What is the Value of the Environment?

Carolyn Nicholls, Robert Ritchie and Aimee Russell, Risk and Hazard Management Consultants, RAS Ltd., 73 New Crane Street, Chester, CH1 4JE

Following on from an environmental risk assessment, it is often found that the risk is tolerable if As Low As Reasonably Practicable (ALARP). A study is therefore required to demonstrate the risk is ALARP. This should detail other risk reduction measures and determine which of these are reasonable to implement. The decision is often based on engineering judgement and operational feasibility. Where this is not possible, a cost benefit analysis (CBA) can be conducted. One element of a CBA is the cost of environmental damage (or value of preventing it), which requires assigning an economic value to the environment. If the cost of implementing the proposed risk reduction measure is grossly disproportionate to the justified monetary spend to reduce risk, then the measure can be 'rejected'.

In many environmental ALARP demonstrations, a CBA is not necessary. CBAs are often misused, with potentially incorrect values assigned to the cost of environmental harm. However, there are cases where understanding the economics of suggested measures can be helpful, for example when comparing multiple options.

If CBA is to be used effectively in an environmental context, there needs to be a commonly agreed approach. The Chemical and Downstream Oil Industries Forum (CDOIF) Guideline on Environmental Risk Tolerability for COMAH Establishments provides details on how to include the cost of environmental harm in a CBA. However, unlike analogous guidance for CBAs relating to the safety of people, the guideline does not provide a monetary value for preventing environmental harm. This value is a cornerstone of the assessment, but is also the least well prescribed, so the biggest challenge when conducting a CBA. Although literature and other methodologies are available, they are often inconsistent in regards to the parameters provided. Additionally, not all costs you would expect to be associated with environmental incidents are always included. While in others, parameters that you might not expect do appear.

Even if a definitive list and consistent methodology was established, the cost of these parameters varies from case to case. What's more, fines for environmental harm are no longer capped, meaning the fine paid could be vastly different for two cases of similar events and effects.

This is a vast challenge for both those carrying out the assessments, and the decision makers, who may be unaware of the huge variance and dependence on assumptions makes to the advice they are given. Without set figures, even as benchmarks or guidelines, there is the risk of immense over or under-estimation, prompting questions about the value of performing such calculations. At worst this could lead to negligence of the operator if measures that should have been accepted are rejected based on mis-calculated cost. Conversely, measures that could have been rejected may be accepted, leading to huge over-spends and unnecessary investments.

Using past incidents and literature-based research, this paper explores the different aspects and challenges of determining the cost of environmental harm for use in a CBA, with the aim of shining a light on those challenges and the hope of coming closer to some solutions.

Introduction

In the context of the Control of Major Accident Hazards (COMAH) Regulations (HM Government, 2015) and associated guidance such as the Competent Authority's (CA) "*All Measures Necessary" - Environmental Aspects* (CA, 2016), the operators of high hazard establishments are required by Regulation 5 (1) to "*take all measures necessary to prevent major accidents and to limit their consequences for human health and the environment*". Whilst it is not a requirement to perform a quantified risk assessment, it is now an expectation (from the regulator) that the environmental risk posed by an establishment should be assessed according to the approach suggested in the Chemical and Downstream Oil Industries Forum (CDOIF) Guideline on Environmental Risk Tolerability for COMAH Establishments (CDOIF, 2015). This suggested approach has been discussed previously (Nicholls, 2018), but to summarise, it involves a phased investigation of whether there is the potential for any Major Accidents To The Environment (MATTEs), rated A through D with increasing consequence. It then looks at how tolerable the unmitigated risk of potential MATTEs is (i.e. assuming all risk minimising measures fail), based on criteria pitched for a level of risk posed to individual receptors by a typical establishment as a whole. For theoretical unmitigated establishment risk that is intolerable (which in practise appears to always be the case) or Tolerable if As Low As Reasonably Practicable (TifALARP), the mitigated risk then needs to be predicted and the gap between the two 'quantified'. The final part of the process is arguably the most important; the demonstration that risks falling within the TifALARP region are in fact ALARP.

"*In theory, once a prediction of the level of risk is made, an infinite amount of time, effort and money could be spent in attempting to reduce that risk to zero. However, in reality this is not sensible or practicable as organisations do not have unlimited resources to be able to do this, and completely removing the risk would likely involve removing the establishment entirely. The ALARP principle addresses this issue by introducing the idea of demonstrating that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. Demonstration is often made in the form of cost benefit analysis calculations.*" (Nicholls, 2018).

Demonstrating that the risk is ALARP involves the consideration of what further measures could be taken to reduce the level of risk and which of those are reasonable to implement. Working out which suggestions are reasonable is sometimes the difficult part. Some risk reduction suggestions may easily be accepted or rejected at face value, based on judgement and operational feasibility, e.g. putting a sign up to increase the clarity of something out on site is likely to be accepted as a relatively effective and low-cost improvement that does not warrant more in-depth debate. From the point of view of demonstrating that the risk to the safety of people is ALARP, it is not uncommon to encounter a cost benefit analysis (CBA) where it is not so obvious that a measure should be accepted or rejected. Part of this, the justified spend calculation (JSC), determines a justifiable monetary spend for a specified level of risk reduction. A key component of a justified spend JSC is the cost of damage (or value of the prevention of it). From the point of view of people, the HSE provides a monetary value for the prevention of the loss of one life; £1,336,800 in 2003 (Health and Safety Executive, 2003), which inflates to around £2,100,000 in 2018. Therefore, from an environmental point of view, some analogous figure is required to quantify the value of preventing harm to the environment, with one key challenge being that 'the environment' is far broader than 'one (human) life'. If the installation and maintenance cost of a proposed measure is grossly disproportionate to the value determined in the JSC, then the measure can be rejected.

In many environmental ALARP demonstrations, a CBA is not necessary and improvement measures are easily accepted or rejected. However, the temptation and encouragement to use a CBA is higher where the decision is not so clear-cut. In these cases, CBAs are often misused, with little thought about quantifying the harm component. However, there are cases where understanding the economics of suggested measures could be helpful, for example when comparing multiple options relative to one another.

If CBA is to be used effectively in an environmental context, there needs to be a commonly agreed approach, otherwise the results will be meaningless and of no legitimate use; everyone will be doing something different, which is not helpful to operators or the regulator. The CDOIF guideline provides limited details on how to include the cost of environmental harm in a CBA. However, unlike analogous guidance for CBAs relating to the safety of people, the guideline does not provide a monetary value (or set of values) for preventing environmental harm. This notional value is a cornerstone of the assessment, but it is also the least well prescribed, so the biggest challenge when conducting an environmentally focussed CBA.

This paper aims to discuss the different aspect of the costs which contribute to the overall cost of environmental harm, using different parameters identified in literature and past incidents. This paper also explores the challenges faced when attempting environmentally focussed CBAs, with the aim of shining a light on those challenges and coming closer to some solutions, or at least a way forward. This is done by considering the economic costs in two aspects; firstly, the economic costs associated with a spill are discussed. This includes some of the parameters listed in the CDOIF guideline, such as the cost of clean up and site restoration. Secondly, consideration is given to the economic value of the environment. The environment has some economic value in regards to resources provided, as well as non-value uses.

Economic Costs Associated with Environmental Harm

Section 5 of the CDOIF guideline introduces CBA with a statement that the existing guidance on CBA for ALARP demonstration, from the point of view of safety to people, is equally applicable to environmental risk as it is to people. It then very briefly mentions disproportion factor, benefits, costs, discounting rates and evaluation of environmental remediation. The section on the evaluation of environmental remediation suggests that company-specific costs should be used where available and then provides a list of what may be helpful when estimating a value to use for the prevention of harm to the environment. This list includes, but is not limited to, pre- and post-accident baseline data, scope of remedial work, necessity for temporary facilities and utilities, removal, storage and treatment of contaminated material, clean up and restoration, civil liability claims (e.g. loss of fisheries, impact on tourism, loss of abstraction) and environmental fines. This list alone introduces numerous variables, within each of which there will be multiple contributing factors. Based on these variables, the same sized spill at two locations, or event one location at different times of the year could result in huge disparity in the economic cost of the spill

This section explores a range of factors that feed into the economic costs of environmental harm in order to illustrate the complexity and huge challenge in trying to get to an easy to use set of numbers. The focus is primarily from the point of view of liquid chemical spills coming into direct contact with environmental receptors. It should be noted however, that it is theoretically possible for a MATTE to occur not only from liquid spills, but also due to the damage caused by the overpressure from an explosion, by the thermal radiation of a fire and as a result of an atmospheric dispersion of a toxic substance.

The economic costs incurred after a spill can be both direct and indirect, and the overall costs depend on factors such as time taken to clean-up and restore the environment, the size of the event and the use of the areas affected (Health Protection Agency, 2012). Direct costs link to the cost of the clean-up and removal of waste products, whereas the indirect costs include costs such as relocation fees, infrastructure costs due to closed transport links, loss of tourism and impacts on the consumer market (Health Protection Agency, 2012).

As shown in Figure 1 below, there are many factors which influence the economic cost of a spill. The use of a single parameter may result in the over or under-estimation of what an event would cost (White & Molloy, 2003). It may not always be the case that all the aspects discussed below will be affected in every spill. For instance, fisheries will not be affected if a release only impacts agricultural land and soil.

Monetary values reported in subsequent sections have all been inflated, and where applicable exchanged, to 2018 GBP in order to allow comparison between different cases. Note, the values where exchanged from the year in which they were provided, which may not always correspond to the year the incident occurred. Exchange rates have been taken from the following references: HM Revenue & Customs, (2019), Antweiler, (2018) and OFX, (2017). Inflation rates have been taken from the following references: Bank of England, (2019).

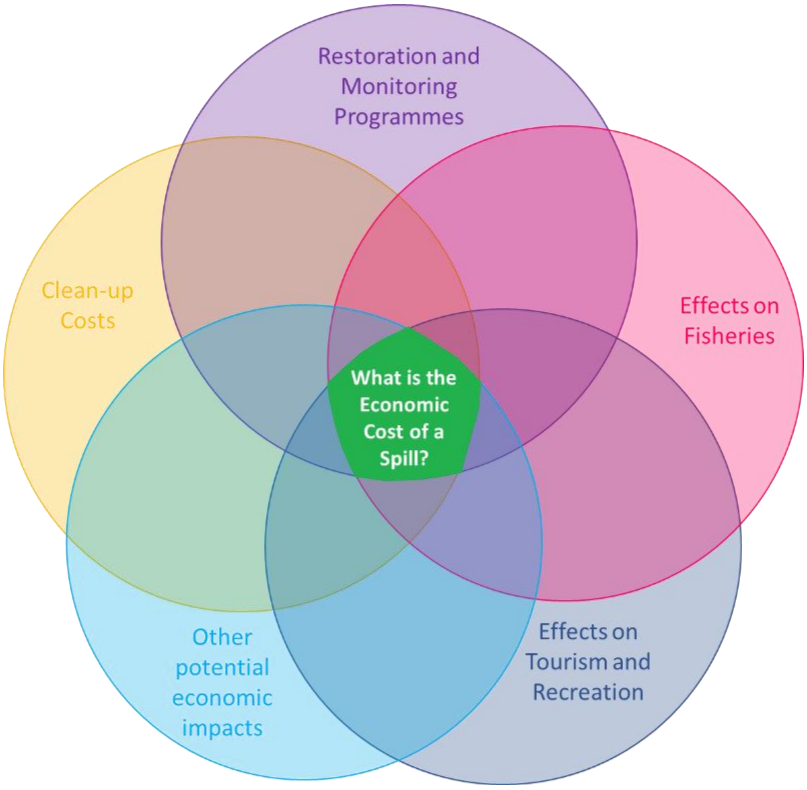

Figure 1 - Factors influencing the economic cost of a spill

Fines

Environmental fines are listed in the CDOIF guideline as a parameter which should be included in determining the cost of environmental harm (CDOIF, 2015). The following discussion of factors that contribute to the magnitude of environmental fines is based on information from the Sentencing Council (Sentencing Council, 2014). The nature of the offence will determine the baseline for the magnitude of the fine. This is split into two categories; culpability and harm. The culpability of the operator is grouped into deliberate, reckless, negligent and low or no culpability. The definition given for deliberate and reckless include the failure of organisations to put in place the systems which could be considered reasonable to avoid the event. The environmental harm categories are split from 1 to 4, with 1 being the more serious and 4 being minor. The organisations responsible are also required to provide accounts for the previous three years to determine the financial status of the company, with the turnover used to determine which category the size of the company falls into, ranging from micro (<£2 million) to large (£50+ million). A category is also given for very large companies, which should be used where the turnover or equivalent of a company grossly exceeds a large company. The starting point for the fine is greater for larger companies, for the same offence level, than it is for smaller or micro-companies. The guidelines also give factors which should increase or decrease the fine. Factors which increase the seriousness of the event, and thus the fine, include considerations such as; previous convictions, repetition of incidents, history of non-compliance, the presence of sensitive receptors surrounding the event and where an offence was committed for the financial gain of the organisation. Factors which could reduce the seriousness of the event include, but are not limited to; companies that have no previous or relevant/recent convictions, can show they have taken remediation steps, have already paid out compensation and have little or no financial gain, the company reported the event, have co-operated with the authorities and accepted responsibility. It is important to note however that as of March 12th 2015, there is no longer a cap on the fine which can be given if prosecuted under criminal law (Coxall & Hardacre, 2018).

Due to the various parameters and considerations listed above, the fines given to a company can vary greatly. The following table provides some examples of fines which have been received by companies following chemical and oil spills. Both the 2005 and 2007 kerosene oil spills received similar fines, but involved different spill volumes and consequences. Although both spills affected groundwater, the Milford Haven spill affected a larger area, which also resulted in other receptors, such as a nearby stream, being contaminated (Institution of Chemical Engineers, 2008). In both cases, there was a delay in detecting and isolating the releases, which would increase the fine using the parameters listed above (Brownfield Briefing, 2010; Water Briefing, 2010; Institution of Chemical Engineers, 2008; Sentencing Council, 2014). Milford Haven is also a Special Area of Conservation, which is covered as an additional parameter listed above. However, the resulting fines were similar, even though one event had a more severe consequence and resulted in a larger loss of containment. The parameters and variabilities of fines make it difficult, if not impossible, to confidently predict what the resulting fine from an incident may be. This is further complicated by fines no longer being capped, which means the maximum fine for the company's size could not be used as a conservative estimate for calculation purposes.

Table 1 - Fines for a selection of spills to ground or surface waters

Year	Location	Substance and Volume Spilled	Main Receptor	Fines (£ 2018)	Reference
2012	Orton Mere	Pesticides, 5 m^3	Surface Water	£56,500	(BBC News, 2013)
2007	*Heathrow Airport*	*Jet A1, 139 m^3*	*Groundwater*	*£50,400*	*(Water Briefing, 2010)*
2005	*Milford Haven*	*Kerosene, 653 tonnes (777 m^3)*	*Groundwater*	*£42,600*	*(Institution of Chemical Engineers, 2008)*
2005	Buncefield	Kerosene and Firewater 67,786 m^3	Groundwater	£1,701,000*	(Clyde & Co, 2010)
1997	Runcorn	Chloroform, 147 tonnes	Groundwater	£519,000	(The ENDs Report, 1998)
1997	Runcorn	Trichloro-ethylene, 56 tonnes	Groundwater	£138,400	(ICIS, 1998)
1996	Milford Haven	Crude Oil, 72,000 tonnes	Surface Water	£1,237,500**	(Davison, 2000)
1991	Stansted Airport	Kerosene, quantity unknown	Surface Water	£237,510	(National Rivers Authority, 1993)
1989	Mersey Estuary	Thick crude oil, 150 tonnes	Surface Water	£2,230,000	(Advisory Committee on Pollution of the Sea, 1990)

* This refers to the environmental fines only.
** The original fine for the Milford Haven 1996 event was £4,000,000 (£6,600,000 in 2018 values) but this was reduced to £750,000 (£1,237,500 in 2018) on appeal.

This all raises the question as to whether companies that are ‘well behaved’ are then able to avoid spending so much on protecting the environment, which would seem an odd situation. Standardisation of these variations is necessary in order to establish a workable figure for the value of the environment.

Clean Up Costs

This section discusses the cost of clean up for groundwater/soil and surface/marine water separately. This is because different methods are required to clean up a spill; not all groundwater/soil contamination will affect surface waters and vice versa. It has been suggested that operators should contact their contracted spill responders and request rough estimates of how much it could cost to remediate a given receptor following a MATTE.

Groundwater/Soil

The cost to clean-up groundwater will vary greatly between different locations. The aquifer properties, the ease with which contaminants can be removed, steps required (i.e. in situ remediation or abstraction to specialised water treatment plants), and the properties of the mixture will all play a role in determining the clean-up cost (Environmental Protection Agency, 2001). The area and depth of a contaminant plume will also impact on the costs of the remediation systems and it is worth stressing that extent and severity of harm estimations made in the risk assessment are just that; estimations based on a series of assumptions.

Groundwater can be treated by active or passive systems. Active treatment typically involves processes such as reagent dosing in more highly engineered systems, an example of which would be water treatment works, and tends to involve the input of energy. Conversely, passive treatment employs natural/inherently present energy such as gravitational potential and biochemical energy in systems that imitate nature (e.g. wetlands and in-situ permeable reactive barriers (PRB)). Generally speaking, the costs involved in active treatment can be higher than those for passive treatment due to the need for repeated reagent purchase and active input of energy. That said, the land area required for passive treatment options can also result in high costs. An active treatment system for groundwater remediation involves the pumping and ex-situ treatment of water to remove contaminants, whilst a passive treatment system could involve the installation of an in-situ PRB (Simon, 2002). The design of an active system will vary from site to site, including the number of boreholes dug, the treatment process used and effluent discharge (Environmental Protection Agency, 2001). All these factors will have a bearing on the cost to clean-up groundwater. Research conducted by the Environmental Protection Agency has shown that the capital costs for PRBs are generally lower than those for active ‘pump and treat’ systems (Environmental Protection Agency, 2001). The differences in the treatment options available can heavily influence the total clean-up cost for a given body of groundwater. Not all options will be workable in all locations, for example a small site won’t necessarily have space or access to land to accommodate some of these treatment methods, so again it is not fixed.

The differences in cost will come with the chosen clean-up method, the time taken for the spill to be remediated and the amount of monitoring required, the size of the spill and the type of contaminant (Environmental Protection Agency, 2001). These systems will also require maintenance and have associated operating costs (Environmental Protection Agency, 2001). It should also be noted that there is not a linear relationship between the size of a spill and the cost to clean it up, i.e. a spill 100 times larger than another will not necessarily cost 100 times more. Research conducted by the EPA (Environmental Protection Agency, 2001), has shown that active pump and treat systems which treated more than 20 million gallons were cheaper, per gallon, than those systems which treated less than 20 million gallons. This is also shown when comparing the clean-up costs for the Milford Haven spill in 2005 and the spill which occurred at Heathrow Airport in 2012.

In 2005, there was a release from a storage tank at a refinery in Milford Haven. This resulted in 653 tonnes (777 m^3) of kerosene being released and contaminating groundwater (Institution of Chemical Engineers, 2008). Milford Haven has a Secondary A bedrock aquifer, which is a member of the Milford Haven Group, consisting primarily of interbedded argillaceous rocks and sandstone. There is a small patch of superficial deposits of diamicton, but most of the site does not have a superficial geology layer (British Geological Survey, 2017; British Geological Survey, 2018). In 2007 an incident at Heathrow Airport resulted in a release of 139 m^3 Jet A1 (essentially kerosene) that also contaminated groundwater (Water Briefing, 2010). Here, there is a principal aquifer in the superficial geology layer. The superficial geology layer is a Taplow Gravel Member, which consists of sands and gravel. The bedrock geology is London Clay and as such does not provide a source of groundwater which can be abstracted for use (British Geological Survey, 2017; DEFRA, 2018). In both cases the aquifer is close to the surface and is considered highly vulnerable. The Milford Haven spill involved 5.5 times more kerosene, but the overall cost was only 3.5 times more and the cost per unit was only 1.6 times more. Both systems used pump and treat methods, opting to remove the contaminant rather than treating in-situ.

Table 2 - Heathrow Airport and Milford Haven clean-up cost comparison

Year	Location	Substance and Volume Spilled	Clean-up method	Clean-up Cost (£ 2018)	Cost Per m^3 split (£2018)	Reference
2007	Heathrow Airport	139 m^3 of Jet A1 spilled	Exploratory boreholes, skimmer kits and rubber hoses.	£1,260,000	£9,065	(Water Briefing, 2010; Brownfield Briefing, 2010)
2005	Milford Haven	653 tonnes (777 m^3) of Kerosene spilled	Pumping of contaminated water through boreholes. Skimmers were used on a local stream.	£4,410,000	£5,676	(Institution of Chemical Engineers, 2008; BBC News, 2005)

There is also a difference in the clean-up costs between light and dense non-aqueous phase liquids (LNAPLs/DNAPLs). This is because DNAPLs do not float on the top of the groundwater body and are therefore significantly less accessible for removal. Instead, they sink and lie on the bottom of the groundwater body, along the aquitard, or underlying impermeable bedrock (CL:AIRE, 2014).

Clean-up of other areas may also be required following groundwater contamination. Ground and surface waters interact and support each other. Groundwater can support riverine systems and other terrestrial systems such as marshes and wetland ecosystems (CL:AIRE, 2014). The 2005 Milford Haven release resulted in contamination of terrestrial areas away from the site due to the interactions between groundwater and the surface. The release resulted in the contamination of farmlands and local gardens, as well as a stream, foul water sewer and an area of the Pembrokeshire shoreline located hundreds of meters from the site boundary (Institution of Chemical Engineers, 2008). This would also affect the final clean-up costs, and it may not be possible to determine whether these areas will be affected until after a spill has occurred.

The clean-up of soil which is not contaminating ground water is generally simpler, and generally costs less, than cases where groundwater contamination has occurred. In 2010 a pipeline compensator broke whilst a ship was unloading resulting in 128 m^3 of paraffin being released (European Commission, 2017). Approximately 88 m^3 of the paraffin soaked into the soil and was siphoned off using four skimming wells (European Commission, 2017). The total costs for the removal and clean-up of the contaminated soil were approximately £520,128 (2018 values) (European Commission, 2017). In comparison, the Heathrow incident was of similar volume but cost significantly more, most likely due to the presence of groundwater. However, large spills that contaminate soil can still be costly. In 2013 a pipeline spill occurred in North Dakota (USA), spilling 3,800 m^3 of crude oil contaminating 29 ha of soil and approximately 3 ha of farmland (Hazardex, 2018). As part of the clean-up the soil had to be dug to a depth of 18 m to remove the oil-tainted layer (Hazardex, 2018). The clean-up of the soil took five years, costing an estimated £69.2 million (2018 values) (Hazardex, 2018).

Although sites should have emergency response plans (ERPs) in place which detail what they plan to do in the event of a spill, the various factors make it difficult to predict the final costs. This makes it hard when conducting a CBA as the clean-up costs are one of the most significant and variable factors. The potential for additional work, such as treatment systems or a change in the method used could result in unforeseen costs, which would not have been applied when determining the cost of remediation. Quotes from reputable clean-up companies would help in determining the predicted clean-up costs for a site based on the information available. However, different clean-up companies will have different rates, and even within the same organisation, there may be better business rates for some clients in comparison to others. This means that two nearby sites, theoretically contaminating the same receptor with the same substance and volume could receive two completely different clean-up cost estimates.

Even when using past incidents, there would be the potential to over or underestimate the cost. Take the Milford Haven and Heathrow Airport examples. Using the cost per cubic metre for Milford Haven and applying this to Heathrow Airport, the clean-up cost would be approximately £789,000 (£471,000 cheaper than in reality). Vice versa, applying the cost per cubic metre for Heathrow Airport to Milford Haven resulted in a clean-up cost of approximately £7,043,000 (£2,633,000 more expensive than in reality). In regards to Heathrow Airport, this could result in measures being rejected rather than accepted, potentially leading to unknowing negligence of the operator. Milford Haven on the other hand would potentially implement measures which were not feasible on the risk basis due to the drastic differences in the cost to clean-up. This poses a problem for CBA, as the clean-up costs can contribute a large proportion of the overall costs of environmental harm.

Surface/Marine Water and Associated Ecosystems

All events will have a baseline cost, in regards to the equipment used, personnel required and other resources, which means in theory that there would be an absolute minimum an event would cost (Etkin, 2000). Similar issues to those outlined above for groundwater apply to the clean-up of surface waters. As with groundwater, even when using past incidents, there is the potential to over- or underestimate the cost.

The location in which a spill occurs will have a significant bearing on the clean-up methods and processes used and the harm caused to the environment (White & Molloy, 2003). Additionally, substances denser than water will cost more to clean-up than substances less dense than water (White & Molloy, 2003). As with groundwater, smaller spills will also cost more per cubic metre than larger spills.

The method used to clean-up a spill is vital in determining the clean-up costs of an event (Etkin, 2000). The following discussion is based on information from the International Tanker Owners Pollution Federation (ITOPF) (ITOPF, 2014a; ITOPF, 2014b). The clean-up method used will be dependent on both the receptor and the substance. Releases can be broadly split into three groups; soluble materials, materials denser than water and materials lighter than water. For substances which are soluble, the released chemical will spread forming a plume which will decrease in concentration with distance from the point source. Most chemicals will disperse rapidly and are not visible. These plumes can be neutralised, flocculated, oxidised or reduced by adding other chemicals, which in confined water bodies, and with permission, can be successful if applied appropriately. It should be ensured that any method used does not cause additional harm to the environment which could result in further clean-up costs. Oil and chemicals that float on the surface of the water should be using clean-up methods such as the use of booms, vacuum trucks, skimmers and sorbents can be deployed. It should be noted, with chemical releases, additional technologies such as IR or UV aerial surveillance and satellite imagery may be needed to locate the slicks which are not visible to the naked eye. If this is the case, then additional costs may be incurred for these surveys. For oil and chemicals which sink, mechanical dredgers and pump/vacuum devices can be used in shallow waters or along the shoreline. In all cases, man power will be needed to help clean-up the oil from the surface of the water, and along riverbanks and shorelines. Flushing can also be used to help clean-up oil which is stranded, buried or located in sensitive areas, including flora and fauna, or along flood defences and jetties. This method is gentler, reducing the potential for additional physical damage to the affected area. During the later stages of clean-up, once the bulk and heavy oil material have been removed and/or treated, additional methods can be used to clean-up the remainder of the spilt substance. These include washing, ploughing, wiping, sieving, bioremediation and natural cleaning. Natural clean-up is the cheapest method, whilst manual clean-up is the most expensive (Etkin, 2000). In practice though, most clean-up methods use multiple options, but the preferred options should be identified in site ERPs. That said, whilst preferred options can be specified, in the event of a real spill, people will have to think more on their feet and the current environmental factors etc will change what is actually done – things are more dynamic.

Consideration also needs to be given to the clean-up of the surrounding ecosystems which are supported by the surface/marine water. External agencies will likely be used for the clean-up of contaminated birds. These agencies will have their own costs which will be passed on to the company responsible for the spill and which will include any expenditure such as staff time, accommodation, travel and expenses, the disposal of dead birds to suitable laboratories or facilities, PPE and any equipment and cleaning materials used, and the analysis and publication of any research which has been conducted (Camphuysen & Heubeck, 2007). Any coastal/riverine defences will also need to be decontaminated alongside any affected boats, jetties and fishing equipment (IPIECA, IOGP, 2015).

As discussed for groundwater above, all sites should have ERPs which detail what clean-up methods they will used in the event of a spill. Companies can provide quotes for the cost of clean-up, but differences in rates between the sites and the spill companies could result in the same receptor having different clean-up costs. However, these could provide information on the preferred clean-up method, which may provide a better estimate for the receptor of concern. Additionally, the time of year can have a major impact on the effect a spill has (White & Molloy, 2003).

There are high levels of variation which can occur during a spill, which can make it hard to determine what the actual clean-up cost would be. Additionally, sites may only have plans in place for the clean-up and containment of the immediate spills, and not for the wider picture and associated costs. The number of parameters for the clean-up costs, for both surface and ground water, can make it extremely difficult to predict an ultimate cost.

Environmental Restoration and Monitoring Programmes

Following a spill and once the contaminant has been removed, steps should be taken by the company responsible to restore the environment, which will likely require the help of outside contractors. Where soil is contaminated, monitoring of groundwater should be conducted to ensure that this waterbody source has not been contaminated (Health Protection Agency, 2012). The CDOIF guideline also states that when conducting a CBA, consideration should be given to the costs associated with restoring the natural environment, such as fish restocking. Under the environment damage regulations, the persons responsible must remediate against the damage, where there is failure to do so, the regulatory authority can serve notices setting out the work which should be undertaken (Coxall & Hardacre, 2018).

As with clean-up, it is difficult to predict the cost of restoration. There are many factors which influence the impact a spill has on the wider environment. For example, the time of year will affect the level of remediation needed. For instance, a smaller spill which occurs during the breading seasons will likely have a larger impact than a larger spill that occurred at a different time of year (ITOPF, 2014c). Another consideration is the species which are affected; for example, penguins are more resilient to oil spills, and are more likely to survive the cleaning process, in comparison to other bird species (ITOPF, 2014c). Additionally, some ecosystems, such as salt marshes, are best left to recover naturally without human intervention (ITOPF, 2014c). So, although there would be no direct costs, i.e. cost of equipment, seeds etc, there would be an indirect cost associated with the loss of ecosystem during its recovery time.

The time it takes for ecosystems to be restored, and how easily they can be restored, is dependent on the type of ecosystem. Mudflats for example could take between 1 and 10 years to restore; how easy it is to restore the mudflats is dependent on the position within the tidal frame (NeBhover, 2009). In comparison, reedbeds and saltmarshes may take 10-100 years to restore with ancient woodlands taking 200 to 2,000 years to fully restore (NeBhover, 2009). In some cases, full restoration may not be possible with the best outcome being to rehabilitate the site, but even this process will be slow (NeBhover, 2009). This would result in increased costs for the company responsible for the clean-up and restoration of the site. In regards to the CBA it is difficult to tell how badly an ecosystem will be harmed until after the event, making it different to predict what restoration is needed and therefore the estimated cost of the recover/rehabilitate the ecosystem.

Additional Costs

This section covers other potential costs which could be incurred in the aftermath of a spill. It is important to note that not every spill that occurs will affect the categories listed below. For example, a spill-affected groundwater which is located far away from a surface water body is not expected to impact recreational or commercial fisheries. Similarly, a spill from a pipeline running through the middle of a field, which is surrounded by farmlands is not expected to impact tourism. The inclusion of these factors will need to be considered on a case by case basis, considering the receptors affected and their wider uses. However, it is this increasingly obvious need for case by case basis considerations of a vast number of variables that may become a prohibitive barrier to meaningful and legitimately useful results from CBA calculations.

Recreational and Commercial Fisheries

Contamination of surface and marine water bodies has the potential to cause severe disruption to both recreational and commercial fisheries. Spills can result in a loss of stock, contamination of fishing equipment which will need replacing or cleaning and fishing exclusion which result in a loss of products sold (commercial) and a loss of fishing licenses (recreational) (IPIECA, IOGP, 2015; ITOPF, 2014d). Additionally, there is potential for wider economic damage in relation to the seafood trade. Consumers may be reluctant to purchase seafood from areas affected by, or near to, the source of contamination, even if there is no actual contamination of the products (IPIECA, IOGP, 2015; ITOPF, 2014d). The economic loss associated with this is however difficult to quantify, as it requires that both loss of sales and reduction of prices have occurred as a direct result of the spill (ITOPF, 2014d).

After a spill has occurred, the direct losses can be calculated by using the processes of counting and weighing the affected fish and seafood species (ITOPF, 2014d). This information is then compared against projections and market costs to determine what the sale price would be, the cost of staff wages, food and fuel is then subtracted alongside the degree of natural mortality that occurs within normal operations (ITOPF, 2014d). However, if the release has yet to occur, how can the number of fish that will be affected and the associated costs be predicted?

In 2001 the EA published a report into the economic evaluation of inland fisheries. The report provides a series of tables which detail the cost per acre or square meter for different types of fish and different surface water bodies. The report states that the total value, in England and Wales, for still water fisheries, is greater than the value for moving or canal water fisheries; approximately £3.1 billion in comparison to £1.8 billion (2018 values) (Environment Agency, 2001). Additionally, for the year 2016-2017 there were over one million rod licences sold, with a total cost of approximately £20.7 million (Environment Agency, 2018). The loss of fishing in any of the UK rivers or waterbodies could result in a reduction of fishing rod licences sold leading to a lower income. A portion of this income is used to help restock fish levels and improve fisheries (Environment Agency, 2018). Fishing restrictions, could also result in a loss of income for local fishing clubs. The use of fishing licences costs and membership fees costs could provide a suitable value for determining the loss of income from affected fisheries; however, this would not include the loss of fish itself. Additionally, this would also rely on suitable and accurate data regarding the number of fishermen who fish in the predicted affected areas.

The 2012 pesticide spill into the River Nene in Orton Mere resulted in thousands of fish dying along a 30 mile stretch of river and affected the start of the cockle fishing season in The Wash (Wisbech Standard, 2013; Wisbech Standard, 2012). The resulting spill cost hundreds of thousands of pounds to the Greater Wash Finishing Industries Group, with local cockle fisherman claiming to have lost more than £11,000 (2018 values) each (Wisbech Standard, 2013). Additionally, the local angling association had to cancel fishing matches, leading to a cost of just over £1,000 (2018 values) (Wisbech Standard, 2013).

Tourism and Other Recreational Activities

Oil and chemical spills can have an adverse effect on the tourism industry. The Milford Haven (1996) disaster resulted in a reduction in tourism to the area affected (Environment Agency, 1998). Tourism losses can affect a wide range of businesses and attractions such as reduced income for national parks or heritage sites, loss of business for hotel owners or camp sites (IPIECA, IOGP, 2015; ITOPF, 2014e). Additionally, temporary closures of some attractions may be required so clean-up can be conducted (IPIECA, IOGP, 2015). Heavy media attention may also cause disproportionate harm to the tourism industry, and could result in a negative image of nearby areas which remain unaffected (IPIECA, IOGP, 2015; ITOPF, 2014e). This could however result in a boost in tourism for other areas not affected by the release (ITOPF, 2014e). On the other hand, where clean-up and resources are required from outside of the local area, accommodation and sustenance will be needed by workers (IPIECA, IOGP, 2015). Additionally, some releases can attract so called ‘disaster tourism’, which involves tourism to areas in the aftermath of, and specifically because of, a disaster (Environment Agency, 1998).

The overall cost for the tourism impact from the Milford Haven Sea Empress spill (1996) is predicted to have been between £44,160,000 and £82,800,000 (2018 values) (Environment Agency, 1998). However, on review of the impact on tourism across the Pembrokeshire region the Wales Tourism Board concluded that overall tourism performance remained relatively unchanged, although there were some significant impacts to individual operators (Environment Agency, 1998). This included a water-based activities company which recorded a loss of half its 1996 turnover in addition to losses in 1997, albeit smaller than those losses in 1996 (Environment Agency, 1998).

The 2004 crude oil release into the Delaware river resulted in an estimated 41,709 trips along the river being affected by the spill; which equates to an estimated loss of value of approximately £1,117,735 (2018 values). In comparison, the Milford Haven (1996) release resulted in a loss of recreational activities resulting in a cost of between £1,749,838 and £5,234,358 (2018 values) (Environment Agency, 1998). Whereas the Gulf of Mexico oil spill (2010) resulted in a cost of approximately £332,267,879 (2018 values) to restore the recreational losses, and provide and enhance recreational activities as a result of the oil spill (United States Department of Justice, 2016).

The effect on the tourism industry/recreational actives is likely to be highly dependent on the receptor affected and the time of year the release occurs. Releases just before or during the height of the tourism season for an area will likely result in larger losses than events which occur outside of tourism season (ITOPF, 2014e). There is also likely to be a boost in recreational activities during the tourism season, although it is important to note that recreational activities can occur in areas which do not experience high levels of tourism. Additionally, losses affecting recreational activities will only be applicable where recreational activities are located. For example, a release which affects agricultural land only will likely have a lesser, or no, impact on recreational activities than a spill which affects a river that hosts outdoor pursuits centres and which uses the water body for canoeing, kayaking or rowing purposes. Such pursuit centres may also be used by tourists, or schools, visiting the local area.

One problem identified whilst conducting this research is that it is heavily skewed towards the effects of oil releases on coastal environments. The scale of the impact on tourism for releases which affect a small river will likely be smaller than a major oil release that has occurred from an oil tanker. This could pose a problem when determining how the tourism industry might be affected by releases from a site which is not located near major tourism areas, such as a popular coastline destination.

Other Costs Associated with a Spill

Alongside the cost of clean-up, remediation/restoration and loss of recreational activities and tourism, spills can also affect house prices, health and other industries. There are also other associated costs such as research following the spill and compensation to the towns affected.

Releases of oils or other chemicals may result in physical damage to properties and belongings. Following the Milford Haven Sea Empress release (1996), £90,160 (2018 values) was paid out to cover the clean-up of buildings which had been sprayed with oil and to cover the damage that occurred to homes, carpet, clothing, private roads and vegetation (Environment Agency, 1998).

Additionally, spills can have a direct impact on the value of a property. There is a negative relationship between environmental impact and the value of the property, with properties located closer to the spill experiencing a greater effect (Simon, 2001). Even where there is not direct impact on the property itself, there is still a loss in the value of the property due to the heightened awareness that an event may occur; although the loss is significantly smaller than any homes affected by the release. The scale of the spill will also have an impact on how much of the property's value is lost as a result. The effect on the price of properties can occur for years after a release has occurred (Simon, 2001).

Predicting house price fluctuations in the absence of a major accident is difficult enough. Fluctuations occur within the housing market, and it is hard to determine what the actual cost of a house would be over the lifetime of a proposed risk reduction measure.

Releases can also pose physical and psychological impacts on human health. Exposure to releases may occur through air, soil, dust or water (Alberini, 2017). Physical harm can affect those cleaning up the spills or those in close proximity to the release. The Sea Empress (1996) release resulting in complaints of nausea, coughs, headaches, sore eyes and throat, and skin irritation in the surrounding general population due to the vapour cloud stemming from the oil spill (Environment Agency, 1998).

Physiological impacts can also arise following a spill, as a result of media coverage, disruption to local industries, potential physical health impacts and the harm caused to local ecosystems and wildlife (Kwok, et al., 2017). Those with previous experiences, such as a natural disaster, may also have a higher chance of being psychologically affected following a spill (Kwok, et al., 2017). Post-traumatic stress disorder (PTSD) and depression may be more likely to occur in the residents, including those who help in the clean-up itself (Kwok, et al., 2017). Those who helped clean-up the Gulf of Mexico oil spill had a significantly higher manifestation of PTSD and depression, even when the study considered other factors which could contribute such as previous mental health issues and disaster experience (Kwok, et al., 2017).

The Milford Haven Sea Empress (1996) release also impacted on local oil refineries, the defence industry, power stations and local engineering companies (Environment Agency, 1998). The spill also resulted in the loss of local engineering contracts due to the money going towards the clean-up of the spill (Environment Agency, 1998). The cost to industry is hard to predict, and may vary depending on whether the industry has a peak season which would result in maximum losses.

Intrinsic Value of the Environment

As well as the costs associated with the clean-up and restoration of the environment, it is arguable that the environment itself also holds some intrinsic societal value that could be represented in economic terms. Ecosystems provide direct and indirect values and non-use values which can benefit individuals, commercial entities and the public sector on varying scales from local to global (Economics for the Environment Consultancy, 2005). One example is the protection some ecosystems, such as wetland areas, can provide against flooding. These ecosystems can also provide a source of nutrient recycling and groundwater recharges. Different ecosystems can also host various recreational actives such as walking/hiking or water sports.

Direct use of the ecosystem regards the primary use of goods, such as timber or biomedicines, whereas indirect use is where the user benefits from secondary goods such as fresh water, erosion control, recreation activities and improved soil quality (White, 2009). Non-use values regard the value for future generations and the value of the ecosystem's existence. This includes aspects such as educational services, carbon storage, wildlife, biodiversity and scenic value.

An economic value cannot always be placed on these ecosystems due to the different uses they provide. Often a so-called willingness to pay (WTP) methodology is used to determine the non-use value of the environment (Hearne, 1996). This method uses massive assumptions leading to highly subjective resulting data (Patel, 2018). This method asks people questions about the receptor as opposed to observing their actual behaviour towards the receptor. This could lead to biasedness of those either collecting the data or those answering the questions. Factors such as demographics, location and time of day can all influence the results from a questionnaire (Patel, 2018).

Other factors such as conservation statuses, value of resource provided or cultural, societal and political contexts can also alter the value of an ecosystem (Patel, 2018). These factors and the way in which we view the environment also changes over time with standards being updating and altered, and the definition of environmental damage is also subject to change (Patel, 2018). So, what is considered feasible now, may not be considered feasible in future, or vice versa, what is considered unfeasible now in ten years maybe considered the norm.

As part of the list provided in the CDOIF guideline, an intrinsic economic value of the environment is not discussed as a parameter which should be considered. Instead, the guideline focusses on the parameters discussed in Section 2; clean-up, fines, restoration, loss of fisheries, tourism etc. CBAs conducted in other industries tend use the economic value of the ecosystem, but these CBAs do not consider situations such as oil spills and look more at ways to improve or protect the ecosystem.

Discussion

The most important aspect of a CBA is determining whether one should be conducted in the first place. Often, CBAs are misused, potentially resulting in disastrous outcomes, especially if the incorrect values for the environment are used. Most of the time it should be evident whether a measure should be installed. There are cases however where understanding the economics of suggested measures can be helpful, for example when comparing multiple options, and for this a reliable value of environmental harm is required.

The main issue identified when reviewing both past events and the literature, is that the cost is difficult to predict until after the event occurs, and even then, the cost may not be clear until some years after the event. With clean-up, even the use of previous incidents can result in misleading predicted costs. Even when considering the ecological value of the environment, there are still variations in the associated value. What's more, it often relies on people's willingness to pay, which may be different before and after an event.

There is also a significant lack of data regarding what incidents cost. In some cases, it will be acknowledged that harm was caused and remediation programmes or clean-up was conducted, but there are no associated costs. Going forward, consideration should be given to a database which details the different costs associated with all oil and chemical spills in the UK. This *may* be able to provide a more comprehensive comparison of what the actual costs associated with an event are, and provide a better estimation for those conducting a CBA.

The primary issue as things currently stand is the huge variability in the data available for the numerous factors that contribute to a notional value for the prevention of environmental harm. The contributing factors are numerous and highly variable individually.

There is the risk that, without set guidelines and cost parameters, those conducting CBAs could be drastically under or over estimating the justified monetary spend, leading to measures being implemented which were not cost effective, or worse, measures being rejected which should be implemented to provide additional protection to the environment. Due to the way in which fines are determined, there is the risk that those companies may face a larger fine than if they had implemented the measure and it had failed. Additionally, two different people conducting the assessment may end up with completely different resulting values based on the assumptions, parameters and data used.

The CDOIF guideline uses broad categories for severity and duration of harm. Additionally, frequency is assessed in orders of magnitude and has its own vast uncertainties, especially by the time it has been manipulated/processed to estimate the frequency of a MATTE occurring at a given receptor. So, if these are all categories, should we not be using a similar approach to the cost of environmental harm? Instead of trying to determine an exact figure (as in safety risk assessment and ALARP demonstration), the use of broader categories, which are tailored to each of the receptors defined in the CDOIF guideline, could provide a suitable alternative. The addition of modifiers would also allow for this value to be tailored to the individual receptors, whilst giving all those conducting assessments the same baseline.

Currently, sub-MATTE events are not considered for their tolerability, and thus would not appear in an ALARP demonstration. This poses a question for CBAs, because any measure installed may help with sub-MATTE events, so should the frequency and cost to clean-up be considered? The cost of a sub-MATTE event could still be millions in clean-up and restoration; for example, the Heathrow Airport spill was a sub-MATTE event, but still cost more than £1 million to clean-up; this could have a significant bearing on whether a measure is considered feasible.

Conclusions

Making a demonstration that the level of risk posed to the environment by COMAH (and other) establishments is as low as reasonably practicable is arguably the critical point of the risk management process. In doing so, it is useful to be able to compare suggested risk reduction measures both relative to one another and outright in order to identify which to implement. Cost benefit analysis is one tool that is used in support of these decisions for both safety and environmental risk. However, as things currently stand, the results of such calculations, particularly for the environment, are of questionable reliability.

It follows that if CBA is to be used from an environmental point of view, then work is necessary to establish a standardised and consistent monetary value (or values) for the prevention of harm to the environment. This paper has touched upon a handful of factors that might influence the process of assigning this value and has revealed that the number and variability of factors is overwhelming. However, this should not be seen as a deterrent to future debate and research on this topic, otherwise the status quo will remain, with the potential for false or misinformed ALARP arguments to continue.

Such research could strip the topic back to the most basic influential factors and investigate the potential for CBAs to be based on orders of magnitude or categories, rather than specious figures and calculations. Any work done in this area would need to involve industry operators, environmental experts and the regulator for success. It is also suggested that any collaborative work that does occur on this topic should prominently include a debate on whether or not cost benefit analysis/ justified spend calculations are appropriate tools in the first place. This is a difficult question because there are currently no established obvious or simple alternatives, but it is nevertheless very important that we consider whether CBA is a judicious approach to take before then working out how to use it.

References

Advisory Committee on Pollution of the Sea, 1990, Year Book 1990, Oxford: Pergamon Press.

Alberini, A., 2017, Measuring the economic value of the effects of chemicals on ecological systems and human health, OECD Environment Working Papers, 116.

Antweiler, W., 2018, Foreign Currency Units per 1 British Pound, 1950-2016. Retrieved from PACIFIC Exchange Rate Service: http://fx.sauder.ubc.ca/etc/GBPpages.pdf

Bank of England, 2019, Inflation Calculator. Retrieved from https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator

BBC News, 2005, Clean-up continues after oil leak. Retrieved from BBC News: news.bbc.co.uk/1/hi/wales/4134018.stm

BBC News, 2013, River Nene Chemical Spill Company Fined, Retrieved from BBC News: https://www.bbc.co.uk/news/uk-england-cambridgeshire-22477788

British Geological Survey, 2017, Geology of Britain. Retrieved from http://mapapps.bgs.ac.uk/geologyofbritain3d/index.html?

British Geological Survey, 2018, Geoindex Onshore, Retrieved from http://mapapps2.bgs.ac.uk/geoindex/home.html

Brownfield Briefing, 2010, Massive aquifer clean up continues as Heathrow fuel spill fine imposed, Retrieved from Environment Analysis: https://environment-analyst.com/dis/brownfield/34423/massive-aquifer-clean-up-continues-as-heathrow-fuel-spill-fine-imposed

Camphuysen, C. J., & Heubeck, M., 2007, Assessing the Damage. In K. C. Camphuysen, R. Bao, H. Nijkamp, & M. Heubeck, Handbook on Oil Impact Assessment (Vol. 1), Retrieved 09 10, 2018, from www.oiledwildlife.eu

Nicholls. C. and Ritchie. R (2018), Addressing the Challenges of Applying the CDOIF Guideline for Environmental Risk Tolerability in Risk Assessments for COMAH Establishments, IChemE Hazards 28.

CDOIF (Chemical and Downstream Oil Industries Forum), 2015, Guideline [on] Environmental Risk Tolerability for COMAH Establishments v2.0.

CL:AIRE, 2014, An illustrated handbook of LNAPL transport and fate in the subsurface.

Clyde & Co, 2010, Buncefield Explosion - Fines and Costs of £9.5 million, Retrieved from Clyde & Co: https://www.clydeco.com/uploads/Files/Publications/2010/Buncefiled%20explosion.pdf

COMAH Competent Authority, 2016, "All Measures Necessary"- Environmental Aspects (Guidance for Competent Authority Inspectors and officers).

Coxall, M., & Hardacre, E, 2018, Environmental law and practice in the UK (England and Wales): overview, Retrieved from Thomas Reuters Practical Law: https://uk.practicallaw.thomsonreuters.com/6-503-1654?transitionType=Default&contextData=(sc.Default)&firstPage=true&comp=pluk&bhcp=1

Davison, J., 2000, £4m fine for tanker spill is reduced to £750,000, Retrieved from Independent: https://www.independent.co.uk/environment/4m-fine-for-tanker-spill-is-reduced-to-750000-282264.html

DEFRA, 2018, Magic, Retrieved from https://magic.defra.gov.uk/MagicMap.aspx

Economics for the Environment Consultancy, 2005, The Economic, Social and Ecological Value of Ecosystem Services: A Literature Review. London: Economics for the Environment Consultancy.

Environment Agency, 1998, Sea Empress Cost-Benefit Project.

Environment Agency, 2001, Economic Evaluation of Inland Fisheries - Module A: Economic Evaluation of Fishing Rights.

Environment Agency, 2018, Annual Fisheries Report 2016 to 2017.

Environmental Protection Agency, 2001, Cost Analyses for Selected Groundwater Cleanup Projects: Pumps and Treat Systems and Permeable Reactive Barrier, United States Environmental Protection Agency.

Etkin, D. S., 2000, Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors, Arctic and Marine Oilspill Program Technical Seminar.

European Commission, 2017, Release of C5-C6 n-parafinn in a storage tank of a refinery, Release of hydrogen sulphide in a zinc dithiophosphate plant, Retrieved from eMars database: https://emars.jrc.ec.europa.eu/en/emars/accident/view/2a1d7512-b958-8353-3cbe-ac4119c46707

Hazardex, 2018, Huge North Dakota oil spill finally cleaned up after five years, Retrieved from Hazard ex: http://www.hazardexonthenet.net/article/162122/Huge-North-Dakota-oil-spill-finally-cleaned-up-after-five-years.aspx?utm_campaign=NL180926&utm_source=emailCampaign&utm_medium=email&emailaddress={~email~}&utm_source=emailmarketing&utm_medium=email&utm_campa

Health and Safety Executive, 2003, Cost Benefit Analysis (CBA) Checklist, Retrieved from http://www.hse.gov.uk/risk/theory/alarpcheck.htm#footnotes

Health Protection Agency, 2012, UK Recovery Handbook for Chemical Incidents.

Hearne, R. R., 1996, Economic valuation of use and non-use values of environmental goods and services in developing countries. Project Appraisal, 11(4), 225-260. doi:10.1080/02688867.1996.9727552.

HM Government, 2015, Control of Major Accident Hazards Regulations 2015, SI 2015/483.

HM Revenue & Customs, 2019, Average for the year to 31 December 2017. Retrieved from Gov.UK: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/768556/average-year-to-december-2018.csv/preview

ICIS, 1998, ICI Fined £80000 for Trichloroethylene spill, Retrieved from ICIS: https://www.icis.com/resources/news/1998/06/26/61247/ici-fined-80-000-for-trichloroethylene-spill/

Institution of Chemical Engineers, 2008, Hazards Conference: Process Safety and Environmental Protection Harnessing Knowledge - Challenging Complacency.

IPIECA, IOGP, 2015, Economic Assessment and Compensation for Marine Oil Releases. London.

ITOPF, 2014a, Response to Marine Chemical Incidents.

ITOPF, 2014b, Clean-up of Oil From Shorelines.

ITOPF, 2014c, Effects of Oil Pollution on the Marine Environment.

ITOPF, 2014d, Effects of Oil Pollution on Fisheries and Mariculture.

ITOPF, 2014e, Effects of Oil Pollution on Social and Economic Activities.

Kwok, R. K., McGrath, J. A., Lowe, S. R., Engel, L. S., Jackson, W. B., Curry, M. D., Sandler, D. P., 2017, Mental health indicators associated with oil spill response and clean-up: cross-sectional analysis of the GuLF STUDY cohort, Public Health, e560-e567. doi:10.1016/S2468-2667(17)30194-9

National Rivers Authority, 1993, Water Pollution Incidents in England and Wales - 1992. Bristol: National Rivers Authority. Retrieved from http://ea-lit.freshwaterlife.org/archive/ealit:4084/OBJ/20002949.pdf

NeBhover, C., Aronson , J., Blignaut, J., Eppink, F., Vakrou, A., & Wittmer, H., 2009, Investing in Ecological Infrastructure. In TEEB, The Economics of Ecosystems and Biodiversity for National and International Policy Makers.

OFX., 2017, Yearly Average Rates. Retrieved from https://www.ofx.com/en-gb/forex-news/historical-exchange-rates/yearly-average-rates/

Patel, M., Cariglia, N., Marchand, P., Brandt, J., & Soares, D., 2018, Environmental damage: changing perceptions and future outlook. ITOPF.

Sentencing Council, 2014, Environmental Offences Definitive Guideline, Crown Copyright, Retrieved from https://www.sentencingcouncil.org.uk/wp-content/uploads/Final_Environmental_Offences_Definitive_Guideline_web1.pdf

Simon, F. G., Meggyes, T., & Tunnermeier, T., 2002, Groundwater remediation using active and passive process. In F. G. Simon, M. Tamax, & C. McDonald, Advanced groundwater remediation: Active and passive technologies. doi:10.1680/agr.31210.0001

Simon, R. A., Winson-Geideman, K., & Mikelbank, B. A., 2001,. The Effects of an Oil Pipeline Rupture on Single-Family House Prices. The Appraisal Journal.

The ENDs Report, 1998, ICI Fined £300,000 for major chloroform spill, Retrieved from The ENDs Report: https://www.endsreport.com/article/4537/ici-fined-pound300000-for-major-chloroform-spill-

United States Department of Justice, 2016, Fact Sheet Proposed Consent Decree with BP for the Deepwater Horizon/Macondo Well Oil Spill. United States Department of Justice. Retrieved from https://www.justice.gov/enrd/file/834511/download

Water Briefing, 2010, Company fined £40K for Heathrow groundwater pollution, Retrieved from Water Briefing https://www.waterbriefing.org/index.php/home/regulation-and-legislation/item/2817-company-fined-%C2%A340k-for-heathrow-groundwater-pollution?tmpl=component&print=1

White, I., & Molloy, F. (2003), Factors that determine the cost of oil spills (2003), Retrieved from ITOPF: http://www.itopf.org/knowledge-resources/documents-guides/document/factors-that-determine-the-cost-of-oil-spill-2003/

White, S., Simmons, B., ten Brink, P., & Weick, V., 2009, Integrating ecosystem and biodiversity values into policy assessment, In TEEB, The Economics of Ecosystem and Biodiversity for National and International Policy Makers.

Wisbech Standard, 2012, The Wash to reopen for fishing at 5pm as chemical firm blames vandals for toxic spill in River Nene. Retrieved from Wisbech Standard: http://www.wisbechstandard.co.uk/news/the-wash-to-reopen-for-fishing-at-5pm-as-chemical-firm-blames-vandals-for-toxic-spill-in-river-nene-1-1417795

Wisbech Standard, 2013, Chemical company prosecuted for pollution of River Nene which killed thousands of fish. Retrieved from Wisbech Standard: http://www.wisbechstandard.co.uk/news/chemical-company-prosecuted-for-pollution-of-river-nene-which-killed-thousands-of-fish-1-1959076