Final report Annex 3: Methods for assessing environmental consequences (Task 3)

Development of an assessment methodology under Article 4 of Directive 2012/18/EU on the control of major-accident hazards involving dangerous substances (070307/2013/655473/ENV.C3)

Report for the European Commission (DG Environment)

AMEC Environment & Infrastructure UK Limited

in association with INERIS and EU-VRi

December 2014

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European Commission, DG Environment
Directorate C – Sustainable Resources Management,
Industry and Air
Unit ENV C.3 – Industrial emissions, air quality and noise
Brussels B-1049
Belgium

Main Contributors

Caspar Corden (AMEC)
Victoria Cherrier (AMEC)
Juan Calero (AMEC)
Christophe Bolvin (INERIS)
Jacques Bureau (INERIS)
Clément Lenoble (INERIS)
Olivier Salvi (EU-VRi)

Issued by

....
Victoria Cherrier

Approved by

....
Caspar Corden

AMEC Environment & Infrastructure UK Limited

17 Angel Gate, City Road, London EC1V 2SH,
United Kingdom
Tel +44 (0) 207 843 1400
Fax +44 (0) 207 843 1410

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European Commission (DG Environment)

Development of an assessment methodology under Article 4 of Directive 2012/18/EU on the control of major-accident hazards involving dangerous substances

Final report – Annex 3

AMEC Environment & Infrastructure
UK Limited

December 2014

List of abbreviations

ADAM	Accident Damage Assessment Module
ADR	European Agreement Concerning The International Carriage Of Dangerous Goods By Road
ALARP	As Low As Reasonably Practicable
ARIA	Analysis, Research and Information about Accidents
ATEX	Explosive Atmosphere
BLEVE	Boiling Liquid Expanding Vapour Explosion
BOD – COD	Biochemical Oxygen Demand – Chemical Oxygen Demand
CE	Critical Event
CFD	Computational Fluid Dynamics
CLP	Classification Labelling Packaging
COMAH	Control Of Major Accident Hazards
DA	Deterministic Approach
ECHA	European Chemicals Agency
e-MARS	Major Accident Reporting System
EU	European Union
EWGLUP	European Working Group on Land Use Planning
F&EI	Fire & Explosion Index
GHS	Globally Harmonised System
JRC	Joint Research Centre
LPG	Liquefied Petroleum Gas
LUP	Land-Use Planning
MAHB	Major Accident Hazard Bureau
MATTE	Major Accident To The Environment
M_F	Material Factor of the Dow’s Fire & Explosion Index
MIMAH	Methodology for Identification of Major Accident Hazards
NFPA	National Fire Protection Agency
NOEC	No Observable Adverse Effects Concentration
PA	Probabilistic Approach
PLG	Pressurised Liquefied Gas

RID	European Agreement Concerning the International Carriage of Dangerous Goods by Rail
RMP	Risk Management Plan
STOT-SE	Specific Target Organ Toxicity (Single Exposure)
USEPA	United States Environmental Protection Agency
UVCE	Unconfined Vapour Cloud Explosion

Physicochemical parameters

BCF	Bioconcentration Factor
EC_{50}	Median Effective Concentration
ΔH_r	Standard enthalpy of reaction
K_{st} / K_g	Maximum rate of explosion pressure rise for dust clouds/gas
LD_{50} / LC_{50}	Median Lethal Dose / Median Lethal Concentration
LFL / LEL	Lower Flammability Limit / Lower Explosion Limit
LOC	Limiting Oxygen Concentration
MIE	Minimum Ignition Energy
MTSR	Maximum Temperature of the Reaction Synthesis
NOEC	No Observed Effect Concentration
P_{max}	Maximum explosion pressure
P_{vap}	Vapour pressure
ΔT_{ad}	Adiabatic temperature rise
T_{eb}	Boiling point
TMR_{ad}	Time to maximum rate in adiabatic condition
UFL / UEL	Upper Flammability Limit / Upper Explosion Limit

Contents

1. Introduction

1.1 Purpose of this report

This report forms part of the outputs of a contract for the European Commission on ‘development of an assessment methodology under Article 4 of Directive 2012/18/EU on the control of major-accident hazards involving dangerous substances’. The work has been undertaken by AMEC, INERIS and EU-VRi.

The present report concerns one of a number of specific tasks under the project. It should not be read in isolation, but in conjunction with the main report and in conjunction with the reports concerning the other project tasks.

1.2 Scope of task 3

Task 3 of the contract concerns ‘identification of specific models or guidance allowing assessment of the environmental consequences of accidents’. The aim was to identify suitable and robust models, methods or guidance on the assessment of environmental consequences of accidents, taking into account that these are less well documented in literature than health consequences.

The work involved gathering information on the basis of literature research, complemented with a survey and discussions with relevant institutions and experienced experts in the field, with a view to obtaining a good understanding of the models and methods.

The report describes the models and methods, including details of the outputs that they can generate and including information on their sensitivity, as well as clarifying how they could be used in the context of Article 4 of the Seveso Directive.

As set out in the terms of reference, it is recognised that assessment of environmental consequences of accidents is currently less developed than for health-related consequences. A key aspect of the scope of work under the present task was a focus on the water environment, with toxicity to water understood as being an indicator of the overall environmental impact of a substance[1]. The modelling of impacts upon the environment due to atmospheric releases are also briefly considered (and linked to modelling approaches in Task 2), as estimating actual impacts via this route also poses significant challenges.

The idea within the assessment methodology is that one would assess what major accident scenarios are possible involving a dangerous substance, before undertaking any detailed consequence assessment (see the Task 4 report).

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[1] This is not to say that impacts on the environment via atmosphere (for example) are not important. However, the models and methods used to assess such impacts are largely the same as those used to assess toxicity impacts on humans, so they are not reviewed in detail here.

Whether modelling of consequences should be undertaken will depend on factors such as:

- Whether there are identified major accident scenarios that cannot be ruled out based only on factors such as physicochemical properties.
- Whether modelling will add value to understanding the potential for a major accident. In particular, since exclusion under Article 4 should not take into account site-specific considerations, any modelling will need to take into account the worst-case conditions across the EU in terms of potential for a major accident. This could involve, for example, undertaking many different modelling scenarios.

It is important to note that all of the material presented in this report is considered only in the context of the Seveso Article 4 assessment methodology and is not prescriptive. The conclusions drawn do not necessarily apply in any other contexts. The approaches to consequence and risk assessment considered in this report are not the only approaches available, and those persons undertaking an assessment under Article 4 could decide to adopt alternative approaches where they are better suited to the particular case or substance under consideration.

1.3 Structure of this document

Following this introduction, Section 2 provides a brief overview of the approach undertaken to Task 3 of the project. Section 3 provides details of some of the most relevant methods identified for assessing environmental consequences of accidents. Finally, Section 4 draws together some relevant conclusions on the use of these methods in the context of Article 4 of the Seveso Directive.

2. Approach and initial identification of methods

2.1 Approach

In the context of the current task, a distinction is made between assessments that aim to understand the direct effects of accidents on people (not covered by the current task) and effects upon the wider environment i.e. flora and fauna.

In order to identify relevant methods for assessment of the environmental consequences of accidents, the following information has been sought/ reviewed:

- As part of the survey undertaken for the current contract, relevant organisations and individuals were asked to identify available methods for the assessment of environmental consequences of accidents.
- A number of existing reviews which each mention several such approaches were considered, such as:
  - A report comprising one of the outputs of the SHAPE-RISK project[2] on ‘management of environmental risks generated by accidents’.
  - A Portuguese paper[3] covering a number of the commonly-applied approaches in Europe.
  - A document from the European Commission’s Joint Research Centre[4] on land use planning guidelines, which also covers a number of methods for environmental consequence assessment.
- A separate review of relevant literature to identify relevant assessment methods.

In general, while there are a number of available techniques for conducting an environmental consequence/ risk assessment, there is often a lack of good quality data on the environment. Furthermore, the environment varies hugely across Europe, with some Seveso establishments being present within internationally protected areas with many sensitive environmental receptors and multiple pathways for released substances to affect flora and fauna (e.g. freshwater, aquifers); other Seveso establishments are located in much less vulnerable environments. Moreover, the actual environmental characteristics vary substantially, for example in terms of the number, density and sensitivity of different animal and plant species, meaning that it is challenging to identify a method that can cover all of the potential environmental consequences of an accident involving the many substances subject to the Seveso Directive based on their environmental hazardous properties.

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[2] Danielka P (2006): SHAPE-RISK: sharing experience on risk management (health, safety and environment) to design future industrial systems), synthesis document on WP5 (“Management of environmental risks generated by accidents”),

[3] Velosa JC, Palma MC and Ventura J (2007): Definition of an environmental risk assessment methodology, within the framework of Seveso II directive - application on a case study.

[4] JRC (2006): Land use planning guidelines in the context of Article 12 of the Seveso II Directive 96/82/EC as amended by Directive 105/2003/EC, European Joint Research Centre Institute for the Protection and Security of the Citizen.

2.2 Initial identification of relevant methods

There are a large number of different methods available and in use for the assessment of environmental consequences of accidents. Many of these share very similar characteristics and approaches, but there are distinct types of methods available. These range from qualitative approaches based mainly on expert judgement, through various approaches based on indexes of environmental consequences, models to predict environmental behaviour/ dispersion following accidents, and approaches to assess the environmental risks of accidents.

There is no consensus as to which type of approach is most suitable in terms of environmental consequence assessment, and approaches vary significantly amongst member states, and also amongst individual establishments/ operators within member states.

The table below provides a summary of the main assessment methods identified in the current contract. This is not an exhaustive list but does give a good overview of the main types of approaches adopted.

Within the table, a note is made of whether a more detailed analysis has been undertaken (in Section 3 of this report).

Table 2.1 Summary of main identified methods for environmental consequence assessment

Method	Where mentioned	Detailed analysis
H&V index (Czech Republic)	Survey	Yes – Example of an index-based approach referred to by several organisations (e.g. responses to survey).
Environmental risk assessment approach (United Kingdom)	Survey	Yes – Example of a recent (2013) approach to environmental risk assessment.
KONTIĆ, Branko, GERBEC, Marko. The role of environmental accidental risk assessment in the process of granting development consent. Risk anal., 2009, vol. 29, no. 11, 1601-1614 N.B. Uses risk*assistant model. Note EA EP154 document.	Survey	Yes – As an example of general approaches to water dispersion modelling.
Schadensbegrenzung bei Dennoch-Störfällen Empfehlungen für Kriterien zur Abgrenzung von Dennoch-Störfällen und für Vorkehrungen zur Begrenzung ihrer Auswirkungen (Germany)	Survey	No – Does not appear to be specific to environment.
Guide for conducting environmental risk analysis (Spain) (http://www.proteccioncivil.es/catalogo/carpeta02/carpeta22/g_rarm_presen.htm)	Survey	Yes – Another example of a risk assessment approach, also referred to by respondents from other member states.

Method	**Where mentioned**	**Detailed analysis**
Technical and operational criteria and guidelines for the assessment of major accidents with environmental consequences (Italy) (http://www.isprambiente.gov.it/it/pubblicazioni/pubblicazioni-del-sistema-agenziale/criteri-e-indirizzi-tecnico-operativi-per-la-valutazione-delle-analisi-degli-incidenti-rilevanti-con-conseguenze-per-lambiente) The purpose of this report, in continuity with previous work (technical report APAT / CNVVF no. 57/2005) relating to accidental releases of liquid hydrocarbons on the ground, is to provide agency system technicians, involved in the checks provided by Legislative Decree no. 334/99, as amended (Italian implementation of the "Seveso II" directive) with technical and operational criteria and guidelines to support the analysis of accidents of possible relevance to the environment and, in particular, those arising from the uncontrolled release of eco-toxic substances in surface water, such as rivers, lakes, coastal waters and marine waters. For such situations, the document includes technical elements to address actions applicable in the first phase of emergency management (first 24 hours) to mitigate consequences.	Project workshop (October 2014)	No – Only identified late in the project
Rapporto conclusivo dei lavori svolti dal Gruppo misto APAT/ARPA/CNVVF per l'individuazione di una metodologia speditiva per la valutazione del rischio pe rl'ambiente da incidenti rilevanti in depositi di idrocarburi liquidi. See above for more recent publication.	Survey [N.B. a brief description in JRC 2006 (LUP)]	No – Relates to hydrocarbon emissions specifically so unlikely to be generally applicable.
Proteus model (http://www.helpdeskwater.nl/algemene-onderdelen/structuur-pagina'/zoeken-site/@1315/proteus/)	Survey	Yes – Example of approach being applied widely across a member state. Also referred to by respondents from other member states.
Reference Manual Bevi Risk Assessments (Netherlands)	Survey	No – Not specific to environmental consequences
ORDER/FROST software packages for natural gas (mainly) and other hydrocarbon releases;	Survey	No – Relates mainly to natural gas – not expected to be directly relevant to Article 4.
DBAM (Danube basin alarm model) limited for the tributaries until the first reservoir (ICPDR)	Survey	No – Relates to a specific geographical location
FEAT (Flash Environmental Assessment Tool)	Survey	No – Relates to post-accident investigation.
Reban (RIVM, Netherlands)	Survey	No – Understood to have been superseded.
Swedish FOI simplified hazard index	JRC 2006 (LUP)	No – Another example of hazard index and others already reviewed.
Preliminary methodology for the assessment of the global impact of a production site, Roberto Bubbico	Internal literature review	No – Site specific approach, but does provide useful examples.
Environmental Accident Index (Sweden)	Literature review. Also mentioned in: http://www.zmne.hu/aarms/docs/Volume5/Issue1/pdf/12sand.pdf	Yes
French guideline for pipeline safety report (2012), GESIP (French Oil and Chemical Industry Safety Group)	http://www.gesip.com	No - Estimation of environmental impact is estimated, using a multi-criteria approach but is for pipelines, not fixed installations.

Note: Others that were e.g. mentioned in the survey responses but which did not appear to be specifically relevant to environmental consequences are not mentioned here. The list does not purport to be a comprehensive list of available methods for assessing environmental consequences of accidents.

The methods that were taken forward for more detailed analysis were selected because they were considered potentially relevant in the context of Seveso Article 4. However, as shown from the analysis below, it seems difficult to specifically recommend any particular method for use in the context of Seveso Article 4. The methods discussed below have been selected because they are considered to give an overview of the different types of approaches in use.

3. Details of relevant methods selected for further assessment

3.1 Overview

The following sections provide an overview of the methods identified in the previous section that were taken forward for more detailed description. As mentioned above, the aim was to provide an overview of the main types of approaches in use, but inclusion in this section does not constitute a recommendation for the use of the approaches in the context of Article 4, nor does it imply that these are the most robust or widely used methods available for this type of analysis. The variety of different substances that might be considered under Article 4, as well as their associated properties, their potential dispersion/ pathways through the environment and effects upon the range of different ecosystems means that no single method or model available will cover the most appropriate way to assess consequences in all cases.

For each of the methods, an overview of the approach is provided based on relevant literature sources describing the methods. Some conclusions are drawn regarding the robustness and sensitivity of methods and commentary is given on the potential use of each method in the context of Article 4 of the Seveso Directive. References used for each method are included at the end of each subsection.

3.2 Czech Republic H&V index

3.2.1 Description of the method

Overview

The Czech Hazard and Vulnerability Index (H&V Index) is used in the context of Seveso in the Czech Republic and some other member states. It can be used for the assessment and prioritisation of risks in specific circumstances.

Use of the index involves the following key steps:

- Determining an ‘index of toxic hazard’;
- Determining and ‘environmental vulnerability index’;
- Determining the severity of an accident on the environment; and
- Determining the acceptability of an accident.

Index of toxic hazard

The index of toxic hazard is defined according to four different categories:

- Index of hazard to biota (T_B).
- Index of hazard to the soil environment (T_S).
- Index of hazard to the water environment (T_W).
- Index of flammability affecting biota (F_R).

The approach for the water environment is described below. The source documents should be consulted for further information on the other indices and approaches. Index of hazard to the water environment is defined according to two parameters: Code A (toxicity) and Code B (physical properties), which are defined in the tables below:

Table 3.1 Definition of A Code - toxicity

Category	LC50 fish (96h)	"A" code
Extremely toxic	<0.1 mg/l	5
Highly toxic	0.1 – 1 mg/l	4
Toxic	1 – 10 mg/l	3
Moderately toxic	10 – 100 mg/l	2
Slightly toxic	> 100 mg/l	1

Table 3.2 Definition of B Code – physical properties

Category	"B" code
Solubility > 100 mg/l	4
Liquid	4
Vapour pressure > 0.3 bar at 20ºC	2
Other	1

The index of toxic hazard is then defined by the sum of the A and B codes, as illustrated below.

Table 3.3 Determination of index of toxic hazards

Sum of A + B codes	Toxicity class	Index (T_W)
>7	Extremely high	5
7	Very high	4
6	High	3
5	Medium	2
<5	Low	1

Vulnerability index

The next step is the determination of the index of the vulnerability of the environment for a specific situation. The following parameters are derived:

- Index of vulnerability of surface water (I_{SW}).
- Index of vulnerability of groundwater (I_{UW}).
- Index of vulnerability of soil environment (I_S).
- Index of vulnerability of the biotic environmental compartment (I_B).

Again taking surface water, the index of vulnerability is defined, using hydrogeological maps (including maps of vulnerable water bodies), with different scores assigned according to the type of water body of relevance for the specific site in question, for example:

- Separate categories are defined for flowing water and standing water.
- A score of 5 is assigned to standing drinking water.
- A score of 4 is assigned to peat bogs and wetlands.
- A score of 3 is assigned to sewage draining to WWTP.
- A score of 1 is assigned to tailing ponds.
- Various other categories of watercourse are defined.

Evaluation of toxicity indices

Based on the index of toxic hazard and the vulnerability index, an overall toxicity index is defined for surface water, groundwater, soil, the biotic environment, and leakage of flammable substance for the biotic environment. Again taking surface water, the index is defined as:

$$I_{TSW} = max\ \sqrt{I_{SW} \cdot T_W}\ ;\ \sqrt[3]{(T_W \cdot I_{SW} \cdot I_S)}$$

So, for example, a substance with an index of toxic hazard for water (T_W) of 3 and a location with an index of vulnerability for surface water (I_{SW}) of 3 and for the soil environment (I_S) of 2, the toxicity index (I_{TSW}) would be either 3 or 2.62, with the maximum value taken i.e. 3.

Determination of accident severity category

The toxicity index is combined with the potential amount of the toxic substance that could be released to each environmental compartment to give an accident severity category. By way of example, for surface water, the categories are defined as follows:

Table 3.4 Determination of accident severity category for surface water

I_{TSW} value	Amount of substance released to surface waters (t)				
	<1	1-10	10-50	50-200	>200
1	A	A	B	B	C
2	A	B	C	C	D
3	B	C	C	D	E
4	B	C	D	E	E
5	C	D	E	E	E

So, for a substance with an I_{TSW} value of 3 which could be released in a quantity of 80 tonnes (e.g. the capacity of a relevant vessel), the accident severity category would be ‘D’. The five categories are defined as follows:

A = negligible impact

B = low impact

C = considerable impact

D = very marked impact

E = maximum impact

3.2.2 Evaluation of robustness and sensitivity

The H&V index approach seems to provide a useful method for screening of substances (toxicity and physicochemical properties likely to lead to notable concentrations in the environment), as well as establishment locations (in terms of vulnerability) and the potential significance of an accident taking into account the quantity of inventory released. In the context of Seveso implementation in general, it therefore provides a useful tool to assist with prioritisation of substances and establishments. It takes into account a variety of environments including surface water, groundwater, soil and the biotic environment, and takes into account impacts of leakage of flammable substances upon the biotic environment, as well as toxic effects.

However, the method itself does not give any indication of the potential consequences of an accident involving the substance under investigation, in terms of the receptors that may be affected and the degree to which they may be harmed. (For example, it does not indicate the spatial spread of adverse effects or the extent to which different types of organisms would be harmed as a result of a release, or duration of effects.) As recognised by the authors of the method, it is therefore to be seen as a first step, leading to further investigation of those situations that have relatively higher potential for significant consequences.

The index calculated is reliant upon information on the specific environment around a Seveso establishment. In the context of Article 4 (aimed at EU wide situations), a more generic approach would be required in order to cover the range of different establishments in which a substance could potentially be used. One option, therefore, would be to assume the worst case vulnerability situation (i.e. that the 'vulnerability index' for each environmental medium is 5) and then calculate the index for the substance of interest.

Taking into account the types of substances relevant in the context of Seveso (Annex I Part 1), the toxicity index could be calculated as follows, in order to estimate the lowest potential value of the index for an accident involving a Seveso-relevant substance with the aforementioned worst-case assumptions on vulnerability:

- Toxicity category A code = 3 based on LC_{50} of 1-10 mg/l (e.g. aquatic chronic toxic category 2 substance[5]).
- Toxicity category B code = 1 (e.g. a solid with low solubility and low vapour pressure would have the lowest score here).
- This gives an overall index of toxic hazard (TW) of 1, which is the lowest category based on Table 3.3.
- Assuming vulnerability index (e.g. ISW and IS) of 5 to represent the most vulnerable EU environments, the minimum overall toxicity index (ITSW) is ~3 based on the equation above.

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[5] Substances in Category E2 of Seveso (aquatic chronic toxic category 2) could be assumed to have an “A code” of 3 (i.e. LC_{50} fish (96h) of 1-10 mg/l in the table above) as this corresponds with the CLP Regulation for classification as Chronic 2 in cases where adequate chronic toxicity data are not available (Annex I, Table 4.10, part iii). Other Seveso-relevant substances would have higher aquatic toxicity and so would have a higher “A code”.

- However, with a maximum inventory released of >200t (which coincidentally is the Seveso Lower Tier threshold for aquatic chronic 2 substances), a severity category of C (considerable impact) is calculated.

Therefore, even when the (hypothetically) least toxic Seveso-relevant substance is taken, if the most vulnerable environment in the EU is taken into account, the output of the overall index still indicates considerable impact, which would seem to make it difficult to rule out a major accident in practice.

According to the authors, the approach is intended for prioritisation i.e. the results are combined with the probability of an event occurring and more detailed analysis is recommended where the category is D or E, such as modelling the spread of contamination to determine whether the potential contamination could reach the threshold for reporting under the national legislation (similar to Annex VI of Seveso).

Overall the method provides a useful screening process for the potential significance of accidents but does not provide information on whether an accident could be considered a MAH according to Seveso without additional modelling.

3.2.3 Assessment of use in the context of Seveso Article 4

This method provides a useful first screening of substances in terms of their:

- Relative toxicity, highlighting those with relatively lower toxicity for different environmental compartments.
- Physicochemical properties, taking into account the way that these effect environmental fate and behaviour.

If such a method were to be used in the context of Seveso Article 4, it would presumably be necessary to assume a worst case in terms of both vulnerability of the environment (to take into account possible use in locations across the EU), and in terms of potential quantity released (in order to take into account establishments with different inventories, foreseeing potential future uses). This would seemingly make it impossible to conclude that the accident severity category is either 'negligible' or 'low'.

Whilst the underlying data and approaches used do seem to help with indicating the relative significance of a potential accident (for substances and establishments), the method does not seem appropriate, on its own at least, for determining whether a major accident is impossible in practice for any particular substance.

The method may also provide a useful means of comparing a candidate substance for Article 4 against other Seveso (and non-Seveso) substances. It could therefore be useful in the context of an initial screening of a substance.

3.2.4 References

Fiserova L, Kellner, J and Blaha M (n.d.): Evaluation of the influence of hydrazine hydrate 24 on the environment, Advances in Environmental Science and Sustainability, http://www.wseas.us/e-library/conferences/2012/Sliema/NACGURES/NACGURES-07.pdf.

Technical Univeristy of Ostrava (2002) : Metodika pro analýzu dopadů havárií s účastí nebezpečné látky na životní prostředí “H&V index”, http://www.mzp.cz/C1257458002F0DC7/cz/metodicke_pokyny_odboru_enviro_rizik/$FILE/oer-HaV_index-2002.pdf.

ShapeRisk (2006): Synthesis document on WP5, Management of environmental risks generated by accidents.

3.3 Sweden environment-accident index

3.3.1 Description of the method

Overview

A paper by Andersson (2004) describes an approach proposed in Sweden involving the so-called “Environment-Accident Index” (EAI). This was proposed as a planning tool intended to facilitate assessment of environmental effects related to chemical accident scenarios and hence assist with implementing preventative programmes.

The paper describes the EAI as originally proposed and also its development based on a review of accidents and use of questionnaires and expert judgement to further develop the EAI, which avoids the need to use reference tables, and to allow classification to a proposed new classification scale.

The original method is described below, along with details of further developments undertaken as reported in the Andersson (2004) paper and further work needed in its development.

Key steps

The EAI was developed so as to use key information on chemical properties combined with site-specific properties concerning the major accident site. Andersson (2004) usefully provides the following statement to describe the rationale for development of the index:

> *“Due to the number and wide range of existing chemicals it is unfeasible to assess the environmental effects of each and every one of them. Furthermore, data related to factors such as their toxicity, bioavailability, degradation and potential synergistic and antagonistic effects are only available for a minor fraction of the chemicals. Thus, making a proper assessment of the environmental risks after a chemical accident is not straightforward.*

> *"According to the European Environment Agency (1998), other problems related to chemical accidents include the potential scale of their effects, their unpredictability and the uncertainties of their consequences. These problems, in combination with the lack of data and the complexity of the environment, make the task of environmental risk assessment (ERA) appear to be almost impossible. Therefore, tools such as indicators, indices and other models for ERA have been developed to assist and facilitate such assessment."*

The EAI was initially proposed in 1995, with the objective of providing a quick and simple tool to guide the identification and ranking of chemical accident scenarios in a planning process. The EAI can indicate the type of further assessment that should be performed and predictive measures to be taken for each specific scenario.

The EAI is defined based on the following equation, with the parameters described in the table below:

$$\mathrm{EAI} = \mathrm{Tox} \cdot \mathrm{Am} \cdot (\mathrm{Con} + \mathrm{Sol} + \mathrm{Sur})$$

Table 3.5 Details of parameters used in EAI

Parameter [Note 1]	Description
Tox (acute toxicity to water-living organisms)	Score of 1 (LC_{50}/EC_{50} >1,000 mg/l) to 10 (for <1 mg/l) [Note 2]
Am (amount of chemical stored/transported)	Score of 1 (quantity <0.5t) to 10 (quantity >500t)
Con (consistency/viscosity)	Score of 0 (solid compound) to 5 (viscosity <0.5 cSt)
Sol (water solubility)	Score of 1 (solubility <1% w/w) to 5 (solubility >90 w/w%)
Sur (surroundings)	Sum of four parameters (score from 1 to 10 based on summarised scores for): • Distance to nearest well, lake or watercourse ranging from 0 (>2000m away) to 9 (0-10m away). • Depth to groundwater surface ranging from 0 (>60m) to 9 (0-0.2m) • Lean of groundwater flow, from 0 (no well/lake/watercourse within 1km in direction of groundwater flow) to 5 (groundwater surface inclined towards such a body). • Matrix of soil type and thickness ranging from 0 (frosted ground >30m thick) to 9 (gravel <3m thick). • Total score is from 0 to 32 and this is scaled in 5 categories to give the 'Sur' parameter with a total score of 1 to 10).

Notes: (1): Con, Sol and Sur in the table above describe the potential for the chemical to spread in the environment, in terms of its physicochemical parameters particularly its consistency/viscosity and its water solubility, but also in terms of the surrounding environment. (2) Lowest available LC_{50} or EC_{50} for fish, daphnia or algae.

It is of note that the approach gives less weight to Con and Sol than to the other parameters. Once the EAI has been calculated, a three-graded classification scale is used to determine the need for further assessment:

- EAI from 0 to 100: Hazard analysis (HA) concerning inherent properties of the substance, including assessment of inherent chemical properties and identification of where in the environment the chemical may accumulate and how long the environmental effects might last.

- EAI from 100 to 500: HA plus introductory environmental risk assessment (ERA), which includes data on the site of chemical handling.
- EAI > 500: Advanced ERA based on comparison between predicted environmental concentration (PEC) and predicted no-effect concentration (PNEC), based on acute toxicity values.

Further developments

The paper by Andersson (2004) describes a number of further steps that were taken to refine the EAI method. These involved testing the EAI on a number of chemical accidents, as well as estimation of environmental effects of accidents based on a survey to obtain expert judgement on the scale of effects. The judgements of an expert panel were combined with the results of the original EAI within a mathematical model, and a ‘regression mode’ was derived, providing a ‘new’ EAI value, which also incorporated a number of new or modified parameters describing the chemical (vapour pressure, viscosity, density, etc.) and the site-specific property values (e.g. hydraulic conductivity and porosity). The new EAI value was reported to have the advantage of being derived directly from raw data (without the use of the data tables to assign scores). It could also be developed as a regression model, so that it could be used without the need for detailed modelling undertaken by the authors. It is based on a selected set of accidents, deemed to be larger than that used for the old method and developed to be as unbiased as possible, by covering a wider range of accident scenarios.

A range of additional work was recommended in the paper by Andersson (2004), such as external validation, refining of the structure of the formula used, refining the classification of classes of results, and consideration of other measures of toxicity.

3.3.2 Evaluation of robustness and sensitivity

The EAI is valid for discharges to ground, water or groundwater, but not to fires, explosions or accidents in which gases are released to air. It is not currently known how widely-used the EAI approach is, but it has been identified and referenced in several sources consulted for the purposes of the current study.

The paper by Andersson (2004) indicates that further development of the approach was desirable in order to make the EAI more robust.

The EAI approach clearly takes into account some of the important parameters used for determining the potential scale of accidents for the environment, both in terms of the substance properties and the site-specific characteristics. The paper by Andersson (2004) has evaluated and refined the method based on a number of real accidents, though it is of note that expert judgement was a key factor used in assessing the scale of the consequences.

The original EAI is very dependent on the parameters describing toxicity, amount on site and surroundings, and less so on some of the physicochemical properties, although further physicochemical properties were incorporated into the revised EAI.

3.3.3 Assessment of use in the context of Seveso Article 4

The EAI approach, along with other indices, does not give an absolute measure of the potential to cause a major accident affecting the environment. Instead, it is largely used in order to identify whether further analysis is required in order to understand the potential impacts better. Moreover, the results, because they are based on estimates and assumptions regarding the properties of other substances/ sites, give largely a *relative* measure of the potential consequences, rather than absolute estimates.

The approach is based only on consequences and does not take into account likelihood of relevant release/accident scenarios, but this is unlikely to be appropriate in the context of Article 4 in any case.

Taking the original EAI as described above, it is worth examining the potential results if one assumes that the worst-case assumptions apply regarding (a) quantities stored on site i.e. >500t[6]; and (b) surrounding environment. In order to test the results for potential candidates under Article 4, one could assume:

- The lowest tox (aquatic toxicity) score is 1. (Note that any substance included under Seveso due to its acute aquatic toxicity would score 10: acute toxic category 1 is for substances with aquatic acute LC_{50} < 1 mg/l, the same as that for a score of 10 using the EAI. However, aquatic chronic category 2 substances could have a lower tox score depending on the data available: the tox score for such substances could be a minimum of 6.).

- Con = 0 for a solid compound.

- Sol = 1 for an effectively insoluble substance.

- Sur = 10 in order to represent the full range of conditions potentially encountered across the EU.

Using these parameters, the resultant EAI value would be 110, indicating that as a minimum, further hazard analysis and preliminary environmental risk assessment is required. For any substances fulfilling the criteria for inclusion under Seveso for acute aquatic toxicity, the minimum score would then be 1,100 (and 660 for chronic toxic 2 substances), indicating that advanced environmental risk assessment should be undertaken according to the approach described.

At most, therefore, it seems that the approach would be best suited to an initial screening exercise to see whether further analysis should be undertaken. In this context, it could be useful as a means of comparing an Article 4 candidate substance with other substances that are (and are not) included under Seveso. However, more detailed analysis would be required to determine whether potential for a major accident truly exists.

3.3.4 References

Andersson AS (2004): Development of an Environment-Accident Index – a planning tool to protect the environment in case of an accident.

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[6] The upper value for Am in Table 3.5.

3.4 UK environmental risk assessment approach

3.4.1 Description of the method

Overview

A joint industry, trade union and regulator group has produced a guidance document which aims to provide a common methodology by which environmental risk assessment can be carried out in the context of Seveso, in order to demonstrate that environmental risks have been reduced to a tolerable level. The method can be used by both operators and authorities when preparing or reviewing risk assessments. This is set out in the Chemical and Downstream Oil Industries Forum Guideline – Environmental Risk Tolerability for COMAH Establishments (CDOIF, 2013). This document provides a screening mechanism by which risks to environmental receptors can be reviewed, following which more detailed analysis may be needed.

The CDOIF guideline builds upon and refers to a number of other guidance documents and approaches to environmental risk assessment under the COMAH regulations[7], including:

- Guidance on the Environmental Risk Assessment Aspects of COMAH Safety Reports (COMAH CA, 1999).
- Guidance on the Interpretation of Major Accident to the Environment for the Purposes of the COMAH Regulations (DETR, 1999).
- Guidance for Environmental Assessment of COMAH Safety Reports (SRAM, 2010).

The method is based on the **‘source > pathway > receptor’** concept.

Key steps

The CDOIF Guideline specifies a number of key steps in the process of determining the potential of a Seveso establishment to cause a major accident to the environment (MATTE):

- Understanding the types of environmental receptors.
- Determining the MATTE thresholds that apply to environmental receptors.
- Evaluating the risk from the establishment to the environmental receptors.
- Completing a cost-benefit analysis in support of determination that risks are reduced to a level as low as reasonably practicable (ALARP).
- Completing the risk assessment.

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[7] COMAH refers to the ‘control of major accident hazards’, the UK’s implementation of the Seveso legislation.

Types of environmental receptors and MATTE thresholds

Four types of environmental receptors are considered: terrestrial habitats, freshwater habitats, marine habitats and groundwater bodies.

For each of a number of different categories of environment[8], thresholds are defined for the extent of damage in the event of an accident, which are used in order to determine whether such an accident would be considered a MATTE. The figure below provides an example for marine water. It can be seen that these are similar to, but go beyond, the criteria in Annex VI of the Seveso Directive on notification of major accidents to the Commission[9]. It should be recalled that the Commission considers that the criteria in Annex VI can be useful in identifying a subset of major accidents, but that the definition in Article 3 of the Directive (covering “serious danger to health and to the environment”) goes beyond the major accidents subject to notification.

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[8] Designated land/water sites (national, international and ‘other’), scarce habitats, widespread habitats, aquifers/groundwater, soil/sediment, built heritage, particular species, marine and freshwater/estuarine habitats.

[9] For example, the criteria for reporting in Annex VI of Seveso concern: significant or long-term damage to freshwater and marine habitats: (iv) 2 ha or more of a coastline or open sea. The UK guidelines provide more specific information on the type of environment affected within this 2 ha area, but also provide figures for numbers of animals killed or injured, for example.

Figure 3.1 Example of thresholds for level of harm constituting a MATTE

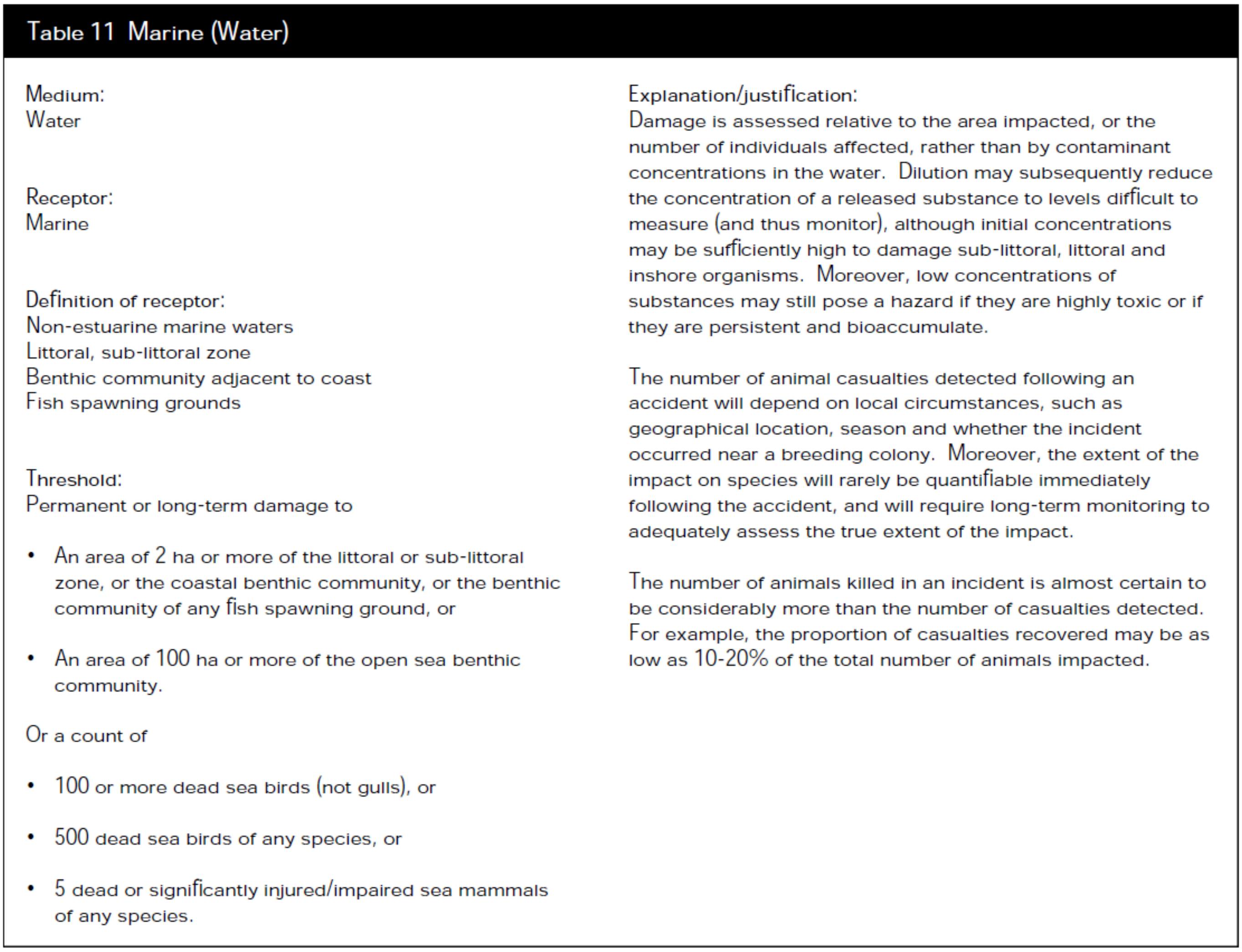

Table 11 Marine (Water)

Medium:
Water

Receptor:
Marine

Definition of receptor:
Non-estuarine marine waters
Littoral, sub-littoral zone
Benthic community adjacent to coast
Fish spawning grounds

Threshold:
Permanent or long-term damage to

- An area of 2 ha or more of the littoral or sub-littoral zone, or the coastal benthic community, or the benthic community of any fish spawning ground, or
- An area of 100 ha or more of the open sea benthic community.

Or a count of

- 100 or more dead sea birds (not gulls), or
- 500 dead sea birds of any species, or
- 5 dead or significantly injured/impaired sea mammals of any species.

Explanation/justification:
Damage is assessed relative to the area impacted, or the number of individuals affected, rather than by contaminant concentrations in the water. Dilution may subsequently reduce the concentration of a released substance to levels difficult to measure (and thus monitor), although initial concentrations may be sufficiently high to damage sub-littoral, littoral and inshore organisms. Moreover, low concentrations of substances may still pose a hazard if they are highly toxic or if they are persistent and bioaccumulate.

The number of animal casualties detected following an accident will depend on local circumstances, such as geographical location, season and whether the incident occurred near a breeding colony. Moreover, the extent of the impact on species will rarely be quantifiable immediately following the accident, and will require long-term monitoring to adequately assess the true extent of the impact.

The number of animals killed in an incident is almost certain to be considerably more than the number of casualties detected. For example, the proportion of casualties recovered may be as low as 10-20% of the total number of animals impacted.

Source: CDOIF (2013), DETR (1999).

Assessing risk of potential harm

Once possible environmental receptors have been identified around a particular site[10], the next step is to determine whether the substance stored on site (or e.g. firewater or reaction by-products) has the potential to cause a MATTE to those receptors. The quantities and types of substances stored are considered, and the analysis covers the following:

- **Sources** of pollution which could give rise to a MATTE (e.g. tanks, pipework, reactors).

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[10] Note that in the context of Article 4, an assessment would need to consider the various types of sites and environments across the EU, so as to cover all possible eventualities.

- Identification of **credible scenarios** under which a source could credibly pollute a receptor (e.g. spills, fires).

- Identification of **consequences**, based on a combination of the severity, extent and duration of harm to a receptor.

The CDOIF guidelines provide tables to help identify the potential for substances to cause a MATTE if released to the receptor unmitigated. These include:

- MATTE potential summary matrix, which involves assigning a tick or a cross to indicate whether a MATTE could occur if a credible scenario occurred.

- A ‘receptor detail’ table.

- A table of ‘MATTE scenarios’ ‘to describe the potential consequences to a receptor from credible scenarios (e.g. tank overfill, catastrophic tank failure, leak from tank base, pipework failure, warehouse fire, and escalation).

Examples are extracted below.

Figure 3.2 Examples of tables to assess MATTE potential

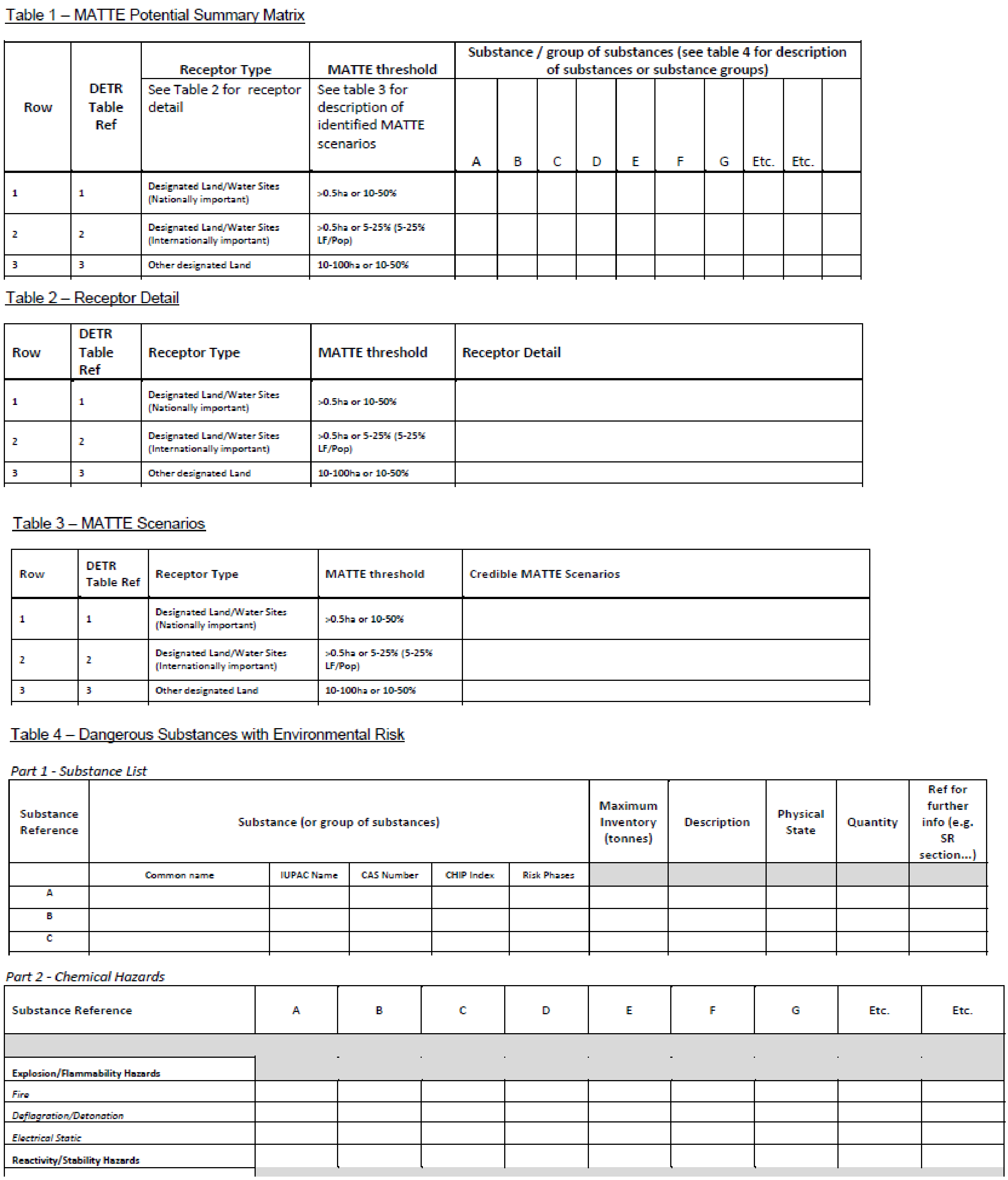


Table 1 – MATTE Potential Summary Matrix

Row	DETR Table Ref	Receptor Type	MATTE threshold	Substance / group of substances (see table 4 for description of substances or substance groups)									
		See Table 2 for receptor detail	See table 3 for description of identified MATTE scenarios	A	B	C	D	E	F	G	Etc.	Etc.	
1	1	Designated Land/Water Sites (Nationally important)	>0.5ha or 10-50%										
2	2	Designated Land/Water Sites (Internationally important)	>0.5ha or 5-25% (5-25% LF/Pop)										
3	3	Other designated Land	10-100ha or 10-50%										

Table 2 – Receptor Detail

Row	DETR Table Ref	Receptor Type	MATTE threshold	Receptor Detail
1	1	Designated Land/Water Sites (Nationally important)	>0.5ha or 10-50%	
2	2	Designated Land/Water Sites (Internationally important)	>0.5ha or 5-25% (5-25% LF/Pop)	
3	3	Other designated Land	10-100ha or 10-50%	

Table 3 – MATTE Scenarios

Row	DETR Table Ref	Receptor Type	MATTE threshold	Credible MATTE Scenarios
1	1	Designated Land/Water Sites (Nationally important)	>0.5ha or 10-50%	
2	2	Designated Land/Water Sites (Internationally important)	>0.5ha or 5-25% (5-25% LF/Pop)	
3	3	Other designated Land	10-100ha or 10-50%	

Table 4 – Dangerous Substances with Environmental Risk

Part 1 - Substance List

Substance Reference	Substance (or group of substances)					Maximum Inventory (tonnes)	Description	Physical State	Quantity	Ref for further info (e.g. SR section...)
	Common name	IUPAC Name	CAS Number	CHIP Index	Risk Phases					
A										
B										
C										

Part 2 - Chemical Hazards

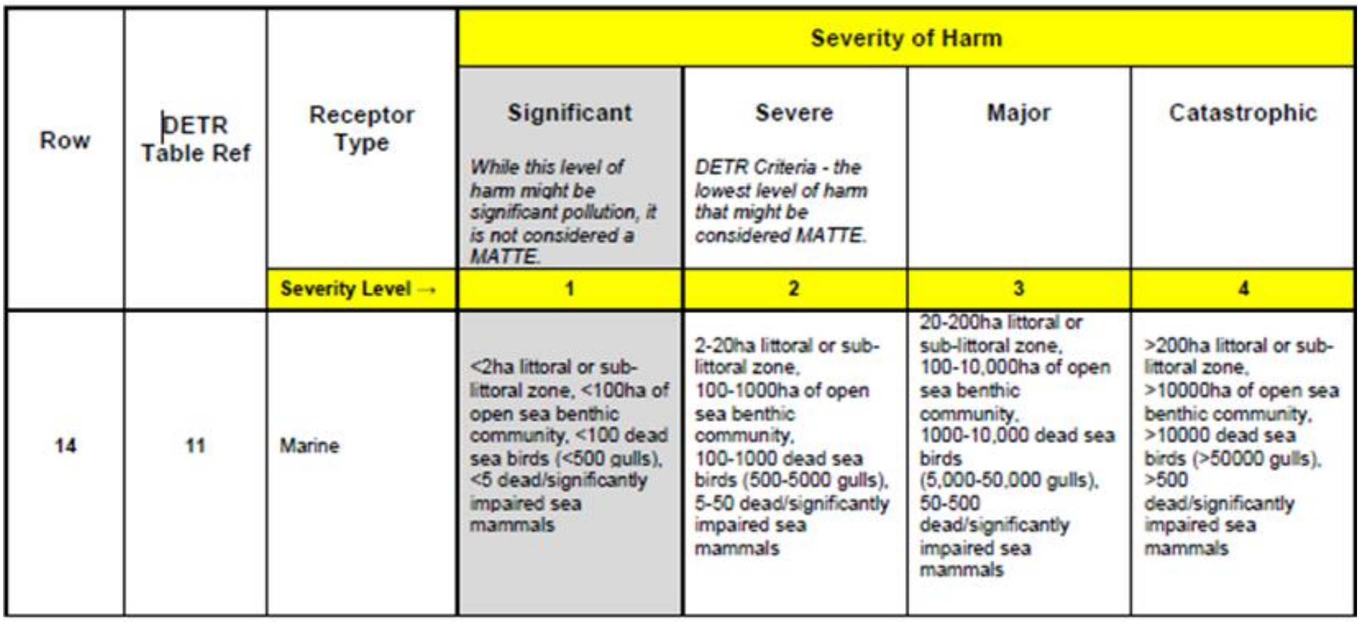
Substance Reference	A	B	C	D	E	F	G	Etc.	Etc.
Explosion/Flammability Hazards									
Fire									
Deflagration/Detonation									
Electrical Static									
Reactivity/Stability Hazards									

Source: CDOIF (2013)

Assessing tolerability of accidents

For each type of environmental receptor the guidance defines severity/ harm criteria in order to assign accidents into one of four categories (significant, severe, major or catastrophic). The figure below provides an example.

Figure 3.3 Severity of harm criteria for consideration as a major accident

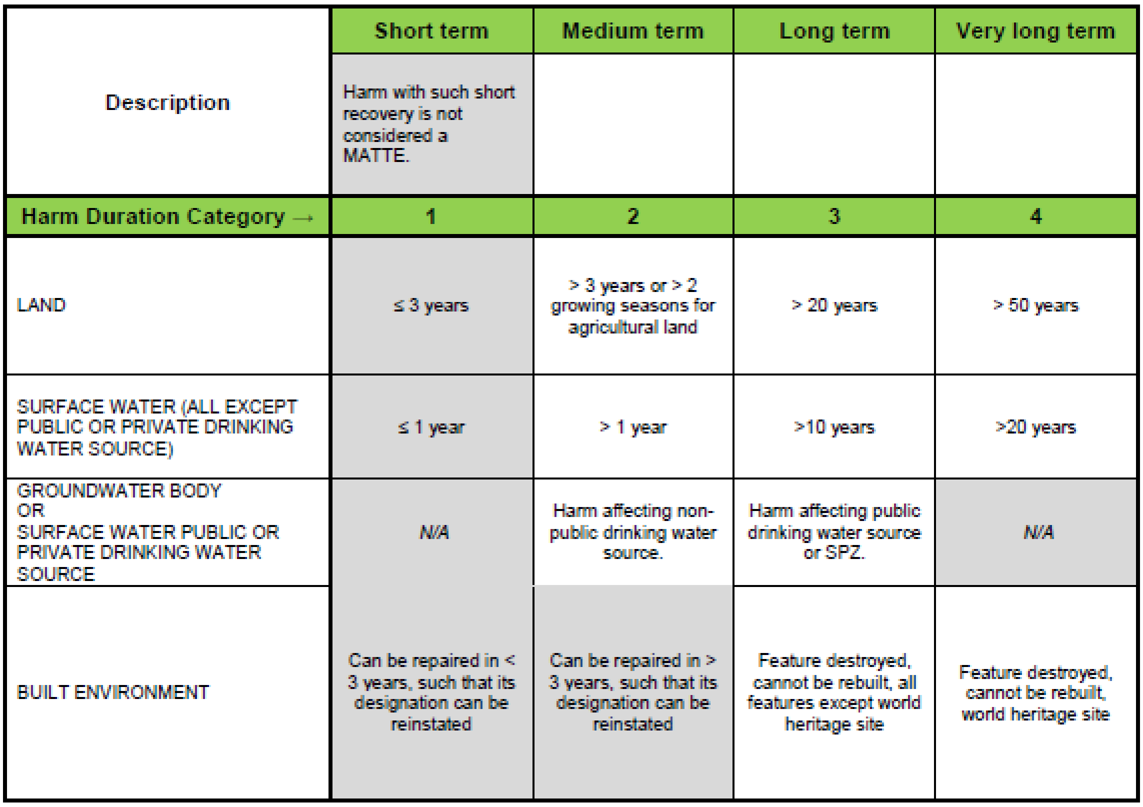


Row	DETR Table Ref	Receptor Type	Severity of Harm			
			Significant *While this level of harm might be significant pollution, it is not considered a MATTE.*	**Severe** *DETR Criteria - the lowest level of harm that might be considered MATTE.*	**Major**	**Catastrophic**
		Severity Level →	**1**	**2**	**3**	**4**
14	11	Marine	<2ha littoral or sub-littoral zone, <100ha of open sea benthic community, <100 dead sea birds (<500 gulls), <5 dead/significantly impaired sea mammals	2-20ha littoral or sub-littoral zone, 100-1000ha of open sea benthic community, 100-1000 dead sea birds (500-5000 gulls), 5-50 dead/significantly impaired sea mammals	20-200ha littoral or sub-littoral zone, 100-10,000ha of open sea benthic community, 1000-10,000 dead sea birds (5,000-50,000 gulls), 50-500 dead/significantly impaired sea mammals	>200ha littoral or sub-littoral zone, >10000ha of open sea benthic community, >10000 dead sea birds (>50000 gulls), >500 dead/significantly impaired sea mammals

Source: CDOIF (2013)

Next, duration and recovery criteria are defined, to give one of four harm duration categories, as shown below.

Figure 3.4 Harm duration categories

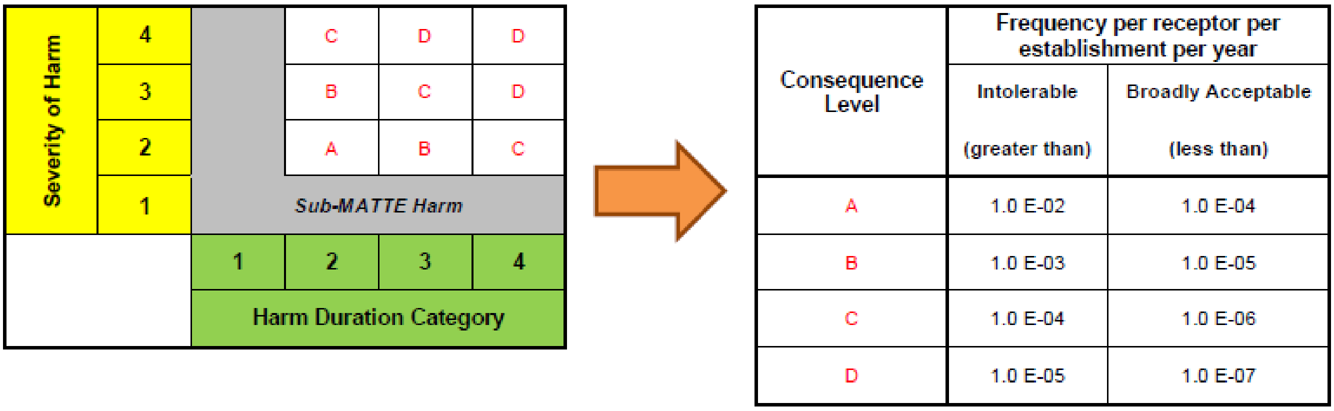


Description	Short term	Medium term	Long term	Very long term
	Harm with such short recovery is not considered a MATTE.			
Harm Duration Category →	**1**	**2**	**3**	**4**
LAND	≤ 3 years	> 3 years or > 2 growing seasons for agricultural land	> 20 years	> 50 years
SURFACE WATER (ALL EXCEPT PUBLIC OR PRIVATE DRINKING WATER SOURCE)	≤ 1 year	> 1 year	>10 years	>20 years
GROUNDWATER BODY OR SURFACE WATER PUBLIC OR PRIVATE DRINKING WATER SOURCE	*N/A*	Harm affecting non-public drinking water source.	Harm affecting public drinking water source or SPZ.	*N/A*
BUILT ENVIRONMENT	Can be repaired in < 3 years, such that its designation can be reinstated	Can be repaired in > 3 years, such that its designation can be reinstated	Feature destroyed, cannot be rebuilt, all features except world heritage site	Feature destroyed, cannot be rebuilt, world heritage site

Source: CDOIF (2013)

The ‘severity of harm’ and ‘harm duration’ categories are used to determine whether, for each environmental receptor, the risks are tolerable, as shown below. The frequency is estimated by aggregating the risk estimates for all of the accident scenarios that could cause a MATTE for each receptor (frequency per receptor, per establishment, per year).

Figure 3.5 Method for deriving receptor tolerability for MATTE



Severity of Harm					
	4		C	D	D
	3		B	C	D
	2		A	B	C
	1	*Sub-MATTE Harm*			
		1	2	3	4
		Harm Duration Category			

Consequence Level	Frequency per receptor per establishment per year	
	Intolerable (greater than)	Broadly Acceptable (less than)
A	1.0 E-02	1.0 E-04
B	1.0 E-03	1.0 E-05
C	1.0 E-04	1.0 E-06
D	1.0 E-05	1.0 E-07

Source: CDOIF (2013)

This assessment is done initially based on the ‘unmitigated’ risk for each receptor (with no prevention or mitigation measures in place), for all accident scenarios. The ‘mitigated’ risk is then calculated (with existing measures in place), to determine whether the risk is either:

- ‘Broadly acceptable’ e.g. total frequency of $< 10^{-7}$ per year for an accident with consequence level D; or
- ‘Tolerable if ALARP’ (10^{-5} to 10^{-7} per year for level D), where a cost-benefit analysis may be needed to determine whether further mitigation is required; or
- ‘Intolerable’ ($> 10^{-5}$ per year), where further mitigation is necessary.

Modelling of consequences

The above description provides details of the overall assessment methodology expected to be used for Seveso establishments. It is of note that the method does not specify the details of any particular modelling approaches (e.g. dispersion models) for assessing the scale of potential consequences of a release for determining whether an accident can be considered to be ‘major’. It is therefore up to the user to identify and apply any such models, if and where relevant.

The UK’s Guidance on the Environmental Risk Assessment Aspects of COMAH Safety Reports (COMAH CA, 1999) provides some additional elaboration on approaches to consequence assessment. Some of the relevant expectations for environmental risk assessment have been incorporated into the authorities’ manual for assessment of safety reports (SRAM, 2013).

Consequence assessment is undertaken for hazards which have a non-insignificant likelihood of occurrence and have not been ruled out on the grounds of being incapable of causing a MATTE. Assessing the effects of a release requires details of:

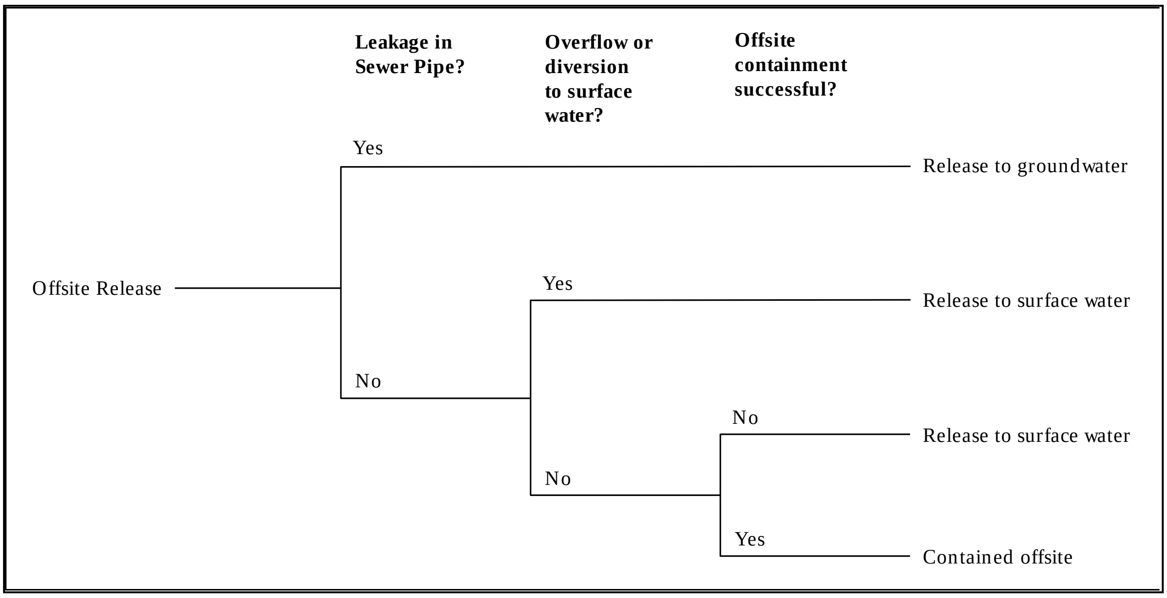
- Any changes in the released substance as it travels to a receptor (for example, dilution/ dispersion); and
- Appreciation of the effect of the resultant exposure (concentration-time profile) at the receptor.

The guidance highlights the main environmental factors which affect transfer to a receptor once a substance is released, including weather, water flow conditions and any chemical/physical transformations. It suggests that the methods used should be suitable for the distances involved and ideally take into account transformation before reaching the receptor.

Importantly, the guidance notes that: “Quantitatively evaluating impacts on the environment involves considerable uncertainty and complexity. Some degree of quantification is possible but a large amount of qualitative judgement is usually necessary.” It highlights that the following may be used for evaluating impacts: toxicity relationships (e.g. dose-response relationships); environmental harm criteria (e.g. LC_{50} data, critical loads); negligible effect criteria (e.g. No Observed Effect Concentrations); past accident experience; and population dynamics modelling.

The report states that environmental consequence/exposure modelling should be undertaken after an ‘offsite pathway analysis’ has been undertaken e.g. as per the figure below:

Figure 3.6 Example of offsite pathway analysis



Source: COMAH CA (1999).

The guidance (COMAH CA, 1999) does not specify the use of any particular model for undertaking consequence analysis. It does, however, refer to models such as PRAIRIE (Pollution Risk from Accidental Influxes to Rivers and Estuaries) which was developed in order to assess surface water pollution risks to rivers and estuaries.

In practice in the UK (personal communications), it is understood that impacts of releases to air upon the environment are typically modelled using software such as PHAST and ADMS (air dispersion models). In terms of dispersion in water, it is understood that these are less frequently modelled using any particular software modelling packages, although there are some such models that can and have been used in the past (e.g. river flow models such as PRAIRIE as mentioned above[11]).

Expectations in safety reports

The UK’s manual for assessment of safety reports includes a number of relevant points related to the expectations on assessing environmental risks, including:

- Safety reports should include details of all major ‘source-pathway-receptor trios’, preferably summarised by maps/ plans indicating where aerial dispersion and spills, etc. may affect sensitive receptors, including pathways.

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[11] Other (more recent) examples of such models are described in Sections 3.6 and 3.7.

- Source details for each accident scenario should include details of substance released; size, rate/ duration of release; conditions of release (pressure, temperature, phase); location, elevation, direction of release.

- Potential releases should be identified on the basis of worst-case failures.

- All factors that may determine the extent of environmental impact should be considered (e.g. ignition, detection, secondary containment failure, drains, and emergency procedures).

- Resultant environmental concentrations for each member of the set of releases should be given.

- Effects in the environment should be determined from predicted environmental concentrations and toxicity data. The length, area or volume of the environment affected should also be given.

- When using variables such as toxicity relationships (e.g. dose-response relationships or no observed effect levels), the manual notes that the LC_{50} threshold represents an impact of the severest nature and for risk assessment purposes suggests that a threshold of LC/2 or LC/3 provides a suitable indicative environmental harm threshold.

3.4.2 Evaluation of robustness and sensitivity

The UK’s approach to environmental risk assessment is certainly not an off-the-shelf approach or model that can be used to assess the potential for a major accident (MATTE) without additional detailed consideration of the substance, its potential releases and its transport to and effects upon environmental receptors.

It explicitly recognises that a large degree of qualitative judgement is necessary in this sort of environmental risk assessment, even if some potential consequences can be quantified.

The approach does, however, provide a useful and systematic approach to identifying, the sources of potential release and the pathways by which the range of receptors around an establishment could potentially be affected. The CDOIF guidelines recognise the importance of duration of effects and recovery time, as well as the extent of consequences on environmental receptors (geographical scale and other factors). The criteria used to determine whether an accident constitutes a MATTE go substantially beyond the criteria for reporting of major accidents to the Commission, and provide a greater number of parameters which may be used to determine the scale of an accident.

As with any environmental consequence assessment approach, the robustness and sensitivity are entirely dependent on the quality of the data and analysis used in defining potential release scenarios, environmental fate/behaviour and environmental concentrations/ effects at receptors.

3.4.3 Assessment of use in the context of Seveso Article 4

The UK’s approach is based on tolerability of risk, not just hazard or scale of potential consequences in the event of an accident. (The approach takes into account the frequency of all accidents that could potentially cause a MATTE for each receptor.) It is also intended to be applied to specific sites, and to take into account levels of risk mitigation in place, which does not necessarily reflect the full range of establishments across the EU.

Having said that, the approach provides a useful framework for ensuring that all sources, pathways and receptors are considered in the context of reasonably foreseeable uses of a substance at Seveso establishments. It also provides useful guidance on the ‘severity’ of harm and the ‘duration’ of harm from an accident, which could provide a useful framework for demonstrating whether an accident involving an Article 4 candidate substance could cause an accident constituting a MATTE.

The approach is (presumably deliberately) not specific about the use of any particular models for atmospheric dispersion or releases to water and, in practice, whilst modelling will often be undertaken for the former (using e.g. models such as those considered in Task 2), modelling of releases to water may often be undertaken using relatively simplistic calculations taking into account offsite pathway analyses and quantities of substances potentially released through leaks or catastrophic rupture of vessels[12]. A significant challenge remains in defining the range of environmental characteristics which may influence a substance’s fate and behaviour following a release, when these can vary so significantly amongst establishments across the EU.

The UK’s approach also incorporates, but builds upon, the criteria in Annex VI for reporting on major accidents to the European Commission. Whilst these criteria do not define what a major accident is, they provide provide a guide to the effects that may be significant. In this respect, the UK’s distinction between different levels of harm, as well as the elaboration of effects on a wider range of environmental receptors, may be of help in determining whether an accident should be considered to be ‘major’ or not.

3.4.4 References

CDOIF (2013): Guideline – Environmental Risk Tolerability for COMAH Establishments, Chemical and Downstream Oil Industries Forum, October 2013.

COMAH CA (1999): Guidance on the Environmental Risk Assessment Aspects of COMAH Safety Reports, COMAH Competent Authority, December 1999.

DETR (1999): Guidance on the Interpretation of Major Accident to the Environment for the Purposes of the COMAH Regulations, Department of the Environment, Transport and the Regions, June 1999.

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[12] For example, a simplistic assessment (undertaken by the authors of the current report) could involve: (1) estimating the release rate of a substance from a pipe or vessel (e.g. hypothetically 10 kg/s for 10 minutes); (2) estimating percentage passing to surface water (e.g. 50% or 5 kg/s); (3) estimating flow in a receiving water body e.g. 600 m^3/h or 100 m^3 in 10 minutes; (4) estimating the concentration in the water body assuming uniform dispersion = 10kg * 50% * 600s / 100,000 litres = 0.03 kg/l or 30,000 mg/l. This concentration can then be compared to e.g. LC_{50} or LC_0 values to determine the margin of safety (or exceedance) of dangerous concentrations. Factors such as water solubility and degradation also need to be taken into account, and there is then a degree of judgement required in determining whether a major accident is possible, taking into account the criteria for defining a major accident (in this case in the UK) as well as populations of relevant species in the receiving water body.

SRAM (2010): Guidance For Environmental Assessment Of COMAH Safety Reports Under Remodelled COMAH Assessment and Inspection procedures, Safety Report Assessment Manual (SRAM), Section 13, COMAH Competent Authority.

3.5 Spain environmental risk assessment approach

3.5.1 Description of the method

Overview

The text below provides information on the methodology used to undertake Environmental Risk Analysis in the framework of Spain's Royal Decree 1254/1999 (Seveso II).

The methodology is intended to assess the risk associated with a hazard source in the framework of Royal Decree 1254/1999 regarding the Seveso Directive in a simple but reliable way. For this purpose, the analysis takes into account the possible accident scenarios, an index called the "global index of environmental consequences" and the probability or frequency of the event assessed. This is used to produce the Environmental Risk Index.

The use of this index considers the different scenarios that may occur as a result of an accident along with the Global Index of Environmental Consequences; and the Risk related to Human Health (probit[13] equations available for the different products and effects). Then, the following calculation is applied:

Environmental Risk Index = Probability or frequency (1-5 points) **x** consequences (Global Index of Environmental Consequences (1-20 points)).

This value can be plotted into a risk tolerability matrix.

Scenarios

The inputs for the scenarios include:

- Type of release (liquid, solid, gas) and substance/s.
- Type of container (including volume and parameters such as pressure, dimensions or discharge coefficient) and type of spill/ leakage.
- Total quantity released and how and where it is released.
- Environmental conditions.

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[13] Probability unit.

Global index of environmental consequences

This is defined by four risk elements that are characterised and parameterised as follows:

- Risk sources (potential hazard, potential quantity of the substance involved, factors that influence how the substance behaves in the environment).
- Primary control systems adopted by the industry/facility, envisaged for preventing and controlling environmental risks.
- Transport/ spread mechanisms in the environment of the harmful effects (air, water, soil).
- Sensitive receptors' vulnerability (human, socioeconomic, biological).

Risk sources

'Intrinsic properties of the substances' are defined according to acute toxicity, bioaccumulation, adsorption and biodegradation.

If the substance is included in Annex I of the Royal Decree that describes and transposes the Seveso Directive, the points are already allocated for these 5 categories, and the total points for risk sources can be calculated. However, if this is not the case, a score for each of them has to be allocated, as follows:

Table 3.6 Risk sources score categories related to the intrinsic properties of the substances

Category	Score
Toxicity	1-10 points
Volatility	1-5 points
Bioaccumulation	0-2 points
Adsorption	0-2 points
Biodegradation	0-2 points
TOTAL	**2-21 points**
It is then weighted to	**1-6 points** [a]

The substances included in Annex I of the Royal Decree 1254/1999 have a pre-configured score.

[a] The 2-21 scale is weighted to a 1-6 points range to include 4 points related to synergies and mixture effects, giving a total of 10 points for intrinsic properties.

For the substances not included in Annex I of the Royal Decree, toxicity may be defined in various ways:

- If the substance is classified as hazardous for the environment according to Directive 67/548/EEC (classification, packaging and labelling of dangerous substances (now superseded)), the score for toxicity will be determined by its "R code" (Table 3.7).

- Otherwise, toxicity may be determined according to Table 3.8 (if data available) or Table 3.9.

Table 3.7 Criteria for toxicity (Dangerous substances with R codes)

Aquatic environment		Non-aquatic environment	
R code	**Score**	**R code**	**Score**
R50	10	R54/R57	10
R50/R53	10	R54	10
R51/R53	8	R55/R57	8
R52/R53	5	R56/R57	5
R52 and/or R53	5	R58	4
		R59	4

Table 3.8 Criteria for toxicity (Acute toxicity data in the form of LC_{50} or EC_{50} available)

Acute toxicity LC_{50} or EC_{50}	Score
<1 mg/l	10
1-6 mg/l	8
6-30 mg/l	6
30-200 mg/l	4
200-1000 mg/l	2
>1000 mg/l	1

Table 3.9 Criteria for toxicity (Acute toxicity data not available)

Acute toxicity LC_{50} or EC_{50}	Score
Very toxic	10
Toxic	6
Noxious	3
Irritant, corrosive	1

The rest of the categories are scored as follows:

Table 3.10 Criteria for volatility

(Log H), H being the Henry constant in atm m^3/mol	Score
Log H <-3	5
-3 ≤ log H <-1	4
-1≤ log H <1	3
1≤ log H <2	2
Log H ≥3	1

Table 3.11 Criteria for bioaccumulation

Log (BF), BF being Bioaccumulation factor	Score
Log BF>2	2
1<Log BF≤ 2	1
Log BF≤ 1	0

Table 3.12 Criteria for adsorption

Log K_{ow}, K_{ow} being Octanol-Water Partition Coefficient	Score
Log K_{ow} >2	2
1<Log K_{ow} ≤ 2	1
Log K_{ow} ≤ 1	0

Table 3.13 Criteria for biodegradation

Biodegradation (BD)	Score
BD >2 (months or longer)	2
2≤ BD <2.5 (months/weeks)	1.5
2.5≤ BD <3.5 (weeks/days)	1
3.5≤ BD <4.5 (days/hours)	0.5
BD≥4.5 days	0

The ‘**quantity**’ of substance is important for the determination of the score for the “risk source” component. If there are containment measures, this will be weighted with a factor of primary measures (described below), but normally the information about this is limited, so a precautionary approach is taken and the quantity is included in the model (Table 3.14).

Table 3.14 Criteria for the “quantity” component

Quantity involved in the event (metric tonnes)	Score
>500	10
50-500	7
5-49	5
0.5-4.9	3
<0.5	1

The component on **‘primary control systems’** takes into account the existence of containment measures. A score of 0-100 (0 being no measures and 100 being measures that contain 100% of the substance) is derived and multiplied by the quantity involved to reflect the existence (or not) of these measures.

Once the score of the component on primary control measures is applied to the score related to ‘quantity’ (e.g. if no containment measures are available, the score for quantity will be a maximum of 10). The score related to the substance properties (1-10) is assigned a weight of 2, to reflect the higher importance of the substance characteristics in the model.

Then, the final score for the risk source is:

Score for substance x 2 + score for quantity = 3-30 points. These are then weighted to obtain a score of 1-12 points (30% relative weight in the final value).

The **'transport/ spread mechanisms'** component derives a score taking into account the type (e.g. aquatic, terrestrial) and vulnerability of the habitat affected, the long-term or short-term characteristics of the potential damage, and the total area of potential damage. The scores are of 1-10 points and are then converted into a 1-8 points scale (20% relative weight in the final value). Dispersion models are used but no specific models are mentioned.

'Sensitive receptors' vulnerability' is taken into account through the exact location (coordinates) of the affected site and the potentially affected habitats. The habitats will be defined as per the Habitats Directive (92/43/EEC) or, if not possible, as per the National Inventory of Habitats. If there are several habitats, the one with a higher coverage in the selected area will be chosen. A preliminary score is given according to the type of habitat, and then a series of conditional factors are applied to obtain a score of 1-20 points (50% of relative weight in the final value). The conditional factors are whether the area is a protected habitat, whether it contains endangered species, whether it contains historic/ artistic patrimony, whether the damage is irreversible and potential socioeconomic impacts.

All the scores for risk sources, primary control systems, spread mechanisms and sensitive receptors' vulnerability are added up to obtain the final score for the Global Index of Environmental Consequences, obtaining a number from 1 to 40, which is then converted to a score of 1-20 to produce a result in the last stage that is easier to represent and interpret.

Probability/frequency

The score of the Global Index of Environmental Consequences is then multiplied by the probability/frequency values. The probability value is obtained from a score (1-5) that takes into account a Quantitative Risk Analysis[14], when this has previously been done in the sites. If this is not possible, the estimated frequency will be used (the criteria used is in Table 3.15).

Table 3.15 Criteria for the frequency component

Frequency	Score
Between once a year and once every 5 years	5
Between every 5 years and once every 25 years	4
Between every 25 years and once every 50 years	3
Between every 50 years and once every 100 years	2
Between every 100 years and once every 200 years	1

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[14] Guidance on the Environmental Risk Assessment Aspects of COMAH Safety Reports. COMAH Competent Authority, 1999.

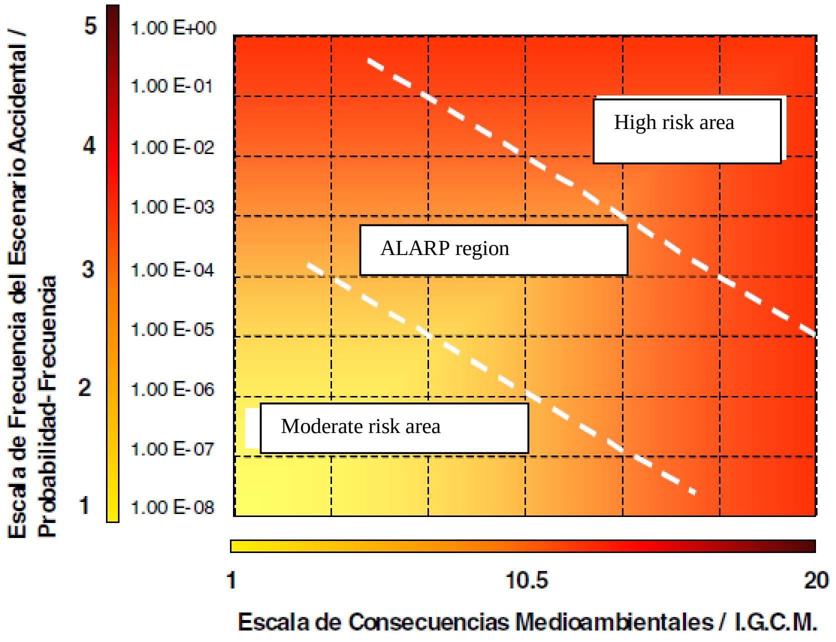
Outputs

The output is the Environmental Risk Analysis Index value (1-100).

This is then compared against the Risk Tolerability Level. There are no legally binding values for this, and many industrial sectors are expected to have their own level of tolerability that would vary over the years.

The methodology description includes an example with the method developed in a study[15] by the former UK DETR (Department of the Environment, Transport and the Regions), adapted for the Environmental Risk Analysis Index score (Figure 3.7).

Figure 3.7 Environmental risk tolerability



X axis: Global index of environmental consequences score.

Y axis: Probability/Frequency score.

ALARP: As low as reasonably practicable. This risk can be reduced without incurring disproportionate costs.

If the risk is classified in the high or the ALARP region, the site/ company shall establish mechanisms to diminish the risk so it can be classified in the "moderate risk area". These are deemed to be either critical regardless of the associated costs (high risk area) or possible at reasonable/ acceptable costs (ALARP area).

For this, the company (normally a designated committee) shall conduct a Cost-Benefit Analysis (CBA) with various ways of reducing the risk and undertake sensitivity tests to assess how the risk could be reduced in the most cost-effective way. The possible changes include improvements in the containment measures, design parameters

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[15] DETR (2000) *Management of Harm to the Environment*. Department of the Environment, Transport and the Regions.

and other factors influencing the Global Index of Environmental Consequences as well as in the frequency of inspections to reduce the potential likelihood of an accident. Due to feasibility, organisational, technical and economic constraints, this CBA is not made for all the scenarios used to construct the model, but for those with a higher associated risk.

3.5.2 Evaluation of robustness and sensitivity

This approach provides a useful means of screening for the potential for accidents affecting the environment. It takes into account a range of different parameters relating to the substance (environmental toxicity, state, physicochemical properties, data influencing environmental fate and behaviour), as well as the quantities involved, primary control systems, transport mechanisms and the vulnerability of relevant receptors.

When likelihood of accident scenarios is taken into account, the method uses an approach consistent with (modified from) approaches used in other member states in relation to tolerability of risks. However, the method does not provide specific guidance on assessing the consequences of accidents e.g. spatial extent of significant or long-term damage to habitats.

The approach therefore provides a useful tool to assist with prioritisation of substances and establishments, as well as for identification of areas warranting priority risk management action at individual establishments.

The method suggests the use of dispersion models which can give an indication of the scale of an accident's consequences, which is relevant in the context of reporting under Seveso, and other national systems for categorisation of major accidents. However, no specific models are mentioned.

Overall the method provides a useful screening process for the potential significance of accidents. The dispersion modelling involved may give some indication of the potential scale of accidents that may occur, but this is dependent on the models used, which are to be selected by individual users (and are not mentioned in the guidance).

3.5.3 Assessment of use in the context of Seveso Article 4

The method provides a useful approach that takes into account many of the key parameters that will affect the potential for a substance to cause a major accident affecting the environment.

It is noted that a large part of the score for the 'global index of environmental consequences' is based on the vulnerability of relevant receptors. In the context of Article 4 of Seveso, it would seem to be appropriate to assume the worst-case (i.e. most sensitive) for the receiving environment, to take into account the range of situations across the EU. If this were done then the resultant score can be used to assess where and how the risk can be reduced considering how its inputs influence the score, but it is unlikely that a score low enough to rule out a major accident could be derived, once worst-case assumptions about the receiving environment are taken into account.

In conclusion, an approach such as this could be useful in comparing potential Article 4 candidate substances against other substances in terms of potential to cause a major accident. The outputs, however, are unlikely to be sufficient to conclude that a major accident cannot occur.

3.5.4 References

Dirección General de Protección Civil y Emergencias (2002) *Guía para la realización del análisis del Riesgo medioambiental (en el ámbito del Real Decreto 1254/99 [Seveso II])* (Guidance for the calculation of the Environmental Risk Analysis (in the framework of Royal Decree 1254/1999 [Seveso II]). General Directorate of Civil Protection and Emergencies. http://www.proteccioncivil.es/catalogo/carpeta02/carpeta22/g_rarm_presen.htm

3.6 Modelling of releases into water

3.6.1 Description of the method

Overview

Task 2 considers in detail a number of methods that are available for the modelling of releases of substances to air as a result of accidents. Many of the models described therein are typically used to assess the dispersion of substances in the air and hence the potential to effect the terrestrial environments (flora and fauna), taking into account for example relevant toxicity data and dose-response relationships of the substances released. Such models are therefore not described further in Task 3.

However, another key means by which major accidents may affect the environment is through releases of substances to water. In particular, the potential for damage to freshwater and marine environments is specifically reflected in the reporting criteria in Annex VI of the Seveso Directive.

The authors of the present report have applied methods to assess environmental impacts in the water environment, and a typical approach would involve for example:

- Examining and characterising both protected and other water bodies near to Seveso establishments.
- Examining the realistic worst case release scenario for releases e.g. assuming catastrophic rupture of a storage vessel and subsequent release. Releases from overtopping of any bund/dike can be estimated using a number of different published correlations.
- Considering the expected fate of the substance following release (e.g. proportion likely to pass to water bodies based on substance physicochemical properties).
- Considering different release durations, taking into account leak sizes (and recognising that a smaller, non-detected leak could potentially cause more damage than a larger, quickly-detected one).

- Taking into account flows in receiving waters (based on published low, high and average flow data), to estimate likely dilution/ dispersion and hence predicted environmental concentrations of the substance of interest.
- Comparison of these predicted environmental concentrations, and their geographical extent, with dangerous concentrations for relevant receptor species.

An important point evident from the results of the survey for the current study, and discussions with some authorities, is that there is no one computational model that is widely used across the EU for assessing the dispersion of chemical releases following accidents at Seveso establishments. Some examples mentioned include:

- The PRAIRIE[16] model used by some operators in development of safety reports in the UK. This model was developed in order to assess surface water pollution risks to rivers and estuaries. It is understood that this is not currently widely used in Seveso safety reports and is not freely available at present. Given its apparent limited current use, it is not therefore considered in detail within the present document.
- The PROTEUS model, developed in the Netherlands as a technical and management model for aquatic risk assessment of industrial spills (considered in a separate chapter).
- Various models produced in the USA. The example provided below used the Risk* Assistant model, which is now understood to be no longer in use.

There does not seem to be any sort of consensus on the types of model that can be used for estimating the effects of accidental releases to the aquatic environment, and no particular model can be recommended. However, the example below provides an example of an approach adopted in one specific case, as published in the open literature.

Example of approach reported in the literature

The following example provides details of an approach adopted to assessing the consequences of a release of a substance in a specific case. It is included here because the methods adopted are similar to those understood to be adopted in Seveso safety reports in a number of different member states. It is therefore an example of a generic approach to estimating consequences which could be of particular use when estimating the spatial extent of water bodies affected, allowing comparison with criteria such as those for reporting of major accidents (Annex VI of Seveso) and other relevant thresholds.

In a paper by Kontic and Gerbec (2009), a description is provided of an approach used in developing an 'accidental risk assessment' for a new installation as part of an environmental impact assessment (EIA) in Slovenia. This illustrates how a risk assessment related to accidental release of methylene diphenyl diisocyanate (MDI) and other substances from a new planned unit of a chemical factory in Slovenia was performed. Two scenarios were considered, one of which is described below: a spill of 20m^3 of MDI. The overall approach was as follows:

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[16] Pollution Risk from Accidental Influxes to Rivers and Estuaries software model. This was developed by AEA Technology in the 1990s but does not seem to be publicly available. It is referred to in COMAH CA (1999) and AEA Technology (1997).

- Hazard identification considering the characteristics of raw and auxiliary materials for the production of polyurethane foam bottles, features of the production process, specifics of the equipment, and working practices (a HAZOP study).

- Development of accident scenarios.

- Analysis of the likelihood of barrier failure and human errors; including calculation of the frequencies of various scenarios.

- Calculation of accidental releases.

- Analysis of transport and accumulation (fate) of materials released into the environment.

- Identification of the impact area, duration, and levels of elevated concentrations of substances released.

- Identification of exposure modes and pathways for humans and other sensitive/vulnerable environmental components and calculation of doses.

- Risk assessment (evaluation of the probability/ frequency of consequences for humans and the environment).

The analysis identified the river Soča as the most vulnerable receiving environment and a key part of the analysis focused on release of a spill of MDI to this river from a specific factory (TKK chemical factory at Srpenica).

The accident scenario considered was a leakage of LPG from a vessel followed by vapour cloud explosion, leading to the driver of a tank truck containing chemicals losing control and the truck rolling into the river, where there was no barrier at the side of the facility. The 20m^3 content of the tank truck then flows into the river (either instantly or over a period of 2 hours depending on the scenario). The analysis considered the characteristics of the river bed (rocky) and how that would affect mixing of the dissolved spill.

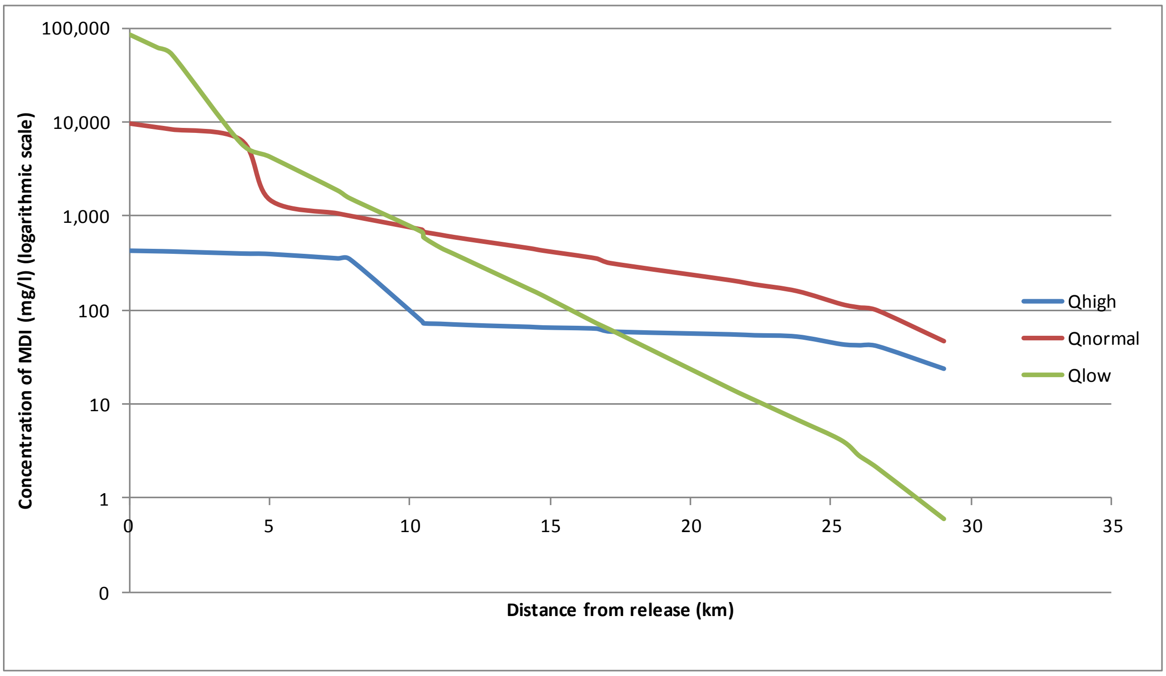
MDI is reacted with a ‘polyol’ (a compound with multiple hydroxyl groups) in the process of polyurethane production. Both MDI and the polyol could potentially be released. The study focused on MDI as the worst-case, and factors such as the hydrolysis half-life in water were taken into account. In addition, data were collected on the fish population density in the river Soča (number of different species per ha). River flow rate data were identified (low, normal and high flow rates in m^3/s).

The likelihood of the event was identified by taking into account the likelihood of VCE (4.5×10^{-6} per year) using a fault-tree analysis, and the likelihood of a tank truck carrying MDI being present (0.001) to give a frequency of this event of 4.5×10^{-9} per year.

Modelling of the consequences (dispersion of MDI in the river) was undertaken using the 'Stream model' as incorporated in the Risk* Assistant model[17].

The results of the modelling showed that an instantaneous (1 minute) release would lead to significantly higher concentrations over longer distances than a prolonged spill, and this was considered to represent the most unfavourable (worst-case) accident. This is illustrated in the figure below.

Figure 3.8 Downstream Concentrations of MDI after a 1min spill of 20 tonnes under different flow conditions



Based on Kontic and Gerbec (2009)

The LC_{50} for fish was identified as >100 mg/l and so 100 mg/l was taken as a conservative assumption. As shown from the figure above, the distance over which this concentration could be reached would be up to around 26km from the release, depending on the flow conditions.

The study went on to consider factors such as:

- The duration of the effects (extent of ecological damage), taking into account the range of flow rates (estimated as between 0.5h and 16h).

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[17] The Risk * Assistant model was developed by the Hampshire Research Institute for the US EPA. Note that we understand these models are no longer available. However, other similar models are available from the US EPA which may be of use in the context of Seveso (see e.g. http://www.epa.gov/athens/wwqtsc/html/water_quality_models.html).

- The area affected, based on river width and the distances above (estimated as 25ha to 49ha). These were represented on a graph.
- The expected environmental damage in terms of weight of fish killed and fines expected to be imposed.

3.6.2 Evaluation of robustness and sensitivity

The above example is provided not as a suggestion as to how the process of environmental consequence assessment should be undertaken (it is recognised that different authorities advocate different approaches e.g. use of different values to the LC_{50} for estimating effects). Instead, it is provided as an example of a general methodological approach which is used in environmental risk/ consequence assessment for Seveso establishments.

Relatively simplistic calculations can be used for estimating the geographical extent of potential damage (e.g. environmental concentrations high enough to kill fauna) and different models are likely to give different results. No particular model is advocated here.

What is evident, however, is that there are a number of parameters that are very specific to the establishment in question, and this applies equally to examination of other receptors such as land or groundwater. These parameters in this example include *inter alia*:

- The location and characteristics of vulnerable environmental receptors (the nearby river in the example above).
- The size and other characteristics of the release of the substance under the specific accident scenarios considered.
- The substance properties influencing its subsequent dispersal in the environment (e.g. physical form, hydrolysis, water solubility).
- The flow characteristics of the receiving water, and the associated ranges of values.
- The potential of the receiving environment to be damaged by a spill, which in this case was based on analysis of the types of fish species present and their density in the river, allowing an estimate to be made of the number of fish likely to be killed.

These types of characteristics will clearly vary significantly among the range of different establishments across the EU.

3.6.3 Assessment of use in the context of Seveso Article 4

Approaches such as that described above (Kontic and Gerbec (2009)) represent a typical (and useful) way of estimating the potential for damage to the receiving water environment in the event of a spill/ release following an accident. However, the parameters needed to undertake an assessment such as this are very site-specific. Therefore, in order to use such an approach in the context of Article 4 – where one would need to demonstrate that a major accident is not possible in practice across the EU – a huge amount of data and scenarios would presumably need to be defined, reflecting the range of different parameters (such as those listed above) likely to be encountered across the EU.

It might be possible to define worst-case parameters for this type of spill based on (for example) the physicochemical properties of a substance and its likely environmental fate and behaviour, but the approach needed would likely be very case-specific and no particular approach or parameters can be recommended here (nor should they be).

It may therefore be more appropriate to rely upon data related to the inherent physicochemical properties of a substance to demonstrate (for example) that dispersion within water bodies is not a credible outcome following a release (for example in the case of substances that form solid masses under ambient conditions).

3.6.4 References

AEA Technology (1997): PRAIRIE Guidance, Technical Report 68 for the Environment Agency.

COMAH CA (1999): Guidance on the Environmental Risk Assessment Aspects of COMAH Safety Reports, COMAH Competent Authority, December 1999.

Kontic B and Gerbec M, The Role of Environmental Accidental Risk Assessment in the Process of Granting Development Consent, Risk Analysis, Vol. 29, No. 11, 2009, pp 1601.

3.7 Proteus model

3.7.1 Description of the method

Overview

The Proteus model is used in the Netherlands to assess risks of potential industrial accidents in terms of surface water runoff. Proteus facilitates and structures development of the environmental risk assessment. Proteus I was released in 2000 followed by Proteus II in mid-2007 and Proteus III in 2013. The model is available from the Dutch Water Helpdesk[18].

Proteus was originally developed by combining two separate models: ‘VERIS’ which was developed to provide information on major accidents related for the safety report; and RISAM which was developed from the perspective of controlling risks for facilities that may pollute surface waters through accidents (Stam et al, 2000).

The Proteus model uses the concept of an ‘environmental harm index’ MSI, which is defined based on the ratio of the volume of water affected by the accident under consideration to a reference volume of 15 million m^3, which is based on the effects of the Sandoz fire in Switzerland in 1986. A weighting factor is also used, in order to take into

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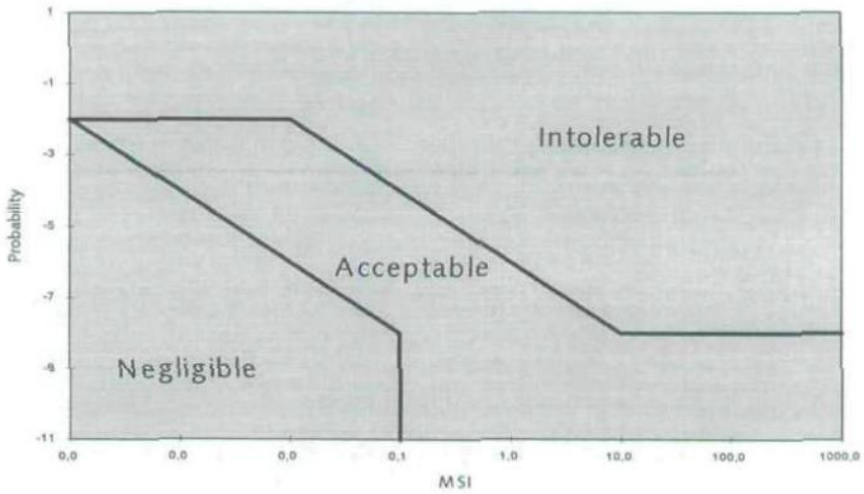
[18] http://www.helpdeskwater.nl/algemene-onderdelen/structuur-pagina'/zoeken-site/@1315/proteus/.

account the sensitivity of the water. Risk criteria are defined according to the combination of MSI for individual accident scenarios and probability, based on the assumption that an accident such as Sandoz (MSI = 1) should be considered intolerable if the probability is higher than once in a million year (Riza, 1999). This is illustrated in the figure below.

Figure 3.9 Criteria for tolerability of risk implemented in the Proteus model



Source: Riza, 1999.

Concept of the model

The method takes into account events which take place leading to initial release to specific areas such as storage tank bunds or liquid-tight floors in the case of chemical handling (these areas are modelled as primary containment systems with outlets). The model allows different routes for a spill to be investigated, such as release into a process sewer or rainwater sewage system. As well as releases into these primary containment systems, the possibility of jet releases and overtopping are considered. It also takes into account that flammable releases can result in a fire within primary containment and takes into account potential domino effects e.g. from warehouses.

A probabilistic approach is applied whereby a ‘generic’ QMFT is defined[19]. The generic QMFT is converted to an ‘initial’ QMFT based on technical and site management influences on the frequency and re-routing of spills (e.g. safety management systems, skills of operators, working procedures, efficiency of repression and distinctive characteristics of installations).

The ‘initial’ QMFT is then used in taking into account the spill passing into e.g. a sewer system (where re-routing to spill basins or wastewater treatment is taken into account).

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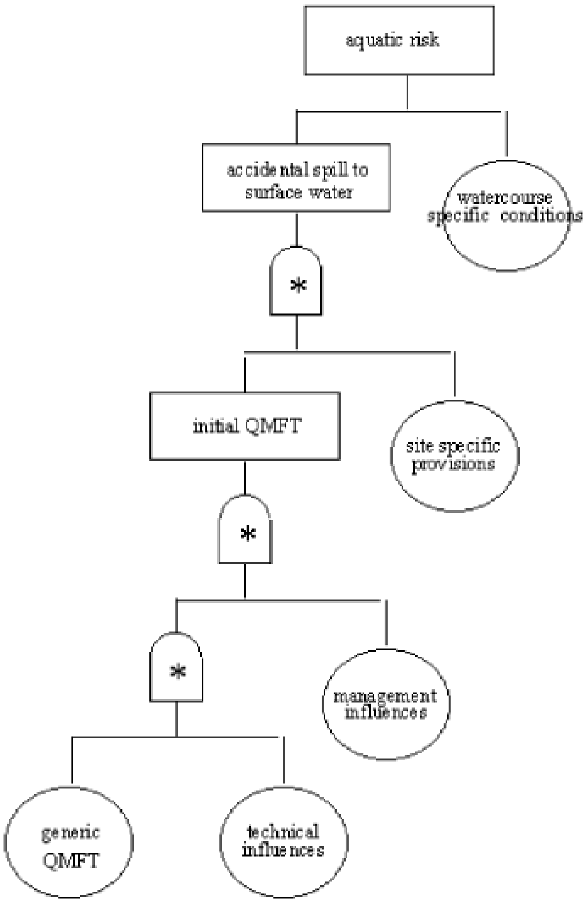
[19] Q = hydraulic flow in m^3/s, M is mass of chemicals involved in kg, F = frequency in 1/y and T = time-span of a spill in s.

A final QMFT to surface water or waste water treatment plant is then calculated. It is assumed that the spill disperses in surface water as a half-circular slick, with soluble pollutants diffusing to the water phase (concentrations being estimated based on Gaussian dispersion, without taking into account degradation, evaporation or sorption). The volume (m^3) of potentially affected surface water (for toxic effects) is determined, and this relates to an area where the predicted environmental concentration (PEC) is higher than the lowest reported EC_{50} for acute toxicity to fish, algae or crustacea. The volume affected is also calculated for lack of oxygen and formation of a floating layer. This process is illustrated in the figure below.

Figure 3.10 Illustration of Proteus methodology



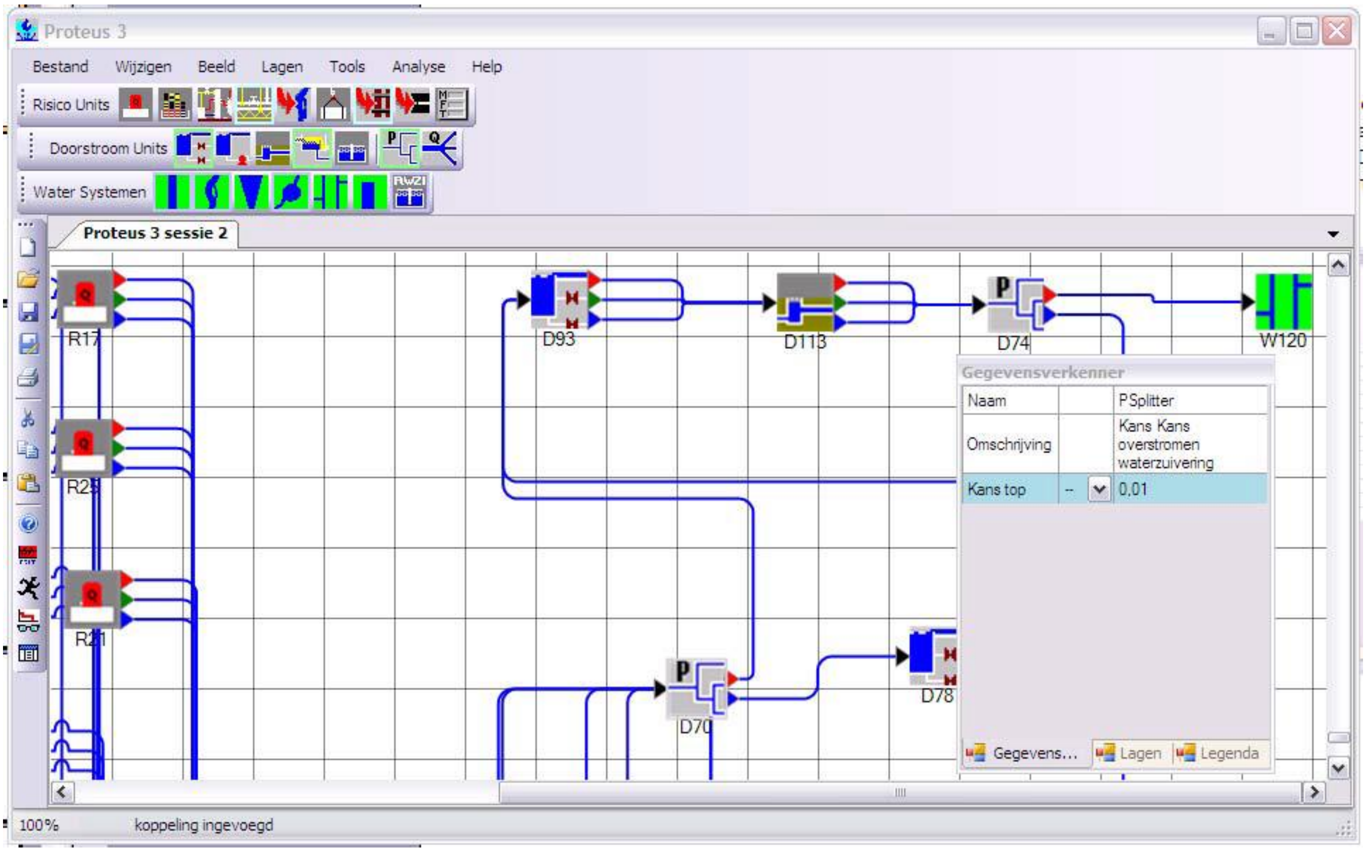
Source: Stam et al (2000).

The maximum effect (extent of toxic concentration, lack of oxygen, floating layer) is combined with the probability of the spill entering surface water, giving a measure of the risk for the activity concerned. The model can also take into account inhibition of sludge in waste water treatment plants. (The above is based on Stam et al, 2000. Note that the latest version of the model documentation is only available in Dutch).

Use of the model and results

Use of the model involves placing objects (e.g. bulk storage, production unit, pipeline) on a worksheet and connecting these to buffer units (e.g. sewer systems, basins) and thence to a water system (river, lake, etc.). This is illustrated in the figure below.

Figure 3.11 Proteus main screen



Naam		PSplitter
Omschrijving		Kans Kans overstromen waterzuivering
Kans top	--	0,01

100% koppeling ingevoegd

Source: Van Gulik et al (2013).

The model includes a database of chemicals and associated properties and also allows the user to enter parameters for other substances[20]. A minimum set of data can be used to undertake the risk assessment, such as the quantities involved and the way in which they are stored (tanks, packing). There are default values for technical and management correction factors, but a more sophisticated analysis can be undertaken using activity and site specific data. An example of the output from the modelling exercise is provided in the figure below.

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[20] Name, CAS number, LC50 and associated time (for fish, daphnia and algae), density, water solubility, octanol-water partition coefficient, BOD, vapour pressure, molar mass and flash point.

Figure 3.12 Example of output from Proteus model

Kwalificatie	Unit	Installatie	Scenario	Stof	Afstroomroute	Frequentie [1/j]	Massa uitstroom [kg]	Volume contaminatie [m3]	MSI [-]	MSI factored [-]	Uitstroom tijd [s]
Acceptabel	K1 tankput	Tank 9	CONTINUFALEN	K1 - gedenaturee...	R4->D66->[D] D5...	2,330E-8	6,971E+5	2,267E+7	1,511E+0	3,080E+0	3,020E+4
Verhoogd risico	K1 tankput	Tank 9	CONTINUFALEN	K1 - gedenaturee...	R4->D66->[D] D5...	2,097E-7	6,891E+5	2,241E+7	1,494E+0	3,045E+0	2,985E+4
Acceptabel	K1 tankput	Tank 9	CONTINUFALEN	K1 - gedenaturee...	R4->D66->[D] D5...	1,376E-9	6,971E+5	2,267E+7	1,511E+0	3,080E+0	3,020E+4
Acceptabel	K1 tankput	Tank 9	CONTINUFALEN	K1 - gedenaturee...	R4->D66->[D] D5...	1,239E-8	6,891E+5	2,241E+7	1,494E+0	3,045E+0	2,985E+4
Acceptabel	K1 tankput	Tank 9	TOPPING	K1 - gedenaturee...	R4->D57->[D] W71	3,330E-6	5,512E+5	3,132E+6	2,088E-1	4,255E-1	6,000E+1
Verwaarloosbaar	K1 tankput	Tank 8	INSTANTAANFA...	K1	R4->D66->[D] D5...	2,353E-10	3,240E+5		3,576E-2	9,328E-2	6,000E+1
Verwaarloosbaar	K1 tankput	Tank 8	INSTANTAANFA...	K1	R4->D66->[D] D5...	2,353E-10	3,240E+5	1,623E-3	1,082E-10	2,205E-10	6,000E+1
Verwaarloosbaar	K1 tankput	Tank 8	INSTANTAANFA...	K1	R4->D66->[D] D5...	2,330E-9	3,232E+5		3,567E-2	9,306E-2	5,986E+1

Source: Help file from Proteus 3.1.5.2.

3.7.2 Evaluation of robustness and sensitivity

It is understood that the Proteus model is widely used in the Netherlands and it includes a facility to generate reports that can be incorporated into Seveso safety reports. This provides a good indication of its robustness.

The model in its typical usage is very dependent on site-specific parameters such as the nature of storage units, size/ type of ‘buffer’ units such as sewer systems and the characteristics of the receiving waters. Furthermore, the risk estimates are calculated based on assumptions regarding technical and management-related safety systems, which will differ considerably amongst establishments (though the model does include default parameters based on typical safety management systems in the Netherlands).

Putting the frequency aspect of the model to one side (as these are less relevant in the context of Article 4), the results expected from the Proteus model are likely to be very dependent on the input parameters used to define the analysis, such as the size and type of storage units, potential for release to and via bunds/buffers and the characteristics of the receiving environment (e.g. dimensions, flow).

3.7.3 Assessment of use in the context of Seveso Article 4

In the context of Article 4 of the Seveso Directive, one can envisage using a model such as this to estimate the potential scale of accidents and to compare these against criteria representing a major accident. There are a number of factors which should be taken into consideration:

- The standard substances (for which properties/ parameters are already built into the model) included in the model are unlikely to be suitable candidates for Article 4 (as they are substances with known potential for significant effects). However, the model could be used for ‘new’ substances using a relatively limited number of, readily available, input parameters.

- One would presumably need to tailor the input parameters such that they represent the worst-case situation capable of occurring across the EU. In practice this might mean neglecting the effect of any protection measures such as the ‘buffer units’ incorporated in the model.

- It is likely that a large number of different scenarios would need to be run (e.g. using different storage units and receiving water characteristics) in order to identify the worst-case situation capable of occurring.

- The model outputs are based on the likelihood of different accident scenarios and releases occurring. One would presumably need to neglect this aspect of the analysis in the context of Article 4.

- The scale of the events considered in the model is expressed in terms of the MSI (an index value). It might be necessary to draw out the details of the actual calculated geographical extent of the effects, rather than this index, to allow comparison with parameters used for determining what constitutes a major accident (e.g. if these are in a similar form to the reporting thresholds in Annex VI). It might also be necessary to convert the values for volume of water affected to an estimate of the area or length affected.

- The model itself uses the Sandoz incident as a reference value for determining whether an accident scenario is tolerable or not. However, this is based on the combination of both scale and frequency (as described above) and it is unlikely to be appropriate to take into account frequency in the context of Article 4. An alternative means of determining whether the results could correspond to a major accident would therefore be needed.

- The results are based on the concentration of the substance in water above the (lowest) LC_{50} value for a substance. It is noted that some member states would define a more protective (lower) concentration value for use in estimation of whether a major accident could occur.

One way that the method could be used in the context of Article 4 is to use the option to develop a user defined scenario which provides the opportunity to self-define a QMFT (rather than using the predefined scenarios including buffer capacity). By linking this user defined scenario directly to a water system and a specific substance it should be possible to calculate a number of well-defined cases. These could subsequently be linked to a range of situations characterising European surface waters. This could allow analysis of the effect size for each type of water system using different quantities of release of the substance. The results of calculations could then be compared with the maximum effect areas defined for consideration of a major accident (those mentioned in the Seveso directive or other threshold values considered to be appropriate in the context of Article 4).

This straight forward approach offers objective starting points for discussions to determine thresholds for substances to potentially impose a significant risk to surface water

3.7.4 References

Riza (1999): Naar een referentiekader voor risico's van onvoorziene lozingen op oppervlaktewater, RIZA rapport 99.034.

Stam GJ, Bottelberghs PH, Post JG, Bos HG. (2000): PROTEUS, a technical and management model for aquatic risk assessment of industrial spills, J Hazard Mater. 7 Jan 2000;71(1-3):439-48.

Van Gulik A., Braam L., and Kuiper P (2013): Proteus III manual, Ministry of Infrastructure and Environment, 20 October 2013.

3.8 Considerations on releases to air

Although the focus of the current document is primarily on releases to water, it is worthwhile commenting on the use of approaches to assessing environmental consequences following releases to air.

Some of the models set out in the report on Task 2 are commonly used across the member states for assessing potential consequences for the environment, in addition to their primary use in assessing consequences for humans. For example, the PHAST model is widely used, as are others such as EFFECTS, and others not specifically mentioned in Task 2 (e.g. ADMS).

These models can be used in the context of estimating environmental consequences using steps such as:

- Define relevant accident scenarios.
- Define source term parameters.
- Estimate consequences of a release using relevant models. Typically for environmental effects this would be concentrations of toxic gas/ vapour or thermal radiation.
- Extract results on the calculated distances and footprint for relevant effects from the model (e.g. area where concentration is above acute LC_{50}, LC_0 or similar, or area with thermal radiation above a relevant threshold effect).
- Estimate whether relevant receptors around a site could be affected e.g. based on distance to sensitive/ protected areas or area affected by the toxic release/ thermal radiation.

- Identify whether a major accident is deemed to be possible under that scenario, taking into account relevant thresholds such as the reporting thresholds in Annex VI of Seveso or other relevant national thresholds[21].

In addition to direct effects on species (flora and fauna) it is also appropriate to consider effects of deposition from the air and consequent impacts on soil and groundwater. In the context of soil, various member states have national guideline values which could provide a basis for identification of soil contamination, when combined with the outputs of relevant models. For example, the Swedish EPA used a model to develop guideline values for contaminated soils in Sweden[22], and these values (along with the relevant modelling approaches used in defining these values), through estimating transport and distribution of pollutants could provide a useful basis for assessing the spatial extent of land areas potentially affected by an accidental release and deposition on land.

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[21] This would typically involve detailed review of relevant species (flora and fauna) in sites of nature conservation interest (and other sites). This is clearly highly specific to a particular location.

[22] Development of generic guideline values – Model and data used for generic guideline values for contaminated soils in Sweden, report 4639, Swedish Environmental Protection Agency, 1997 (http://www.naturvardsverket.se/Documents/publikationer/620-4639-X.pdf)

4. Conclusions on available methods

4.1 Types of available assessment methods

The previous section provided details of a number of different methods for assessment of the environmental consequences of accidents (focusing primarily on risks to the water environment). These are methods that are understood to be in use within EU member states, but as stated previously are not necessarily the most widely used (as data are not available on how widely different methods are used). The approaches fall into a number of categories which can be broadly characterised as follows:

- Indexes of environmental hazard or risk. The examples provided were the Czech Hazard and Vulnerability (H&V) Index and the Swedish Environment-Accident Index (EAI)[23].

- Environmental risk assessment approaches, as exemplified by the UK and Spanish methods.

- Approaches for estimating dispersion of substances in water, as illustrated by the approach in the paper published by Kontic and Gerbec and in the Netherlands Proteus model.

Some high-level considerations are included below on the different types of approaches and their possible use in the context of Article 4.

Firstly, the **index-based methods** provide examples where some of the key parameters influencing potential environmental consequences can be taken into account – such as water solubility, physical form, vapour pressure, viscosity – as well as the inherent hazards of a substance (typically based on LC50 values or similar). They also allow the characteristics of the receiving environment to be taken into account, represented by various scales for the vulnerability of water bodies and other media, as well as proximity to a particular site.

These methods could potentially be used in the context of Article 4 by setting the parameters related to the receiving environment to the worst-case values, in order to represent the range of environments present across the EU. Likewise, the highest-scoring categories within each index method for quantity of substance released could be taken into account, to reflect the potential range in sizes of establishments and potential releases across the EU.

Initial consideration of the two indexes covered in the previous section of this report suggest that taking such an approach could not in itself lead to a conclusion that a major accident is not possible (because the indexes are highly dependent on parameters related to the receiving environment and the quantities potentially released). Instead, they suggest that further analysis would be required. In any case, these methods provide a relatively simplified set of results which are likely to be insufficient to conclude on the potential for a major accident.

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[23] The Spanish method also uses a form of index, which also takes into account probability of occurrence, and so is essentially a risk index, rather than a hazard index. Note: in the current report the term "hazard" is used to refer to a potential source of harm; "risk" is a combination of the probability of an event and its consequence (outcome of an event), based on ISO/IEC Guides 73:2002 and 51:1999.

What the methods do provide is a useful indication of the *relative* potential for a major accident. They could therefore be useful if used to compare index values with other substances which are considered to have potential (or perhaps minimal potential) for a major accident affecting the environment. They might therefore be useful as part of an initial screening process to illustrate the relative potential to cause a major accident, but are unlikely to be a sufficient basis for decision-making on their own.

Furthermore, the index approaches enable consideration of the potential effects of an accident taking each hazard category separately, but they do not generally allow the combination of hazards to be taken into account, as discussed in the Task 1 report.

The two **environmental risk assessment methods** provide useful illustrations of some of the important factors that should be taken into account in assessing the potential for a major accident affecting the environment. Both methods reviewed include some consideration of the likelihood of accident scenarios (hence they are risk-based approaches), but the consequence assessment parts of these approaches could be very useful in the context of Article 4, and highlight key considerations such as:

- The importance of defining appropriate source-pathway-receptor relationships to identify how a release could affect different types of environmental receptors.
- The need to go beyond the Seveso Annex VI reporting criteria in deciding what constitutes a major accident (e.g. the UK approach includes a number of other criteria to define what constitutes a 'MATTE'). (Note the link to Task 6 of the current project.)
- The need to take into account both the severity of harm as well as the duration of effects (the UK's approach for example classifies incidents where harm to surface water environments recovers in <1 year as not being a major accident).
- Both methods highlight the likely need to undertake some form of modelling of dispersion of pollutants, but do not specify the use of any particular models.
- The Spanish approach is effectively another example of an index-based approach, albeit integrated into a framework for determination of the tolerability of risks as applied in several member states.

These are very useful approaches and one can envisage that at least some components of these methods could be useful in assessing the potential for Article 4 candidate substances to cause a major accident. (This does not imply, however, that a full environmental risk assessment would be necessary, nor would it be appropriate because such risk assessments are usually very site-specific.)

For example, identifying the potential pathways for a release to reach the wider (e.g. off-site) environment is considered to be a useful approach. If, for example, the physicochemical properties of a substance are such that it would never be expected to leave a Seveso site, the absence of identifiable pathways to the environment could be a very useful indicator in the context of Article 4.

It is recognised that a degree of qualitative judgement is needed in assessing the potential environmental risks of Seveso sites.

Two modelling approaches for estimating **water dispersion** were described. As stated previously, these are by no means the only available approaches but do provide a useful illustration of the approaches that are typically applied.

The example from the Kontic and Gerbec (1999) paper illustrates an approach involving hazard identification, development of accident scenarios and estimation of the extent of releases (taking into account barriers, environmental transport, etc.) in a form that allows benchmarking against criteria such as those in Annex VI of Seveso.

The Proteus model provides an approach whereby the source-term can be defined (e.g. catastrophic release or release over time). It uses a number of 'buffers' which affect the extent of release to water, but these can be circumvented (to take into account the potential worst-case situations across the EU) and effects of direct release to water bodies can thus be calculated. The results are not presented in directly comparable terms to e.g. those in Annex VI of Seveso, but it is understood that they could relatively easily be converted to such values. This method also uses a past accident (the Sandoz accident) as a reference for the scale of release, and also its likelihood.

It is of note that both approaches described use acute aquatic LC50 values as a basis for assessing the scale of potential consequences. Alternative (e.g. more protective) values might need to be used in the context of Article 4, but this is likely to be very dependent on the hazardous properties of the substance in question.

What these methods also highlight is that there are very many parameters that can influence the potential dispersion of a substance in the environment, both related to the source term (e.g. mass flow) and the conditions of the receiving environment (e.g. dimensions of water bodies; water flow; relevant species present and their density). So, in addition to the importance of identifying a relevant 'pathway' for a substance to pass from the source to the environmental receptor, the use of this type of model in the context of Article 4 is likely to require consideration of a range of different scenarios for each of these parameters, in order to represent the range of conditions encountered across the EU. Reliance on such models in the context of Article 4 is therefore likely to be a resource-intensive process.

4.2 Use of methods in the context of Article 4

Note that, as per the terms of reference for this project, the analysis has primarily focused on toxicity for the water environment as an indicator of the environmental impact of a substance. However, the approaches and issues involved in relation to other environmental receptors (e.g. the terrestrial environment or groundwater) are similar, and the approaches applied for consequence assessment are also similar. In relation to releases to air, some of the models considered in Task 2 for effects on humans (i.e. atmospheric dispersion models) are also relevant for assessment of consequences for biota in the terrestrial environment: the assessment process is essentially the same (e.g. it can use the same accident scenarios), but the effects thresholds used may need to be different, in order to account for effects upon plants and animals, rather than on humans.

Any or all of the above types of approaches may be useful in the context of a substance considered under Article 4 of Seveso. It is not considered to be appropriate to recommend any one method for use in this context. Instead, expert judgement will be needed based on the properties of the substance and its expected conditions of use to determine what method best demonstrates the potential (or not) for a major accident to occur.

Furthermore, as indicated in the introduction to this report, the approaches to consequence and risk assessment considered here are not the only approaches available, and those persons undertaking an assessment under Article 4 could decide to adopt alternative approaches where they are better suited to the particular case or substance under consideration

A key challenge lies in how to use these methods in determining whether a major accident could occur. A useful starting point is considered to be the criteria in Annex VI for reporting on major accidents to the Commission. As indicated elsewhere in these reports, these criteria do not 'define' what a major accident is, but do provide a useful guide as to the type and significance of effects that are likely to be relevant. Assessors could also consider:

- The UK approach which elaborates on the types and scale of consequences that are considered relevant in the context of a major accident to the environment. These are largely based on the Annex VI reporting criteria (for accidents with environmental consequences) but also consider other habitats, species, etc.

- Other EU legislation which covers environmental damage. For example, the Environmental Liability Directive (2004/35/EC, as amended) defines environmental damage in relation to damage to protected species/ natural habitats; water damage; and land damage (see Article 2(1)). Likewise, the Water Framework Directive (2000/60/EC) includes environmental quality standards and limit values for certain pollutants which may provide useful reference points with regard to potential for environmental damage. The Drinking Water Directive (98/93/EC) also provides guidelines for various pollutants and limits that could be relevant for one to take into account in assessments under Article 4. However, in addition to whether relevant environmental concentrations can be exceeded, one should also take into account the geographical extent of the pollution, as well as how long the elevated concentrations and the associated environmental damage may last.

To assess these factors in a way that has EU applicability is far more complex than undertaking a site-specific assessment of environmental consequences. To be able to reliably conclude that a major accident is impossible in practice would require consideration of the range of conditions across the EU, and those that have most potential to contribute to a major accident. This is likely to involve extensive analysis and many iterations, which may not necessarily be proportionate to the issue in question.

It may be that in some cases a reasoned argument based on the physicochemical properties of a substance could provide the main element of a demonstration of limited/no potential for a major accident (e.g. a substance used only as a liquid which solidifies under ambient conditions, illustrating no credible source-pathway-receptor linkages), rather than undertaking detailed modelling of environmental dispersion.