

ICAM do more – What are the true benefits of averting a MATTE?

Jack Davy, Senior Consultant - Safety and Risk, Wood, 601 Faraday Street, Birchwood, Warrington, WA3 6GN, Jack.Davy@woodplc.com

What more SHOULD we do to protect the environment?

This question is now at the forefront of public discourse and MATTE is now in the lexicon of every site risk/HSE manager, due in no small part to Seveso III and the CDOIF guidance, giving renewed emphasis and a robust structure to Environmental Risk Assessments (ERA).

However, while assessing Major Accident potential, the use of quantifiable risk metrics to drive decision making is nothing new to any Safety Engineer, but until recently the process and concept of ALARP has been less rigorous in the environmental arena. This was partly due to historic regulatory focus, but also due to the arduous nature of accurately defining the benefits of decreased levels of environmental risk.

To address this complexity, Wood has assessed case studies of previous MATTE incidents across the full spectrum of severities to determine the ultimate cost of various Major Accidents to the Environment, considering clean-up, restoration, and other financial and quantifiable costs. The aim was to better quantify the benefit element of a Cost Benefit Analysis (CBA) when making ALARP decisions for MATTE. These 'benefits' should include potential fines, costs of remediation and other costs that could have been avoided by more effective environmental protection measures.

The analysis starts by contrasting the costs of major accidents to the various benchmarks applied for Safety Major Accidents, and examining the concept of broadly acceptable, intolerable, and tolerable if ALARP as applied to Environmental Risk Assessments.

While the CDOIF methodology provides an accepted basis for the quantitative tolerability of events, this paper draws on our experience of determining what is reasonably practicable for COMAH sites around the UK. Within this, we have sought to determine appropriate benchmarks for environmental equivalent metrics such as Implied Cost of Averting a MATTE (ICAM) and Gross Disproportion.

This paper provides a methodology for undertaking CBA of environmental improvement measures and reviews the data available on environmental benefits. The paucity of available data allows some general trends to be drawn but it does not allow for a full ruleset to be derived.

Keywords: COMAH, MATTE, Major Accident to the Environment, ALARP, CBA, Cost Benefit Analysis, Environmental Harm, ICAM, CDOIF

Introduction

Major Accidents to the Environment (MATTE) from industrial establishments are rare but extremely damaging events that have occurred sporadically over the past few decades, both in the UK and globally. There are numerous regulations in the UK which ensure the protection of the environment from major accidents, those of primary importance for the major hazards industries are the Control of Major Accident Hazards (COMAH) regulations (UK Government, 2015), the UK implementation of the EU Seveso directive. Regulation 2 of COMAH defines a Major Accident and the HSE COMAH guidance document (L111) (HSE, 2015) gives further explanation.

The past decades have seen an increasing regulatory push for MATTEs to be considered on a par with safety hazards. This has generated legislation such as the Seveso III directive and national guidance, along with sustained regulatory focus. The UK has also revised its sentencing guidance for environmental harm and allows for unlimited fines to be levied against those deemed negligent in their duties to protect the environment (Sentencing Council, 2014).

In 2013, the Chemical and Downstream Oil Industries Forum (CDOIF) Joint Regulator-Industry working group produced its namesake guidance for assessment of Environmental Risk Tolerability in COMAH Establishments (Chemical and Downstream Oil Industries Forum, 2016), based upon the DETR guidance from 1999 (DETR, 1999). Despite lack of formal ACOP status, the CDOIF methodology has quickly become the *de facto* approach for assessing MATTE potential at COMAH sites, due to its comprehensive framework for assessing environmental harm; guidance suggests it can be applied outside of the COMAH regime (Energy Institute, 2015), as has been done in the US (Manton, 2016).

A requirement of both the COMAH regulations and the CDOIF ERA guidance is to undertake a demonstration that the environmental risk has been reduced to a level that is either 'broadly acceptable' or 'As Low As Reasonably Practicable (ALARP)'. Further guidance on these definitions are given by the HSE (HSE, 2001). In practice, this requires a qualitative or quantitative demonstration that the cost (time, monetary, operational disruption etc.) is grossly disproportionate to the benefit gained from further improvements. Prior to this assessment, the CDOIF ERA methodology requires a consequence and frequency assessment to allow the aggregated environmental risk to be determined. The level of detail and quantification in these assessments should be proportionate to the level of risk inherent in the establishment.

When compared against ALARP justification for safety MAH, MATTEs have proved difficult to standardise for a few reasons, not least:

- Consequences are more complex to predict as the behaviour in certain environments is less well understood than traditional safety hazards: weather, tidal and seasonal effects can significantly influence the ultimate consequence;
- A large number of potential receptors would have substantively different responses to the same incident (e.g. avian species, ancient woodland, aquatic species, and historic structures such as Stonehenge could theoretically be exposed to the same substance within the same consequence assessment);
- Fauna-based receptor populations are harder to predict than human populations;
- Toxicity responses can vary substantially between species and by exposure route;
- Additional pathways must be considered (groundwater, surface water, atmospheric, bioaccumulation, soil/sediment, etc);
- Harm duration must be considered, and natural recovery is difficult to estimate empirically;
- The wide variety of potential accidents is hard to directly compare in terms of risk; and
- The ultimate cost of a MATTE is hard to accurately predict given these uncertainties, and the bespoke nature of most environmental restoration agreements.

This paper addresses the final two points. While it may fall short of providing a plug-and-play methodology for ALARP demonstration for all foreseeable MATTEs, it highlights key uncertainties and provides insight into the range of costs based on data available in the public domain for environmental incidents. It also provides a robust methodology for undertaking CBA on environmental major accidents.

Basis

This paper is structured into several sections detailing different areas of work undertaken. The remainder of this section sets out the assumptions and approach to this study.

We start with a review of how environmental risk should be considered by comparison to safety metrics.

Then, we propose Implied Cost of Averting a MATTE (ICAM) as a potential metric to decide on whether additional risk reduction measures should be considered grossly disproportionate when determining if the risk is ALARP.

Next, we review available incident data to consider a) the relative prevalence and severity of different types of MATTE and b) the different costs associated with different types and severities of MATTE.

Finally, we present a worked example for a fictional site to demonstrate the concepts discussed in the paper.

What are the costs?

Environmental accidents are complex events. There are many potential sources of cost that are directly or indirectly attributable to a major accident. For the purpose of defining the cost of an accident in this paper, we include the following:

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

A number of potential cost types that could be directly or partially attributable to an accident, these are listed in Table 1 with reasons for their exclusion.

Table 1 Excluded Costs

Cost Type	Examples	Reason for exclusion
Asset loss	Cost of repairing or replacing the assets damaged in the accident	Site specific and not correlated to the level of environmental harm.
Production losses	Cost of lost production or downtime	Site specific and not correlated to the level of environmental harm.
Reputational losses	Reduction in share price, increased difficulty or cost in accessing finance, increased insurance premiums	Hard to quantify and not definitively attributable to an accident; also it is weakly correlated to the level of environmental harm.
Regulatory costs	Increased regulatory focus/inspections, cost of required improvement actions	Dependent on the nation state, size and status of operational establishment, rather than the level of environmental harm.

Some of these costs can be substantial, but they are generally both hard to quantify and are not correlated to the level of environmental harm. This is not to say they should not be considered when making risk judgments but that they should be calculated for each establishment as they are more dependent on local/company specific factors rather than the type of incident.

HSE states that issues such as reputation, share price and customer base 'are not ones that HSE would require a duty holder to consider' but that these issues 'often play a significant part of any judgement on whether to invest' (HSEc, n.d.).

In fact, these costs can dominate the total costs in some extreme cases. For example, in the 3 months following the Deepwater Horizon disaster, BP's market capitalisation fell by £46bn to £48bn, a fall of 49%. Coincidentally, £46bn was also the estimated total cost to BP that was declared to shareholders in 2016 (Financial Times, 2016). This value has since been recovered with BP now worth £96bn; however, with an annualised growth rate of less than 0.5% it trails far behind near rivals Chevron and Shell at 4.7% in the 6 years following the disaster. Obviously, there are many factors influencing the stock market, so these fluctuations can never be definitively assigned, but it would be entirely wrong to suggest that the Macondo disaster had no effect on BPs profitability beyond direct costs. Interestingly, in the three months following the spill, the other supermajors all experienced a reduction in market capitalisation by 4-19% representing a further £79bn loss of value borne by oil and gas investors.

Assumptions

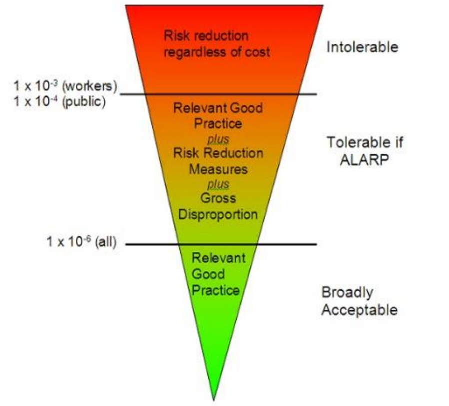
The following methodological assumptions were made during the study:

- All values within this paper are presented as 2017 GBP. Where these were reported in previous years and other currencies, they were factored based on inflation in their base currency and then converted based on the prevailing exchange rate between the initial currency and GBP in November 2017. For Euro-based values, the EU Harmonised Index of Consumer Prices (HICP) was used to define inflation across the Eurozone; for those which predate the Euro, an average of 6 western European consumer price indices was used to reflect the composition of the EU/EEC at that time.
- The assessment of MATTEs was undertaken in line with the CDOIF guidance (Chemical and Downstream Oil Industries Forum, 2016) and for ease of comparison between various events. The CDOIF methodology entails assignment of a harm level from A to D based on a 4x4 matrix of harm severity against harm duration for unmitigated events. While this is a UK-based methodology, it is broadly applicable and transferable, and allows greater consistency when grouping events.
- Most of the available incident data fails to provide a complete picture to assess the potential extent of damage and associated costs of clean-up and restoration. Specifically, where harm duration data is unavailable, the latest Energy Institute guidance (Energy Institute, 2017) was used. Where this was unsuitable due to the nature of the incident, the author's professional judgement or contemporary reporting by expert/regulatory bodies was used. In the absence of this, a rule-of-thumb was applied that the severity/duration of harm would be one CDOIF category higher than that which was observed considering the clean-up efforts engaged.
- Data on share prices and market capitalisation was sourced from www.ycharts.com on 25th November 2017.
- CBA under COMAH requires discounting of future costs and benefits when compared to current monetary values. As this paper is solely concerned with the theoretical derivation of methodology, discounting has *not* been considered, for simplicity and brevity while defining the methodology. If this is to be applied, then the appropriate HSE guidance should be followed (HSEa, n.d.).

Assessment Metrics

Comparison with safety metrics

Figure 1 Individual Risk Tolerability (HSE)

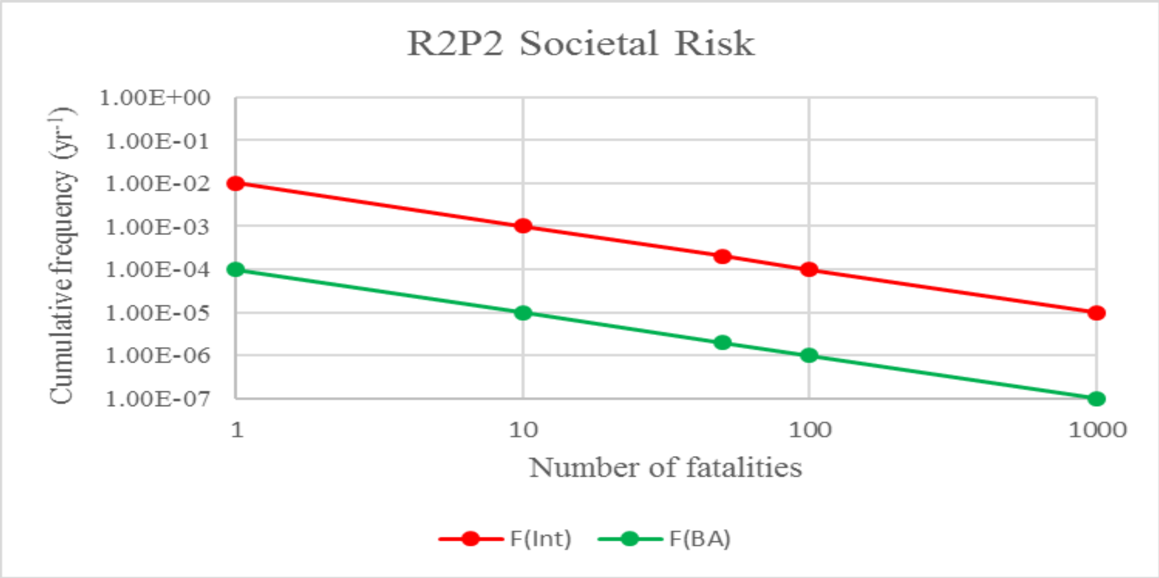


Various safety metrics are in use across Europe and tolerability benchmarks also vary. The UK requires consideration of both individual and societal risk to ensure that risk levels are within either tolerable or acceptable limits. Individual risk is the likelihood of harm to a specific individual and societal is the risk of harm to any individual within a population. Figure 1 is reproduced from the HSE guidance on ALARP in COMAH (HSEb, n.d.). Individual risk works well as a concept to protect human life. However, it does not work well for environmental receptors: all the receptor harm parameters in CDOIF are suitable for a societal rather than individual consideration. Our approach to assessing environmental risk is similar to the societal risk approach, i.e. the relevant fact is that we kill X number of fish species Y within river Z: it does not matter which specific fish are affected or that if we adversely affect 2 km of a stream (unless otherwise designated), it does not matter which 2 km stretch is affected.

For societal risk within the UK, the *de facto* standard (at least for COMAH) is Reducing Risks Protecting People (R2P2) (HSE, 2001) prepared by HSE in 2001. Paragraph 136 of this document states 'the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency is estimated to be more than one in five thousand per annum'. In practice, this value is referred to as the 'R2P2 point. It has been applied to the aggregated risk from a site and has been extrapolated using FN curves with a gradient of -1 on log-log axes to assess tolerability on a societal risk basis for events other than 50 fatalities (HSEb, n.d.). The broadly acceptable level of risk is considered to be two orders of magnitude lower; this is in line with individual risk criteria for workers. It should be noted that this allows for no scale aversion, i.e. an event that results in 10 fatalities is equally acceptable as 10 single fatality events, whereas if scale aversion was applied, the larger single event would be less favourable. This approach was later confirmed by HSE in paragraphs 34-35 and Figure 4 of (HSEb, n.d.) and suggests PLL as the preferred metric (also referred to as Expectation Value (EV)).

The FN curve showing the R2P2 point and the intolerable and broadly acceptable limits are shown in Figure 2. When trying to compare the CDOIF MATTE levels to fatality tolerability, it should be noted that while human harm is essentially a continuous scale with ever-larger events becoming less favourable, the CDOIF criteria allow for 5 discrete categories (SubMATTE, A, B, C, D) of which the categories at either end (SubMATTE & D) are essentially open-ended.

Figure 2 Societal Risk Tolerability FN Curve



The tolerability criteria for the MATTE levels given in the CDOIF guidance was compared against various points extracted from the R2P2 FN curve and these are given in Table 2. It is immediately apparent that there is clear agreement between the two systems i.e. a MATTE C is equally tolerable to a 100-fatality event caused by industrial processes. The discontinuity occurs, however, if forced to consider a 99-fatality event: under the FN curve, this would have an intolerable risk threshold of 1.01E-4 per year, whereas CDOIF would consider the equivalent event a MATTE B and have an intolerable threshold of 1E-3 per year.

Table 2 Comparison of R2P2 and CDOIF Tolerability Criteria

Fatalities	**Societal Risk (y^{-1})**		**MATTE (y^{-1})**		**MATTE Level**
	Broadly Acceptable	**Intolerable**	**Broadly Acceptable**	**Intolerable**	
1	1.00E-04	1.00E-02	1.00E-04	1.00E-02	A
10	1.00E-05	1.00E-03	1.00E-05	1.00E-03	B
100	1.00E-06	1.00E-04	1.00E-06	1.00E-04	C
1000	1.00E-07	1.00E-05	1.00E-07	1.00E-05	D

ICAF vs ICAM

Safety metrics are well established and embedded within industry. Implied Cost of Averting a Fatality (ICAF) in Equation 1 is a simple approach to ALARP decision-making to justify either committing or not committing additional resources on reducing risk.

The use of PLL allows multi-fatality events to be considered while using the same value for a human life as the reduction in PLL rather than IR accounts for the number of theoretical persons killed in the event prevented. Originally, HSE used a Value of Preventing a Fatality (VPF) of £1m based upon the value the Department for Transport used when undertaking Cost Benefit Analysis for road upgrades (HSE, 2001). Since then a value of £1,336,800 was given by HSE in (HSEc, n.d.) based on 2003 GBP. Using Bank of England inflation rates (Bank of England, n.d.), this equates to a value of ~£2m at the end of 2017. This is the value used for this paper and should be considered for demonstration purposes only.

$$ICAF = \frac{Cost\ of\ implementation}{Expected\ Plant\ Lifetime \times \Delta PLL} \tag{1}$$

if $ICAF < DF \times VPF$ then the measure should be implemented

This calculation should be simple to convert for use in an environmental context simply becoming ICAM rather than ICAF, but the individual variables require careful consideration. Equation 2 below contains the following terms which need to be defined: ICAM is a metric that allows direct comparison of new risk reduction measures across the different MATTE levels and to help demonstrate ALARP. The others are further discussed below.

- ICAM – Implied Cost of Averting a MATTE (£)
- ΔPED – Change in Potential Environmental Damage (y^{-1})
- DF_A – Disproportion Factor (unitless) for aggregated MATTE A risk
- VPM_A – Value of Preventing a MATTE A (£)

$$ICAM = \frac{Cost\ of\ implementation}{Expected\ Plant\ Lifetime \times \Delta PED} \tag{2}$$

If $ICAM < DF_A \times VPM_A$ then the measure should be implemented

ΔPED

The change in potential environmental harm is harder to quantify. A direct translation of the methodology used for safety as demonstrated by the HSE (HSEc, n.d.) is not possible. This is because the harm types for safety can be coincident and are pseudo-continuous (theoretically any integer), whereas the harm for environmental incidents are discrete, binary and exclusive, i.e. the safety consequence of an MAH could be 1 fatality, 1 serious injury, 10 fatalities, 1 fatality and 1 serious injury, or any conceivable combination of the two. Whereas a MATTE (affecting a single receptor) can occur at MATTE A through to MATTE D for different receptor categories; but for the same receptor it cannot be a MATTE A and MATTE B simultaneously and neither can two MATTE A's occur from a single incident. In addition, a release can impact multiple receptors and the option should be considered against the receptor with the highest PED.

To avoid potential confusion, it is noted that under the requirement to aggregate risk under CDOIF, if a MATTE B is identified, the mitigated frequency of this event should also be aggregated with all the MATTE As, as well as the MATTE Bs.

Therefore, an environmental metric is proposed, to replace PLL, Change in Potential for Environmental Damage (ΔPED). ΔPED is proposed as a metric which accounts for the difference in tolerability and benefit values of the various MATTE levels and allows different events to be considered in a single metric. To calculate ΔPED, you need to know the DF for each MATTE level (calculated based upon aggregated risk), the VPM for each MATTE level, and the change in frequency at each MATTE level (unaggregated).

$$\Delta PED = \Delta F_A + \frac{DF_B}{DF_A} \times \frac{VPM_B}{VPM_A} \times \Delta F_B + \frac{DF_C}{DF_A} \times \frac{VPM_C}{VPM_A} \times \Delta F_C + \frac{DF_D}{DF_A} \times \frac{VPM_D}{VPM_A} \times \Delta F_D \tag{3}$$

Where ΔF is calculated by multiplying the initial frequency by 1 – PFD, to calculate the reduction in frequency at each MATTE level.

For illustration, consider a scenario where a safeguard affects two events A (1×10^{-3} y^{-1}) & B (1×10^{-4} y^{-1}), the DF_B/DF_A ratio would be 1, and if the VPM_B/VPM_A ratio is 10 and with a proposed safeguard with a PFD of 0.1. The ΔPED would be 1.8 $\times 10^{-3}$ y^{-1}.

Where there are no MATTE A scenarios, Equation 3 can be adapted to use MATTE B as the base event and MATTE B values for DF and VPM can be used when calculating cost benefit in Equation 2 above.

This approach to calculating ΔPED is more complicated than for PLL, as it requires ratios of VPM and DF to be applied when calculating the ICAM. However, this is needed as the VPM may not be linearly correlated with either the tolerability or the extent of harm. This approach also allows direct comparison of measures which are only effective against different MATTE scenarios.

Disproportion Factor

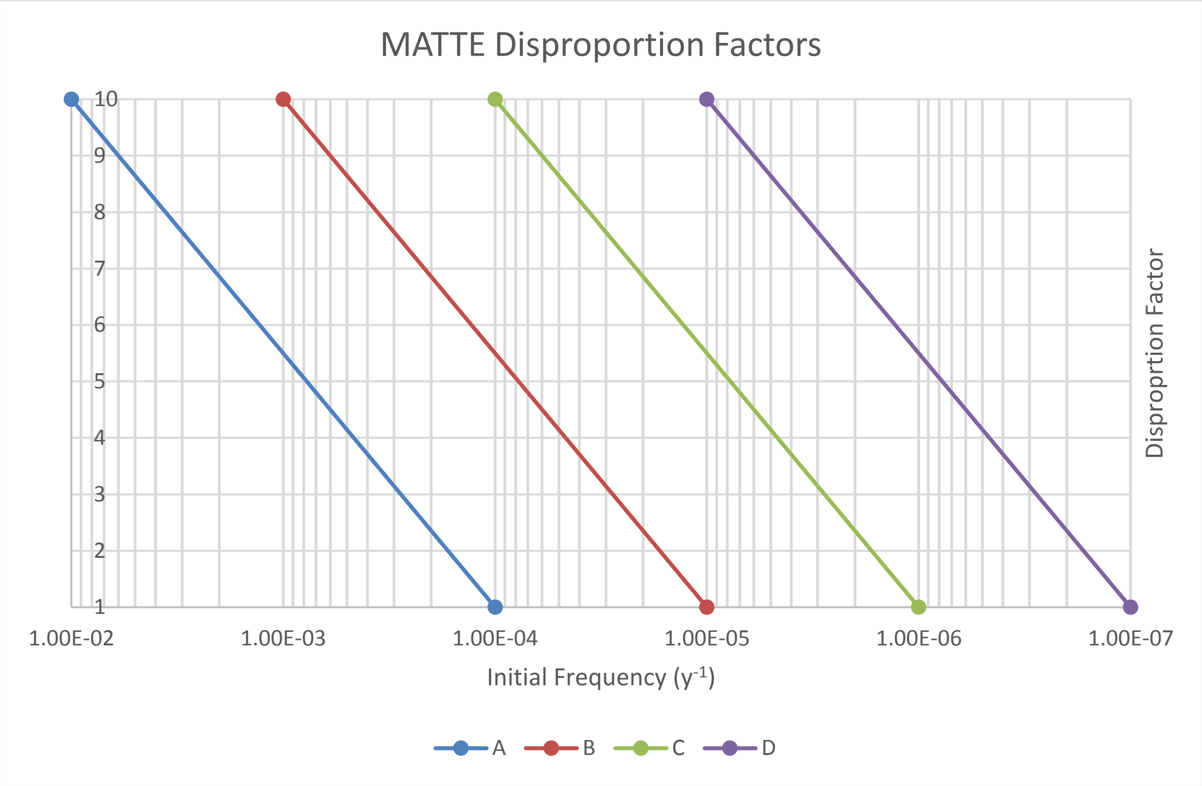
The method for assigning an appropriate disproportion factor is not well defined even for safety: various industries use different metrics but for onshore COMAH, it is generally accepted in industry and by HSE that a factor of 1 – 10 should be used (HSEb, n.d.) (HSEc, n.d.). Some sources state that the DF used should reflect the proximity to the intolerable individual risk threshold, while others state that it should be related to the novelty of the design (HSEd, 2006).

Given that MATTE assessment considers discrete categories of harm with varying tolerability levels, it is deemed appropriate to consider the selection of a DF purely on the basis of proximity to intolerable risk. As the difference in disproportion is already included in the factor of 10 applied to the intolerable/broadly acceptable frequency criteria at each increasing MATTE level, a simple log-linear relationship between the frequency criteria and DF is proposed for each of the four levels of harm, shown in Figure 3Error! Reference source not found.. The equation for each line can be determined using Equation 4.

$$DF = 4.5 \log PED + \alpha \tag{4}$$

Where α is 19 for MATTE A, 23.5 for MATTE B, 28 for MATTE C, and 32.5 for MATTE D

Figure 3 MATTE Level Risk and Disproportion Factor



Value of Preventing a MATTE

Defining the value of preventing a MATTE is the hardest variable to assign. Various resources can be utilised to help define the likely costs for each scenario. Given the variability in clean-up techniques in the event of an accident, there is likely to be a different VPM value defined for each material-receptor-MATTE level combination unless an extremely precautionary approach was taken that accounted for variability amongst substances.

A review of some available data sources is included below:

- *Historic Company Data.* Sites may have access to records of previous spill/clean-up events or access to emergency planning documents that specify contingency funds allocated to clean-up; these would serve as a good base for estimating future requirement.
- *Contractors.* Most sites with substantial environmental risk will have identified contractors who offer emergency response capability beyond the capability of the site itself. These companies will typically focus on environmental clean-up, restoration and remediation and may be able to provide an anticipated per-ha clean-up cost for various response strategies.
- *Industry models.* Several models already exist for estimating the costs of oil spills from vessels and installations to waterbodies. Two such models originate from the USA: firstly, the EPA's Basic Oil Spill Cost Estimation Model (BOSCEM) (Etkin, Modeling oil spill response and damage costs, 2004) which is designed for inland navigable waterways, and secondly the work of Dagmar Etkin and the Oil Spill Intelligence Report (Etkin, Estimating cleanup costs for oil spills, 1997) which considers historic releases of oil from shipping. Finally, a bespoke study was commissioned by Oil and Gas UK and OPOL (OPOL and Oil & Gas UK, 2012). It is noted that the first model has not been validated for the UK context; the second considers the UK as part of a wider European category, and the third is for offshore oil wells.

- *English Partnerships (English Partnerships, 2008)*. Best Practice guidance from the now-defunct national regeneration agency indicates that the required costs of remediating former brownfield land for development range from £50k to £1.73m per hectare even where no specific major accident has occurred. The data is based upon typical remediation required for chronic pollution attributed to historic site use for various types of development.
- *Sentencing Council (Sentencing Council, 2014)*. The UK has published guidance on fines that should be imposed on those making 'illegal discharges to air, land and water'. These are dependent on the level of culpability, category of harm, and size of the organisation, but will typically be in the region of £140k to £3m for a large organisation, or higher for very large organisations and those with other aggravating factors.
- *Regulator Records (EA, 2017) (Environment Agency, 2017)*. The EA publishes a list of prosecutions and enforcement undertakings, but insufficient information is available to map these to MATTE criteria. However, more detailed records may be available in anonymised format to allow better quantification.
- *Public Data.* The remainder of this paper comprises an analysis of publicly available major accident records.
- *Benchmark against fatalities.* If one were to assume that because a MATTE B is equally tolerable to a 10-fatality event in terms of frequency, the value of preventing either event could be considered the same, in practice, this would drive potentially very conservative values for VPM of £2m, £20m, £200m and £2bn for each of the respective MATTE levels (in 2017). However, this method would rely purely on a statistical comparison and divorce the Value of Preventing a MATTE from the actual benefits gained.

The multi-receptor problem

For more complex cases, where multiple receptors can be impacted by the same event, the application of the CBA technique becomes more difficult. This is due to the fact that in CDOIF, there are many different receptor types, while for safety only, effect on humans is considered.

This can be broken down into two main categories:

1. Where the receptor is physically the same e.g. a site that is designated as both a SSSI and a Ramsar wetland or a species that is represented as a particular species, and a reason for designation of an SPA.
2. Where the receptors are physically distinct e.g. impacting a river that then flows into the sea and impacts the marine receptor.

In Case 1, the CBA should be undertaken on the basis of the receptor, which is less tolerable. Where this is not immediately obvious (if they have differing MATTE levels and frequency), Equation 3 can be used and the one with the higher DF is more sensitive/exposed assuming the risk reduction is equally effective for both.

In Case 2, the CBA should be undertaken for each receptor individually and if any of the analysis show that the measure is not grossly disproportionate then the measure under consideration should be implemented. NOTE: The values for ICAM x DF and VPM should not be summed for a single comparison. This could result in an over-optimistic result, where measures that should be implemented are erroneously shown to have gross disproportion.

Previous Accident Data

In this section, a review of open-source accident literature was undertaken including those published by the European Commission, news outlets and state regulators. The purpose of this was to derive general trends in observed consequences for Major Accidents to the Environment, their typical extent and distribution and clean-up.

The primary data source used for this was the eMARS system supplemented by external reports from environmental groups, state regulators and news agencies; due to the large number of incidents considered, it is not feasible to cite all of these supporting studies.

eMARS is the European Commission's electronic Major Accident Reporting System, and is the primary database for the statutory reporting of major accidents within Europe. It is open-access and the event database can be downloaded and manipulated from the website (European Commission, n.d.).

It is noted that given the additional complexity in modelling environmental scenarios, conservatism is likely inherent in most consequence models such that similar releases may be seen to represent lower severities when observed in previous accident data. This is because of a variety of factors which can result in a lower magnitude event such as weather or migration.

Major Accidents by receptor type

As most of the recorded MATTEs concern the release of hazardous liquids (including contaminated firewater) (Nicholas, 2016) to the environment, a subset of the eMARS data was downloaded which considered liquid releases. These were then filtered to remove any duplicate records and incidents which did not affect environmental receptors. This yielded 68 events for analysis. Of these events, some affected multiple receptors, while others affected only one. Sixty-eight events affected 85 receptors, an average of 1.25 receptors per event.

Considering the CDOIF receptor types, 5 receptor types made up the majority of the receptors: drinking water (both ground and surface water sources), widespread land, groundwater, fresh and estuarine water, and marine receptors. There was also a single event which affected a Special Area of Conservation (a site of international importance).

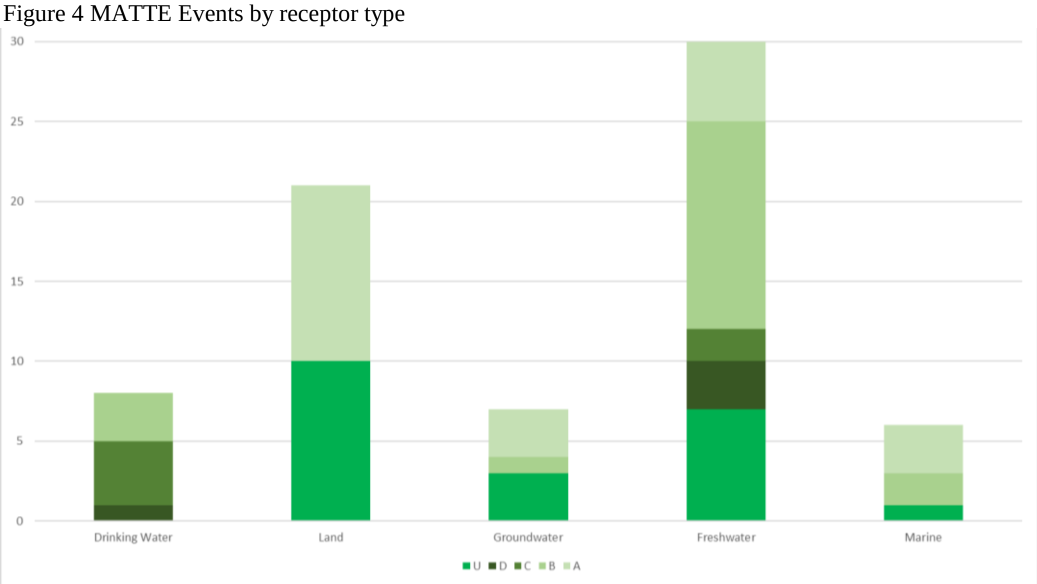
Unfortunately, the structure of the eMARS system is not optimised for quantified analysis: a relatively large number of records had insufficient data for precise assessment. Where possible, the information contained has been extrapolated and supplemented with other materials to allow a MATTE level to be assigned by the author. However, 25% of the records were too incomplete and have been labelled 'U' for unassignable MATTE.

Table 3 Incidents by Receptor Type and MATTE Level

MATTE Level	Drinking Water	Land	Groundwater	Freshwater	Marine	Total
SubMATTE	0	8	1	3	1	13
A	0*	11	3	5	3	22
B	3	0	1	13	2	19
C	4	0	0	2	0	6
D	1	0	0	3	0	4
U	0	10	3	7	1	21
Total	8	29	8	33	7	85

* Note it is not possible for a MATTE A to occur to drinking water as the minimum CDOIF ERA harm duration is long term for any effect on drinking water.

Figure 4 MATTE Events by receptor type



Given the relative rarity of these accidents, caution is advised about drawing any definitive trends. However, several would initially seem to be present:

- Accidents contaminating drinking water, groundwater and the marine receptors combined are less prevalent than those affecting either the freshwater or land based receptors.
- Land-based, groundwater and marine receptors appear to have lower consequence events than freshwater and drinking water receptors as no MATTE events at C or D were recorded in the sample. Speculatively, it could be argued that land and groundwater receptors are physically more difficult for releases to spread over long distance and the marine environment tends to dilute and disperse releases rapidly as there is essentially an unlimited supply of dilution water. However, it is obviously not the case that events on this scale cannot occur as previous incidents are known to have caused harm on this scale. Events such as Fukushima Daiichi, Buncefield and Deepwater Horizon would likely represent a MATTE level D for each of these receptors respectively.
- On the basis of the events that could be assigned, accidents at MATTE A & B level outnumber those at C & D level by a factor of 5:1. It is anticipated that the majority of the unassignable events are smaller magnitude events (A&B), so it is possible that this may rise as high as 7:1. This is in line with the principle of the Safety Triangle and societal risk tolerability, that larger events should be substantially rarer than smaller events. However, the author notes that these accidents are not an order of magnitude less frequent as UK environmental risk tolerability criteria given in CDOIF would suggest is the aim.

Clean-up costs

In order to establish trends in the costs associated with previous incidents, available data was analysed to consider operational experience. The complete eMARS database was downloaded as of 19th Nov 2017, and was filtered to include only those events which reported costs for onsite or offsite effects. This yielded 88 records for analysis; actual monetary values were supplied only for the costs included above (clean-up/ restoration/ compensation/ fines) in 57 cases. Of these, 33 cases also reported the costs associated with asset loss. Where asset loss was not reported, it was assumed that the data was not reported rather than there were no associated costs, so the averages exclude all zero values. It should be noted that the dataset also includes Safety Major Accidents as well as MATTE.

Table 4 Costs reported for all major accidents in eMARS database

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

* Based on 57 clean-up costs and 33 asset-loss events

One substantial outlier was excluded but is worth independent consideration: a detonation at a fertiliser plant in Toulouse, France which resulted in 31 fatalities, over 10,000 people receiving medical attention and substantial contamination of nearby river systems. This event cost approximately £9m in clean-up and £1.8bn in asset losses. It has been excluded as it disproportionately skews the averages such that an average major accident would result in £75m of property damage (a value more than 3 times larger than the next nearest accident).

These 57 events reporting costs were compared against the 85 MATTE events assessed in the previous section. Unfortunately, there was minimal overlap and there were only 8 events that were sufficiently quantifiable to appear in both lists. Four affecting land receptors (3 A & 1 SubMATTE), one groundwater (B), two freshwater (A & D) and one marine MATTE (unassignable). This data set is too small to draw any meaningful empirical conclusions, other than to confirm that MATTE events vary widely in their required clean-up costs (between £31k and £6.3m).

Three observations can be made from this analysis:

1. It appears that dealing with a major accident will cost the operating company £1m to 6m in a typical case for direct costs alone. Given that these are typically reported before final costs are known, and the patchy nature of the recording in the dataset, it is likely that these values are understated, especially when comparing to a UK regulatory environment.
2. There is essentially no correlation between the reported clean-up costs and the asset losses. For those major accidents reporting both costs, the average clean-up cost was a factor of 4 higher than associated asset losses. It is proposed that this value is meaningless given a range of 0.009 to 200. Therefore, asset losses cannot be predicted as a function of the major accidents. This is broadly similar for the dataset containing only MATTEs.
3. It is clear that the publicly accessible data in eMARS is not suitable in its current format to provide a base dataset to generate any form of quantified analysis for MATTE. For example, the Buncefield incident's devastating effect on local ground water stretching for several kilometres where, despite remediation efforts, contaminants were still present a decade later. This would clearly represent a MATTE C or D, but the eMARS record on the environmental effects is limited to the statement '*Early indications are that some product, water and foam flowed off site. Remediation work has commenced and work continues to evaluate the long and short term effects on the environment, on ground and drinking water contamination and effects on the health of persons in the vicinity*'.

The data is highly variable when considered as a whole, as can be seen by the high standard deviation (greater than the mean) for both clean-up and asset loss costs. Most events report with insufficient detail to allow proper understanding of the effect on the environment or the cost impact on the operator. However, it does remain useful for hazard identification purposes, especially when undertaking Hazard Identification studies as it provides a list of previous incidents and their causes.

Worked Example

This section provides a worked example of a fictional site which stores kerosene to demonstrate the application of the metric and variables proposed above. For simplicity, a single receptor example is used, the fictional example borders a freshwater river which holds no national or international designations, so is simply considered under the Fresh and Estuarine Water Habitats receptor type for CDOIF. The site has established VPMs in consultation with the Competent Authority and their emergency response contractor.

Inputs

The site has 3 scenarios which comprise a range of MATTE levels, frequencies and VPMs for each scenario.

Table 5 Initial Scenario Risk

ID	Scenario	MATTE Level	MEF (/yr)	VPM
1	Small spill of kerosene	A	1.00E-03	£100,000
2	Large spill of kerosene	B	9.00E-04	£1,000,000
3	Catastrophic spill of kerosene	C	7.00E-06	£2,000,000

The DF is calculated based upon the aggregated MEF using Equation 4 and is 7, 10 & 5 for MATTE A - C respectively.

Three example potential risk reduction options have been identified for the fictional site.

- A small interceptor costing £10,000 effective at preventing Scenario 1 with a probability of failure on demand (PFD) of 0.1
- Repairs to site-wide tertiary containment costing £30,000 effective at preventing Scenarios 1 & 2 (PFD = 0.1)
- Modifying bunding of kerosene storage tanks costing £25,000 effective at preventing Scenario 3 (PFD = 0.01)

Calculations

The risk reduction offered by each of the measures is calculated as a ΔPED value in Table 6. It has been calculated at the MATTE A level using Equation 3 for each of the safeguards as in this simple case, that was effective and correct. In more complex cases, some sensitivity analysis regarding the aggregation and tolerability of risk across several levels may be needed especially where different substances have very different clean-up costs.

Table 6 ΔPED Calculation

PFD of measure	Scenario			ΔPED (y^{-1})
	1	2	3	
Interceptor	0.1	-	-	9.00E-04
Tertiary Containment	0.1	0.1	-	1.27E-02
Bund	-	-	0.01	9.85E-05

Table 7 undertakes the CBA on the basis of the information provided in Table 5, Table 6 and the input information.

Table 7 Cost Benefit Analysis

Measures	Interceptor	Tertiary Containment	Bund
Cost of measure	£10,000	£30,000	£25,000
Plant lifetime (y)	25	25	25
ΔPED (y^{-1})	9.00E-04	1.27E-02	9.85E-05
ICAM	£444,444	£94,855	£10,157,283
DF_A	7	7	7
VPM_A	£100,000	£100,000	£100,000
Justifiable Spend (VPM x DF)	**£700,000**	**£700,000**	**£700,000**
Result	Disproportion but not Gross Disproportion (Further Assessment)	Implement	Grossly Disproportionate

Conclusions

The CBA results in Table 7 show that on the initial appraisal, repairing tertiary containment is the most cost-effective risk reduction. On comparison of the ICAM and justifiable spend, it should be considered for implementation as it is not disproportionate, let alone grossly disproportionate.

It shows that the additional costs of improving the bund on the kerosene tank are clearly grossly disproportionate despite being the most reliable and preventing the highest magnitude event.

The cost of providing an interceptor capable of preventing MATTE A spills is disproportionate to the benefit gained but only by a factor of 4.4, i.e. less than the required disproportion factor of 7. Equation 3 suggests a disproportion factor of 7 should be used for this scenario and therefore if this is the only option, it should be implemented. However, more detailed analysis may be beneficial as there may be other less costly risk reduction measures. Alternatively, there may be merit in undertaking the cost benefit as an iterative process, as measures already committed to may reduce the 'initial' risk sufficiently for the measure to become grossly disproportionate.

Summary and Conclusion

This paper has presented an approach using the ICAM metric, to reliably benchmark environmental improvement options and select those which should be implemented. ICAM provides an approach which overcomes the complexities of societal and individual metrics, and the discrete nature of criteria for MATTE. As it allows a standardised approach across all environmental events, it prioritises reduction of risk rather than consequence, and it removes the need for any additional benchmarking when prioritising improvement options after the CBA.

Further enhancements could be made for ease of use in more complex situations. For example, improvement options which are effective at protecting multiple receptors from different scenarios are currently not possible to consider without repeating the calculation.

It has also been shown that the public records held in the eMARS database are not suitably quantifiable alone to provide a basis for identification of trends or key variables.

It is clear that further work needs to be done to better understand the cost implications of environmental incidents. In a future paper, the author hopes to take a number of case studies for various receptor types and compare them to the publicly available models for environmental harm.

The author believes that this is the last large 'gap in the market' for CDOIF guidance following the publication of the EI harm duration guidance in 2017 (Energy Institute, 2017). The primary concern arising from a lack of guidance would be a wide variation in practice between those who would take an extremely conservative approach and those who would pursue the most accurate assessment, while reducing safety margins. Both of these approaches have downsides: excess conservatism can lead to a poor allocation of available resources, and too little conservatism may lead to insufficient protection. It should be incumbent on all – not just the regulators – to close this gap and ensure consistent effective protection is uniformly provided.

Given the number of incidents which have occurred and the world-leading technical expertise developed over the past 30-50 years of industrial practice, a myriad of data must lie hidden on servers and in storerooms around the UK, which could be used to ensure more effective environmental protection. Therefore, development of a unifying methodology for assessing the likely cost impacts (clean-up, regulatory, reputational and otherwise) which could provide guidance on 90% of MATTEs would be greatly welcomed. This work should involve the full spectrum of those responsible for protecting the environment, including operators, regulators, contractors, insurers, and environmental risk professionals.

References

Bank of England. (n.d.). *Inflation Calculator*. Retrieved December 5, 2017, from http://www.bankofengland.co.uk/education/Pages/resources/inflationtools/calculator/default.aspx

Chemical and Downstream Oil Industries Forum. (2016). *Guideline - Environmental Risk Tolerability for COMAH Establishments Rev 2.* Retrieved from http://www.hse.gov.uk/aboutus/meetings/committees/cif/environmental-risk-assessment.pdf

DETR. (1999). *Guidance on the Interpretation of Major Accident to the Environment for the purposes of COMAH Regulations.*

EA. (2017). Environment Agency Prosecutions January 2000 - March 2017.xlsx.

Energy Institute. (2015). *Guidelines on environmental management for facilities storing bulk quantities of petroleum, petroleum products and other fuels.* 3rd Edition.

Energy Institute. (2017). *Guide to predicting environmental recovery durations from major accidents. Supporting guide to the Environmental risk tolerability for COMAH establishments guideline.*

English Partnerships. (2008). *Best Practice Note 27 Contamination and Dereliction Remediation Costs.*

Environment Agency. (2017). *Enforcement Undertakings (EUs).* LIT5789.

Etkin, D. S. (1997). Estimating cleanup costs for oil spills. *International Oil Spill Conference.*

Etkin, D. S. (2004). Modeling oil spill response and damage costs. *Freshwater Spills Symposium.*

European Commission. (n.d.). *European Major Accident Report System*. Retrieved December 2, 2017, from https://minerva.jrc.ec.europa.eu/en/emars/accident/search

Financial Times. (2016, July 14). *BP draws line under Gulf spill costs*. Retrieved December 3, 2017, from https://www.ft.com/content/ff2d8bcc-49e9-11e6-8d68-72e9211e86ab

HSE. (2001). *Reducing Risks Protecting People (R2P2).*

HSE. (2015). *The Control of Major Accident Hazards Regulations 2015.* L111.

HSEa. (n.d.). *HSE principles for Cost Benefit Analysis (CBA) in support of ALARP decisions*. Retrieved December 6, 2017, from http://www.hse.gov.uk/risk/theory/alarpcba.htm

HSEb. (n.d.). *Guidance on ALARP Decisions in COMAH*. Retrieved December 3, 2017, from http://www.hse.gov.uk/foi/internalops/hid_circs/permissioning/spc_perm_37/

HSEc. (n.d.). *Cost Benefit Analysis checklist*. Retrieved December 5, 2017, from http://www.hse.gov.uk/risk/theory/alarpcheck.htm

HSEd. (2006). Offshore Installations (Safety Case) Regulations 2005. *HSE IS 2/2006*.

Manton, F. N. (2016). “An "Intolerable" Risk: Applying the UK Environmental Risk Assessment Methodology to Freedom Industries, WV. *AIChE Spring Meeting and 12th Global Congress on Process Safety* .

Nicholas, M. (2016). Environmental Risk Gap Analysis: Major Accident to the Environment Case Studies. *HAZARDS 27, Symposium Series 162*.

OPOL and Oil & Gas UK. (2012). *Oil Spill Cost Study - OPOL Financial Limits.* ISBN: 1 903 003 79 9.

Sentencing Council. (2014). *Environmental Offences Definitive Guidance.*

UK Government. (2015). *The Control of Major Accident Hazards Regulations 2015.* SI 2015 No. 483.