Economic value (or series of values) which can be applied when undertaking a Cost-Benefit Analysist for onshore major hazard establishments for environmental purposes: Phase 1 – Incident and cost data and gap analysis

Rocio Salado, Technical Director for Economics, Risk & Policy Analysts Ltd, Suite C, 2nd floor, The Atrium, St Georges Street, Norwich, Norfolk, NR3 1AB

Teresa Fenn, Director, Risk & Policy Analysts Ltd, Suite C, 2nd floor, The Atrium, St Georges Street, Norwich, Norfolk, NR3 1AB

Amaia O'Reilly, Senior Technical Officer – Environment and Sustainability, Energy Institute, 61 New Cavendish Street, London W1G 7AR, UK

The Control of Major Accident Hazard (COMAH) Regulations 2015, implementing the Seveso III Council Directive (2012/18/EU), aim to prevent and mitigate the effects of major accidents involving dangerous substances that can cause serious harm to people and/or the environment. Should a major industrial accident happen, COMAH Regulations require businesses to limit the effects on people, local communities and the environment.

In the UK, it is a requirement for COMAH sites to demonstrate that risk is managed to a level that is as low as reasonably practicable (ALARP). Reasonably practicable involves weighing a risk against the trouble, time and money needed to control it.

This paper presents the findings of research commissioned by the Energy Institute. The research was commissioned by the Energy Institute (EI) to review, collate and analyse existing guidance on the value of preventing harm to the environment, both nationally and locally, to develop a single technical document that contributes to an increased consistency in risk management decisions and the development of best practice in undertaking Cost Benefit Analysis (CBA) under COMAH for environmental purposes.

The study aimed at reviewing existing data on incidents and costs as well as guidance in order to develop guidance in the future that can be applied when undertaking a CBA. The study also included a case study to illustrate how the benefits of preventing MATTE can be estimated. The findings show that not all incident databases and reports provide monetary estimates of environmental damages, whilst some evidence has been found on the extent of clean-up costs. Moreover, there is often significant variance in the level of costs for a given severity rating. As a result, a follow-up Phase 2 to gather more data is expected.

Introduction

The Chemicals and Downstream Oil Industries Forum (CDOIF) was established in 1997 by HSE, bringing together regulators and many of the sectors to inform regulatory and industry approaches to issues affecting the safety and health of people, sustainability and the environment.

In 2015, CDOIF published the Guideline on Environmental Risk Tolerability for COMAH Establishments. There are a total of 359 Upper Tier COMAH sites in the UK (HSE[1]). Furthermore, RIDDO statistics (from HSE focussed on dangerous occurrences) show 7,140 dangerous occurrences in 2014/15 to 2019/20. Of these 1,302 were reportable except in relation to an offshore workplace , of which:

- 155 were due to explosion of fire resulting in plant stoppage;
- 204 were due to escape of flammable substances (sudden uncontrolled release), and
- 826 were due to accidental release or escape of substances liable to cause harm (HSE, 2nd[2])

The intent of the Guideline is to provide a reference for those organisations completing environmental risk assessments (ERA) and to help them making decisions and demonstrating that the risk is As Low as Reasonably Practicable (ALARP). According to the Guideline, an ALARP demonstration, which might include Cost Benefit Analysis, may be required to further justify a claim of Tolerable if ALARP (or TifALARP) or Broadly Acceptable. The Guidelines note with regard to benefits:

> *Health, safety and environmental benefits should be included in the CBA where these relate directly to a MAH. Business related benefits such as avoided loss of production, higher insurance premiums, damage to an operators own assets, insurance costs etc. should not be included as a benefit. These business related benefits may be considered by the operator when considering investment, but this is not required to be included as part of a CBA supporting an ALARP demonstration to the Competent Authority.*

The Guideline is a building block of the ERA process but although it provides some guidance in conducting the CBA, this falls short of explaining how the benefits should be included and/or valued. As a result, the Energy Institute commissioned a

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[1] HSE: This data was provided by HSE resulting from a freedom of information request.

[2] HSE: HSE RIDDO statistics. Available at: https://www.hse.gov.uk/statistics/tables/riddo.xlsx

study to review the current evidence with a view to provide a single, accessible source of technical guidance on conducting CBAs. This is intended to remedy the current situation whereby multiple sources of information on the value for the prevention of harm to the environment are available at a local and national level, leading to risk managers consulting the various available sources and making their own decision on what is reasonable, or not, when considering risk improvement measures without any guidance for consistency.

The study reviewed evidence data on costs and benefits covering Loss of Containment (LoC) incidents and larger-scale events, with a threshold of overall cost of above £100,000. It also includes a case study of how one may estimate the benefits of preventing a Major Accident to the Environment (MATTE) in order to extrapolate some findings that can be carried forward to the next phase. This case study is based on information provided to the consultants but modified for illustrative purposes.

The Role of CBA in preventing MATTE

CBA, cost-benefit analysis, is a tool to assist in decision making where costs and benefits are expressed in the same unit of value, normally money.

In the context of COMAH sites and supporting ALARP decision, the HSE principles note that *CBA is a defined methodology for valuing costs and benefits that enables broad comparisons to be made between health and safety risk reduction measures on a consistent basis, giving a measure of transparency to the decision making process* (HSE, 2nd[3]). The principles also note:

- *In undertaking a CBA, all relevant costs which accrue from the inputs into a health and/or safety intervention must be identified and costed. Inputs are defined as any additional human, physical and financial resources that are used to undertake an intervention;*
- *Likewise, all relevant health and safety and non-health and safety benefits arising from the intervention must be identified and expressed in monetary terms. Health and safety benefits include the avoidance of actions that would be taken after an incident such as evacuation, food bans, land use restrictions, etc. Non-health and safety benefits are savings and should be included in the CBA as an offset to the duty-holder's costs.*

In addition, the concept of gross disproportion requires duty-holders to weigh the costs of a proposed control measure against its risk reduction benefits. Specifically, it states that a *proposed control measure must be implemented if the 'sacrifice' (or costs) are not grossly disproportionate to the benefits achieved by the measure*.

Although the Courts (notably in Edwards v. National Coal Board (1949: 1 All ER 743) have decided that, in judging whether duty-holders have done enough to reduce risks, practicable measures to reduce risk can be ruled out as not 'reasonable' only if the sacrifice (in money, time, trouble or otherwise termed costs) involved in taking them would be grossly disproportionate to the risk, there is no authoritative guidance from the Courts yet as to what factors should be taken into account in determining whether cost is grossly disproportionate.

The view of the HSE is that a CBA can help a duty holder make judgements on whether further risk reduction measures are reasonably practicable. However,

- *A CBA cannot be used to argue against the implementation of relevant good practice, unless the alternative measures are demonstrated unequivocally to be at least as effective;*
- *The depth of analysis should be fit for purpose, i.e., more rigour is required where the risk is higher or the consequences themselves are great e.g., multiple fatalities;*
- *A sensitivity analysis is usually required to support any conclusions suggesting that the costs are disproportionate to benefits of implementing a measure;*
- *A CBA on its own;*
    - *Does not constitute an ALARP case;*
    - *Cannot be used to argue against statutory duties; and*
    - *Cannot justify risks that are intolerable, or justify what is evidently poor engineering.*

The costs from a Major Accident to the Environment (MATTE)

The study reviewed the available evidence of the costs of MATTE and environmental incidents more generally from different databases. A sample of sources reviewed is listed in

Table 1.

[3] HSE (nd): HSE principles for Cost Benefit Analysis (CBA) in support of ALARP decisions. Available at: https://www.hse.gov.uk/managing/theory/alarpcba.htm

Table 1: A sample of databases on environmental incidents

Name	Further details
eMARS (Major Accident Reporting System)	The Major Accident Reporting System (MARS and later renamed eMARS after going online) was first established by the EU's Seveso Directive 82/501/EEC in 1982 and has remained in place with subsequent revision to the Seveso Directive in effect today. eMARS contains reports of chemical accidents and near misses provided to the Major Accident Hazards Bureau (MAHB) of the European Commission's Joint Research Centre (JRC) from EU, EEA, OECD, and UNECE countries (under the TEIA Convention). Reporting an event into eMARS is compulsory for EU Member States when a Seveso establishment is involved and the event meets the criteria of a "major accident" as defined by Annex VI of the Seveso III Directive (201218/EU). For non-EU OECD and UNECE countries, reporting accidents to the eMARS database is voluntary so it may be an underrepresentation of the total risks.
RAS Ltd environmental incident database, v3 Issue 2, provided by RAS Ltd	The RAS database includes 90 records under 'past incidents fully detailed' ranging from the late 1960s to 2019 and covering international incidents. The database also identifies if the incidents meet the minimum MATTE level, where this is known, and if so what the maximum MATTE level was.
ARIA database:	The Analysis, Research and Information about Accidents (ARIA) database was set up by the French Ministry of Sustainable Development and is available at: https://www.aria.developpement-durable.gouv.fr/?lang=en&s= . It includes a worldwide inventory of industrial accidents, although it is primarily focused on incidents in France. The database in operated by the Analysis Office of the Risks and Industrial Pollutions (BARPI). As of August 2020, the database included 54,177 events of which 43,037 had environmental consequences. It is available at https://www.aria.developpement-durable.gouv.fr/?lang=en&s=
ZEMA database	The ZEMA database (in German) documents industrial accidents in Germany (and selected other countries) (available at : https://www.infosis.uba.de/index.php/en/site/13947/zema/index.html). The database is maintained by the Accident reporting and Assessment Unit (ZEMA) of Umwelt Bundesamt. It records all accidents and incidents that are subject to statutory reporting requirements. The database includes 854 records, of which 520 have occurred since 1 January 2000.
FACTS chemical accident database	The Failure and Accidents Technical information system (FACTS) is an industrial database that contains information on 26,509 incidents (as of August 2020) that involved hazardous materials or dangerous goods that have occurred across the world since 1930. It was originally produced by TNO in the Netherlands and is now maintained by the Unified Industrial & Harbour Fire Department in Rotterdam-Rozenburg. It is available at: http://www.factsonline.nl/
Finnish Safety and Chemicals Agency (TUKES) database	The Finnish Safety and Chemicals Agency (Tukes) collects information and investigates accidents that are then recorded in the VARO database (available at: https://varo.tukes.fi/). As of August 2020, the database contains 3,767 incidents.
US Chemical Safety Board	The US Chemical Safety Board (CSB) is an independent federal agency responsible for investigating chemical accidents. The database (available at: https://www.csb.gov/investigations/completed-investigations/) provides investigation details for 102 incidents from 1998 to present.

The review of case study incidents showed that not all of the incident databases and reports give a monetary estimate of the damages although some do provide information on the environmental damages, and in some cases the monetary estimate of those damages. Most of the damages reported in the literature included the costs of clean-up plus other costs such as fines following prosecution.

The review of the data showed however significant variation in costs. In some cases, severity does not seem to match the level of estimated damages. For instance the Buncefield fire, in 2005, was only reported as a category 2 incident but commanded £30 to £50m in damages (also leading to prosecution offences following investigation). Moreover, the review showed the following:

- Difficulty of knowing exactly what has been captured in damage costs included alongside incident data: some of the incidents also resulted in economic and social impacts, which may also be captured within the costs that are reported. These could include costs associated with injuries or fatalities, disruption costs or compensation payments. Other costs included are clean-up and remediation costs, which may not reflect the actual damages caused;
- Limited description of environmental impacts within incident data: not all incident data reports give a full description of the impacts that have occurred. Sometimes there are gaps in terms of receptors affected, or estimates of impacts (e.g. animals/fish killed). This means that severity ratings cannot always be assigned with the risk that some damages are not taken into account in the estimate of environmental damage costs. Other gaps may result from a lack of knowledge on the environmental impacts when the incident report was prepared. As a result, immediate impacts may be covered but longer-term effects may be missing. This can also make it tricky to assess the impacts on condition of natural capital. Incident reports may give an indication of fish kills which indicates loss of stock. However, information is often limited to length of water course affected or area of groundwater, with no indication of how the condition was changed (e.g., status of a

watercourse). This can make it difficult to identify which damage values to use (e.g., values for reduction in Water Framework Directive status of water course are available based on whether the change in a class change, more than a class change, etc.);

- Limited or no information on the duration of damages: very few of the incident data reports identify how long impacts have persisted for. Some reports do include the length of time for restoration efforts, but this may under-estimate the impacts on ecosystems and their ability to function (and deliver ecosystem services) to an optimal level. There is a gap generally in the environmental economics field on the linkages between change in condition of natural capital and level of ecosystem services (and hence benefits) that are delivered, although work is being done, e.g., through the European Commission's Mapping and Assessment of Ecosystems and their Services (MAES). This means it is currently difficult, even where descriptions of change in condition are given, to estimate the knock-on effects on ecosystem services and benefits, and the time period for these to recover to pre-incident levels; and
- Effects of mitigation measures on reducing the environmental damage that occurred: actual incidents almost always involve some degree of mitigation measures. In many cases, these help to contain loss of containment or recover material that would otherwise have entered the environment. These can result in the damages being lower than would be expected in an unmitigated case. Conversely, some of the incident data show examples where mitigation measures resulted in other impacts (e.g., collection of firewater in the first instance, but this then being discharged accidently) such that additional environmental damage may have been incurred that is not itself directly related to the loss of containment. These issues can confound other uncertainties within the environmental damage data making it difficult to explain differences between incidents of similar severity but with very different reported environmental damage costs.

These four uncertainties combine to mean that it is difficult to use actual incident cost data to identify potential costs. There is too much variation between incidents to provide a robust evidence base for developing an economic value from actual events. No two incidents are sufficiently similar due to the factors that resulted in the incident in the first place, the substance released, the geographic location and receptors in the affected area and the mitigation measures that were undertaken. This makes the extrapolation of indicative costs from available incident data not possible at this point in time. However, there is more agreement in the literature on the type of factors affecting the level of costs.

Key factors affecting costs

The review also showed a significant level of agreement on the different factors affecting the level of costs, including but not limited to:

- Substance being spilled and toxicity: although it is evident than more toxic substances are more likely to cause larger environmental damage, there is currently not comprehensive data from the incident data reported to make a significant comparison (most of the incident are for oil spills but not so much for other chemicals);
- The type of costs included in the valuation, e.g., compensation costs. In our view, compensation and litigation costs do not always reflect environmental costs although the former can be linked to the environmental damage (i.e., based on polluter pays principles and putting the harm right); and
- Type of receptor, e.g., rare species normally command a higher value. There appears to be enough data on the costs for instance of restocking fish but not enough granular data on the impacts of loss of different fish species or of particular class sizes/ages.

Influencing factors are important as they will determine: the extent (the area / distance); the severity (the degree of harm within the area of impact); and the duration (the recovery period). Duration and recovery aspects are also considered for deriving the tolerability for MATTE (applying the Tolerability Assessment Matrix to determine tolerability boundaries).

The benefits from preventing MATTE and environmental recovery

The benefits from preventing MATTE would include all the costs avoided, in other words, the benefits should include the reduction in risk to members of the public, to workers and to the wider community, environmental damage, avoidance of deployment of emergency services and avoidance of countermeasures such as evacuation and post-accident decontamination if appropriate.

With regard to the risk of reducing environmental damage, counted as environmental benefits, there are different approaches in the literature to value them. Two of the most prominent approaches identified in the literature are:

- The ecosystem services approach: Ecosystem services are the services that elements of nature provide to people as benefits (e.g. Provisioning services result in the provision of fresh water for human consumption). This is the preferred approach by Defra[4], which in turn uses the Millennium Ecosystem Assessment (MA) framework for categorising ecosystem services; and

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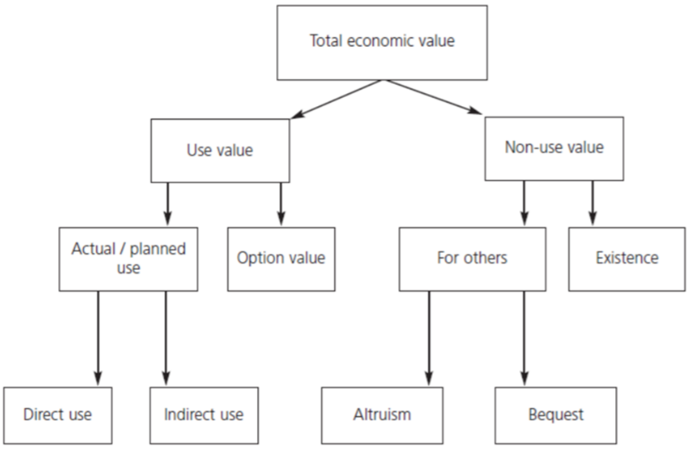
[4] Defra (2007) An introductory guide to valuing ecosystem services. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/191502/Introductory_guide_to_valuing_ecosystem_services.pdf

- The natural capital approach: Natural capital is a conceptualisation of the natural environment, in which nature is considered an asset, or a set of assets from which services flow to provide final benefits to people.



Both approaches aim to capture the concept of "Total Economic Value" (TEV). The TEV framework provides a way of structuring information about values to people, recognising that there may be multiple sources of values, including use and non-use values, as depicted in the next Figure.

Figure 1: The TEV framework

Source: Dunn H (2012)[5]

These values include:

- Use values:
  - Direct use (e.g. consumptive such as catching fish to eat);
  - Indirect use (e.g. non-consumptive such as recreation); and
  - Option value (covering the option to use the service in the future).

- Non-use values:
  - Availability of the service for use by others (altruistic) or for future generations (bequest); and
  - Value placed on the knowledge that the site exists (existence).

Methods to value the above include both market and non-market-based approaches but they have different resource implications. Market-based approaches capture the proxy values from the use of the environment, such as, revenues from visitors, expenditure, value of crop-yields. Non-market-based approaches create hypothetical markets where individuals are asked for their willingness to pay for specific environmental attributes and features. Both approaches have their advantages and disadvantages but surveys to elicit values are not without expense. As a result, alternative approaches such as benefit transfer have been used as quick fixes. Benefits transfer (also called value transfer) allows existing economic valuation evidence to be applied in a new context and is commonly used for environmental valuation, with UK government guidance having been developed to this end.

In practice however, very little effort has been put into valuing the benefits from preventing MATTE using any of the approaches above. One of the main challenges in doing so relates to that of defining the environmental baseline, i.e., establishing the environmental receptors that can be affected and the services they provide, but also establishing the potential impact and applying the right valuation. Most of the costs reported in the incident databases include clean-up costs but these can underestimate the benefits from preventing a major accident. This is because the clean-up costs will not take account of any long-term environmental damage that may be caused due to impacts on the functioning of an ecosystem. This may take a lot longer to recover and is unlikely to be captured in the clean-up costs. Examples of other type of costs associated with accidents are given in Box 1. These costs shall be averted should the incident be avoided through prevention or mitigation and thus should be counted as benefits.

Table 2: Impacts from accidents on the environment – Examples of impacts on ecosystem services and costs

Recreational and commercial fisheries: Spills which impact on recreational and commercial fisheries can have a bearing on the overall cost of the environment. The factors that influence the cost of damage to water bodies which are used for recreational and/or commercial fisheries include:

- Loss of stock;
- Loss or damage to equipment; and
- Loss of recreational fishing (including fishing licences or membership fees).

Tourism and Other Recreational Activities: Spills can also adversely impact tourism to the affected area. Costs can arise from the following:

- Temporary closure to nearby sites of interest;
- Loss of income to local business; and
- Negative media attention can reduce the number of tourists.

Other services, including amenity impacts: Other costs associated with spills are listed below:

- House prices in the local area;
- Damage to local property; and
- Opportunity cost of investment into other ventures being missed out on because funds spent on clean-up costs.

[5] Accounting for environmental impacts: Supplementary Green Book guidance, HM Treasury and Defra https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/191500/Accounting_for_enviornomental_impacts.pdf

Carbon sequestration: Accidents affecting habitats could affect carbon sequestration. The carbon sequestration effects will depend on the type of habitat affects, with variations between land and marine habitats being reported. Also UK government values available for shadow price of carbon (traded/non-traded)

Establishing the environmental receptors that can be affected by the incident is discussed in Nicholls C et al (2018)[6] and is part of the ERA process. This document refers to receptors and the process for screening which of these may be affected and experience a MATTE in the absence of mitigation. The CDOIF Guideline notes that is reasonable to screen for receptors within 10km of the establishment but make allowances for linear pathways (such as rivers). The document notes that the area to look at depends on the nature of the potential major accidents. It also notes that if any particularly sensitive features are identified just beyond the estimated credible hazard range, then these would still be included. The environmental baseline should thus be focused on the credible receptors within the environment and their value, based on consideration of the nature of the hazards, major accident scenarios and the pathways, and how these values could be affected.

Davey J (2018) discusses another approach to calculate the benefits called the Implied Cost of Averting a MATTE (ICAM). The costs categories included in Davy's paper include:

- Direct clean-up and mitigation costs;
- Indirect clean-up costs levied by government bodies or regulatory agencies; and
- Fines and compensation due as a result of the accident.

Davey J (2018) reports average clean-up and restoration costs and asset loss costs from the eMARS database[7]. Only eight events had sufficient information to assign a MATTE level. The author notes that with such a small sample size, no insightful conclusions can be drawn, other than highlighting the vast discrepancy in clean-up costs by incident (between £31,000 and £6.3m). Moreover, he notes, clean-up costs are more frequently reported (e.g., in eMARS) and used as a proxy to the environmental damages from incidents but these are highly variable depending on a range of factors. As a result, Davey J (2018) concludes that eMARS in its current format is not suitable to provide a base dataset to generate any form of quantified analysis for MATTE.

Table 3: Costs reported for all major accidents in eMARS

Costs	Clean-up and restoration costs	Asset loss
Total	£97,530,102	£82,063,138
Mean*	£1,773,274 ± £2.8m	£4,429,544 ± £4.6m
Median	£485,550	£606,733
* Average excludes all zero values for asset loss based on the assumption that these were not reported rather than there was no cost Reported in Davey, J. (2018) ICAM do more – What are the true benefits of averting a MATTE? Wood Plc. Symposium Series No 163, Hazards 28; incident data taken from eMARS		

Davey J (2018) also sets out the cost types which may be directly or indirectly attributable to an incident, but which have been excluded from the analysis on the basis that they are hard to quantify, are usually site specific and in some cases are not correlated to the level of environmental harm. These include asset losses (e.g. cost of repairing or replacing the assets damaged in the accident), production losses as a result of the incident, reputational losses, or regulatory costs (e.g. increased inspections, cost of required improvement actions). Davey J (2018) excludes however the environmental costs of the damage in terms of environmental services affected, as these are not reported in existing databases (or the opportunity costs from the environmental damage).

Key factors affecting benefits

There are different values of the environment identified in the literature. Sources of data on values include the Environmental Valuation Reference Inventory (EVRI) , the Environmental Services Valuation Data (EVSD – Part of TEEB), Defra's Environmental look-up tool (EVL) and other values were also reviewed by RPA in a number of projects in the past. Factors that may impact the level of benefits include:

- The existence of alternative sites: if alternatives are available, the value may be reduced. The level of reduction will depend on proximity and the attributes of the site and its alternatives (particularly for some ecosystem services such as recreation and tourism but equally important for other services, such as non-use or water abstraction);
- Type of goods and services: specific habitats, e.g., wetlands and saltmarshes, are particularly well regarded for carbon sequestration; sites designated for conservation such as SPAs may provide birdwatching and

[6] Nicholls C et al (2018): Addressing the Challenges of Applying the CDOIF Guideline for Environmental Risk Tolerability in Risk Assessments for COMAH Establishments

[7] The sample size consisted of 88 records, for which only 57 reported monetary values for the various cost types of interest. Of the 57, 33 incidents also reported the costs associated with asset loss. Of the events that reported cost data, there was not sufficient overlap with the incidents which had been classified according to their MATTE level.

recreational opportunities, etc. as well as valued for non-use. Moreover, some sites may be designated at national and international levels and may command a larger use and non-use value;

- The type of users: whether these are local or from elsewhere may have an impact on the value. Generally, hotspots or national/international designations will command a larger value than sites only used/designated at the local level (and although the value per user may not differ significantly, the level of use may be the main determinant of total value); and
- The time of the year: e.g., the time of the year can significantly affect the extent to which a spill impacts tourism. For example, if a spill occurs in the lead up to, or during, the height of the tourist season, then losses are likely to be greater than if the spill occurred outside of the tourist season. Moreover, specific costs to tourism will naturally depend on the nature of the spill and the habitats it affects (e.g., river used for kayaking). It will be difficult to predict in all cases when the incident may occur, but scenario modelling can help to illustrate the scale of impacts.

Other factors affecting the level of benefits are given in the CDOIF guideline and set out in the **Table 4**.

Table 4: Influencing factors on environmental benefits based on CDOIF Guideline

Severity	Recovery
• Type of chemical being considered (substance) • Quantity of chemical released • Nature of release • Pathways of environmental exposure accounting for chemical fate and transport • Type of receptor (habitat or species and its status) • Effect of the release in terms of area or population impacts (scale) • Whether the receptor is land or water-based (turnover rates tend to be shorter in aquatic systems than terrestrial systems) • Season/time of the year	• Type of chemical and its environmental fate, behaviour and/or potential effects in the environment, covering the 60 chemicals listed in the COMAH regulations • Type of habitat or species • Whether the receptor is land or water-based
Source: extracted from CDOIF Guideline	

The CDOIF Guideline also notes the following:

- Land generally takes longer to recover naturally than surface water environments;
- Groundwater generally has the longest recovery periods;
- It is common for the chemical quality of receptors to recover more rapidly than ecological/conservation status. In particular:
    - For ecological criteria, complete recovery is difficult to judge and hence it is suggested that this should be clarified as >80% of the damage recovered;
    - For chemical criteria (e.g. drinking water standards), recovery to below standard concentration should be considered; and
    - For harm to particular species, duration of recovery relates to the population as a whole.

The recovery time will be part of the CBA but current databases on accidents reviewed for this study do not provide details on natural recovery periods. The recovery time should be included in the valuation of benefits as the duration over which benefits from avoiding a MATTE will accrue for. Duration and recovery can influence the level of damages avoided as follows:

- Longer duration will command larger benefits from avoiding a MATTE when the damage is sustained and recovery is not possible; and
- Shorter duration may be equally damaging to the environment but recovery may start earlier thus minimising the incidence, total environmental costs and benefits of averting.

A potential framework for CBA for COMAH sites

Based on a review of the literature, we recommend the following benefits to be included in the estimation of environmental benefits from preventing MATTE:

- Averted impact on the value of ecosystem services;
- Clean-up costs for similar incidents and environmental baseline (from previous incident data if available); and
- Opportunity cost of investment into other ventures being missed out on because funds spent on clean-up costs.

It is believed that fines and legal fees are better excluded from any environmental justified spend (as they are highly subjective and will vary depending on a multitude of factors, including size of organisation, and the actions they take following the release). Additionally, UK fines are also dependent on the level of earlier non-compliance, not just the consequences of a specific incident. A good correlation between fines and consequences is therefore unlikely so it is not suggested that these are included within the environmental benefits.

The review of environmental valuation guidance suggests that the estimation of the monetary value of damages requires a description of the damages to natural capital (stocks) and ecosystem services (flow). These then identify the benefits that are foregone as a result of the environmental damage caused (or potentially caused). This requires an understanding of the receptors (as these represent the stocks or natural capital) and then the magnitude, extent and duration of harm (as this will reflect the loss of ecosystem services from the affected natural capital). With a description of the damages, it is possible to use a value for impacts on specific natural capital or ecosystem services to place a monetary estimate on those damages.

The following steps are suggested in the valuation of environmental benefits linked to the existing process in the CDOIF Guidelines:

1. The first step to assess the environmental benefits will be to use the details on the receptors from the Environmental risk assessment (ERA). For any environmental features identified as credible receptors, a table of information about each receptor is provided. This includes details such as the receptor size, type and location;
2. The next step is to identify, through the review of incident databases and damages from specific incidents whether there are particular existing values that may be useful in a more generic sense, to help ensure that the valuation approach is proportionate. At this stage, it is also useful to document impacts qualitatively. This may include visible impacts, type of impact, relevant geographical characteristics, description of the users of services, local importance of services impacted and the extent of use, availability of alternative sites, species in the habitat, names of local recreational clubs or activities;
3. Quantify the impacts on ecosystem services. This stage involves attempting to quantify the magnitude of impact on ecosystem services. This will elaborate on step 2, but with an attempt to quantify these impacts. For example, the length of watercourse affected, the number of users affected, time horizon of impact, membership rates at local recreational clubs, number of users. Some values are provided below, in **Table 4**, covering some of these ecosystem services (e.g., the value of water and abstraction, the value of crop productivity). Where quantification of these impacts is not possible, classifying them as ‘high’, ‘medium’, ‘low’ is advised. This will help when monetising impacts; and
4. Monetise the impacts by ecosystem service. This step involves applying economic values to the ecosystem services that have been impacted, taking into account the magnitude of impact previously identified in step 3. Disproportionate factors could be applied to ecosystems that provide really important habitats to endangered species or be vital in the wider system.

Table 4: Environmental benefits transfer value from avoiding MATTE and potential values for severity

Receptor			**Value**	**Unit**	**Note on value**
Designated Land/Water Sites (Nationally important)	Land or Surface Water	NNR, SSSI, MNR	**£201,707**	TEV of average SSSI site	Based on the value of total benefits provided by SSSI in England, divided by number of SSSI sites
Designated Land/Water Sites (Internationally important)	Land or Surface Water	SAC, SPA, RAMSAR	**£23,825,494**	TEV of average RAMSAR site	Based on the TEV of wetlands based on 200 case studies. Does not include medicinal, historic and spiritual values, sediment control so likely an underestimate
Other designated Land	Land	ESA, AONB, National Park, etc.	**£639.09**	Per ha/year	Based on TEV of an AONB per ha per year
Scarce Habitat	Land or Surface Water	BAP habitats, geological features	**£5.91**	Per ha/year	Based on the average value of 19 BAP habitats
Widespread habitat (non designated land)	Land	Land/water used for agriculture, forestry, fishing or aquaculture	**£49**	Per ha/year	Likely underestimate. Based on loss of crop productivity due to soil compaction.
Groundwater Source of Public or Private Drinking Water	Groundwater or surface water drinking water source (public or private)	Drinking water sources (SPZs in England and Wales) - See 3.2.3 for further guidance.	**£0.0033**	Per person/hour	Based on the 3 values including water abstraction and treatment, long run marginal costs for water companies, and average water replacement costs
Groundwater Non Drinking Water Source	Groundwater (except drinking water sources)	Aquifers (non-drinking water sources) : Principal and secondary as depicted as coloured areas on aquifer maps - See	**£3,536**	Per ha/year	TEV of groundwater for the following habitats: Inland Marsh, peat bog, saltmarsh, intertidal. Adjusted by removing valu of drinking water

Receptor			Value	Unit	Note on value
		3.2.3 for further guidance.			
Soil or Sediment	Land		**£19.90**	Per ha/year	Highly uncertainly. Maintaining soil fertility, reflects lack of data
Built Environment	Built Environment	This is limited to Grade 1 / Cat A Listed buildings, scheduled ancient monuments, conservation area, etc.			Value range too wide to provide an estimate / lack of data
Particular Species	Land				Values highly dependant on species
Marine	Surface Water		**£19,604**	Per ha/year	TEV of marine environment (comprising open ocean and coastal systems)
Fresh and estuarine water habitats	Surface Water		**£20,200**	per km/year	Assumed value of status lowered by 1 equal value of status raised by 1. Value taken from HM Treasury Green Book

An illustrative case study

A case study is given in the report to illustrate how one may estimate the benefits of preventing a MATTE following the steps above and also in order to extrapolate some findings that can be carried forward to the next phase. The case study also serves as a means for highlighting the relevant data gaps and to illustrate the large variation in benefits should one use the output of the ERA and MATTE severity levels alone.

The case study uses benefit transfer methods for valuing environmental damages or the benefits of preventing MATTE. It is based on information provided to the consultants but modified to a considerable degree; thus, it is not suggested that these findings are replicated elsewhere.

In this illustrative case study, the environmental risk assessment has identified two possible scenarios which may result in MATTE level harm, set out below as scenario A and scenario B. Both scenarios concern an oil spill but of different levels of severity as follows:

Scenario A: An oil spill occurs at site A. The initial MATTE screening identifies three credible receptors which may be impacted as a result of the oil spill. These are:

- Groundwater (non-drinking water);
- Groundwater (drinking water); and
- Some nearby widespread habitat (non-designated land).

Under scenario A the environmental risk assessment identified impacts on groundwater (non-drinking water) as MATTE A; whilst the impacts on groundwater (drinking water) and widespread land habitat were assessed as Sub-MATTE.

Scenario B: A more severe oil spill occurs at site A, caused by an explosion at a nearby manufacturing facility. The initial MATTE screening identifies five credible receptors which may be impacted as a result of the oil spill and explosion. These are:

- Groundwater (non-drinking water);
- Groundwater (drinking water);
- Nearby widespread habitat (non-designated land);
- River A; and
- Designated land (SSSI).

Under scenario B, the environmental risk assessment concluded the following:

- Designated Land/Water Site (Nationally important; SSSI): MATTE A;
- Fresh and Estuarine Water Habitats: MATTE A;
- Widespread Habitat (Land): MATTE A;
- Groundwater (non-drinking water): MATTE B; and
- Groundwater (drinking-water): MATTE B.

Data on the area affected and the duration of harm has also been used to estimate the benefits. By making assumptions about the duration of harm and the extent of damage caused (without deviating from the CDOIF classifications for severity and duration of harm), the benefits from averting MATTE are as follows:

- Under scenario A, the estimated benefit of avoiding the incident) is **£486k.**
- Under scenario B, the estimated benefit of avoiding the incident (Scenario B) is **£3.75 million**. This is based on a longer list of receptors being affected, with the largest benefits stemming from avoiding detrimental impacts on groundwater for a longer duration, relative to other impacts. The value encompasses all ecosystem services.

CDOIF bands for severity and duration mean that the resulting estimates are large in range. The wide-ranging nature of the current CDOIF classification of severity and duration mean that these estimates cannot be further refined without making assumptions on the extent of damage and the duration. The findings show that for the estimates to be meaningful in the context of justified spend under TifALARP, the range of estimates need to be narrower than those presented by simply applying the CDOIF thresholds. Data from the ERA process however could be of use when calculating the benefits and significantly improve the reliability and effectiveness of any CBA that needs doing under the process.

It is important to note that these benefits reflect only the environmental benefits of avoiding the incident. To calculate justified spends further information, such as benefits on people's safety (not within the scope of this study), direct mitigation costs to the operator, frequency of incident, level of risk reduction achieved, and duration of the proposed risk reduction measure need to be included into the CBA calculation.

Summary and findings

This paper presents the findings of a study in its early phases of developing guidance that can be applied to CBA processes for COMAH sites. The study reviewed, collated and analysed guidance on the value of preventing harm to the environment, with a focus on MATTE, to complement the CDOIF Guideline and processes for the ERA. The literature review has shown a high degree of consistency of the factors affecting the level of impacts, and rightly included in the ERA, are:

- Type of substance;
- Quantity released;
- Speed of release;
- Pathway to receptor(s)/connectivity;
- Vulnerability/sensitivity/rarity/designations;
- Extent of damage (area, length affected); and
- Duration of harm (time).

The findings show that not all of the incident databases and reports give a monetary estimate of the damages, but some do provide some information for the valuation approaches applied, mostly clean-up costs. There are variations on the significance of costs for the same severity rating. This is due to different factors, including but not limited to:

- Substance being spilled and toxicity: although it is evident that toxic substances are more likely to cause larger environmental damage, there is currently no comprehensive data from the incident data reported to make a significant comparison (most of the incident are for oil spills but not so much on other chemicals);
- The type of costs included in the valuation, e.g., compensation costs. In our view, compensation and litigation costs do not always reflect environmental costs, although the former can be linked to the environmental damage (i.e., based on polluter pays principles and putting the harm right); and
- Type of receptor, e.g., rare species normally command a higher value. There appears to be enough data on the costs for instance of restocking fish but there is less data on the costs of impacts on other receptors.

Clean-up costs are more frequently reported (e.g., in eMARS) and used as a proxy to the environmental damages from incidents but these are highly variable depending on a range of factors and can significantly undervalue the environmental benefits from mitigation. Various clean-up costs have been found through the research for this phase of the project, but it has not been possible to discern any trends or determining factors in the level of clean-up costs and as such it is considered not to be suitable to provide a base dataset to generate any form of quantified analysis for MATTE. Thus, at present, clean-up costs can therefore not be estimated per MATTE level, due to the wide variance in cost level.

The review and case study findings show that it is neither possible, at this point in time, to calculate a set of robust estimates of environmental benefits that can be used to apply ALARP and the CBA process based on the thresholds within the CDOIF guidance. This is due, partly, because of the aforementioned variance in the level of damages for a given severity of incident. Additionally, the severity ranges and thresholds present in the CDOIF guidance are too wide for meaningful estimates to be generated by the application of a unit value transfer. There are also other reasons such as the uncertainty around the duration of damages, whether mitigation has been included, and uncertainty about the level of environmental impacts.

Because of the current weaknesses in data, this report suggests embedding the valuation of environmental benefits within the process and/or after CDOIF Phase 2. It is not possible to establish what the value is of avoiding a specific MATTE without further analysis. The review of uncertainties and data gaps suggests that there are specific activities that could be undertaken that would narrow the scope of work and move towards more reliable economic values of environmental damages, including the collection of further evidence on incident by means of a survey and interviews with those involved. This will involve filling in information gaps or details such as the receptors affected and more description on the impacts. The following data gaps need to be covered to build more evidence for the future:

- More detailed information on incidents. It may be possible that this can be collected directly from those involved in incidents, especially recent events and major accidents where independent research may have been undertaken to investigate the environmental impacts. Evidence on the duration of harm following major accidents is a key data gap and research undertaken several years after an event could help identify if and where there are longer-term effects on recovery of natural capital;
- More detailed information on clean-up costs. More data needs to be obtained on clean-up costs. This needs to include more clean-up costs associated with incidents that have been assigned a MATTE level, and the factors that influenced the overall cost;
- More detailed information on receptors affected. Incident reports often give an indication of the type of receptor affected, or this can be inferred from the description of the impacts but it is not always straightforward to then assign the impacts to one or more of the CDOIF receptor types. This can make it difficult to compare across incidents;
- Further information on environmental consequences of accidents. This could be based on modelling or wider investigations as well as research that is being undertaken to explore linkages between the level of ecosystem services (and hence benefits) that are generated based on the condition of natural capital; and
- Further investigation into values for environmental damages. The valuations readily available are often associated with changes to condition of natural capital, but these may not always reflect the size, extent or significance of changes that could be seen following a major accident. Per unit values may under-estimate the total effect (as ecosystem services may reach critical thresholds in larger accidents that make recovery not possible).

The study thus proposes further evidence gathering, by means of a survey and interviews with site operators. This is expected to be commissioned shortly by the Energy Institute.

Annex 1: References

Examples of main guidance reviewed
Baseline guidance
• Chemical and Downstream Oil Industries Forum (2016): Guideline – Environmental Risk Tolerability for COMAH Establishments. • Energy Institute (2017): Guide to predicting environmental recovery duration from major accidents. Supporting guide to the *Environmental risk tolerability for COMAH establishments* guidance.
Guidance on assessing risks or damages caused by loss of containment incidents
• AMEC (2014): Development of an assessment methodology under Article 4 of Directive 2012/18/EU on the control of major accident hazards involving dangerous substances, Overall project report, Final report. • AMEC (2014): Final report Annex 3: Methods for assessing environmental consequences. • AMEC (2014): Final report Annex 4: Accident scenarios, condition and parameters. • Cefic (2016): Cefic Guidance for Reporting on the ICCA Globally Harmonised Process Safety Metric • COMAH (2016): All Measures Necessary - Environmental Aspects. • Czech Hazard and Vulnerability Index (in AMEC, 2014) • DiMattia, D. G. (2011): Predicting the risk of a loss of containment from a novel LNG propulsion system using a fuzzy logic-lopa method • European Commission (2006): IPPC reference document on economics and cross-media effects • HSE (2002): Application of QRA in operational safety issues • HSE (1999): Reducing risks, protecting people. HSE's decision making process • HSE (2001): Principles and guidelines to assist HSE in its judgements that duty-holders have reduced risk as low as reasonably practicable. Accessed at Risk management: Expert guidance - Principles and guidelines to assist HSE • HSE (n.d.): Cost-benefit analysis checklist. Accessed at Risk management: Expert guidance - Cost Benefit Analysis (CBA) checklist (hse.gov.uk) • Ibarra-Mojica et al (2017): Methodological proposal for evaluation of oil spills vulnerability in rivers. • Institute of Petroleum (2005): Risk-based framework for assessing secondary containment of bulk liquid storage facilities.

Examples of main guidance reviewed
• JRC (2015): Guidance Document on Commission Implementing Regulation (EU) No 1112/2014 determining a common format for the sharing of information on major hazard indicators by operators and owners of offshore oil and gas installations • Law, R. J., Kirby, M. F., Moore, J., Barry, J., Sapp, M. and Balaam, J. (2011): Pollution response in emergencies: marine impact assessment and monitoring: Post-incident monitoring guidelines. Science Series Technical Report, Cefas. • Spanish environmental risk assessment approach (in AMEC, 2014) • Swedish Environment-Accident Index (in AMEC, 2014)
Guidance on environmental valuation
• Defra (2007): An Introductory Guide to Valuing Ecosystem Services: Supplementary Green Book Guidance. • Defra (2015): Environmental Value Look-Up Tool • Defra (2020): Enabling a Natural Capital Approach (ENCA) • DG Environment (2001): Study on the valuation and restoration of biodiversity damage for the purpose of environmental liability • Dunn, H. (2012): Accounting for Environmental Impacts: Supplementary Green Book Guidance. • ECHA (2016): Evaluation for restriction reports and applications for authorisation for PBT and vPvB substances in SEAC • Eftec (2010): Valuing Environmental Impacts: Practical guidelines for the Use of Value Transfer in Policy and Policy Appraisal. • Environment Agency (2003): Guidance – Assessment of Benefits for Water Quality and Water Resource Schemes. • Environmental Valuation Reference Inventory (EVRI) • Groot, R., Brander, L. and Solomonides, S. (2020): Ecosystem Services Valuation Database (ESVD) • HM Treasury (2018): The Green Book: Central Government Guidance on Appraisal and Evaluation. • RPA (2020): Economic Benefits of Incident Management • Wakefield & Davis (2017): Assessing natural resource damages for commercially and recreationally harvested populations
Table Error! No text of specified style in document.**-5: Incident data and databases reviewed**
• eMARS database (European Major Accident Reporting System) • RAS Ltd environmental incidents database • ARIA database (French Bureau for Analysis of Industrial Risks and Pollutions, BARPI) • ZEMA (accident reporting and assessment unit of Umwelt Bundesamt) • FACTS chemical accident database • Finnish Safety and Chemicals Agency (TUKES) database • US Chemical Safety Board • Japanese Failure Knowledge Database • NOAA damage assessment, remediation and restoration program • National Transportation Safety Board accident reports • European Commission (2017): Analysis and summary of Member States' reports on the implementation of Directive 96/82/EC on the control of major accident hazards involving dangerous substances • IChemE Loss Prevention Bulletin • Oil and Gas UK Annual Health & Safety Report • Oil and Gas UK Annual Environment Report • HSE COMAH report • IVM Institute for Environmental Studies: benchmark development for the proportionality assessment of PBT and vPvB substances