Are we overlooking something in the context of environmental protection?

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

Chemical pollution is an evolutionary side effect in a society where the complexity of chemical production continues to increase. This is primarily due to technological advances, and consumer demands, in an age where modern living standards rely upon the use of thousands of chemicals. Studying the impact of these substances on the environment therefore represents an ever-increasing challenge. As a result, a large amount of time and expense has been invested, around the globe, into understanding the consequences of discharging toxic chemicals into the environment.

Over time the impact of toxic substances has been understood and protection measures implemented. However, the impacts of substances or industrial practices which are not classified as toxic, but which are still potentially harmful to the environment, has been studied to a lesser extent. In order to effectively implement measures, to protect the environment from less well-known sources of pollution, it is important to first improve understanding throughout industry by discussing the issue.

Some examples of substances or industrial practices that may be overlooked, from an environmentally hazardous perspective, include firefighting foam concentrates and components of wastewater streams. If uncontrolled, they could enter the environment and result in harm by altering the chemical and/or physical composition of a habitat. It is important to understand the wider hazards that industrial activities might present in order to effectively implement, or improve, control measures.

Foam concentrate, that does not contain PFOS (perfluorooctane sulfonate) which is now prohibited, is not classified as a toxic substance. However, in high concentrations it still presents a risk to the environment, particularly aqueous receptors, as a result of high biochemical oxygen demand (BOD). Substances like this could therefore have an indirect effect on the health of an aqueous ecosystem by limiting the availability of oxygen. Control measures, such as secondary containment around foam concentrate storage areas, should therefore be considered, but might not be prompted through traditional thinking.

Eutrophication is another consequence of pollution and can occur following an increase in nutrients within a waterbody, resulting in the exponential growth of algae. The subsequent reduction in sunlight beneath the algae reduces the ability of plants to produce oxygen via photosynthesis, culminating in the inability of organisms to survive. This may occur through high nutrient levels within wastewater streams. Wastewater may also affect an aquatic habitat by increasing the temperature and thus reducing the dissolved oxygen within the waterbody. This represents a potential consequence of industrial practices that may not be addressed by current process safety thinking, leading to a lack of protection measures.

This paper aims to promote an in-depth discussion surrounding ways in which industry may unknowingly pose a risk to the environment, with the final aim of ensuring that substances and/or industrial processes are not overlooked. In order to protect the environment, it is crucial that control measures are installed prior to any harm being realised, rather than looking to clean up after ourselves. Through discussing these issues and highlighting industrial practices or chemicals that may be potentially hazardous, this represents the first step towards achieving an all-encompassing approach to environmental protection that considers all hazards at an establishment.

1. Introduction

The chemical industry is essential for a variety of economic activities which are integral to 21st century living. As the number of people inhabiting the earth increases, the quantity and complexity of chemicals in use will continue to increase. As the number of chemicals in use increases, so does our exposure to them, particularly if they are allowed to freely enter the environment under uncontrolled conditions. Large sections of modern society believe that the impact of chemicals on the environment can be remediated through technological innovation without altering their consumption habits (Røpke, 1999). However, with an ever increasing global population, consumption habits will have to change in order to protect the planet for future generations.

Currently there are over 100,000 chemicals available on the EU market with only a portion of these having been evaluated for their potential impacts to the environment (European Commission, 2017). However, significant progress has been made in this area within the EU since the introduction of the REACH (Registration, Evaluation, Authorisation and restriction of Chemicals) Regulations in 2006. These regulations provide a baseline for chemical categorisation across the EU; this is an area of concern as it could be in jeopardy following the UK's exit from the EU, whereby a new database may need to be established.

Of all the chemicals available for purchase and use there is a large number which have been tested and classed as dangerous for the environment. In the UK, assessment of the potential impact of these substances is required by The Control of Major Accident Hazards Regulations (COMAH, 2015) which implement the Seveso III Directive (EU, 2012). In order to satisfy the requirements of the COMAH Regulations, the de-facto approach favoured by the Environment Agency (EA) is for the substances present at a given COMAH establishment to be assessed against the criteria specified within the Chemical and Downstream Oil Industries Forum Guideline [on] Environmental Risk Tolerability for COMAH Establishments (CDOIF, 2015). However, substances which are not categorised as hazardous, or are not directly related to process operations, may be overlooked or under-managed from an environmental perspective, as resources may be focused on manging the impact of COMAH qualifying substances with more obvious hazardous properties. Substances that do not obviously qualify as COMAH substances (either specifically or not specifically named) include those which do not have any COMAH-related hazard statements, but which could nevertheless still cause environmental harm. For example, substances that reduce the dissolved oxygen content of a watercourse and as such have a negative impact on wildlife. This can include releases with high sugar content which result in the increase of bacteria and thus a reduction in dissolved oxygen content. Substances like this are referred to as having a high biochemical oxygen demand (BOD). As identified within Ezbakhe (2018), water pollution is becoming a major challenge in the 21st century.

Other overlooked chemicals in the past were constituents of firefighting foams which were allowed to enter water courses, and groundwater bodies, and therefore contaminate drinking water. Firefighting foams containing PFOS are now no longer available to buy due to their harmful properties for the environment, brought to light following the Buncefield incident; however, this highlights the negative impact that can occur following activities which are essential in some cases to protect health and wellbeing.

Environmental pollution due to the release of substances can occur during production, transport and storage. Some of these stages may be overlooked, for example the safe handling of a substance during transportation can be poorly managed due to responsibility changing hands between suppliers, hauliers and production operators. Management of chemicals and understanding the risks that they present is crucial in limiting the impact that the process industry has on the environment.

The persistence of chemicals within the environment is also a concerning issue. Chemicals with a high persistence in the environment can impact a greater area than less persistent substances as they are removed more slowly through natural environmental processes. Due to the lack of information on the persistence of some chemicals their fate within the environment may be unknown, for example the impact that microplastics have, especially on the marine environment and ultimately on human health through the marine food web, was historically not considered, or considered benign. This re-emphasises the need to fully understand the properties, fate and consequences, of substances stored and produced within industry in order to manage them appropriately.

The aim of this paper is to discuss the negative impacts of human activities on the environment due to unidentified, or less well known, sources of pollution. This is done primarily in the context of the UK (COMAH) process industry, but also draws from other industries handling non-COMAH substances with a view to improving the way in which all sources of environmental harm are accounted for in COMAH risk assessment. Environmental pollution can occur through a number of pathways be it via air, land or water. The main focus within this paper will be the pollution of aqueous environments which have the potential to be greatly impacted by a range of industrial activities. Through discussion it may be possible to raise the profile of these industrial practices, and associated pollutants, so that they are considered within risk assessments, enabling effective control measures to be established.

As discussed within Crathorne et al., 2001, permits are in place within the UK for practices that involve harmful substances which are discharged directly to water courses or sewers. The main legislative acts within the UK which dictate the controls required are the Environmental Protection Act 1990, IPC Water Industry Act 1991 and the Water Resources Act 1991. However, there may be lesser known impacts of these practices or a lack of guidance for some substances which are not designated as harmful when stored but could have a negative impact when released into the environment. The goal of this paper is to encourage further discussion around sources of environmental pollution that may be overlooked. Past incidents will be reviewed to highlight the impact that less well known sources of pollution can have. This discussion can then be utilised to develop an approach to assess protection measures for establishments.

2. Literature Review

The following sections discuss sources of environmental pollution that may be overlooked when considering the wider impact of toxic chemicals. There are many ways in which humans can impact the environment beyond the typical realms of thought in industry, due to inherent hazards, this is illustrated through a review of case studies which illustrate the potential for environmental pollution and determine the lessons that can be taken for wider industry.

Thermal Pollution

Water discharged from industrial practices is tightly regulated within the UK to limit the introduction of hazardous chemicals and limit degradation of natural environments. One aspect of this is controlling the maximum temperature at which wastewater can be discharged to the environment. Thermal pollution of watercourses can have a big impact on the health of an ecosystem; however, this topic receives less coverage than other industrial practices such as the fossil fuel industry, which is currently in the spotlight due to emissions concerns. Manufacturing plants that use water to cool machinery have the potential to raise the temperature of surrounding watercourses through ineffective management of wastewater. Thermal pollution encompasses all deviations from the typical temperature regime of a waterbody. Increases in water temperature have the effect of decreasing the oxygen concentration of the water, therefore impacting aquatic organisms. If the watercourse is slow moving the effect is heightened as lower turbulence reduces the base oxygen levels. As discussed within (Hannah et al., 2008) water temperature is a key indicator of water quality and therefore health of an aquatic habitat. As a result, there has been an increased focus on this topic within literature in recent years.

Temperature alterations also affect decomposition and nutrient cycling. Furthermore, the natural temperature of an aqueous ecosystem does not fluctuate to a great extent, therefore animals may be more susceptible to sudden changes as they do not have the ability to adapt. Sharp increases in the temperature of a watercourse as a result of industrial activities has the potential to result in mortality of fish stocks via thermal shock.

Madden et al (2013) discuss the impact of thermal effluent on surface water temperature in the United States from 1996 to 2005. This paper identifies that a number of power plants studied exceeded the limit for water discharge temperatures due to poor regulatory enforcement. However, the paper also identifies that as the planet warms, average water temperatures will also increase, meaning that industrial activities such as power generation will struggle to maintain water discharge temperatures within regulatory limits. Over time this may affect how we produce energy while striving to continue to protect the environment.

Industrial Landfill Leachate

A sometimes little discussed issue is the potential for water pollution as a result of leachate from waste facilities. However, the production of waste is increasing rapidly on a global scale (Bhatt et al, 2017). When waste is buried underground the breakdown of materials produces harmful chemicals which can enter water bodies in the form of leachate runoff. A number of industrial practices produce waste as a by-product which then requires disposal in a manner which safeguards the environment. In a number of cases waste is either burnt to prevent it going to landfill or designated as hazardous and therefore disposed of by means other than landfill. It is therefore important to emphasise that it is the responsibility of both the disposal company, and the establishment that produced the waste, to ensure that the waste is disposed of safely. There may in some instances be a disconnect between those that produce the waste and the final destination therefore the whole lifecycle of a substance needs to be considered.

Some known pollution of waterbodies may come from historical sources; however, industry should be responsible for past and potential future contamination. Most landfills are sealed at the bottom to prevent leachate reaching the environment however it still poses issues when it comes to treatment due to the complex mixture of contaminants which cannot be treated using traditional water treatment methods. Certainly, within the UK there is strict legislation which dictates the need to store and treat landfill leachate before it is discharged into the environment (IPPC, 2007). However, it is not always possible to prevent leachate reaching the environment, particularly in some less developed countries where regulations and monitoring are less rigorous.

In 2013 an extreme rainfall event resulted in a landfill site in Cornwall (Goulding, 2017) breaching their environmental permit. Upon inspection by the EA, they identified serious pollution in nearby watercourses and concluded that water quality had also been affected beneath the landfill site. In addition, poor remediation practices which involved placing polluted surface water on nearby fields resulted in soil contamination. The company were fined for their actions and measures were taken to reduce the potential for a future incident including capping and upgrading leachate treatment facilities. This incident highlights the need for effective consideration of external events that could result in failure to contain hazardous chemicals.

In addition to the potential for leachate to seriously harm ecosystems, it can also have a direct impact on societal amenities including water used for drinking, domestic and irrigation purposes. In recent years society has become less detached from the impact it is having on the environment as sources of food and water are being contaminated. This represents the stark reality that waste pollution from industry can have a direct impact on health and wellbeing.

Alcohol and Sugar Production

Within the process industry there are a number of regulations which aim to reduce risk within the workplace. These include the dangerous substances and explosive atmospheres regulations (DSEAR) (HSE, 2002) and storage of flammable substances regulations (HSE, 2015). From a safety perspective alcohol production would be covered under the flammable substances regulations while sugar production would be covered under the DSEAR regulations due to the risks associated with dust. However, are the environmental consequences of a release of these substances covered under these regulations adequately considered? For instance, the production of alcohol results in the evolution and release of carbon dioxide and a significant contribution towards emissions and ultimately climate change. Furthermore, products which contain a high volume of sugar have the potential to seriously affect aqueous ecosystems. Crathorne et al (2001) identify that spills of products containing sugar can cause serious pollution incidents due to their high organic content. They go on to emphasise that the bulk of incidents within the UK are organic pollution. This section will review a few of these products and incidents which highlight the impact that they can have on the environment.

The following case studies go on to highlight the impact of introducing sugar rich substances into watercourses due to their high biochemical oxygen demand. In 2010 a fire within a warehouse at the Jim Beam plant in Kentucky resulted in 45,000 barrels of bourbon being released into a nearby river (Withers, 2019). This impacted the health of the river, but the severity of the event was reduced through emergency clean-up efforts and a controlled burn strategy, which resulted in less runoff reaching the river due to a reduction in the application of firefighting media. This event highlights the need to undertake an establishment risk assessment which would identify the nearby watercourse and suggest that containment measures should be in place within the warehouse to contain spills should they occur.

Saranaj and Stella (2014) conclude that sugar production in India is the second largest agricultural industry in the country but that effluent discharges are causing serious environmental degradation. This was highlighted in 2018 (Rana, 2018) when a molasses leak into a river in Beas, India resulted in the death of thousands of fish due to a depletion of oxygen. In order to remedy the issue water was released from dams upstream to dilute the release. The process industry in India is heavily underregulated with many sites operating using outdated equipment and improper management in order to cut costs. This results in a high number of incidents of this nature compared to more highly regulated countries. This event again emphasises the need to implement effective containment measures to protect the environment from all substances which could result in harm.

Transporting Chemicals

It is important that chemical manufacturers continue to be intelligent customers and ensure that haulier companies make their drivers aware of hazards, and the steps that should be taken, in the event of a loss of containment incident. It may be the case in some instances that once chemicals leave the boundary of an establishment, then there is a perceived lower responsibility to control the fate of hazardous chemicals. For example, if there is a road traffic incident that involves a tanker which contains potentially harmful chemicals there is the potential for them to enter watercourses via road drainage systems. However, there are strict rules enforced by the HSE in the UK which dictate how chemicals must be labelled and measures which need to be taken following a release. Depending on the nature of the chemicals that are being transported, there is also legislation on the pollution control equipment that is required to be on board the vehicle.

The potential for vehicle collisions during road transport presents an additional risk of environmental pollution. This poses the question as to whether, from a risk perspective, hazardous substances should be preferentially distributed via railways. However, even with an agreed preference, there are economic considerations as well. Additionally, when considering the UK as a whole, limited infrastructure versus high demand from freight and passenger trains plays a role.

Firefighting Foam

Foam containing perfluorooctane sulfonate (PFOS) is toxic to the environment and therefore has been phased out in recent years. Nevertheless, foam in high concentrations still presents a risk to the environment, particularly aquatic receptors, as a result of high biochemical oxygen demand (BOD) (Environment Agency, 2017). It is therefore imperative that systems are put in place to prevent releases reaching the environment.

Protecting the environment from firefighting substrates, following application in emergency situations, has been a topic of discussion in recent years. The consequences of foam runoff from firefighting activities were clearly seen at Buncefield in 2005 whereby groundwater was significantly impacted. In this instance the foam contained PFOS and was mixed with hydrocarbons when it reached the chalk aquifer beneath the site. The pollution was able to reach groundwater as a result of leaking bunds and unidentified soakaways (HSE, 2011). When carrying out a risk assessment for an establishment it may therefore be prudent to consider storage of foam and the design and maintenance of the containment, in addition to the pathways that it could take to reach environmental receptors.

Foam in its concentrated form has the potential to present a greater risk to waterbodies from a BOD perspective. However, this does not take into account the potential for foam to also mix with hydrocarbons in an emergency situation. The use of firefighting foam should therefore be limited to cases where its use is essential. If application is deemed to be necessary, then suitable controls should be in place to prevent runoff impacting environmental receptors.

Paper Industry

European legislation currently requires paper mills to monitor their emissions (Maximova and Dahl, 2007). However, the paper industry still greatly contributes to the pollution of water, air and land around the globe. The industrial process utilises harmful products such as chlorine and organic materials which have high BOD. Wastewater can also include a high proportion of suspended solids which can affect the amount of light entering a water body and therefore restrict the ability of plants to photosynthesise. The paper industry is one of North America's most important industries economically (Pokhrel and Viraraghavan, 2004) however wastewater can have a serious impact on the environment. This is highlighted by the continued pollution of a lagoon in Halifax, Nova Scotia, Canada (Belliveau, 2019) by paper mill wastewater. Failure to clean up the lagoon over a number of years resulted in a law suit and closure of the plant until remediation was put in place. Pollution of the environment was exacerbated by the lagoon acting as a pathway to other rivers in the area. This case highlights a complete disregard for environmental protection and emphasises the need to introduce strict legislation and monitoring to prevent events like this occurring.

Milk Industry

In 2007 the Department for Environment, Food and Rural Affairs (DEFRA) produced a literature review (DEFRA, 2007) which looked at the environmental impact of the milk industry on the environment within the UK. The dairy industry is a global contributor to environmental decline due to greenhouse gas emissions however the industry can also have a direct impact on water quality. Direct runoff from fields increase the nutrient levels within waterbodies and can seriously impact the diversity and health of ecosystems. However, this can also occur as a result of spills of milk as bacteria use up oxygen within the water as they feed on the milk thus limiting the availability of oxygen for other animals. Pollution of a lake in Staffordshire in 2002 due to a release of milk as a result of a road tanker collision, was averted due to an affective and co-ordinated response effort (BBC, 2002). This emphasises the need for establishments to develop and maintain emergency response plans as without the immediate response operation the ecological diversity of the lake could have been seriously affected.

Milk is a substance that would not be classified as dangerous under the COMAH regulations but would have a seriously detrimental effect if it was released into the environment. This highlights the importance of assessing all substances as part of the risk assessment process to enable appropriate control measures to be put in place to prevent a Major Accident to the Environment (MATTE).

Surface Runoff

As identified by Harbor (1999) sediment is a serious pollutant associated with construction activities. As industry grows around the world there is the need for a greater number of construction activities which can result in the production of large quantities of sediment. Due to the impermeable nature of industrial settings the sediment produced can be introduced to watercourses as runoff, which could negatively affect the health of the ecosystem (Belayutham et al., 2016, Russell et al., 2001). Sediment can damage aqueous ecosystems due to its ability to impair water quality, reduce light penetration and increase sedimentation.

As outlined in Herb et al (2008) due to increased runoff from impermeable surfaces, particularly during periods of intense rainfall, the flow regime of watercourses can be altered thus impacting water quality. Revitt (2004, pg.82) states "*Engineering* *designs have consistently favoured the rapid removal of surface runoff from impermeable areas with the water quality effects being given secondary consideration. This approach is now changing with the recognition that surface discharges can pose serious detrimental impacts to receiving waters and, therefore, that control of runoff quality as well as volume is important*". This statement outlines the impact of the transport industry, notably vehicles and aircraft, which require large areas of impervious surfaces. This is emphasised in China as 86,000 km of new road surface was built in 2018 alone (SCMP, 2019). In the UK the number of cars continues to increase, with it being the third most congested country in Europe; therefore, further roads and additional infrastructure are required to maintain the flow of traffic around the country.

The impact of runoff from airports is covered within Nunes et al (2011) which analyses known pollutants but also the impact of impermeable surfaces. Notably the paper refers to the number of extra airports that will be required to be built around the world as global population increases. This will only contribute to the number of impermeable surfaces and therefore the impact to watercourses due to runoff.

The ever increasing potential for surface runoff to affect watercourses highlights the need for effective management of construction projects. This should include influence from environmental management in the management of change (MOC) process. Effective planning at the start of construction projects will enable suitable safeguards to be put in place to prevent sediment or associated pollutants being washed into the environment.

Pollution Prevention Measures

Risk assessments should be carried out for each establishment to determine factors such as: environmental receptors around the site, harmful activities and materials, and potential pathways that a spill may take. This information can then be utilised to inform a sufficiently robust environmental hazard identification processes which can be used to implement appropriate measures to prevent a loss of containment. It is important that long term impacts to the environment are identified as part of the risk assessment hazard identification process. This due diligence is essential in ensuring that operators take responsibility for protecting the environment and implement appropriate control measures.

Reducing exposure to chemicals that could have a potentially negative affect is paramount. As outlined within the European Commission's 7th Environmental Action Programme (European Commission, 2017) there are different measures which could be implemented to achieve a non-toxic environment: improve knowledge, promote innovation, and reduce exposure. Improving knowledge encompasses commitments to developing a baseline standard which recognises toxicity of chemicals and identifies new threats should they arise. Promoting innovation is vital in the goal of replacing toxic chemicals with non-toxic alternatives. However, this also includes promoting solutions that enable chemicals to be re-used or recycled thus increasing the lifecycle of chemical usage and therefore reducing the risk to the environment.

Recycling is an increasingly spoken about issue in the 21st century which is of course seriously needed if we are to reverse the ever increasing impact that humans are having on the planet. Reducing exposure to chemicals ties in with using less harmful chemicals but also emphasises the need to track which chemicals are within certain products to enable effective management practices to be implemented. Reducing the need to produce new products through the use of effective recycling will dramatically reduce the potential for environmental impact.

Pollution Control Measures

CIRIA 736 (Walton, 2014) presents good practice guidance for use in the industrial sector on the design of containment systems. Encouraging the use of best available techniques for pollution prevention is important and CIRIA 736 aids in guiding facilities to do so. In addition to containing the chemicals stored at a site CIRIA 736 also states that a 1 in 100 year rainfall event should aim to be contained as a worst case volume. This, together with the capacity required for firefighting substrates, highlights the additional capacity required within containment systems. However, this required capacity can be achieved through fairly inexpensive methods such as altering the topography of areas e.g. by raising low points of the site or constructing collection areas which also serve an additional purpose such as car parking. This will enable an establishment to contain a much larger volume of liquid and therefore minimise uncontrolled runoff to nearby watercourses.

Secondary and tertiary containment systems are essential to protect the environment should a release occur. Any industrial establishment should be fully self-contained so that hazardous substances, either accidentally released or intended for treatment and controlled discharge, are contained and then dealt with appropriately. For example, waste streams are often segregated so that collection and mixing of less contaminated water with more contaminated streams is minimised; otherwise, this can be costly and not energy efficient. Secondary and tertiary containment may not be a legal requirement in some cases; however, investment in containment systems will be financially beneficial should a release occur. Promoting the 'polluter pays' principle, as discussed within Tilton (2016), is essential within industry to drive clean incentives and protection of the environment. Ensuring that the original producer pays the full costs for their emissions is critical in driving a green economy. Furthermore, the principle of containment goes beyond simply where bulk inventories are stored as raw materials and finished products; landfill should be thought of as a type of storage, albeit often of historically deposited material and as a source of leachate pollution. Temporary containment measures may also be necessary during construction activities to prevent runoff and sediment pollution of watercourses.

There are many approaches for waste water treatment, depending on the contaminants in question. For example, if water is contaminated with suspended solids. An example of this is at paper and pulp mills; here, the main treatment process is primary clarification. This utilises either sedimentation or floatation, with sedimentation being more widely used in the UK (Thompson et al., 2001). This results in a high removal of suspended solids but only a small amount of organic material is removed. Such processes are usually very costly and unreliable (Chaudhry and Paliwal, 2018). UK regulation is moving towards more stringent colour standards based on river quality objectives (Thompson et al., 2001).

Pollution Mitigation Measures

Watercourses continue to be polluted around the globe due to unregulated industrial practices. There are many challenges facing remediation processes including complex geophysical and geochemical conditions, increasingly complex contaminant mixtures and changing economic conditions (Hadley and Newell, 2012). It is therefore important to review remediation measures which can be utilised to reverse the impacts of industry.

There are multiple approaches to river remediation techniques, these are categorised into physical remediation, chemical remediation, and bioremediation technology. Physical remediation includes methods such as aeration (used successfully for remediation of Portugal's Oeiras River, Germanys Emsche River, UK's River Thames and Homewood Canal in the US (Rogers, 2000), water diversion to flush out pollutants and sediment dredging with the most advanced dredging technique being the cutter suction dredger (Koussouris, 1998). Chemical remediation utilises either flocculation and sedimentation or removal of algae by a chemical agent, these target water treatment with a high number of suspended solids and algae (Li et al., 2007). Bioremediation involves organisms to change the pollutants into a non-toxic form. Aquatic plants such as reed, water hyacinths, cattails (Sato et al., 2008) and aquatic animals such as silver carp and common carp are used to purify eutrophicated water. There are a number of advantages to investing in bioremediation such as lower cost, no alteration to the environment (physical or chemical) and high pollutant reduction when compared to other techniques (Wang et al., 2012).

Another frequently polluted water source is groundwater where pollution can occur as a result of many industrial processes. There are a number of remediation techniques that can be utilised to clean groundwater which include biodegradation, chemical oxidation and adsorption. More recently developed techniques include natural attenuation (Wang and Mulligan, 2006), sustainability appraisal tools (Beames et al., 2014), permeable reactive barriers (Thiruverikatachari et al., 2008), iron sulphide particles (Gong et al., 2016) and zero valent iron particles (Tosco, 2014).

One such industry where remediation is not currently effective is waste management. Many older landfills have no engineered leachate collection system, so remediation of the resulting groundwater pollution is costly and demanding as most of the pollutants are still present in the landfill waste for decades after the site has been closed (Christensen, 2000). There is a therefore a need for economically sustainable approaches that have the ability to remove mixed contaminants with different solubilities, vapor pressures and degradation potential (Zhang, 2017). Further research would therefore be beneficial in this area to improve the remediation of waste storage sites.

3. Approach to Environmental Risk Management

Implementing an effective risk assessment methodology is imperative in reducing the impact of chemicals on the environment. The following diagram highlights the key stages in preventing, controlling and mitigating harm. Key points are included within the flow diagram and expanded on below.

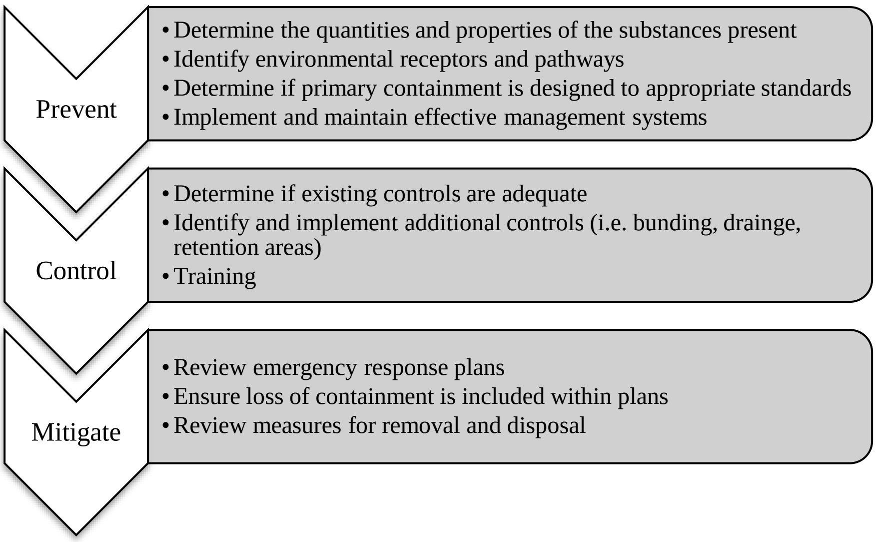

Figure 1: Environmental Risk Assessment Methodology

Prevent

This section outlines the site assessment which is a critical first step to determine the risk to the environment and therefore enable suitable control measures to be put in place. Each establishment is different and therefore a case-by-case assessment process is essential. This process should also be able to determine whether the current measures in place are adequate to contain a release should it occur.

- Substances and properties - first it is important to assess the substances present at an establishment and determine the properties that may be harmful to the environment. The substances stored may not be toxic to humans, but may have a detrimental effect when released, therefore this is important to take this into consideration. Adequate knowledge of the harmful properties of certain substances may also enable industry to utilise substitutes which have less impact on the environment.

- Receptors and Pathways - secondly it is essential to identify all receptors around the establishment and the pathways that potential releases could take. Should an establishment be located in close proximity to a sensitive receptor then further protection measures may be required. As displayed during the Buncefield incident the lack of investigation into pathways to groundwater resulted in serious contamination following firewater runoff. This event also highlights the need for adequate secondary containment which will be discussed within the control measures section below. Receptors may also present a risk to operation of the establishment such as floodwater; therefore, secondary containment may aid in the protection of storage areas.
- Containment - primary containment systems at an establishment should be designed and constructed with the nature of a particular substance in mind to ensure that leaks do not occur. Inspection and maintenance procedures should be upheld to ensure that containment systems function as designed and any defects are picked up prior to a loss of containment.
- Management systems – steps taken to prevent a loss of containment include implementing an effective management system which ensures safe operation of the site but also considers the environment to ensure that risk management activities are proportionate. Examples of this include management of change processes which take into consideration the potential for changes to the site to impact health and safety but also the environment due to the introduction of new potential hazards.

Control

This section outlines measures that are designed to control the potential effects caused by a loss of containment at a site. These include site containment systems and detection and isolation processes. These measures are designed to prevent a release at the site resulting in significant harm to the environment.

- Secondary containment - measures such as bunding should be put in place where a loss of containment would not be retained onsite by topography, or where a release could reach unprotected ground. This should be designed in line with correct design and construction standards and inspected frequently for defects. If bunding is determined to be the best solution for a given establishment, in order to reduce the risk to the environment, then it should be ensured that there are no flammable substances stored within the same bund.
- Tertiary containment - in addition to secondary containment facilities should have adequate tertiary containment systems such as drainage and effluent treatment plants to manage surface runoff from rainfall or spills outside bunded areas. Establishments may already have tertiary containment arrangements in place and the site assessment should be able to determine whether this would contain releases. Particular sites may also be at a greater risk of harming the environment based on their location. It is therefore important to reemphasise the need for a case-by-case assessment approach in order to take all factors into consideration when determining the best measures to implement in order to contain spills.
- External Events - Based on the site assessment the facility will be able to determine whether external events could cause or exacerbate a release. An example of this could be flooding if the site is located in close proximity to a waterbody. Floodwater can damage equipment and cause a loss of containment to occur but may also exacerbate an existing release in such a way that a greater extent of an environmental receptor is reached. Bunding would be a simple solution to protect storage areas from floodwaters however site design should also take flooding into consideration whereby storage areas and power supplies should not be located in the low points of a site.
- Detection and Isolation - The ability to detect and isolate a release will play a significant role in determining the release volume and therefore the impact to any environment receptors, but also the remediation measures required. The establishment should have automatic and procedural methods of identifying a loss of containment and be able to isolate it remotely and manually. Developing an effective emergency response plan, which will be discussed below in an essential step in protecting the environment.
- Training – educating personnel about the hazards of certain substances and the steps they can take in the event of a release is an important step in limiting the impact to the environment.

Mitigate

In the event of a loss of containment at a site, there should be emergency response plans in place to mitigate the potential effects caused by a loss of containment. Emergency response plans should take into consideration all the information collated as part of the initial site assessment including nature of substances present, receptors around the establishment and potential pathways. Isolating pathways to receptors in the event of a loss of containment is a crucial step in the environmental protection process.

- Temporary secondary containment – in the event that permanent secondary containment such as bunding fails or is not beneficial to a loss of containment outside of secondary containment, temporary containment measures such as booms, and mobile bunding can be deployed, depending on the rate of release and flow of released material. This can help significantly to mitigate the effects of a release and minimise the impact on the environment that could otherwise occur.

- Controlled burn – this strategy involves restricting the application of firefighting media such as water or foam to minimise the damage to the environment. The choice to employ this strategy however will be made by the fire service. Controlled burn provides a viable alternative to traditional firefighting measures. Traditional firefighting measures often use firefighting foam or firewater, which can contain contaminants and cause severe environmental damage. For areas of high environmental sensitivity, this can have devastating consequences, potentially leading to a Major Accident To The Environment (MATTE). Controlled burn practices at a site will reduce the quantity of firewater used, which in turn will provide protection to the environment. Throughout the progression of an event, the appropriateness of a controlled burn may change. For instance, in the early stages of a pool fire there may be significant risk to nearby populations, or from escalation, meaning a controlled burn is not an appropriate strategy. Once the fire is under control and the risk of escalation has been minimised, it may become suitable to employ a controlled burn. The use of controlled burn shall be discussed during emergency planning for major accidents. Representatives from the site in question, competent authority, fire and rescue service, public health authorities and insurers will all be included in deciding if a controlled burn is appropriate. In the case study of the fire at the Jim Beam warehouse the use of controlled burn was an effective strategy in reducing the amount of runoff into the nearby watercourse. The alcohol was left to burn and evaporate thus reducing the extent of the fire. However, if a location is close to populated areas then this strategy may not be an option.

- Firewater/foam – in many cases firefighting media may be required to extinguish a fire. Foam used to extinguish a fire should be contained onsite as it may contain pollutants, therefore secondary/tertiary containment should have sufficient capacity for the application rate required to cool equipment or extinguish a fire. On a number of establishments foam concentrate is stored onsite for use in emergency situations. Foam concentrate can have a particularly profound impact on watercourses due to the high biochemical oxygen demand. This emphasises the need to contain firewater runoff but also the concentrate before it is applied.

- Power supply – in emergency situations power availability may been restricted due to damage of power supplies. Back-up power should be available to facilitate emergency response measures and enable critical equipment to remain operational.

- Emergency response - plans should take into consideration the nature of receptors around an establishment. An example of this may be the flow dynamics of nearby watercourses. Fast flowing rivers can result in a release travelling further downstream therefore this may affect the emergency response measures which need to be in place to mitigate harm. However, this may result in pollutants being mixed within the water column thus diluting the release. This is in comparison to a pond or stationary body of water which may be affected to a greater level, but the pollution is restricted to a smaller area, therefore emergency response efforts would be more localised. Assessing the nature of receptors early in the planning process will enable suitable equipment to be available in an emergency situation. Examples of this may be booms for spills on watercourses or gully suckers to remove pollutants from below ground sources. Specialist contractors should be used to carry out specific remediation activities with contact details displayed within emergency response documentation. Should receptors be contaminated it is critical that pollutants are removed and transferred to safe storage facilities to avoid the potential for further environmental contamination. For example, the environment agency state that contaminated environmental media can be stockpiled for a maximum of 72 hours from the time of release on concrete, plastic or asphalt if containers aren’t available. However, the temporary stockpiling of contaminated material should be carried out as a last resort as this process may result in the contamination of other areas of the site (Carey et al., 1999).

4. Environmental Risk Assessment Under COMAH

The Chemical and Downstream Oil Industries Forum (CDOIF) Guideline on Environmental Risk Tolerability for COMAH Establishments provides a methodology to enable all establishments, regulated under COMAH or under other legislation, to identify scenarios that may present MATTE level risk to environmental receptors.

It is essential to identify all credible sources of harm when carrying out risk assessments. This is therefore of high priority during the hazard identification process. For substances covered under COMAH, which have been given specific hazardous designations as a result of rigorous testing, the need to assess the impact to people and the environment is clear. However, for substances not covered under COMAH the process of identifying potential for harm is less straightforward, as highlighted within this paper, due to the interactions that certain substances can have when they enter the environment. The focus in some assessments may therefore be in favour of substances which are known to have a detrimental impact as they have been demonstrated to do so, rather than considering more complex negative interactions. This may especially occur when, as if often unwittingly the case, the assessment and hazard identification is looked at with a bias towards the safety of people.

CDOIF is now a widely utilised guideline for producing environmental risk assessments. Use of this guidance across the industry ensures a consistency in the assessment and description of risk. However, the guidance can prove a challenge in some circumstances due to the grey boundaries of COMAH in an environmental context. For instance, every substance that could cause harm, COMAH or not, should be considered within the COMAH assessment. This introduces some level of ambiguity when deciding what should be included. It is safer therefore to try to identify areas to focus on based on whether the consequences of an accident are of COMAH magnitude (i.e. MATTE), rather than whether or not a given substance is covered by the names of hazard categories in the COMAH regulations.

Environmental risk assessment under COMAH has progressed significantly in recent years. Nevertheless, it is crucial that all credible sources of MATTE level harm are considered, otherwise the objective of the assessment is missed completely. There therefore appears to be room for improvement in ensuring that substances that might easily be overlooked, due to a focus on named substances under COMAH, should not be forgotten about. Consideration of all harmful substances will enable an establishment to implement targeted risk prevention, control and mitigation measures in order to protect the environment.

5. Conclusions

The aim of this paper was to highlight sources of environmental pollution that may be overlooked in certain contexts due to a focus on more established pollutants or regulations covering health and safety in the workplace. It is important to analyse all the properties of substances stored at an establishment to determine adequate and proportionate measures which will help protect the environment. It should be emphasised that responsibility lies with the facility storing hazardous substances which could have a negative impact rather than relying on third party contractors to provide remedial measures. Degradation of the environment is beginning to show signs of affecting the health and wellbeing of society; therefore, addressing this issue should be a top priority for establishments which have identified as part of the risk assessment process that substances held at the site could negatively affect the environment. Ultimately, although robust mitigation measures are certainly a positive, the emphasis of where to direct risk management measures lies strongly in the direction of protecting the environment, rather than cleaning up following an accident.

6. References

Balayutham, S., Gonzalez, V.A., Yiu, T, W., 2016, A cleaner production-pollution based framework for construction site induced water pollution, *Journal of Cleaner Production,* 135:1363-1378

BBC, 2002, Milk spill threatens fish, *[online] news.bbc.co.uk,* available at: http://news.bbc.co.uk/1/hi/england/2149856.stm [Accessed 8 Jan. 2020].

Beames, A., Broekx, S., Lookman, R., Touchant, K. and Seuntjens, P., 2014, Sustainability appraisal tools for soil and groundwater remediation: How is the choice of remediation alternative influenced by different sets of sustainability indicators and tool structures? *Science of the Total Environment,* 470:954-966.

Belliveau, E., 2019, Boat Harbour contamination from pulp and paper industry, Nova Scotia, Canada, *[online] Environmental Justice Atlas,* available at: https://ejatlas.org/conflict/pulp-mill-contamination-of-boat-harbour [Accessed 8 Jan. 2020].

Bhatt, A., Karanjekar, R., Altouqi, S., Sattler, M., Hossain, M. and Chen, V., 2017, Estimating landfill leachate BOD and COD based on rainfall, ambient temperature, and waste composition: Exploration of a MARS statistical approach, *Environmental Technology & Innovation,* 8:1-16.

Carey, M.A., Marsland, P.A., Smith, J.W.N., (Environment Agency), 1999. Remedial Targets Methodology

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

Chaudhry, S and Paliwal, R., 2018, Techniques for remediation of paper and pulp mill effluents: Processes and constraints, *Handbook of Environmental Materials Management,* 1-19

Christensen, TH., Bjerg, PL. and Kjeldsen, P., 2000, Natural attenuation: A feasible approach to remediation of ground water pollution at landfills, *Groundwater Monitoring & Remediation,* 20(1):69-77.

Crathorne, B., Ress, Y. and France, S., 2001, Chemical pollution of the aquatic environment by priority pollutants and its control, *Pollution,* 1-31.

Department for Environment, Food & Rural Affairs, 2007, The environmental, social and economic impacts associated with liquid milk consumption in the UK and its production, *[online],* available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69436/pb13644-milk-envsocecon-impacts-080111.pdf [Accessed 8 Jan. 2020].

Environment Agency, 2017, Environmental protection handbook for the fire and rescue service, *[online],* available at: https://www.ukfrs.com/sites/default/files/2017-09/Environment%20Agency%20and%20DCLG%20environmental%20handbook.pdf [Accessed 8 Jan. 2020]

European Commission, 2017, Study for the strategy for a non-toxic environment of the 7th Environment Action Programme, [online], available at: https://ec.europa.eu/environment/chemicals/non-toxic/pdf/NTE%20main%20report%20final.pdf [Accessed 8 Jan. 2020].

EU (European Union), 2012, Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC Text with EEA relevance.

Ezbakhe, F., 2018, Addressing water pollution as a means to achieving the sustainable development goals, *Journal of Water Pollution and Control,* 1: 1-9.

Gong, Y., Tang, J. and Zhao, D., 2016, Application of iron sulphide particles for groundwater and soil remediation: A review, *Water Resources.,* 89:309-320.

Goulding, T., 2017, Suez fined over landfill pollution incident, *[online] letsrecycle.com,* available at: https://www.letsrecycle.com/news/latest-news/suez-fined-over-landfill-pollution-incident/ [Accessed 8 Jan. 2020].

Hadley, PW. And Newell, CJ., 2012, Groundwater remediation: the next 30 years, *Groundwater,* 50(5): 669-678.

Hannah, DM., Webb, BW. and Nobilis, F., 2008, River and stream temperature: Dynamics, processes, model and implications – preface, *Hydrological Processes,* 22: 899-901

Harbor, J.,1999, Engineering geomorphology at the cutting edge of land disturbance: erosion and sediment control on construction sites, *Geomorphology,* 31: 247-263

Herb, W., Janke, B., Mohseni, O., and Stefan, HG., 2008, Thermal pollution of streams by runoff from paved surfaces, *Hydrological Processes,* 22: 987-999

HSE, 2002, Dangerous Substances and Explosive Atmospheres Regulations 2002, *[online],* available at: http://www.legislation.gov.uk/uksi/2002/2776/contents/made [Accessed 14 Jan. 2020]

HSE, 2011, Buncefield: Why did it happen? *[online],* available at: http://www.hse.gov.uk/comah/buncefield/buncefield-report.pdf [Accessed 8 Jan. 2020]

HSE, 2015, Safe use and handling of flammable liquids, *[online],* available at: https://www.hse.gov.uk/pubns/priced/hsg140.pdf [Accessed 14 Jan. 2020]

HSE, 2015, The Control of Major Accident Hazards Regulations 2015, *[online],* available at: https://www.hse.gov.uk/pUbns/priced/l111.pdf [Accessed 14 Jan. 2020]

Integrated Pollution Prevention and Control, 2007, Guidance for the treatment of landfill leachate, *[online]*, available at: https://www.sepa.org.uk/media/61145/ippc-s503-guidance-for-the-treatment-of-landfill-leachate-part-1.pdf [Accessed 8 Jan. 2020]

Koussouris, TS., Diapoulis, AC. And Bertahas, IT., 1998, Self-purification process along a polluted water in Greece, *Water Science Technology,* 21:1869-1872.

Li, JH., Gao, W. and Zhang, H., 2007, Emergency control of blue algal bloom by algaecide: experimental study in Xuanwu Lake, *Environmental Pollution Control,* 29:60-62.

Madden, N., Lewis, A. and Davis, M., 2013, Thermal effluent from the power sector: an analysis of one-through cooling system impacts on surface water temperature, *Environmental Research Letters,* 8(3): 035006.

Maximova, N. and Dahl, O., 2007, A set up of a modern analytical laboratory for wastewaters from pulp and paper industry, *Chemical Society Reviews,* 36(8): 1323.

Nunes, L., Zhu, Y., Stigter, T., Monteiro, J. and Teixeira, M., 2011, Environmental impacts on soil and groundwater at airports: origin, contaminants of concern and environmental risks, *Journal of Environmental Monitoring,* 13(11): 3026.

Pokhrel, D. and Viraraghavan, T., 2004, Treatment of pulp and paper mill wastewater – a review, *Science of the Total Environment,* 333(1-3): 37-58.

Rana, Y., 2018, Molasses leak from sugar factory kills thousands of fish in Beas, *[online] The Time of India,* available at: https://timesofindia.indiatimes.com/city/amritsar/molasses-leakage-kills-thousands-of-fishes/articleshow/64209879.cms [Accessed 8 Jan. 2020].

Revitt, D., 2004, Water pollution impacts of transport, *Issues in Environmental Science and Technology,* 82.

Rogers, GR., 2000, Water quality management at Santa Cruz Harbor, *Aire-O_2 News,* 7:4-5

Ropke, I., 1999, The dynamics of willingness to consume, *Ecological Economics,* 28(3): 399-420.

Russel, M. A, Walling, D. E, Hodgkinson, R. A. (2001). Suspended sediment sources in two small lowland agricultural catchments in the UK. Journal of Hydrology. 252, 1-24.

Saranraj, P. and Stella, D., 2014, Impact of sugar mill effluent to environment and bioremediation: A review, *World Applied Sciences Journal,* 30(3): 299-316

Sato, K., Sakui, H., Sakai, Y. and Tanaka, S., 2008, Long term experimental study of the aquatic plant system for polluted river water, *Water Science Technology,* 46:217-224

South China Morning Post (SCMP), 2019, China's ever-expanding highway network, *[online],* available at: https://www.scmp.com/video/china/2183176/chinas-ever-expanding-highway-network [Accessed 14 Jan. 2020]

Thiruverikatachari, R., Vigneswaran, S. and Naidu, R., 2008, Permeable reactive barrier for groundwater remediation, *Journal of Industrial and Engineering Chemistry,* 14:145-156

Thompson, G., Swain, J., Kay, M., Forster, C.F., 2001, The treatment of pulp and paper mill effluent: a review, *Bioresource Technology,* 77(3): 275-286

Tilton, JE., 2016, Global climate change policy and the polluter pays principle: A different perspective, *Resources Policy*, 50: 117-118

Tosco, T., Papini, MP., Viggi, CC. and Sethi, R., 2014, Nanoscale zerovalent iron particles for groundwater remediation: A Review, *Journal of Cleaner Production,* 77:10-21.

UK Public General Acts, Environmental Protection Act 1990, *[online],* available at: http://www.legislation.gov.uk/ukpga/1990/43/contents [Accessed 9 Jan. 2020]

UK Public General Acts, IPC Water Industry Act 1991, *[online],* available at: http://www.legislation.gov.uk/ukpga/1991/56/contents [Accessed 9 Jan. 2020]

UK Public General Acts, Water Resources Act 1991, *[online],* available at: http://www.legislation.gov.uk/ukpga/1991/57/contents [Accessed 9 Jan. 2020]

Walton, ILW., 2014, Containment systems for the prevention of pollution, *[online] CIRIA,* available at: http://gptenvironmental.co.uk/application/files/7815/0047/9511/CIRIA_report_C736_-_Containment_systems_for_the_prevention_of_pollution.pdf [Accessed 8 Jan. 2020]

Wang, J., Liu, XD. And Lu, J., 2012, Urban river pollution control and remediation, *Procedia Environmental Sciences,* 13:1856-1862.

Wang, S. and Mulligan, CN., 2006, Natural attenuation processes for remediation of arsenic contaminated soils and groundwater, *Journal of Hazardous Materials,* 14:145-156.

Withers, P., 2019, Jim Beam fire: Huger blaze rips through warehouse – 45,000 barrels of bourbon lost, *[online] express.co.uk,* available at: https://www.express.co.uk/news/world/1149002/jim-beam-warehouse-fire-bourbon-45000-barrels-kentucky-river-fish-environment [Accessed 8 Jan. 2020].

Zhang, S., Mao, G., Crittenden, J., Liu, X. and Du, H., 2017, Groundwater remediation from the past to the future: A bibliometric analysis, *Water Research,* 119:114-125.