PART 1

Major accidents to the environment
INTRODUCTION

As discussed below, Major Accident To The Environment (MATTE) is a defined, if somewhat diffuse, concept under the COMAH (Control of Major Accident Hazards regulations, SI 1999 No.743) regime. As regards the latter, there is a large volume of documentation, much of it freely available on the Health and Safety Executive (HSE) web site, providing very clear and detailed guidance on all aspects relevant to human health and safety. For several reasons, corresponding publications on the environmental aspects of the COMAH are both fewer and less detailed.

Therefore, the purpose of this chapter is not to give an overview (for which see CA, 1999), but to focus in some depth on certain problem areas peculiar to MATTEs, in risk assessment, accident prevention and mitigation, and emergency response. Key sections of COMAH relevant to MATTEs are reproduced in Appendix 1.

While this book concentrates on the impact of chemical accidents on the natural environment (i.e. ecosystems), it should be recognised that environmental impact can also affect people, e.g. through the contamination of farm land and water supplies, overloading of sewage treatment works, damage to amenities, etc. For a detailed discussion of conflicts between safety and environmental considerations (not all major hazard related), see Crawley et al., 2000 and Beale, 2000.

The variety of circumstances surrounding MATTEs (chemicals, processes, immediate causes, outcomes) can best be appreciated by perusing collections of incident reports. Over one hundred records in the EU/OECD Major Accident Reporting System (MARS) database refer to major accidents that have caused environmental harm (not necessarily MATTEs). The records, in the form of short reports, are freely available (MAHB, 2007); full reports have been prepared by the national competent authorities for some incidents. A thoughtful selection of case studies appears in Christou, 2000 (see Appendix 2). A twice monthly roundup
of industrial accidents, available at www.saunalahti.fi/ility/HInt1.htm, has a section devoted to the environment. Appendix 3 lists brief details of environmental accidents in the last twenty years extracted from the MHIDAS database, maintained by AEA Technology on behalf of HSE (AEA, 2007); owing to space constraints, the extract excludes hydrocarbon spills. There are many other sources of incident data.

**RISK ASSESSMENT**

Loss prevention begins with risk assessment. Operators of hazardous installations need to have some understanding of the hazards and associated risks created by their activities to decide rationally what, if any, additional control measures to implement, to prioritise any remedial actions and, specifically under COMAH, to demonstrate that they are adequately controlling the risks.

To judge whether a given degree of control is sufficient, it is necessary to consider both the severity and the likelihood/frequency of events (‘scenarios’) that might result from the hazards being realised. The final step in a COMAH risk assessment is to subject the so-called ‘residual risks’ (i.e. the risks remaining after taking into account the effects of all prevention), protection and mitigation measures in place or planned, to a triage: risks are compared against two threshold criteria and assigned into three categories, often shown diagrammatically as zones. A risk in the highest category, labelled ‘intolerable’, cannot be justified whatever the economic benefits of the activity giving rise to it and, in the last resort, the activity can be summarily prohibited by the authorities until the risk is lowered. Risks in the lowest, ‘broadly acceptable’, category, may need no further attention, beyond monitoring (unless several such risks converge/overlap so as to exceed the ‘broadly acceptable’ criterion, see e.g. HSE, 2003). Intermediate risks must be reduced to ALARP (As Low As Reasonably Practicable), based on some form of cost-benefit comparison. Approaching the upper extreme of ALARP, the operator would be expected to act to reduce risks unless the costs of doing so were shown to be wholly disproportionate to the reduction achievable; conversely, risks marginally above the lower extreme would be acceptable unless a large improvement were feasible for a relatively small investment.

What is an appropriate depth of analysis will depend on the size of the risk, the complexity of the operation and, especially in the case of environmental risks, the availability of data on the vulnerability of ‘receptors’. In practice, however, even on complex, ‘top-tier’ COMAH sites where certain risks may demand the most detailed analysis, it is always possible to simplify the analysis overall, beginning with a preliminary screening-out of risks of palpably low consequence and/or low frequency/probability of occurrence.

Screening can take various forms. In a sense, the COMAH designation is itself a form of pre-screening, based as it is on the presence of threshold quantities of dangerous substances. Scenario selection is also a form of screening, since only
physically credible scenarios should be considered; in particular, there must be an unbroken pathway from source to environmental receptor, there must be the potential for sufficient harmful material to reach the receptor to cause a major accident to the environment (MATTE), etc. The reverse approach has also proved useful, whereby crude modelling is used to delineate a set of events of minimum severity that might give rise to a MATTE, allowing the assessor to ignore (for purposes of COMAH compliance) events falling below the minimum set. Similarly, scenarios can be screened out on the basis of likelihood/frequency; the threshold for catastrophic events generally being taken as $10^{-6}$ per year [NB the value applies to the MATTE itself, not to the release that might cause it if all protection and mitigation measures fail; thus, depending on the circumstances, it may be justifiable to screen out catastrophic releases of harmful substances at considerably higher frequencies than $10^{-6}$ per year].

The safety report required for a ‘top-tier’ COMAH installation must include a risk assessment focused on major accidents, as specified in Schedule 4 of COMAH (see Appendix 1):

Part 1 (purpose of safety reports)

The purposes referred to in regulation 7 [Safety report] are as follows:

2. demonstrating that major accident hazards have been identified.

Part 2 (minimum information to be included in safety report)

4. Identification and accidental risks analysis:

(a) detailed description of the possible major accident scenarios and their probability or the conditions under which they occur including a summary of the events which may play a role in triggering each of these scenarios, the causes being internal or external to the installation;

(b) assessment of the extent and severity of the consequences of identified major accidents;

However, even ‘lower-tier’ sites are required to develop a Safety Management System (SMS), which addresses, among other issues,

identification and evaluation of major hazards – adoption and implementation of procedures for systematically identifying major hazards arising from normal and abnormal operation and the assessment of their likelihood and severity (Schedule 2, para 4b).

Thus, a role for each of the elements of a risk assessment is specified even in the case of lower-tier sites. What distinguishes top-tier risk assessments is the emphasis on rigorous demonstration that the assessment is complete and in adequate depth.
Elements of a risk assessment

The practice of risk assessment is conveniently divided into tasks, commonly four, as follows:

- Hazard identification (What can go wrong?)
- Frequency/probability assessment (How often will it happen/how likely is it to happen?)
- Consequence analysis (What damage will it cause?)
- Comparison with risk criteria (How worried should we be?).

This section will skim lightly over the first two tasks, in the application of which there is very little to distinguish environmental from safety risk assessment, which is well-documented. Interesting difficulties arise with consequence analysis (in safety assessments, often the most straightforward of the four) and, especially, with risk criteria.

Environmental risk assessment is a relatively young subject and research has been under-resourced in comparison with safety risk assessment, with some promising projects discontinued, presumably due to funding difficulties. Research results are published in journals such as *Journal of Hazardous Materials* and *Journal of Loss Prevention in the Process Industries*; in conference proceedings, e.g. the IChemE Hazards series, and in scattered reports often commissioned by EU organs and competent authorities of member states.

For the purposes of COMAH, the environment includes features such as architectural and archaeological heritage, groundwater, farmland and sewage works. However, these features do not present unusual problems in consequence analysis. This section will therefore focus on ecosystems.

Hazard identification

The strategies and techniques of hazard identification in safety studies are just as useful in identifying major accident hazards to the environment, as long as the environmental dimension is consciously included in the scope. Thus, for example, HAZOP studies do not require any parameters, guidewords or deviations specific to potential environmental harm. However, the team must beware of dismissing potential releases with no human health or safety consequences too quickly (and particularly should not skim over the less glamorous nodes, such as drains and utilities). On the other hand, fires can have a major indirect environmental impact through loss of containment of firefighting water; we return to this in detail below. Explosions can rupture tanks or pipework carrying non-COMAH substances – such as milk or fruit juice – which can nevertheless devastate an aqueous ecosystem, and the release would qualify as a MATTE under COMAH.

Frequency/probability

Beyond the initial screening, and particularly in the case of top-tier sites where the initial estimates of severity and frequency call for a quantified risk assessment, the
assessor should take into account any fluctuations in the vulnerability of environmental targets. For example, a toxic release into an estuary may have a very serious impact if it happens at a time of year when migrating birds are present, but little or no significant impact at other times; a species may be more exposed or more susceptible to a given toxic substance in one stage of its life cycle than in another; a release into a river will be more rapidly and effectively diluted when the river flow rate is high than when it is low.

Consequence analysis

MATTEs are defined by their consequences. More precisely, whether an accident is deemed to amount to a MATTE depends on a combination of the ecological or amenity value of the affected receptor(s) and the extent, severity and duration of damage caused to it by the accident.

A major accident is defined in COMAH regulation 2(1) to mean:

an occurrence (including in particular, a major emission, fire or explosion) resulting from uncontrolled developments in the course of the operation of any establishment and leading to serious danger to human health or the environment, immediate or delayed, inside or outside the establishment, and involving one or more dangerous substances.

Interpretation with respect to danger to human health is utterly straightforward. Not so for the environment, where a need for official guidance became apparent even under the old CIMAH regime, with its weaker environmental credentials (DoE, 1991). Current UK guidance on what constitutes a MATTE for the purposes of the COMAH regulations is presented for a variety of environmental receptors in no less than twelve tables (DETR, 1999a) reproduced here in Appendix 4. Alternatively, COMAH Schedule 7 Part 1(1) lists the following thresholds for environmental accidents notifiable to the European Commission:

c) immediate damage to the environment:

(i) permanent or long-term damage to terrestrial habitats:

0.5 ha or more of a habitat of environmental or conservation importance protected by legislation,

10 or more hectares of more widespread habitat, including agricultural land;

(ii) significant or long-term damage to freshwater and marine habitats:

10 km or more of river or canal,

1 ha or more of a lake or pond,

2 ha or more of delta,

2 ha or more of a coastline or open sea;

(iii) significant damage to an aquifer or underground water:

1 ha or more;
Likewise, it is much more complicated to assess the vulnerability of environmental than of human receptors. For the latter, it has been possible to quantify impacts; for example, in terms of the so-called dangerous dose (approximate lower limit for human fatalities) from explosion blast overpressure, from thermal radiation from fires, and from exposure to a variety of airborne toxic chemicals. It has even proved relatively straightforward to make numerical adjustments to allow for more vulnerable or less mobile people, for protection offered by buildings, and for other deviations from standard assumptions. The probable number of fatalities from a given scenario is routinely calculated (subject to data and modelling uncertainties) in various software packages. (It is true that actual incidents seldom, if ever, cause as many deaths as ‘predicted’ by consequence models run after the incident, but this is due to deliberate conservatism in the model assumptions rather than any fundamental shortcomings in the models.)

In contrast, damage to an ecosystem is difficult to assess qualitatively, let alone quantitatively, even in principle, and the difficulty is compounded by the dearth of relevant data. What, for example, is the meaning of a ‘dangerous dose’ of a chemical released into an ecosystem? An OECD conference of experts (OECD, 2002) has usefully summarised the difficulties and made corresponding recommendations to member countries; extracts from the conference report appear in Appendix 5.

Adverse changes in any of a large number of ecological characteristics, occurring in response to widely different doses of a given substance, might legitimately be used as thresholds of significant harm, for example:

- Acute deaths of individuals of any species present
- Reduced survival following subsequent natural stresses
- Reduced reproductive success
- Reduced growth rates
- Increased morbidity or appearance of rare or novel forms of morbidity, e.g. tumours.

Note that the above list applies in isolation to one species: consideration of the affected ecosystem as a whole yields further items, for example:

- Reduction in biodiversity
- Enabling of foreign species to gain a foothold or thrive
- Rebalancing of the food chain through impacts on the nutrient pool.

Many physicochemical and biochemical characteristics of the substance may be relevant to gauging its potential for harm, some of which are not inherent properties of the substance, but vary with the environmental context, for example:

- Volatility
- Formation of immiscible layers, whether floating or sinking
- Acidity/alkalinity
• Chemical and biochemical oxygen demand (COD/BOD)
• Acute and chronic ecotoxicity
• Nutrient content
• Mutagenicity
• Persistence
• Bioaccumulation.

Complex interactions among the above (and other) variables are well documented. Eutrophication is a case in point: contamination of a water body with large quantities of sewage or artificial fertiliser will enhance the growth of plants in general and thus, it might be thought, of organisms further up the food chain. However, the common result is just the opposite, as the speediest beneficiaries tend to be algae. Although algae, like all photosynthetic plants, are net producers of oxygen during the hours of daylight, they consume oxygen at night through respiration. Their rapid decay consumes further oxygen, eventually threatening fish and other fauna with asphyxiation. Further, certain blue-green algae are highly ecotoxic.

Several approaches to marshalling and simplifying the above issues have been attempted (e.g. Danihelka 2006, Gunasekera and Edwards 2006 and Stam et al., 2000). A recent overview by Calder and Capewell (2004) appears in Appendix 6.

We now summarise salient aspects of a project whose theoretical predictions have been tested against real incidents and found to produce reasonable results (Bone et al., 1995; DETR, 1998).

**Simplifying the ecosystem** The detailed part of the study was restricted to aquatic ecosystems – rivers, estuaries and lakes (spills at sea are outside the COMAH regime) – largely because of the even greater difficulty of selecting appropriate parameters to represent the severity of harm to the terrestrial environment. This restriction is less drastic than may at first appear, since the overwhelming majority of MATTEs that have been documented have impacted mainly or exclusively aquatic ecosystems (the Seveso incident itself being a notable exception). As regards airborne releases, the measures taken to manage risks to human health and safety will also generally provide adequate protection to ecosystems; although it should be borne in mind that certain species are unusually sensitive to certain airborne substances. Notoriously, many plant species will be severely injured or killed after exposure to hydrogen fluoride at concentrations of the order of $\mu g/m^3$ – orders of magnitude below those dangerous to humans (FPWGAQOG, 1996).

A simplified food web or energy cycle, applicable to each of the above aquatic ecosystems, focused attention onto five trophic levels with associated functional groups as follows:

• Phytoplankton: primary producers, together with higher plants
• Zooplankton: primary consumers
• Vertebrates (fish): secondary consumers
- Higher vertebrates (e.g. wading birds, seals): tertiary consumers
- Benthos (i.e. bottom dwellers): decomposers.

**Simplifying the concept of harm** It was proposed that relevant toxicity data – the most readily available data on ecological harm – should be obtained for representative species of each group present in the subject ecosystem. The most sensitive of these should be chosen on which to conduct the risk assessment, using specialist ecological expertise or detailed guidance available for environmental site assessment (e.g. DETR, 1999b). In the absence of the required data, toxic effects should be estimated from data on related substances and/or related species and the resulting increased uncertainties taken into account. Toxicity data for aquatic species are most often available as the LC50 value (i.e. the concentration lethal to 50% of exposed individuals). Ideally, the experimental exposure period is long enough (typically 96 hours) to exceed the duration of acute lethal effects.

Although the detailed discussions focused, as we have said, on toxic effects, we should mention that consideration was given to extending the risk assessment to changes in pH, temperature or dissolved oxygen as a result of an environmental accident. Indeed, a number of MATTEs have been documented (Christou, 2000; see, e.g. ‘Typical Accident 9’ in Appendix 2) that were caused by substances not classified as dangerous for the environment (i.e. not assigned risk phrases ‘R50 – Very toxic to aquatic organisms’ or ‘R53 – May cause long-term adverse effects in the aquatic environment’).

A measure of the severity of damage in any region of the affected ecosystem is given by the ratio of the peak predicted environmental concentration (PECmax) to the LC50. Thus, for $\frac{\text{PEC}_{\text{max}}}{\text{LC}_{50}} = 1$, it is predicted that 50% of exposed individuals will die.

By analogy to the concept of dangerous dose in the context of human acute exposure, it was considered that there was a dangerous concentration (DC), much lower than the LC50, above which the substance in question would cause some harm to the environment. The size of the ecosystem affected by the MATTE under consideration ($S_{\text{max}}$) is the length of river or the area of estuary or lake where, at its maximum extent, the release exceeds the DC. It was proposed that, data permitting, the DC should be identified with the lowest concentration that would cause some noticeable adverse effect (typically related to behaviour, growth or reproductive success) to 50% of the most sensitive representative species, i.e. the EC50 for that substance in that ecosystem. In the absence of suitable EC50 data, the DC is set equal to one-tenth of the LC50 as defined above.

Both PECmax and Smax can be computed using a variety of dispersion models, provided there is adequate reliable information concerning the physical environment receiving the spill.

The project authors advised against correcting experimental LC50 values for exposure duration: on the one hand, even very short releases have been shown to lead to environmental exposures of several days; on the other, prolonged exposure is strongly mitigated by volatilisation, adsorption to sediments and chemical
decomposition. However, it was suggested that predicted recovery times should in some rough way be factored in, despite the dearth of data and the fact that the concept of recovery is somewhat ill-defined (in some cases, it is obvious that a damaged ecosystem will never recover to a state near to its original). The recommended categorisation of recovery times after an accidental spill, $T_{acc}$, is as follows:

<table>
<thead>
<tr>
<th>Recovery time category</th>
<th>$T_{acc}$ (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>50</td>
</tr>
<tr>
<td>5–20 years</td>
<td>20</td>
</tr>
<tr>
<td>1–5 years</td>
<td>5</td>
</tr>
<tr>
<td>Weeks–1 year</td>
<td>1</td>
</tr>
<tr>
<td>Days</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The *reference accident* The impact of potential accidents can be measured and expressed on a scale by comparison with a reference accident, defined as the minimum to qualify as a MATTE in the circumstances. Thus, the size of the reference accident, $S_{ref}$, can be found among the tabulated values in the official guidance (DETR, 1999a), while the severity is set at the minimum LC$_{50}$, obtained as described above. Information from substantial environmental accidents resulting in prosecutions suggested that 5 years is a reasonable reference value for recovery time, $T_{ref}$. The reference accident can now be characterised as the product of $S_{ref}$, LC$_{50}$, and $T_{ref}$.

The *environmental harm index* Likewise, the potential accident under consideration can be characterised as the product of its extent, $S_{max}$, the maximum predicted environmental concentration, PEC$_{max}$, of the toxic substance released, and $T_{acc}$. The environmental harm index (EHI) is defined as the ratio of the magnitude (in terms of both extent, severity and duration) of the potential accident to that of the reference accident. The simple, highly conservative, approach is to assume that the peak concentration extends over the entire affected ecosystem, i.e.:

$$EHI = \frac{S_{max} \times PEC_{max} \times T_{acc}}{S_{ref} \times LC_{50, \text{min}} \times 5 [+ T_{ref}]}$$

However, the maximum PEC observed at any point decreases with increasing distance from the source of the release, eventually falling to the DC at the boundaries of the affected region. Therefore, a more accurate estimate of the EHI may be obtained by dividing the affected region into several sub-regions of size $S_j$, with peak predicted environmental concentration PEC$_j$:

$$EHI = \frac{\Sigma (S_j \times PEC_j)}{(S_{ref} \times LC_{50, \text{min}})} \times \frac{T_{acc}}{5}$$

A suitable number of sub-regions can be arrived at by trial and error.
Spills of more than one toxic substance are treated by adding the EHI, i.e. the toxic effects of the substances are assumed to be additive, unless there is information to the contrary. It may be possible to apply a correction factor to the final EHI to account for synergistic or antagonistic effects.

Certain substances undergo chemical or biochemical transformations in the environment yielding products of enhanced toxicity. The authors of the study suggested that, in such cases, the EHI should conservatively be calculated for the degradation products only, assuming the degradation to be complete and instantaneous. This approach might conceivably be extended to account for the alkaloids and toxic peptides released by blue green algae as an indirect result of (non-toxic) spills of nutrients into lakes (see above).

The special case of lakes A comparison of the characteristics of the different aquatic ecosystems reveals several important differences, from the point of view of vulnerability to MATTEs, between lakes on the one hand and rivers and estuaries on the other:

- Temperate lakes beyond a certain depth tend to stratify in the summer (and, in some cases, in the winter) and are well mixed in autumn and spring. Pollutant distribution after a spill will therefore depend on the season and on whether the spill can penetrate into the lower layer. Note that a persistent pollutant released into the upper layer may survive to be brought into contact with the sediment during the next spring or autumn turnover.
- Lakes typically have very long retention times. For persistent pollutants, recovery times for sensitive species may be significant in comparison with the return period for significant spills (average interval between spills of a given magnitude), so the possibility of doses accumulating may need to be considered.
- Lake ecosystems are often under chronic stress from eutrophication, partly through natural causes. In such conditions, substances toxic to the respiratory system can cause fish kills at a fraction of the LC50.

Risk criteria
The above project has also tentatively proposed numerical criteria to define risk zones (intolerable, ALARP, broadly acceptable – as described above) corresponding to given combinations of EHI and predicted frequency of occurrence. The scheme is shown in Figure 1.1.

The reasoning behind the choice of location for the zone limits is not published in full, having been crystallised from the expert views of many participants at key project workshops, but may be summarised as follows:

- Consequence modelling of real accidents indicates that MATTEs typically have EHI values of at least 100
- In respect of consequences for human health and safety, a frequency of $10^{-4}$ per year is regarded by the Health and Safety Commission as being on the
Technical aspects

borderline of tolerability for a major accident on a particular plant (HSC, 1976)

- Risk criteria schemes in common use typically have an ALARP zone extending two orders of magnitude in both consequence and frequency dimensions
- The gradient of the lines forming the zone boundaries (i.e., the rate at which tolerable frequencies decrease with increasing EHI) is the same as that used in other discussions in UK on risk criteria. (More recently, this same gradient, \((-1)\) has been recommended in connection with societal risk criteria; see HSE, 2001). Note that steeper gradients have been in use in other countries, reflecting a putative disproportionate public aversion to larger accidents.

Figure 1.1 Proposed risk criteria. Adapted from DETR (1998). Management of harm to the environment: criteria for the management of unplanned releases (The Stationery Office: London), ISBN 0-11-753456-0.

PREVENTION AND MITIGATION

Introduction

For environmental damage to occur as a result of an industrial accident, there must be a pathway linking potential releases at the industrial site and sensitive receptors in the environment. The pathway is usually a gravitational liquid flow, the harmful release being in the liquid phase and the receptor being an aquatic ecosystem.

With a very few notable exceptions, such as the eponymous Seveso incident, environmental impact from accidental (as distinct from chronic) airborne releases tends to be minor and transient. Dilution of the pollutant cloud via atmospheric
dispersion is rapid and any surface deposition is removed effectively by mechanisms such as rain, adsorption onto soil particles and microbial action in the soil.

In contrast, liquid releases can flow off site with little or no dilution. On the other hand, should they become massively diluted (most often through the use of firefighting water and foam in an emergency) they will be more mobile, more difficult to contain on site and more likely to reach natural watercourses. Aquatic ecosystems can be very fragile, with many aquatic species susceptible to low concentrations of chemicals dissolved in or transported by water; further, harm to one species can affect many others. Such an ecosystem can take a long time to recover, and may, in fact, never fully recover without human intervention (assuming that is feasible), especially if sediment is affected. Finally, liquid releases can percolate into the ground and potentially affect groundwater. Groundwater is a primary source of drinking water in many areas, including heavily populated urban areas such as South-East England, and is also a long-term source of water to maintain river flow. It can be extremely difficult and costly to remove contamination from groundwater.

The COMAH technical measures of most general relevance to environmental protection are therefore those which reduce the risk of accidental liquid releases or enable their retention on site. Many of these measures are similar in principle, if not always in detail, to those designed to protect the environment from much smaller controlled or fugitive releases during normal operation.

This section draws on material contained in HSE, 2007. For further information, see www.hse.gov.uk/comah/sragtech/techmeasures.htm.

Site location

The choice of location for a major hazard installation is subject to various economic and social constraints as well as safety related planning regulations. Conflicting environmental considerations are often viewed as subsidiary to these constraints. Nevertheless, site location is a key feature in controlling environmental hazards. Unfortunately, waterside locations, which are likely to enhance environmental risks, are economically attractive sites for major industrial plants. They are often flat and are therefore easy to develop – having frequently been left undeveloped to avoid flood risk(!) – and can have good access to bulk water transport. Again, an installation situated remote from population centres to control risks to public safety is more likely to intrude on scarce habitats. Following the Baia Mare accident (see below), an incomplete regional inventory revealed 42 'high-risk' potential accident hot-spots in the River Tisa catchment area (ICPDR, 2000). The inventory is reproduced in Appendix 7.

Site layout

Site layout should be informed by detailed knowledge of local environmental sensitivities, drainage catchments and natural hazards such as flooding (discussed in more detail below), in order to help reduce the impact of any accidental release.
Site layout is important in controlling risks of escalation, especially fire spread. Plant separation is an obvious first step, but fire can also spread through drains and vents, or by the ignition of drifting flammable vapour clouds. Where feasible, vulnerable units should be compartmentalised, using suitably fire resistant walls and floors. Explosions can cause releases and secondary fires elsewhere on the site by damage through blast waves or missile impact. These risks can be reduced by the provision of barriers and blast walls, by arranging for relief vents to face away from vulnerable areas and, most effectively, by setting adequate separation distances.

There are further site layout techniques which aim to reduce the consequences of failure. The Health and Safety Executive lists the following in its guidance (HSE, 2007).

- Locating all high-volume storage of flammable/toxic material well outside process areas
- Locating hazardous plant away from main roadways through the site
- Fitting remote-actuated isolation valves where high inventories of hazardous materials may be released into vulnerable areas
- Provision of ditches, dykes, embankments and sloping terrain to contain and control releases and limit the safety and environmental effects
- Siting of plants within buildings as secondary containment
- Siting of plants in the open air to ensure rapid dispersion of minor releases of flammable gases and vapours and thus prevent concentrations building up which may lead to flash fires and explosions
- Providing hazardous area classification for flammable gases, vapours and dusts to ensure adequate control of ignition sources.

**Process selection**

It is a requirement of COMAH that designers and operators of major hazard sites should consider ways to enhance inherent safety, in ways such as:

- Use of alternative, less hazardous substances/processes
- Reduction, e.g. through process intensification, of hazardous inventories in both process and storage
- Use of less hazardous conditions (temperature, pressure, continuous versus batch).

Systematic approaches, e.g. calculated runaway indices, to assess prevention measures such as the above have been available for some time (Papadakis, 1997). Recently, the inherent safety philosophy has been extended to include inherent ‘environmental friendliness’ (Gunasekera and Edwards, 2006). The authors consider in detail the consequences, restricted to acute toxic impact (in terms of EHI values – see above) on aquatic, terrestrial and atmospheric environments, of a catastrophic loss of containment of the entire inventory of a chemical plant. The final output is the inherent environmental toxicity hazard (IETH) for the plant.
process. The methodology inevitably relies on a number of fairly crude assumptions and arbitrary (i.e. based on expert judgement) benchmarks, and takes no account of the actual ecosystems in the vicinity of the site; so absolute values of IETH are meaningless. The usefulness of the methodology is in comparing processes. The authors conclude with an example calculation of IETH for each of six process routes for the manufacture of methyl methacrylate, generating IETH values ranging from the relatively friendly 10.1 to the decidedly unfriendly 68.0 (for the isobutylene and acetone cyanohydrin routes, respectively).

More generally, where the sensitivities of the local environment are fully known, the choice of process can sometimes be adjusted to remove particular threats to the environment, or to remove a harmful process from areas on the site where a pathway exists to the sensitive environment.

**Flood resistance**

In a review of lessons to be learned from recent MATTEs (Whitfield, 2001; reproduced in Appendix 8), the UK Environment Agency (EA) has highlighted threats from flooding as among the most important:

> The environment has usually been regarded as the victim of industrial accidents. The CSG incident and the widespread flooding last winter demonstrate that operators must take into account environmental factors which might initiate major accidents or worsen their consequences. The Environment Agency believes that global warming is already happening and that the future will involve more severe weather events, i.e. flooding, storm-force winds, lightning strikes and even tornadoes. These changes need to be considered carefully in the design and operation of processes handling dangerous substances.

Flooding presents risks to the plant through physical disruption of the plant’s facilities, failure of its power supply, or the sudden need to evacuate the premises.

Flood threats to an industrial site can arise from excessive rainfall on the site, unusually high river flows, high groundwater levels or the catastrophic failure of flood defences, reservoirs or canals adjacent to the site. Coastal sites have additional risks arising from overtopping or breach of sea defences, high and storm surge tides and coastal erosion.

Climate change is exacerbating most of these risks, with rainfall intensity in the UK expected to increase by 30% by the end of the century and sea level to rise by up to half a metre. Since large industrial sites represent a major investment and a significant part of a region’s economic infrastructure, they are likely to be in operation over a long period of time and an assessment of possible changes to flood risk over at least 100 years into the future is likely to be appropriate.

Particular consideration should be given to the protection of critical plant, equipment and control structures, so that the plant can be safely shut down in the event of flooding. Measures might include separate power systems out of the range of flood risk and safe areas for key staff to remain on site during a flood. Consideration must be given to the speed at which a flood might occur,
particularly if a potential source of flooding is from catastrophic failure of flood defences or water storage systems. The erosive power of such floods can be very substantial and can threaten the integrity of plant infrastructure such as storage tanks and pipelines. In these cases, a thorough study of the route, depth and speed of a flood-wave through the plant is necessary.

Buoyancy poses a further hazard during flooding. Empty or partially filled tanks, especially if within wells or deep bunds, may float when a site is inundated, and may bring about catastrophic failure of the tank and associated pipe work with the uncontrolled release of hazardous substances directly into the environment.

THE BAIA MARE INCIDENT

Flooding can arise from the operation of the plant itself, as in the relatively frequent case of the failure of tailings dams in the mining industry. Tailings dams are designed to allow settlement of sediment from process water in mining and opencast operations. The dam is formed from the coarser sediment, with a ‘beach’ of finer sediment against it to prevent flow of water through the dam. Clear water is drained off from the surface of the pond, leaving behind the contaminated sediment which builds up during the operation of the dam. There have been many failures of these systems, often resulting in notable damage to the environment.

The tailings dam for a gold and silver mining operation in Baia Mare, Romania, was designed as part of a closed system, with no effluent stream (Figure 1.2). This was considered especially desirable, because the process water collecting behind the dam was highly toxic, since it contained cyanide added to the tailings to dissolve the precious metals. 
The major accident at Baia Mare was precipitated by coinciding weather events, none of which was extreme; further, the sequence of a freeze succeeded by both heavy rainfall and snow melt was not particularly unusual. There appears to have been no study of the possible variability of the hydrology at the site, or appreciation of the likely convergence of adverse weather events. The design of the system had no fail-safe mode and no provision for emergency storage should dam creation by the hydrocyclones fail for any reason.

For an overview of tailings dam failure modes and their assessment, see UNEP, 2001a.

**Drainage systems**

*Storm water*

A major industrial site will cover a large area and require a good system of drainage to protect the site and its equipment from flooding during periods of
heavy rainfall. An extensive and efficient drainage system is therefore essential and should be installed as a matter of course during construction of the plant. Normal drainage design codes often cite the 30-year event (i.e. one that has a 1 in 30 chance of occurring in any one year) as a suitable standard. For major industrial sites, however, as mentioned above, a less frequent rainfall event is likely to be more appropriate, taking account of the consequences of failure.

Design methods for dealing with storm water are described in Mason and Arnold, 1984. The system should also be designed for safe failure by incorporating storage basins, of a size appropriate to the drainage area, for containment of overflows. It is crucial that clean storm water is kept separate from any spillage or potential contamination. This will avoid release of contaminated water should the drainage capacity be exceeded, as well as the need to treat large volumes of contaminated rainwater after the emergency.

Design of the drainage system should take account of the processes in the plant and the chemicals likely to be present. Gravity-flow systems are designed to run about three-quarters full at a slope of about 0.6 to 0.8% to a catchbasin with a sand trap and liquid seal. However, where flammable liquids could be present, a fully flooded system is more appropriate. This prevents the movement of flammable vapours above the water surface in the pipe and the transmission of burning liquids through the pipe system to other parts of the site.

Aqueous effluent

Major industrial plant is usually provided with two further, separate, drainage systems: a closed domestic sewerage system and a closed sewer for aqueous effluent. Aqueous effluent systems should be designed to prevent the spread of hazardous liquids and vapours around the site. It may also be necessary to keep different liquids separate to avoid chemical reactions and possible ignition or evolution of toxic gases.

Run-off from plant areas should be directed to interceptors or sumps to enable separation of water-immiscible substances and sampling of the aqueous phase prior to discharge. The Health and Safety Executive (HSE, 2007) recommends that consideration should be given to:

- Neutralisation prior to discharge
- Discharge to drums or standby tanks for disposal or re-use
- Level measurement/alarms to detect spillages
- Regular cleaning of sumps to prevent build up of solids
- Protection against freezing
- The use of appropriate materials of construction for sumps, floors and drainage channels.

In most instances, standard materials of construction (e.g. concrete, brickwork) will be adequate. However, where strong acids are likely to be present for prolonged periods, or where structural steelwork might be exposed to corrosive liquids and vapours, consideration should be given to the use of acid-resistant coatings.
In many cases, process effluents and firewater are drained into main sewerage systems. Where there is a possibility that hazardous substances could be discharged into a drainage system, interceptors or sumps of sufficient capacity should be provided to prevent, as far as reasonably practicable, major accidents on site from triggering a MATTE. For process effluents arising from leaks or plant washdown, a good practice is to provide a local sump which is sampled before emptying. Such sumps normally incorporate level indicators/alarms for monitoring. Discharge can be via submersible or mobile pumps to drums for onward disposal, or via manual or manually operated automatic valves into main drainage systems if the contents are non-hazardous. Consideration will need to be given in the safety report to the possibility of valves being left open.

A particular concern is the discharge of flammable liquids that are not water-miscible, and so can form a floating layer. These could ignite considerable distances from the plant after discharge. More sophisticated interceptors can be provided to facilitate removal of floating flammable liquids. These should be designed to meet individual needs and incorporate level sensors (e.g. conductivity-based) to distinguish between layers.

Firewater run-off is likely to involve very large quantities of contaminated water, considered in more detail below. Risk assessments should be undertaken to consider the requirement for segregation of these streams into lagoons or other catchment systems.

Managing liquids on site

The need to contain and manage liquids on site is fundamental to controlling impacts on the aquatic environment. There should be a series of measures, with ample redundancy, to ensure liquid containment. The system should be designed to manage liquids during normal operation, in the event of a small-scale accident such as a spillage, and in the event of a major accident, all in such a way as to prevent contamination of clean water and the spread of liquid chemicals and contaminated water across the site.

Small-scale measures for management of liquids at source include drip trays, concentric pipes and double-skinned tanks and vessels. Drip trays are used to catch small spillages beneath leak-prone plant or vulnerable points (such as filling or draw-off areas) and prevent their entry into storm water drains; and, in some cases, prevent their coming into contact with incompatible chemicals, which could lead to hazardous reactions.

Concentric pipes and double-skinned vessels provide secondary containment for individual elements of a site. They also offer the possibility of monitoring for leakage between the two layers and further opportunity to prevent release of material into the environment. For this reason, double skinning is often used where there is particularly hazardous material present, or where material of a particular nature, such as corrosive fluids, requires the use of relatively weak materials such as glass for the main pipework. Double-skinned vessels and pipes
are also used where simpler bunding (see below) is not possible or desirable; for instance, along overhead pipe runs. More information on the detailed design of these small-scale measures is given in HSE (2007).

Secondary containment

Of greater significance for preventing major environmental impact are bunds and site-wide containment systems. Bunds are walls or embankments around large storage vessels for liquids (including fully refrigerated liquefied gases), designed to provide secondary containment in the event of failure of the primary system. Smaller bunds are sometimes used within plant buildings around process vessels.

It is normal to limit the total storage capacity of tanks in a single bund to 60,000 m³. Tanks often have individual bunds; in any case, incompatible materials should not be stored within the same bund.

Bunds should be sized to hold 110% of the maximum capacity of the largest tank or drum. This will allow some latitude for the addition of foam during response to an emergency (but see further below). The bund design should take into account the likely dynamic loading on the wall resulting from the catastrophic failure of a tank. Even if the bund wall survives intact, such failure can also release a ‘tsunami’ of liquid, with a large proportion of the inventory overtopping the (correctly sized) bund wall (Atherton, 2005). Design guidance on suitable measures to prevent this is given in CIRIA (1997), following investigations reported in Wilkinson (1991).

Bunds vary widely with respect to recommended wall height and there are no set rules relating wall height to other parameters, such as floor area. Low wall heights (1–1.5 metres) are often used to facilitate firefighting, but are a poor defence against spigot flow (where hydrostatic pressure in the tank impels the outflow from a leak to pass above the bund wall), or the tidal wave effect of a catastrophic tank failure. In some cases, bunds as high as the tank are used, but these are quite unusual. For high-walled bunds, consideration will need to be given to the likelihood of tanks floating as the bund fills, with potentially severe consequences as described above.

Bunds are generally fabricated from brick/mortar or concrete, with a cladding of vermiculite mortar or other insulation where refrigerated liquefied gases are being stored. Special coatings are required for the few chemicals, e.g. oleum, that attack the above materials.

Maintenance of bunds is an important aspect, often overlooked, particularly in remote locations. A system of inspection should be in place to ensure the integrity of the bund. Also, due consideration should be given to drainage to allow the timely removal of rainwater. This is usually achieved by ensuring that the bund slopes towards a low point on the wall and installing a drain at this point, equipped with a manual valve, normally kept closed. Operating schedules should include daily opening of the valve to remove accumulated water, thus also incidentally identifying any minor leaks. However, this system carries the
risk that the valve may be left open or fail, thus reducing the effectiveness of the bund if a tank should fail. Also, in winter conditions, ice may form and block the drain. Failure to remove rainwater will reduce the capacity of the bund and may result in overtopping and, if the substance to be contained reacts with water (e.g. oleum), it may result in an increased airborne release.

Bunds are generally unsuitable as secondary containment for toxic volatile liquids. A common alternative is an expansion tank, designed to hold up to 10% excess liquid in the event of overfilling. Alarms and emergency shut-down can be actuated by pressure, level or weight sensors fitted to the expansion vessel. Expansion vessels are also used for pressure relief on long pipelines carrying liquids that have a high coefficient of expansion.

**THE BULK TERMINALS INCIDENT**

An example of the use, and potential pitfalls, of bunds in preventing damage to the environment is provided by the 1974 incident at Bulk Terminals tank farm in Chicago (Lees, 1996). Following the accidental closure of a pressure relief valve, pressure in a tank holding 3300 m$^3$ of silicon tetrachloride built up until a flexible coupling burst, cracking the tank and allowing the escape of liquid product and hydrogen chloride gas. The tank was provided with a bund, which started to accumulate the spilled liquid.

The site operators sought to reduce vaporisation from this spillage with a foam blanket. When this failed, lime was added to neutralise the liquid and fuel oil was spread on the surface. This succeeded in reducing vaporisation, but it then began to rain. With the combined volume of rainwater and the materials added to control vaporisation, the remaining capacity of the bund was now insufficient to hold the whole contents of the failed tank. An emergency operation was begun to provide a pit to take the overflow.

After several days, the operators managed to seal the leak in the tank and brought the emergency under control. While damage to the environment was relatively minor, one person was killed, 160 hospitalised and 16,000 people were evacuated from their homes. The incident demonstrated the need for care in sizing secondary containment for the storage of reactive materials, taking account of the likely need to treat spilled liquid with bulky materials.

Environmental risks from airborne reaction products generated from spills of water-reactive chemicals are discussed in Fernie et al. (2004) (see Appendix 10).

Even if sized to allow for foam addition, bunds can fail in a fire, as happened at a timber-treatment works on a tributary of the River Thames in the UK in 1990 (Dowson et al., 1996). The fire ruptured storage tanks containing 30,000 litres of highly toxic chemicals, including lindane and tributyltin oxide (TBT).
The bunds contained the spill and the fire-fighting water and foam, but then cracked in the heat of the blaze (as later occurred at Buncefield), releasing 25,000 litres of wood preservative. The release caused extensive fish mortality and wiped out the invertebrate population in the tributary. TBT was detected 59 kilometres downstream of the release and the ecosystem took many months to recover.

**FIRE OR FLOOD?**

**The Fire and Explosion Hazard Management process**

Even in countries without specific major hazard regulations, facility operators within the oil, gas and petrochemical industries have for many years used some variant of a formal technique: the Fire and Explosion Hazard Management (FEHM) process, to control major accident hazards. FEHM is applicable also to other emergencies, such as major spills or toxic releases. The use of FEHM has now spread to many other high-hazard industry sectors, including chemical storage and protection of critical buildings.

The process addresses not only technological aspects of major accident hazards, but also unregulated issues such as business interruption and damage to public image. It is often such issues – even more than regulation or potential asset loss – that justify risk reduction measures in cost-benefit terms. In particular, serious environmental damage from an incident has a public image consequence, and can potentially result in additional regulatory requirements and associated costs. Taking these factors into account, the eventual damage to a company which has caused a MATTE can greatly exceed the immediate cost from the incident itself. Therefore, it is vital that facility operators, when developing emergency response and mitigation strategies, should consider in detail the potential environmental impact of both fire and fire response.

FEHM is essentially a four-stage process, as shown in Figure 1.3. **Stage 1** is identification and analysis of potential scenarios, addressing impacts, both immediate and long-term, on life safety, the environment, business interruption, asset loss and public image. The analysis can be qualitative or quantitative. The aim is to provide guidance on the potential losses and so help decide which risk reduction measures are justified. Usually, the worksheets are supported by calculations to determine the quantity and flow of firewater and extinguishing agents required.

The following tasks in the FEHM process are especially relevant to environmental consequences:

- Containment of any product spillage
- Selection and application of firefighting agents to minimise environmental impact
- Containment and subsequent disposal of water or other agents used to control or extinguish the incident
- Consideration of controlled ‘burn-out’ of the fire to minimise environmental impact (despite consequent high levels of smoke).
Usually, controlled burn-out will still require a firewater application to prevent escalation and spread to adjacent facilities, so it should not be considered as a ‘do nothing’ strategy. Even if the water is used only for cooling, it may still be contaminated and require containment. In most instances, it is not possible to segregate what might not be contaminated. Unfortunately, firewater is often unnecessarily applied to adjacent structures that are not subjected to sufficiently high radiant heat levels to be of concern.

Stage 2 of FEHM is a review of risk reduction options, including both prevention and mitigation measures, as well as relevant process control and isolation/containment measures. It is at this stage that conflicts should be resolved, e.g. where a mitigation measure intended to save property (typically foam application to the fire and cooling water to adjacent equipment and structures) can give rise to environmental harm (contaminated run-off).

Stages 3 and 4, policy determination and implementation, respectively, are outside the scope of this book, but are critical aspects of the FEHM process. Valuable guidance has been published by the International Association of Oil and Gas Producers (OGP, 2000). Here, the focus will be on Stage 2.

Fire response options – overall strategies
There are essentially three options available as fire responses to major incidents such as storage tank fires:

- Burn-down
- Fixed system application of fire extinguishing/control agents
- Mobile equipment application of fire extinguishing/control agents.
The choice of option should be risk based and site- and scenario-specific. The main considerations are responder safety, incident consequences, incident duration, and cost. Fixed and mobile systems are often integrated in scenario preplans, as in the example in Appendix 11).

There has been increasing reliance on large-capacity strategic mobile response to attend major incidents, often provided on a mutual-aid or centralised basis. A good example is the scheme which has been developed by the specialist industrial brigade of Rotterdam Fire Brigade for deployment to major incidents within the Europoort area.

**Firefighting and the environment – case studies**

It is generally recognised that fires at petroleum and petrochemical facilities can have significant environmental effects through loss of product containment and generation of smoke and other toxic combustion products. However, inefficient or incorrect firefighting actions can markedly aggravate environmental impacts. In particular, overuse of firewater can carry petroleum products outside bunded areas and through overloaded wastewater treatment plants, to pollute watercourses and groundwater.

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**THE ALLIED COLLOIDS INCIDENT**

The fire at Allied Colloids (Bradford, UK) in July 1992 resulted in considerable environmental damage to the local Aire and Calder rivers, largely due to firefighting activities. The incident highlighted a number of contributory shortcomings both in technical/safety precautions and FEHM measures including management of firefighting run-off.

The incident occurred at one of the company’s raw materials warehouses. The warehouse had two rooms in which oxidising as well as flammable products were kept without proper segregation. The fire was probably caused by impact ignition following loss of containment of the incompatible materials.

Although the Fire Brigade contained the fire on the same day, stand-down was not possible until 18 days later due to the risk of re-ignition. During three hours of firefighting effort, an estimated 16 million litres of firewater was used. Some of this water reacted with materials in the warehouse to form viscous polymers, which blocked the site drainage systems. There were also difficulties in maintaining continuous operation of pumps, with the result that firewater could not drain off in a controlled manner, and spilled into local waterways. An estimated 20,000 fish were killed, with significant pollution downstream of the incident.

Safety reports prepared for the site had identified a greater risk from firewater run-off than from smoke due to any fire. This assessment was borne out by the
incident. A number of factors contributed to the severity of environmental consequences. These included:

- Unsprinklered buildings
- No effective secondary containment (bunds) in place
- Lack of effluent retention facilities
- Elevated location for the warehousing – this allowed run-off to flow downwards and escalate the fire spread to external drum storage.

Some of these issues had been previously identified at a notorious incident – see below.

**Risk reduction measures and good practices** The replacement warehouse had dedicated storage units for chemicals, with separate warehousing for raw materials and finished products, and proper segregation of incompatible materials such as flammables and oxidising agents.

Sprinklers and bunding were installed, and an effluent retention basin was constructed, at a cost of £2 million, with a compartmented capacity of approximately 8 million litres (half the volume used in the incident, presumably based on a scenario analysis of firewater demands using more efficient firewater management). Pumps were fitted to enable inter-compartment transfer. Any run-off entering the basin could now be controlled, held for testing, and transferred either to a treatment system or directly to the sewer.

Further FEHM-related measures, the need for which was highlighted by this incident, are set out in HSE, 1993.

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**THE SANDOZ INCIDENT**

The above lessons might well have been learned six years earlier, from one of Europe’s worst environmental disasters. Firefighting appliances, including tugs on the adjacent Rhine, used an estimated 24,000 litres of water per minute to control a fire at the Sandoz chemicals storage warehouse in Basle, Switzerland. The site drainage containment could not cope with these quantities and flow rates, so that much of the run-off entered the Rhine. The pollution incident lasted for only a few hours, but the firewater, contaminated with about 10 tonnes of unburned insecticides, mercurial fungicides and other toxic chemicals (including high-temperature reaction products of enhanced toxicity) killed nearly all aquatic life for a significant distance downstream – dead eels were found up to 200 kilometres from the incident. The river took many years to recover. The firefighting tugs also inadvertently spread the contamination around a large area on land, to a depth of up to 14 metres, thus affecting the groundwater.
The subsequent investigation established that the concentrations of toxic contaminants, including mercury and dioxins, within the smoke plume had not posed a serious health risk.

**THE SHERWIN-WILLIAMS INCIDENT AND THE CASE FOR 'BURN-DOWN'**

This last observation has been mirrored in other chemical warehouse fire incidents, sometimes leading to different control tactics and outcome.

In 1987, the Sherwin-Williams warehouse in Dayton, Ohio, USA, containing over 5.5 million litres of paint and paint-related products, caught fire and the installed sprinkler systems and fire wall were quickly overwhelmed.

The warehouse was situated over an aquifer that provided drinking water to approximately a third of the local population of 400,000. The warehouse was allowed to burn down. The decision was taken following early consultation among company representatives, fire responders, air and water pollution experts and public officials. The consensus was that the risk of contaminating the underlying aquifer with firewater run-off far outweighed that associated with the smoke plume if the fire was allowed to continue with minimal intervention. Only as much water was applied to manage the burn-down safely as could be retained on site (Copeland and Schaeeman, 1987).

Unfortunately, the lessons from Sandoz, perhaps fresh in the minds of the Dayton responders (the incident report appended a summary of the Sandoz disaster), seem to have been forgotten a few years later in Bradford (see the Allied Colloids incident, p. 25).

The above is not to imply that burn-down is an appropriate fire response in every case. However, a valid FEHM policy might state that burn-down is justified in certain cases where other consequences to life safety, the environment and business continuity are not disproportionate. The EA recognises that, in some cases (subject to a risk assessment) the strategy with least environmental impact may indeed be a burn-down (or 'controlled burn'). The executive summary of EA (2001) is worth quoting at length:

*The Best Practical Environmental Option (BPEO) principle can be applied to pollution releases from fires at site storing substances hazardous to the environment. In purely BPEO terms, the appropriate firefighting response is the one having the smallest overall environmental impact over all media (air, land and water). The concept of the controlled-burn tactic has developed and involves a restricted or controlled use of water or foam on fires to reduce potential environmental impacts of chemicals and contaminated firewater run-off. The Environment Agency wishes to develop policy on controlled burns and to establish workable guidelines on when controlled burn may be appropriate.*
There are many parties with an interest in controlled burn, for instance, regulators, the Fire Service, operators, insurers and local authorities. These parties were contacted so that any guidance and policy on controlled burn could be informed by their views. Most parties agreed with the basic philosophy behind controlled burn provided safeguards were in place to protect public and firefighter health and safety, and provided financial factors were also taken into account.

Six case studies were examined in detail. These highlighted the lack of financial information available on which to look in detail at costs versus environmental benefits. Costs were therefore assigned into broad categories. For each case study incident, the environmental impacts were assessed, including impacts on human health, controlled waters, air pollution and the terrestrial environment. A rigid, quantitative approach was not possible because of the lack of measurements and quantitative data from the incidents. Therefore, a semi-quantitative risk-ranking approach was used. The assessments of case studies involving controlled burns showed significant reductions environmental impacts compared to the probable impacts of conventional tactics.

Drawing on the approach used to assess the environmental impacts in the case studies, guidance has been prepared on the application of controlled burn as a firefighting tactic. Central to the guidance is the need for at-risk sites to carry out a risk assessment and, if necessary, put in place an emergency fire plan. A rapid screening assessment has been developed to identify such at-risk sites. Guidance has been given on the key stages of a full risk assessment and this has been augmented with a worked example.

Potential legal conflicts of adopting controlled-burn guidance were examined. Of particular concern was the relationship between the Fire Services Act 1947 and the Water Resources Act 1991 and the Environmental Protection Act 1990. Current legal opinion on this is that there is no overriding duty under the 1947 Act to extinguish fires, nor is there an overriding duty to protect property. Therefore, a decision whether or not to carry out firefighting operations would be governed by general principles of public law reasonableness (and by any applicable guidance). It is not hard to imagine circumstances where it would be reasonable for a fire officer to decide not to carry out firefighting operations because the consequences of carrying out the operations (whether these be environmental or some other consequences) would be worse than the destruction of property caused by failing to carry them out.

The decision on whether a burn-down strategy is acceptable will depend on factors such as consequences of potential escalation, persistent smoke production – and public image. In general, the public expects fires to be extinguished, so there is public concern if, from necessity or choice, properties are allowed to burn-down. This concern can be further stoked by media coverage, such as the post-Buncefield headlines in national papers, e.g. ‘Apocalypse Now’.
## Codes and guidance

Major incidents such as those described above have resulted in the revision of regulations (discussed elsewhere), codes and guidance. A notable example is the new 2nd edition of the Energy Institute publication (EI, 2007). This code now provides expanded guidance on foam and firewater application rates, as well as pre-fire planning. Crucially, it recognises that over-application poses hazards – to access routes and containment systems as well as the environment – and provides guidance on firewater run-off control strategies.

Specific advice on firewater containment is available in EA (2007). This document also emphasises the need for measures to be in place for the rapid disposal of spills, contaminated material and firefighting water. It describes the adverse effects of foam on the efficiency of on-site oil separators and wastewater treatment plants. The document is reproduced in Appendix 12.

Many other guidance notes are available for specific situations. For example, the US Environmental Protection Agency (EPA) produces guidelines on off-site consequence analysis (EPA, 1999). Publications of the UK HSE deal separately with chemical warehouses, and storage of flammable liquids in tanks and containers (HSE, 1998).

## Firewater containment

The potential for contaminated firewater to cause off-site environmental damage and the consequent need for containment and/or controlled run-off are clearly demonstrated in the incidents described previously – and some risk reduction measures have been highlighted.

The importance of this issue has recently been emphasised in reports by the Buncefield Major Incident Investigation Board (MIIB, 2007). The Board, concluding that the secondary (bunds) and tertiary (lagoons, basins, etc.) containment measures failed to prevent a MATTE, has recommended that regulators and the industry sector should review containment issues and produce new guidance. A specific issue to be reviewed was the installed capability to transfer contaminated liquids to a place where they present no environmental risk in the event of loss of secondary containment and fires.

The Buncefield incident (see Unresolved conflicts, p. 38) has served to highlight, once again, two other related issues: potential contamination by foam or other additives, and the need for decontamination strategies for any contained firewater.

## Foam and other additives

The need to balance firefighting requirements against potential damage to the environment perhaps first emerged with halogenated hydrocarbons, or halons. These substances were used extensively in fire extinguishers (they are not particularly relevant to major incidents), having many advantages such as cleanliness and relatively low toxicity. It was found, however, that they were making a significant
contribution to the destruction of the Earth’s protective ozone layer. They were consequently withdrawn from use for the vast majority of applications.

More recently, environmental concerns have been raised about the components of firefighting foams – especially perfluorooctane sulphonate (PFOS) – and certain related fluorosurfactants. In recent decades, these compounds have been used in most foams on the market. However, PFOS has been classified as ecotoxic, persistent and bioaccumulative. The principal manufacturer, 3M, voluntarily phased out its manufacture in May 2000, although existing stock continued to be used in foam concentrate for some time.

The EA has developed a policy on the disposal of PFOS containing effluents (including firewater), and subsequently a European Directive has been drafted to restrict the marketing and use of PFOS and to prescribe measures for its disposal after it has finally been phased out. At the time of writing, this Directive was still within its consultation period. It is likely that similar restrictions will apply in future to other firewater additives.

The UK Department for Communities and Local Government published a Fire and Rescue Circular – Guidance on the phasing out of PFOS based foams for Class B Fires. This document stated (DGLG, 2006):

*The Environment Agency will also seek to prevent all unauthorized discharges of PFOS to surface water, as this is likely to constitute an offence under the Water Resources Act 1991. There is a defence available if the discharge is made in an emergency to protect people providing the Environment Agency is notified and all such steps as are reasonably practicable in the circumstances are taken to minimize the impact:*

*The Environment Agency would therefore in practice like to see firewater containing foam contained wherever practicable.*

*...PFOS is a List 1 substance under the Groundwater Regulations 1998 and its introduction to groundwater (the water table) is prohibited. The same statement is also true for any other fluorosurfactant in alternative (from 3M) products.*

This situation has led to manufacturers developing fluorosurfactant-free foam concentrates. The effectiveness of each new product needs to be tested against a relevant standard, such as the LASTFIRE fire test protocol for fires in large storage tanks (LASTFIRE, 2007). It is possible that changes in strategy or application technique/quantities may have to be devised to compensate for any reduction in performance relative to fluorosurfactant containing foams.

Besides fluorosurfactants, firewater may contain other additives, such as anti-freeze agents, biocides and corrosion inhibitors, some of which are ecotoxic. Some of these additives may also affect the performance of wastewater treatment plants, particularly those relying on microbiological action, and those based on simple separation – some additives will assist the movement of chemicals from the oily phase into the water phase or, indeed, generate emulsions.
Any contained firewater will require analysis and appropriate disposal. Options range from straightforward controlled discharge, through varying degrees of treatment, to incineration.

**EMERGENCY PLANNING**

**COMAH requirements**

COMAH Regulations 9-13 relate to emergency plans, on and off-site. While these regulations apply only to top-tier COMAH sites, there is an obligation on lower-tier sites to address within the safety management system:

*planning for emergencies – adoption and implementation of procedures to identify foreseeable emergencies by systematic analysis and to prepare, test and review emergency plans to respond to such emergencies;* (Schedule 2, para 4e).

The COMAH regulations laid down four objectives in relation to planning (Schedule 5, Part 1):

- To contain and control incidents so as to minimise the effects, and to limit damage to persons, the environment and property
- To implement the measures necessary to protect persons and the environment from the effects of major accidents
- To communicate necessary information to the public, the emergency services and the competent authorities concerned
- To provide for the restoration and clean-up of the environment.

The principal official guidance document relating specifically to emergency planning for COMAH sites (HSE, 1999) provides checklists and other detailed information for both the on-site and off-site plans.

**The Civil Contingencies Act**

The Civil Contingencies Act 2004 and supporting regulations introduced two new bodies that have a role in planning for major accidents:

1. **Local Resilience Forums.** Based on police force areas in England and Wales, they are effectively planning teams, having no role to play in the response phase. However, Local Resilience Forums may subsume existing arrangements under COMAH (Walker and Broderick, 2006). In Scotland, the corresponding Strategic Coordinating Group has both a planning and response function.

2. **Regional Resilience Forums,** based on corresponding Regional Government Offices. These are the principal mechanism for multi-agency co-operation in planning at the regional level. Their role is to:
   - Compile an agreed regional risk map
   - Consider policy initiatives that originate at government and local level, and from other relevant sources
Major Accidents to the Environment

- Ensure that there is co-operation and relevant information is shared between all relevant organisations within the region
- Ensure that all relevant organisations within the region are aware of the lessons that have been identified in emergencies and exercises occurring in the United Kingdom and overseas
- Support all members in the preparation of multi-agency plans, including the Regional Coordination and Capability Plan, and
- Coordinate training events, including multi-agency exercises.

Regional Civil Contingencies Committees

Not to be confused with the above Forums (which focus on planning), are the Regional Civil Contingencies Committees (RCCCs), which coordinate response and recovery from an emergency affecting a region. Whilst the role of an RCCC will vary depending on the emergency, its generic role is likely to include:

- Maintaining a strategic view of any situation likely to affect the region, rather than purely a local affair
- Assisting with matters that cannot be resolved at the local level
- Obtaining assistance from other Regions if appropriate and necessary for the resolution of the problem
- Ensuring effective communication between national and local government
- Providing a regional spokesperson if appropriate.

Agreed national framework on command and control

There is an agreed national command and control framework in the United Kingdom for responding to, and recovering from, emergencies. Such arrangements will apply to major accidents on COMAH sites.

These arrangements consist of a three-tier command structure. Because a major accident affecting a COMAH establishment is likely to occur suddenly and with very little warning, the three tiers are described from the bottom up:

- The Operational level (sometimes referred to as Bronze in England and Wales – but not in Scotland). Operational Commanders are normally in charge of an area of the incident or accident site, or they will have responsibility for a particular function.
- The Tactical level (sometimes referred to as Silver in England and Wales). The role of the Tactical commander is to ensure that actions of the Operational Commanders are coordinated in order to provide an effective and efficient response to any incident or major accident. In addition, it is the responsibility of the Tactical Commander to ensure that the strategy, once it has been formulated at the Strategic level, is implemented. It is likely that a Tactical Coordinating Group will be formed if the duration of the incident is likely to be prolonged.
- The Strategic level (sometimes referred to as Gold in England and Wales). In very serious incidents, a Strategic Coordinating Group will be set up.
to determine the policy and strategic framework for the response to, and recovery from, the incident. This is normally chaired by the Police Strategic Commander during the response phase and by the Local Authority in the recovery phase, particularly if this is likely to be a lengthy period.

An RCCC (see above) will be established if the impact of the major accident is likely to extend over a wide area.

In order that the affected establishment can play its part in providing an effective response to an accident, the command structure within that establishment must fit into the agreed national framework. To this end, there should be a purpose-built Emergency Control Centre (ECC) on site and the establishment should identify and train key personnel to fill various roles at Operational, Tactical and Strategic levels, as reflected in both the on-site and off-site plans.

Further details on the functions of, and the equipment needed in, the ECC, and associated roles and responsibilities can be found in HSE, 1999.

Planning
To meet the environmental objectives of a COMAH emergency plan, it is necessary to consider each of the following:

- Possible accident scenarios
- The predicted environmental effects of accidents
- Implementation of specific measures to protect the environment
- Liaison with other environmental organisations and the public
- Environmental clean-up and restoration.

The COMAH regulations require both the on-site and off-site emergency plans to provide for the clean-up and restoration of the environment following an accident. Additionally, the need to take action to mitigate the effects of a major accident is required under the Water Resources Act 1991 and the Wildlife and Countryside Act 1981, amongst others.

More specifically, the emergency plan should identify arrangements for:

- Removing contaminated soil and debris
- Restricting foodstuffs (including those grown in private residences)
- Restricting access to areas
- Restocking watercourses, lakes, woods, etc.
- Remedial action on surface and groundwater supplies.

This is not an exhaustive list. In each case, the following need to be identified in the plan:

- Procedures by which action is initiated
- The lead agency for responding
- Contractors who have the capability to carry out the required work.
A baseline survey should be carried out, perhaps following guidelines in DETR, 1999b, to identify key characteristics of the high-quality environmental resources potentially at risk from a MATTE. For example:

- Characteristics of land cover
- Water bodies and groundwater
- Presence of rare habitat types
- Presence of Red Data Book species, etc.

Steps to restrict access to an affected area and the use and distribution of food-stuffs and drinking water may need to be taken urgently as part of the response phase. Removing contaminated soil and debris and restocking watercourses may be delayed until a proper impact assessment has been carried out, and will therefore be part of the recovery phase.

Emergency response

As regards the environment, in order to provide an effective response, the emergency services will need to have the following information available immediately:

- The exact nature and location of the incident
- Safe access points
- Rendezvous point being used, if there is more than one
- Whether ECC or back-up ECC is being manned
- Details of the chemicals involved
- Potential environmental effects in general terms
- Local wind direction and speed (for airborne releases)
- Present location and potential course and extent of pollution (for liquid releases)
- Immediate actions being taken by the establishment to control the incident.

There are numerous questions to be answered in the immediate response phase following a potential MATTE. The following list is not exhaustive:

- What are the quantities, composition and concentration of hazardous materials that are escaping or have escaped?
- If hazardous materials are still escaping, how long is it likely before they are stopped?
- What environmental receptors have been or may be affected?
- What is the likely effect of the hazardous materials on the environment?
- Have new hazardous materials been created as a result of combustion or other chemical reactions?
- Are the concentrations of hazardous materials in water, air, food or soil likely to be in excess of any Environmental Quality Standards or EA guidelines?
- Will the effects vary in severity depending on the time of year?
- Could people’s health be affected by any contamination to water supplies or the food chain, or through indirect effects?
Amongst actions that may need to be considered under the response phase are the following:

- Contaminated water to be held in bunds or otherwise contained and stored for subsequent treatment/removal
- Ashes and light soil to be prevented from being blown over a wider area by the wind
- Dead animals and plants to be removed.

The list is not exhaustive and other actions that may need to be taken, depending on the nature of the accident, may be identified in formulating the emergency plans.

Recovery

As soon as possible following an accident, it may be prudent to carry out a survey with reference to the baseline survey mentioned above, to gain an impression of the acute impact.

The clean-up plan should be informed by a systematic programme of environmental sampling and laboratory analysis, along the lines of the manual produced for DETR (AEA, 1999).

Any clean-up actions taken following an accident should be ‘proportional to the extent, severity and likely duration of damage and risk of causing harm to people and the environment’ (DETR, 1999a). Should the accident affect a Site of Specific Scientific Interest (SSSI) or a site which has been declared by the European Union as a protected area or a site of Community importance (a Natura 2000 site), the clean-up could involve substantial treatment, or even replacement, of soil, sediment of affected water body, or groundwater.

It is essential that, when any remedial or restorative measures are undertaken, progress is monitored to ensure that the measures are achieving the desired aim and objectives. Certain measures may themselves pose environmental (or health) risks, which should be assessed before any works are carried out.

Amongst actions that may need to be considered under the recovery phase are:

- Re-building, repairing and cleaning those parts of the built environment that have been destroyed or damaged
- Treatment or replacement of contaminated soil
- The removal and disposal of contaminated water
- Restocking of water courses
- Reintroduction of severely depleted species.

Again, the list is not exhaustive; other possible actions may be identified during the planning stages.

As mentioned above, a chemical release that directly affects the environment could lead to contamination of the food chain, thus adversely affecting public
health. This could be caused by deposition of airborne chemicals onto pasture, crops or water, or by uptake into plants (and, perhaps, eventually into animals) from contaminated water.

The responsibility of assessing the potential risk to people's health rests with:

- In England, the Department of Health (DoH) (through the Health Protection Agency) and the Department for Environment, Food and Rural Affairs (DEFRA)
- In Wales, the Welsh Office and the Welsh Agriculture Department
- In Scotland, the Scottish Office and the Scottish Agriculture, Environment and Fisheries Department.

Information relating to the nature and the extent of contamination is normally gathered by environmental health officers and local agriculture department officials, from the emergency services and other independent sources rather than from the operator, and the information is then passed to the appropriate central government offices. During the course of the investigation, analyses may be carried out on samples of food and blood samples from animals that may have been affected.

Information to the public and the media about any food emergency caused by a chemical accident would normally be provided by the appropriate health and agriculture departments, either at national or regional level.

If it becomes necessary to exercise control over the entry of affected foods into the food chain, this may be via a voluntary restriction on farmers or action by the local government concerned. However, if this is considered to be inadequate, emergency powers can be invoked under Part 1 of the Food and Environment Protection Act 1985, and Section 13 of the Food Safety Act 1990.

Common problems

Sidelining of stakeholders

In some administrations, the relevant environmental agency has no 'teeth': it may have a place on the disaster management group, but will be entirely reliant on other agencies to take actions on site. Without effective prior planning and agreement, its role can become merely advisory.

Traditionally, the local community has had little or no direct participation within the bodies coordinating emergency planning, response and recovery. The APELL process (UNEP, 2001b), among other aims, seeks to promote such local participation.

Pre-plans may be developed exclusively 'in-house', so that the actual responders may not be aware of the consequences of different fire attack strategies. This is particularly true if a local authority fire brigade is the main responder. High manning levels, shift patterns and staff promotion/turnover make it difficult to train sufficient personnel to ensure that there will always be responders who are fully familiar with the facility and any preplanned strategies.
Whilst every situation will be different, and the specific conditions at the time of the incident may cause generic plans to be modified, it is important to decide on a preferred strategy as part of incident-based preplanning. This is particularly the case with a controlled burn-down policy. It is the natural reaction for fire services to try to extinguish a fire and it may be difficult to get full agreement from all agencies on the subject. It is now very often the case that a firefighting attack is delayed while consideration is given to the option of burn-down. This was certainly the situation at the earlier stages of the Buncefield fire in December 2005 when more than 20 fuel storage tanks and their associated bunds were burning simultaneously.
In the early hours of Sunday 11th December 2005, a number of explosions occurred at Buncefield Oil Storage Depot, Hemel Hempstead, Hertfordshire. Over 40 people were injured; fortunately there were no fatalities. Damage to both commercial and residential properties within the vicinity was extensive and a large area around the site was evacuated on emergency service advice.

Discussions were held between the Fire and Rescue Services and the EA, and due account taken of containment measures and incident consequences, prior to deciding that a large-scale attack could actually go ahead. A plan was developed to contain as much of the firewater – contaminated with product and foam solution – as possible by transferring run-off to an adjacent terminal and holding it in tank bunds. (Such a strategy also raises concerns about contamination of the containment bund and its possible loss of integrity if large quantities of water are allowed to remain in it for long periods.)

A report issued by Hertfordshire Fire and Rescue Services (HFRS, 2006) includes additional material on this subject. This document states that the main area of concern for HFRS was potential pollution of the land that could lead to pollution of water courses. For this reason, the firefighting water supplied by high-volume pumps was repeatedly shut down to reduce the volume of water being applied to the site, and so enable further planning and containment to take place. As expected, this approach vitiated the fire attack, since it is essential to maintain a continuous supply of foam at the correct application rate to extinguish a large fire.

In the past, Emergency Response Preplans (ERPs) have focused narrowly on the actual fire attack. Since inappropriate or poorly implemented plans can cause more environmental harm than the incident itself, it is vital to consider the broader aspects of fire fighting, including post-extinguishment consequences: selection of firefighting agents, management of contaminated firewater and its post-incident disposal are some of the most important issues.

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