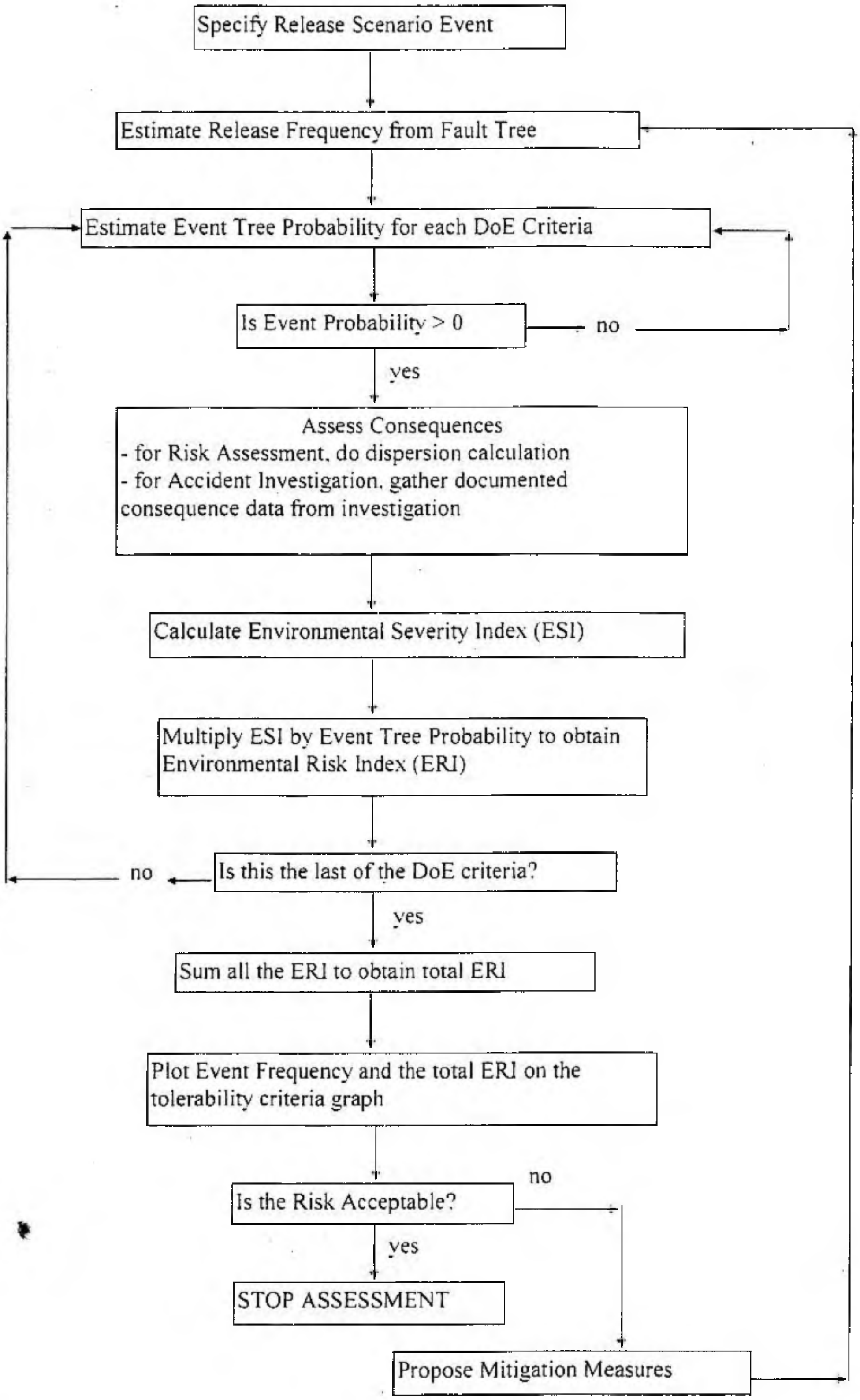

Figure 2 : The Framework of Risk Assessment for Major Accident Hazards to the Environment

The assessment process consists of three or four main stages.The main aim of the framework is to assess whether the release of pollutant from an industrial accident will satisfy the criteria of major accident hazards to the environment given by the DoE in the context of the CIMAH Regulations, together with any frequency criteria for tolerability such as proposed for the EHI method[3].

The first stage of the assessment is to identify release scenarios for the particular plant, which could result in harm to the environment. It will also be necessary to survey the area surrounding the site in order to identify environmental vulnerabilities. These steps are required by the CIMAH Regulations. The frequency of the release event can be estimated from fault tree analysis or generic failure rate data.

The next stage involves consequence assessment using computer dispersion models or other methods which are appropriate. Consequence assessment is also required by the CIMAH Regulations. For the consequence assessment, detailed information about the release scenario, about the pollutants released and also the environmental medium which pollutants would be released into will have to be gathered.

The most important stage of the assessment is to quantify the severity of the accident by using the Environment Severity Index (ESI) method developed by the authors and described below. An Environmental Risk Index (ERI) score is then obtained by combining the ESI for each DoE Green Book criteria with the probability that that criteria will apply for the release being considered. The results of consequence assessments will be used in the severity assessment in order to calculate the ESI. If the consequences were already known, for example for analysis of well documented past accidents, this could be applied directly to the proposed severity assessment method.

The total ERI score obtained when plotted against the frequency of the release event, will be compared with the available tolerability criteria. At this stage, the severity is for the worst case scenario. Later, it may be possible to reduce the severity or the frequency of the release event by the introduction of a series of mitigation measures. The initial assessment result will be reviewed and any mitigation measure proposed may reduce the risk score or frequency of the release event.

Frequency estimation for release events is well-established for safety risk assessment and has been discussed in detail by Lees[10].

Event tree logic divides the accident frequency into a number of fractions, each with its own severity, characterised by the ESI. In many, but not all, cases, the event tree probability for a particular consequence will be either 1 or 0. This event tree logic will produce a table of probabilities for each of the consequences leading to the major accident hazards described by the DoE. These probabilities could add up to more than 1 if several types of consequences could occur simultaneously, e.g. contamination of river, contamination of groundwater and abtracted water unfit for use could each have probabilities of 1 if there was a release to a river which fed the groundwater and from which drinking water is abstracted.

ii) Severity Assessment

The severity assessment, developed here is based on the Environmental Hazard Index method (EHI) proposed by AEA Technology with some modifications. The proposed method is named an Environmental Severity Index (ESI). Before applying the proposed ESI method, computer models have to be used to calculate the dispersion of an environmentally hazardous substance released in the surrounding aquatic or terrestrial environment. From the results of the dispersion calculations, the ESI for every possible type of major accident to the environment given by the DoE can be calculated.

An ESI will be calculated for each DoE criteria of major accident hazards to the environment. The calculations may be different from one DoE criteria to another and may consist of one or more of the components of "toxic effects factor" (concentration, dose etc.), "damage factor" and "recovery factor" described by the following equations.

Generally, ESI is calculated using equation 4 for short-term effects and equation 5 for long-term effects, combined with other factors which are relevant.

$$ESI = \sqrt{Toxic\ effects\ factor \times Damage\ factor} \qquad \text{Equation 4}$$

$$ESI = \sqrt[3]{Toxic\ effects\ factor \times Damage\ factor \times Recovery\ factor} \qquad \text{Equation 5}$$

where. toxic effects factor can be from any of equations 6-10, damage factor can be from equations 13-35 and recovery factor from equation 11. The equations to be used depend on the type of major accident to the environment being considered.

The EHI used the product of a toxic effects factor and a damage factor for non-persistent chemicals. One of the results of this was that the method tended to yield high values of the EHI. The authors prefer the use of the geometric mean of the factors as shown in equations 4 and 5 above. If each of the factors is 1. then equations 4 and 5 still yield an ESI of 1, indicating a severity which is just a major accident to the environemnt. The use of the geometric mean allows a high value for one of the factors to be balanced by low values for the others, in a way which does not lead to very high (an physically unrealistic) values of the ESI.

Toxic Effects Factor

The toxic effects factor gives a measure of the level of toxicity in the environment caused by the particular release.

As for the AEA Technology EHI method. if possible toxicity data for the chemical released should be found for a number of species at different levels in the food chain which are representative of the eco-system as a whole. In practice. toxicity data is usually very difficult to find in the literature. and. if necessary. the data for whatever species found may have to be used.

For our proposed method, the equations to be used for toxic effects factor, depending on the application, are given below :

$$Toxic\ effects\ factor\ (concentration) = \frac{\sum_{i=2}^{N} PEC_i (S_i - S_{i-1})}{S_{total} \times \min LC_{50}} \qquad \text{Equation 6}$$

N	= *number of sections in the system*
j	= *section number of the system*
PEC	= *predicted maximum concentration affecting the section (mg/l)*
S	= *predicted distance(m), area (m^2) or volume (m^3) affected by the concentration within the section being considered*
$\min LC_{50}$	= *the lowest LC_{50} for a species in that particular ecosystem (mg/l)*
S_{total}	= *total distance(m), area (m^2) or volume (m^3) in the system*

$$Toxic\ effects\ factor\ (dose) = \frac{\sum_{i=2}^{N} DOSE_i (S_i - S_{i-1})}{S_{total} \times Dose\ equivalent\ to\ LC_{50}\ or\ LD_{50}} \qquad \text{Equation 7}$$

N	= *number of sections in the system*
j	= *section number of the system*

DOSE		= *predicted average dose affecting the section ($C^n t$), where the value of n is normally taken as 2in the absence of better data for specific chemicals*
S		= *predicted distance(m), area (m^2) or volume (m^3) affected by the concentration of the section*
S_{total}		= *total distance(m), area (m^2) or volume (m^3) in the system*

$$\textit{Toxic effects factor (which affects humans who are present in the contaminated environment)} = \frac{\sum_{j=2}^{N} PEC_j (S_j - S_{j-1})}{S_{total} \times OES}$$ Equation 8

N	= *number of sections in the system*
j	= *section number of the system*
PEC	= *predicted concentration affecting the section (mg/l)*
S	= *predicted distance(m), area (m^2) or volume (m^3) affected by the concentration*
S_{total}	= *total distance(m), area (m^2) or volume (m^3) in the system*
OES	= *occupational exposure standard for the particular chemical (mg/l)*

$$\textit{Toxic effects factor(for aquifers)} = \frac{\textit{concentration of chemical in aquifers}}{\textit{chemical standard for drinking water}}$$ Equation 9

$$\textit{Toxic effects factor (for SSSI or other specific distance from releases)} = \frac{\textit{concentration at specific distance / point}}{\min LC_{50}}$$ Equation 10

Recovery Factor

The recovery factor gives a measure of the time that the environment would take to recover from the release.
The recovery factor has to be based on a subjective judgement or estimation of the recovery time, used in equation 11. The authors made attempts to derive a recovery factor from such information as the half-life (a measure of persistence) and the octanol/water partition coefficient (a measure of bioaccumulation), but these attempts were unsuccessful.

$$\textit{Recovery factor} = \frac{\textit{time for recovery}}{\textit{reference recovery time}}$$ Equation 11

where the reference recovery time is 5 years for aquatic habitat; 15 years for terrestrial habitat; 1 year for accidents which prevent access to crops, domestic animals and other foodstuffs; also 1 year for biological quality of water courses. These are quoted in the DoE criteria.

Development of Damage Factor

The damage factor gives a measure of the total area affected. The development of a damage factor for every DoE criteria will be given in the Appendix.

iii) Environmental Risk Index (ERI)

After obtaining the frequency of the release event, ESI and probability of each event consequence, an overall risk index can be calculated from the following :

$$\mathit{Environmental\ Risk\ Index}\ (ERI) = \sum\left[(\mathit{SubEvent\ Probability}) \times (ESI)\right] \quad \text{Equation 12}$$

This can then be used as the x-axis in a "societal risk" plot as proposed in the EHI method (see figure 1).

However, the authors propose a modification of figure 1. The "societal risk" type criteria used to plot the results of the ERI and the accident frequency was based on those developed by AEA Technology for the EHI method[3]. AEA Technology made a modification to the original FN curve for societal risk.

Although the AEA Technology EHI and the ERI proposed here are different, the AEA Technology tolerability criteria can be used for both methods. This is because the tolerability criteria were developed independent of the EHI method. They were calibrated using a major accident to the environment (EHI =ERI=1) and an accident much less than a major accident (EHI=ERI=0.01).

The original FN curve has no horizontal regions whereas the AEA Technology criteria curves do. The authors consider AEA Technology's horizontal section at low values of ERI to be unjustifiable, since it would mean that no accident with any effect on the environment, however small, could be justified with a frequency greater than once in hundred years. This could probably not be achieved by industry.

It is likely that AEA Technology proposed the horizontal section in order to make it relatively easy to achieve the tolerability criteria. They will not have wanted to propose criteria which were unachievable by industry and may have been concerned about the very high values of EHI which can result from their method. The authors' proposal earlier to use the geometric mean, rather than the product, of the toxic effects factor, damage factor and recovery factor would reduce this problem.

The authors consider that it would be preferable to retain a standard FN curves (without horizontal sections) at high ERI. An accident 10 times worse than a "standard" DoE major accident is nowhere near as severe as certain accidents which could be imagined and which would sterilise large areas of the countryside including important habitats. It is reasonable that such very catastrophic potential accidents should be reduced to an extremely low frequency. The authors therefore proposes the tolerability criteria shown in figure 3.

iv) Mitigation Measures

These are measures considered during a review process to the risk assessment, normally if the assessment goes beyond the initial stage. This is because the initial assessment may cause an overestimate of the risk as the worst case scenario without control or mitigation is normally used. During a review process a reduced value of frequency of release and/or ESI will result in a lower value of the ERI score. This concept of mitigation is introduced by ICI in the Mond Index. In this section, detailed mitigation measures based loosely on the concepts introduced by the Mond Index and developed for our purpose will be presented.

There are two main things that can be done to mitigate the release scenario. First is consideration in the early design stage to foresee the possible problems that may arise. These types of mitigation measures are such as segregation by distance, layout, and also use of containment methods to secure the materials such as physical barriers, fences, kerbs, bunds etc. This type of mitigation would be normally be associated with trying to reduce the frequency of an accident. It may also reduce the probability that a particular type of consequence will occur. Other types of mitigation which may reduce frequency include improved control systems, trip systems and safety management systems.

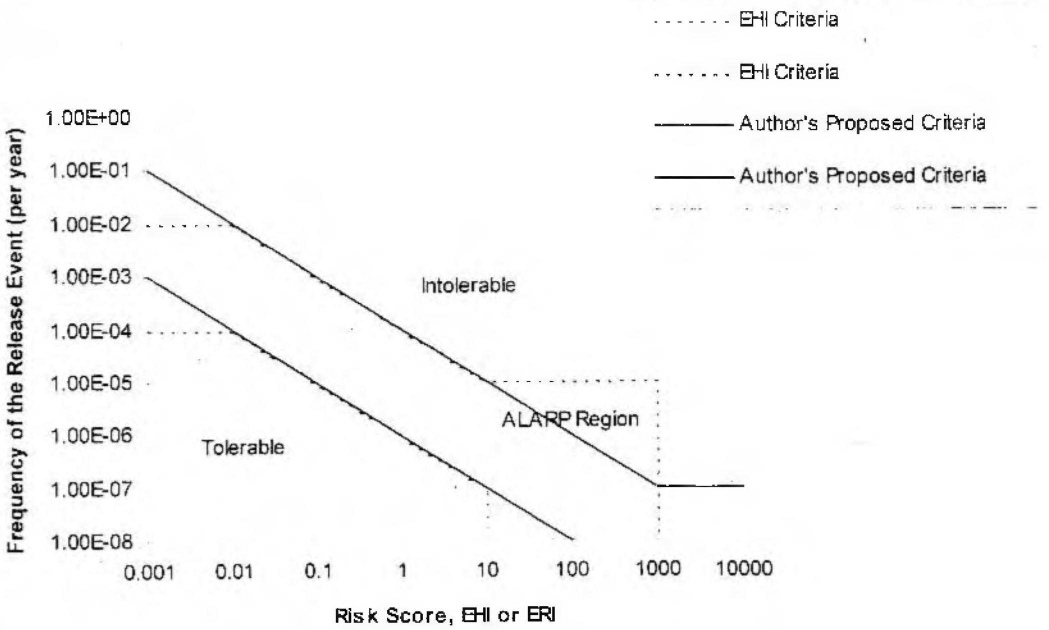

Figure 3 : AEA Technology EHI Criteria Compare with the Authors' Proposed Criteria

The second type of mitigation involves steps taken to minimize harm after the accident has happened, such as an emergency plan and also actions taken to remedy the situation. This type of mitigation is more towards reducing the severity of the accident. Unlike the short-term flammable hazards considered in the Mond Index, long-term environmental harm may result and could be mitigated by measures taken well after the accident, such as soil clean-up or restocking of rivers. Changes made early in the process design, such as reducing the amount of toxic chemicals stored, will also reduce the severity of any accident.

The following procedure is proposed for reviewing the risk assessment :

1. Go back through the assessment (which was done without any mitigation) and review the assumptions made, particularly those to which the overall risk score is most sensitive. By reviewing such assumptions it may be possible to reduce the risk score.
2. Go through the list of frequency mitigation measures. Consider any design changes which might reduce accident frequency. Repeat the fault tree analysis to find the revised value of the accident frequency.
3. Go through the list of severity mitigation measures. These affect the severity of the event and hence the ESI. Recalculate the ESI for each consequence to obtain the reviewed ESI.
4. Consider the effects of measures chosen in steps 1, 2 and 3 on the event tree probabilities for each type of consequence to the environment. Modify these probabilities.
5. Recalculate the ERI.
6. Steps 2-5 may be repeated several times until satisfactory results are obtained.

CASE STUDY

The release scenario for the case study was an accidental release of liquid pesticide from a storage tank into the environment. The process diagram is shown in figure 4. In a base case study, 150 kg of liquid carbofuran has been released (hypothetically) into the River Don for the duration of one hour. Three river dispersion models. PRAIRIE[11] , RIVER[12] and ICI's hand calculation[13] were applied to the case study.

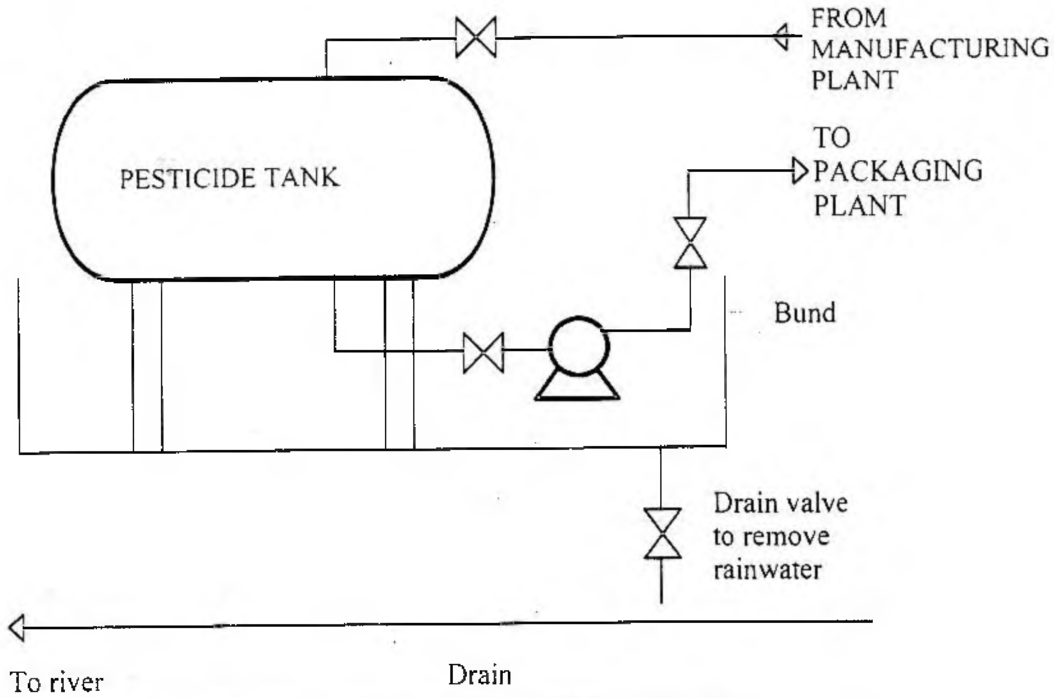

Figure 4 : Line Diagram for the Hypothetical Case Study

For the base case. the pesticide tank is in a bund, but there is a drain line from the bund to the river so that rainwater can be manually drained from the bund. A release to the river could occur if there was a leak from the tank. coincident with the drain value being open. For this event, the release frequency was estimated as 10^{-3} per year using fault tree analysis.

The release frequency and ERI values obtained are then plotted on the graph criteria to assess whether the consequence is a major accident hazard to the environment. For a base case study. it can be seen from figure 5 that the the event is expected to cause a major accident to the environment.

In order to try to reduce either the frequency of the release or the severity of the base case accident, several different mitigation measures are proposed and the risk assessment framework was applied again for each case to see the change in the predicted ERI. The following mitigation options are possible :

1. This mitigation involves a special procedure for operation of the valve on the bund at the storage tank and thus is expected to reduce probability that operator has left the bund drain valve open to 0.01.
2. In this option. a holding tank is to be used to contain the rainwater from the pesticide tank bund before it is allowed to discharge into the river. The discharge to the river will be done batch-wise after testing for pesticide shows that it is safe to do so.The fault tree constructed to estimate the frequency that pesticide enters river from a release shows that it reduces to 10^{-5}/year. After applying the risk assessment framework. it has been found that the ESI has not changed.

3. It is proposed that a smaller storage tank, half its original size, be used. Therefore it will reduce the quantity of material stored in it by half. This reduces the release duration to half of the original value.This mitigation option does not affect the frequency of the release event
4. Here a smaller drain line is proposed to remove rainwater from the pesticide storage tank bund to the river. This will effectively reduce the flowrate of pesticide in the event of accidental released to half its original value. This option does not change the frequency of the release event but only affects the ERI
5. In this mitigation option, water users will be warned of the release which has occured so that water from the river, canal or estuary is not to be used for a specific duration of time. Again, in applying the risk assessment framework, this mitigation affects the ERI and not the release frequency
6. In this mitigation option, the river, canal or estuary affected will be recolonised or restocked with fish or other damaged species which will then effectively reduce the recovery time and thus reduce the ERI scores
7. The pesticide will be stored as 5% solution in water. This reduces the concentration at any point in the river to 5% of its original value.
8. Replace carbofuran with different liquid pesticide. Assume hypothetically that the pesticide used has an LC_{50} which is 5 times higher than that of carbofuran, but everything else is the same.

The results of the case study are shown in table 1.

Table 1: Summary of the ERI Score Calculated Using the Proposed Method for All Options of the Case Study

Dispersion Model Used		PRAIRIE	RIVER	ICI Method
Case Study Option	Frequency of the Release Event	Environmental Risk Index (ERI)		
Base Case	10^{-3}/year	73.4	116.7	142.0
Mitigation 1	10^{-4}/year	73.4	116.7	142.0
Mitigation 2	10^{-5}/year	73.4	116.7	142.0
Mitigation 3	10^{-3}/year	56.3	87.8	106.4
Mitigation 4	10^{-3}/year	40.2	64.0	76.6
Mitigation 5	10^{-3}/year	61.1	97.8	108.2
Mitigation 6	10^{-3}/year	70.3	113.6	138.9
Mitigation 7	10^{-3}/year	5.2	14.1	16.2
Mitigation 8	10^{-3}/year	19.3	39.9	52.5
Combine M2 and M7	10^{-5}/year	5.2	14.1	16.2

DISCUSSION

Results of Applying the Risk Assessment Framework

The results of the hypothetical case study show that the ERI obtained have varied considerably depending on the dispersion models used.

None of the dispersion models used can predict the behaviour of chemical after the River Don goes through the Humber Estuary and then the sea because the models are intended for non-tidal rivers. The authors have therefore estimated concentrations in the estuary and sea in order to demonstrate the use of the risk assessment framework. This also demonstrates that the framework is usable when only very approximate consequence information is available.

The risk scores (ERI) obtained using all dispersion models agree in one respect, in that they indicate that the scenario considered are expected to cause major accident hazards to the environment because the risk is in the intolerable region for all of them. This is as a result of either high ERI scores or high frequency or a combination of both. Because the ERI values are so high, the variation in the ERI due to the use of different dispersion models has no effect on the conclusion that the risk is intolerable. The mitigation measures proposed cannot solve the problem, because one mitigation measure by itself has only reduced either the release frequency or the ERI but has not been sufficient to take the risk out of the intolerable region. A combination of some of the mitigation measures, e.g. options 2 and 7 would render the risk on the borderline between the intolerable and ALARP regions by using RIVER and the ICI Method, while by using PRAIRIE, the risk is in the ALARP region such as shown in figure 5.

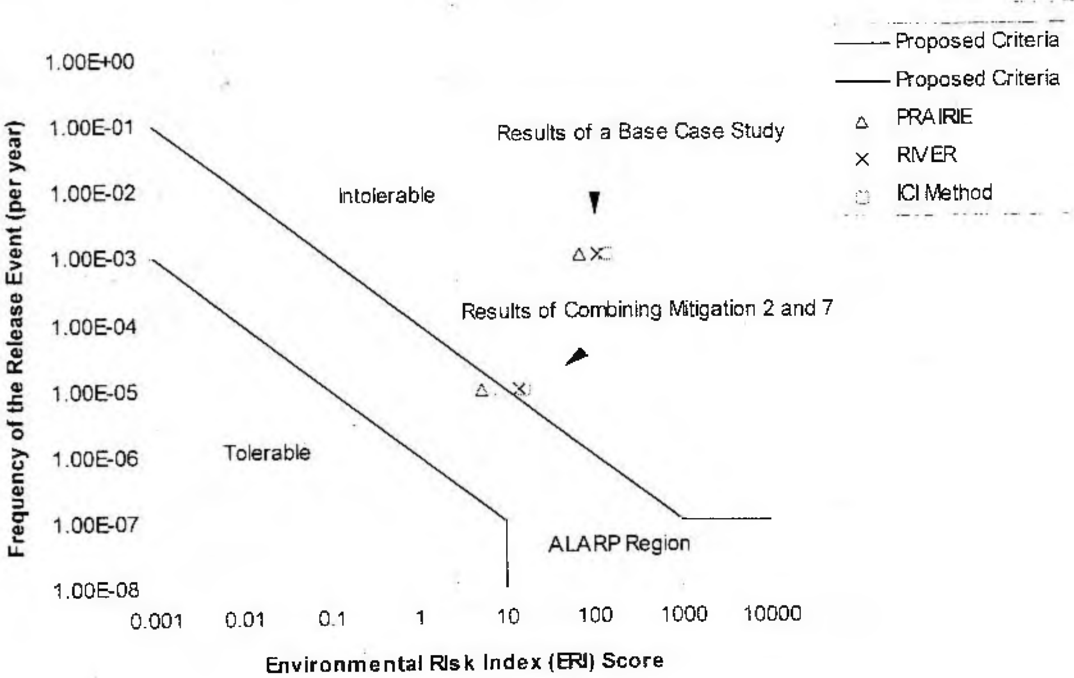

Figure 5 : Results of the ERI Scores Compare with Authors' Proposed Criteria

The ERI was found to be more sensitive to which dispersion model was used than either the concentration or dose which were discussed earlier. It would be expected that the AEA Technology EHI Method would show similar sensitivity to the dispersion models used. The results for the different dispersion models cover a range of a little less than an order of magnitude. The two simplified models, RIVER and the ICI Method tend to result in similar values of the ERI but this may be coincidental. PRAIRIE tends to give the lowest ERI in spite of its tendency to erroneously increase the concentration in places with distance downstream.

It can be seen the ERI is in the intolerable region for the base case scenario. It is recommended that a combination of mitigation options 2 and 7, (mitigation 2 is using holding tank to contain the rainwater in the bund, and mitigation 7 is storing pesticide as 5% solution in water) be implemented to reduce the environmental risk to as low as is reasonably practicable (ALARP). See figure 5.

CONCLUSIONS

A risk assessment framework has been proposed for releases to the environment which might constitute a major accident to the environment. The framework makes use of a risk index method.

The proposed risk assessment framework was applied to a hypothetical case study. The framework was found to be quick and easy to apply. The risk for the base case study was found to be intolerable. A range of mitigation measures were considered during a review process to see if there is an improvement in terms of the risk severity or the frequency of the release event. The combination of mitigation options 2 and 7 was found to reduce the risk to within the ALARP region.

The proposed ESI/ERI Method were found to be sensitive to the river dispersion model used. It is therefore advantageous to use a detailed river dispersion model such as PRAIRIE which models all the physical effects which occur during river dispersion.

An improved tolerability criteria graph has been proposed and is given in figure 3. This does not contain the horizontal sections in the EHI version. The authors consider that these horizontal sections cannot be justified because :

a) They indicate that no accident with any potential to harm the environment can be tolerated more frequently than 10^{-2} per year. This is not achievable for very minor accidents.
b) They indicate that once an accident is 10 times as bad as a reference major accident to the environment, it does not matter how bad it is. This is difficult to justify because it gives no incentive for reducing the frequency of very bad accidents, and also because the EHI and ERI methods can easily predict consequences which are worse than 10 times a reference major accident.

A similar approach could be adopted to be applied in Malaysia, if relevant.

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APPENDIX : EQUATIONS FOR THE CALCULATION OF DAMAGE FACTORS FOR USE IN THE PROPOSED ESI METHOD

Criteria 5.2 - National Nature Reserves, Sites of Special Interest (SSSIs) and other Designated Areas

The damage factor as a result of a loss of scientific interest (i.e loss of nature conservation value) to one or more of the following may be calculated using equations 13-15.

$$Damage\ factor = \sum \frac{\%\ area\ of\ the\ site}{10\%\ area\ of\ the\ site}\ or\ \sum \frac{area\ of\ the\ site}{0.5\ hectares}\quad \text{(whichever is the lesser)}$$

Equation 13

$$Damage\ factor = \sum \frac{\%\ of\ area\ of\ particular\ habitat}{10\%\ area\ of\ particular\ habitat}$$

Equation 14

$$Damage\ factor = \sum \frac{\%\ of\ particular\ species\ affected}{10\%\ of\ particular\ species\ affected}$$

Equation 15

Equations 13-15 will be applied for any long term damage to a national nature reserve, an SSSI (including watery habitat), a marine nature reserve (statutory or voluntary), or an area protected by a limestone pavement order. Because a major accident hazard to the environment could occur due to each of the four factors given above, they should be added together to give the overall damage factor and used to calculate the environmental severity index (ESI).
In calculating the ESI for this criteria. for toxic effects factor. use concentration (equation 6) unless the exposure time is less than 96 hours (non-persistent chemicals) in which case use the dose effect (equation 7). For the ESI, use equation 5 since it is a long-term effect.

Criteria 5.3 - The Wider Environment

The damage factor for permanent or long term damage to the following habitats are :
For scarce habitat,

$$Damage\ factor = \sum \frac{area\ of\ scarce\ habitat\ affected}{2\ hectares}$$

Equation 16

For intermediate habitat,

$$Damage\ factor = \sum \frac{area\ of\ intermediate\ habitat\ affected}{5\ hectares}$$

Equation 17

For unclassified habitat.

$$Damage\ factor = \sum \frac{area\ of\ unclassified\ habitat\ affected}{10\ hectares}$$

Equation 18

Criteria 5.4 - Freshwater and Estuarine Habitats

The damage factor is as a result of either lowering the chemical water quality by one class for more than one month or lowering the biological quality by one class for more than one year, or causing long term damage to a river. canal, stream. pond or estuary. Damage factors are given in the following equations :
For a river. canal or stream.

$$Damage\ factor = \frac{\sum length\ polluted}{10\ km}$$

Equation 19

For a lake or pond.

$$Damage\ factor = \frac{\sum area\ polluted}{1\ hectare}$$

Equation 20

For an estuary:

$$Damage\ factor = \frac{\sum area\ polluted}{2\ hectares}$$ Equation 21

For toxic effects factor, use concentration (equation 6) unless the exposure time is less than 96 hours (non-persistent chemicals) in which case use the dose effect (equation 7).

Criteria 5.5 - Aquifers and Groundwater

This concerns damage to an aquifer leading to contamination which would preclude its use for public domestic or agricultural water supply or have significant adverse impact on the surface waters and biotic systems it supports. Equation 9 will be used to calculate the ESI and no other factors are involved in calculating the ESI.

Criteria 5.6 - The Marine Environment

The damage factors for permanent or long term damage :

$$Damage\ factor = \frac{\sum area\ of\ littoral\ or\ sublittoral\ zone\ affected}{2\ hectares}$$ Equation 22

$$Damage\ factor = \frac{\sum area\ of\ benthic\ community\ adjacent\ to\ the\ coast\ affected}{2\ hectares}$$ Equation 23

$$Damage\ factor = \frac{\sum area\ of\ benthic\ community\ of\ fish\ spawning\ ground\ affected}{2\ hectares}$$ Equation 24

$$Damage\ factor = \frac{\sum area\ of\ benthic\ community\ of\ open\ sea\ affected}{250\ hectares}$$ Equation 25

$$Damage\ factor = \frac{\sum number\ of\ birds\ (excluding\ gulls)\ killed}{100}$$ Equation 26

$$Damage\ factor = \frac{\sum number\ of\ sea\ birds\ of\ any\ species\ killed}{500}$$ Equation 27

$$Damage\ factor = \frac{\sum number\ of\ sea\ mammal\ killed\ or\ unable\ to\ produce}{5}$$ Equation 28

These damage factors should be added together when calculating the ESI.

Criteria 5.7 - Particular Species

The damage factor can be calculated by the following equations :

$$Damage\ factor = \frac{\sum \%\ death\ of\ any\ species}{1\%}$$ Equation 29

$$Damage\ factor = \frac{\sum \%\ inability\ to\ reproduce\ of\ any\ species}{1\%}$$ Equation 30

Criteria 5.8 - Release of Persistent Toxic Substances

To calculate damage factor,

$$Damage\ factor = \sum \frac{amount\ of\ CIMAH\ top\ tier\ substance\ released}{10\%\ of\ top\ tier\ threshold\ quantity}$$ Equation 31

Criteria 6.2 - Built Heritage

This includes damage to built heritage such as Grade 1 listed buildings (England and Wales) or a Category A buildings (Scotland) or a scheduled ancient monument (such that it no longer possesses its architectural historic or archaeological importance and which would result in it being de-listed or de-scheduled) or damage to an area of archaelogical importance or to a conservation area resulting in loss of importance.
If there is such damage as described above, the ESI will be calculated based on the following damage factor for each case because no other factors are involved.

$$Damage\ factor = \sum \frac{Explosion\ overpressure}{2psi} + \sum \frac{thermal\ radiation\ intensity}{200kW/m^2} + \sum \frac{chemical\ concentration}{occupational\ exposure\ standard}$$

Equation 32

This represents measures of demolition by explosion overpressure, burning down due to impinging thermal radiation, or toxic contamination such that it would have to be quarantined until decontaminated.

Criteria 6.3 - Recreational Facility

Damage to recreational facilities such as Long Distance Route (National Trail), Country Park such that it no longer possesses its aesthetic, cultural, amenity or public enjoyment value. Treat same as National Park, i.e., intermediate habitat under criteria 5.3.

Criteria 7.2 - Crops, Domestic Animals and Other Foodstuff : Public Assess

$$Damage\ factor = \sum \frac{area\ of\ land\ contaminated\ for\ more\ than\ one\ year}{10\ hectares}$$

Equation 33

The damage factor is calculated from one or more of the following (and if more than one applies, the damage factors should be added).
Contamination which prevents the growing of crops or the grazing of domestic animals or renders the area inaccessible to the public because of possible skin contact with dangerous substances, or contamination of a significant area of any aquatic habitat which prevents fishing or aquaculture or which similarly renders it inaccessible to the public.
Contamination to land crops and other plants by direct spillage, aerial deposition, or by irrigation with contaminated water or absorbed contamination from soil. Persistent chemicals can bioaccumulate to effect the meat or milk from cattle grazing on contaminated pasture. Game birds and animals may similarly be affected. Humans who consume fish and other aquatic animals or plants will also be affected.
Because this affects the human food chain, the LC_{50} used in equation 6 is too high a concentration, therefore for toxic effects factor use equation 8. For calculating the ESI, use equation 4.

Criteria 7.3 - Water Sources and Supply

$$Damage\ factor = \frac{number\ of\ people\ affected\ from\ contamination\ of\ water\ supply}{10{,}000}$$

Equation 34

Use equation 8 for toxic effects factor and for calculating the ESI, use equation 4.

Criteria 7.4 - Sewerage and Sewage Treatment

$$Damage\ factor = \frac{number\ of\ people\ affected\ with\ water\ supply\ from\ damage\ to\ sewerage\ system}{10{,}000}$$

Equation 35

This damage factor arises from damage to a major sewerage system which results an unacceptable and widespread hazard to public health or safety.

To calculate the ESI, use equation 4 and for toxic effects factor use equation 8.