A Practicable Approach to Environmental Risk Assessment for Sites with Multiple Hazards

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An outline of an approach for assessing the aggregate risk for a site with multiple hazards. The approach uses normalisation of release quantities on the basis of the potential harm arising from different sources and receptors, allowing their integration in a cumulative frequency-quantity plot in a manner analogous to the use of F-N plots for fatal hazards.

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Introduction

There are many factors that will influence the impact a release will have on the environment and even where these might be identified there are enormous difficulties in trying to quantify their effect, with correspondingly large uncertainties in any values that might be determined.

Any attempt to quantify the absolute level of environmental harm is fraught with these difficulties. It is a much more tractable proposition to evaluate the relative level of harm. In terms of risk management, a measure of relative harm and associated risk will allow priorities to be established and resources directed as appropriate. It will allow the risk from a diverse range of enterprises in terms of scale, toxicity and location to be assessed on a nominally equal footing.

We may assess the relative harm on the basis of:

- Substance Potency; what concentration would be harmful?
- Receptor Recovery; for how long will the substance persist in the environment? How long will it take for the environment to recover?
- Receptor Vulnerability; how sensitive is the receptor?
- Receptor Value; what is the value of preventing a given degree of harm? (We can postulate that two receptors that are of the same size and in the same nominal category might nevertheless be seen as having different levels of environmental significance or have markedly differing clean-up costs.)

Relative receptor vulnerability may be assessed on the basis of the impact severity categorisation employed by the Chemical and Downstream Oil Industries Forum in their document 'Guideline – Environmental Risk Tolerability for COMAH Establishments [1]. This assigns an order magnitude separation in tolerability on the basis of categorisation of harm as severe/major/catastrophic, using criteria described in the original DETR guidance [2]. In this way, for example, a given release to a groundwater (non-SPZ) receptor categorised as 'severe', might be categorised as 'major' if to a groundwater (SPZ) receptor; the implication being that the latter receptor is 10 times more sensitive than the former.

Relative substance potency may be assessed on the basis of relative LC50 values or other measures of toxicity. Relative recovery time may be assessed on the basis of nominal recovery time against a base value. Similarly, receptor value may be assessed against a reference base.

Environmental Harm Index

An Environmental Hazard Index (EHI) has previously been used [3] to assess the relative risk of individual MATTE hazards (Major Accident Threat To Environment); this identified relative harm on the basis of the extent (size), the severity (toxic concentration) and the recovery time associated with a release in relation to a reference accident at the nominated MATTE threshold. The tolerable frequency of a release is held to be inversely proportional to EHI. (With a release at the MATTE threshold (EHI=1) assigned a broadly acceptable frequency of 10^{-4}/year, and an intolerable threshold two order of magnitude higher at 10^{-2}/year.)

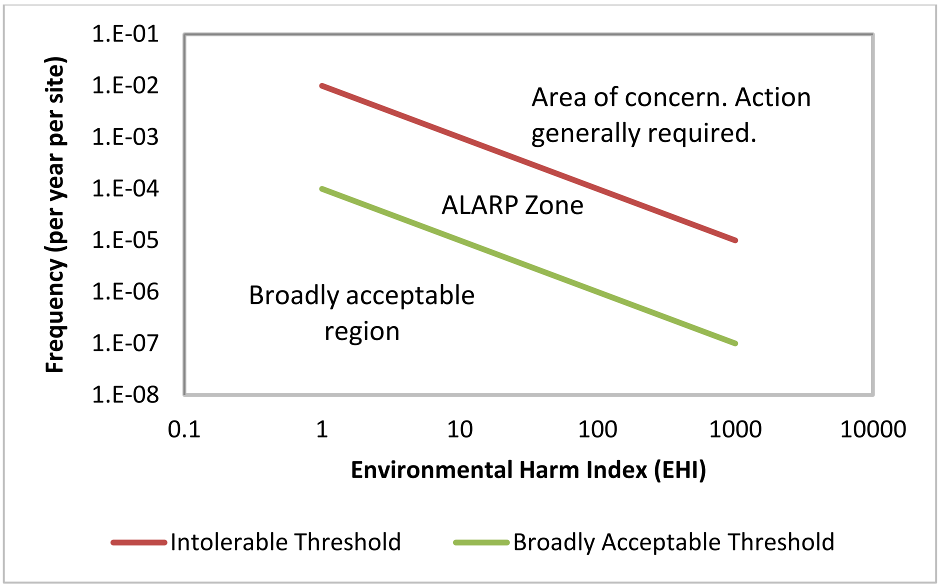

Figure 1: Risk Criteria for Environmental Harm Index as identified in Ref. 3

Aggregate Risk

The approach outlined below allows for an assessment of the aggregate risk from all potential hazards associated with a given establishment. It also supports the use of cost benefit analysis (CBA) for the assessment of postulated improvements in risk reduction provisions which may very well affect multiple receptors of different sensitivities. Basically the approach is to use the EHI reference accident equivalence of release-receptor combinations to normalise the potential harm, since, for example, 500Te of substance X in an estuary may be held to inflict the same nominal degree of harm as 5Te of substance Y in a SSSI pond. Note the designation ‘release-receptor’ combination, as distinct from the more familiar ‘source-receptor’ pairing (via a pathway); this is in recognition that a given source may give rise to a number of different release scenarios.

We can identify the harm reference equivalence factor (HEF) from the ratio of MATTE reference values in respect of size(S), toxicity(LC50), and recovery time (T) for each release-receptor combination (subscript ‘refi’) to the values adopted for a base case MATTE (subscript ‘refb’):

$$HEF_i^* = \frac{S_{refb}}{S_{refi}} \times \frac{LC_{50refi}}{LC_{50refb}} \times \frac{T_{refi}}{T_{refb}}$$

Note that this is the ratio of reference values, not the ratio of EHI values themselves. EHI values are derived from estimates of extent and predicted peak concentration in relation to the reference values and require estimates of release and receptor flow rates and an evaluation of dispersion mechanisms; they are subject to correspondingly broad uncertainties. EHI values are related to specific incidents, whether real or postulated, and do not lend themselves to the assessment of generic release hazards. (Note that the higher a receptor flow the more quickly a pollutant would disperse, but the greater distance the dangerous concentration would be carried, so that to a degree the extent of harm would be insensitive to receptor flow.)

To account for the possibility that receptors may be held to have differing environmental values even though they belong to the same category, or to account for differences in notional clean-up costs for a given release, we may introduce a further factor associated with value (V):

$$HEF_i = \frac{S_{refb}}{S_{refi}} \times \frac{LC_{50refi}}{LC_{50refb}} \times \frac{T_{refi}}{T_{refb}} \times \frac{V_{refi}}{V_{refb}}$$

So for each release-receptor combination (subscript ‘i’) the normalised harm quantity Qni is related to the actual release quantity Q_i by:

$$Q_{ni} = HEF_i \times Q_i$$

A statement of ‘harm equivalence’ for the potential release-receptor combinations might be produced:

1Te of X in receptor A = 5Te of Y in receptor B = 0.5Te of Z in receptor C

F-Q Curves

By identifying individual source release frequencies we may then construct a plot of cumulative frequency ($\mathrm{F} = \sum \mathrm{f_{ni}}$) against normalised harm quantity (Q_{ni}) from identified release-receptor scenarios (Q_{ni} and f_i). (In a manner that is analogous to the use of F-N curves for fatal risk.) Integration of this plot will then represent the aggregate risk of harm to the environment for the establishment. Figure 2 shows an example of the format of such a plot. This particular example was developed for a large fuel storage and distribution terminal, with approximately 100 release scenarios each with approximately 50 possible outcomes identified in an event tree and yielding approximately 5000 f-q pairs. Outcomes of each scenario are computed using a conditional event tree. On the basis of the declared parameters for the scenario, the frequency of each possible outcome is identified. The implication of each outcome is that the identified release quantity will be released into the pathway leading to the receptor(s) relevant to each scenario. The event tree allows the calculation of the frequency with which a given scenario release will reach an identified receptor depending on the defence layers that may be available e.g., whether source bund in place, size of release, bund containment probability of failure, interceptor probability of failure, tertiary containment probability of failure etc. A separate proportioning factor was introduced to account for the possibility that a given outcome might impact on more than one receptor e.g. where one receptor forms a pathway to a second receptor or where there is the possibility of partial hold up of release inventory.

The following tables show the normalisation factors that were employed. Note that these are nominal values and should not be regarded as definitive.

Receptor Type	Sensitivity Factor
Widespread Habitat	1
SSSI	20
Groundwater (Non-SPZ)	5
Groundwater (SPZ)	10
Lake	10
River (Low ecological class)	5
River (>low ecological class)	10
Marine	5
Estuary	5

Table 1: Relative sensitivity factors

Release Material	Relative Toxicity Factor
Gasoline	1
Kerosene	1
Diesel	1
Fuel+Firewater	0.3
Ethanol	0.1

Table 2: Relative toxicity factors

Receptor Type	Recovery Factor
Widespread Habitat	1
SSSI (Land)	1
Groundwater (Non-SPZ)	1
Groundwater (SPZ)	1
Lake	0.3
River (Low ecological class)	0.5
River (>low ecological class)	0.5
Marine	0.9
Estuary	0.9

Table 3: Relative recovery factors

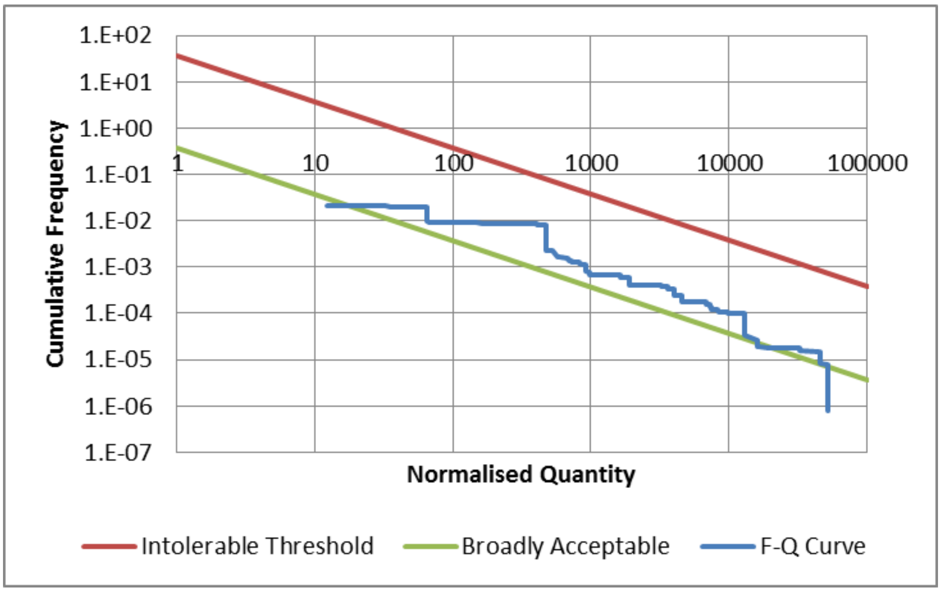

Figure 2: Example format of F-Q plot. (Frequencies are per year. Normalised quantities are in Tonnes.)

It is proposed that such plots will be useful for risk assessment of sites where initial screening has identified a MATTE potential.

Cost Benefit Analysis

The value of preventing a release quantity may then be postulated for a reference case substance and reference case receptor with a reference recovery time. This may be informed by consideration of the clean-up costs associated with historical incidents. (Note that if allocated on a total release inventory basis, these costs will implicitly include the influence of dynamic aspects of the incidents such as release and receptor flow rates and associated dispersion mechanisms.) This then allows a benefit value to be assigned to the prevention of the aggregate harm, and this may then be used in a cost benefit analysis for potential measures to reduce the risk of harm.

If a value of £X/Te is identified, the integral of the F-Q curve can be multiplied by this value and the nominal establishment life, to identify the total value across the establishment life of eliminating the aggregate risk. An improvement (with an associated cost) may be postulated and the integral recalculated to identify the incremental benefit of the improvement.

It should be recognised that categorisation of the reference case provides the calibration for the risk assessment. This calibration will provide the link between release quantity and EHI and is critical to the approach. It must be acknowledged that large uncertainties remain. Nevertheless, the approach will provide a consistent basis for assessing aggregate establishment risk that will support a more focussed and coherent dialogue concerning the calibration and the sensitivity factors to be employed.

References

1. Guideline – Environmental Risk Tolerability for COMAH Establishments v1.0, Chemical and Downstream Oil Industries Forum, 2013.
2. Guidance on the Interpretation of Major Accident to the Environment for the Purposes of the COMAH Regulations, DETR, 1999.
3. Major Accidents to the Environment, Edited by Ivan Vince, Butterworth-Heinemann, 2008.