TECHNICAL INFORMATION PAPERS (TIPs)

ITOPF's series of Technical Information Papers has been updated and expanded to reflect technological advances and ITOPF's more recent collective experience on a wide range of oil pollution topics. Each paper covers a specific subject in a concise manner, illustrated with photographs and diagrams. The series comprises:

1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
6 Recognition of Oil on Shorelines
7 Clean-up of Oil from Shorelines
8 Use of Sorbent Materials in Oil Spill Response
9 Disposal of Oil and Debris
10 Leadership, Command & Management of Oil Spills
11 Effects of Oil Pollution on Fisheries and Mariculture
12 Effects of Oil Pollution on Social and Economic Activities
13 Effects of Oil Pollution on the Environment
14 Sampling and Monitoring of Marine Oil Spills
15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
17 Response to Marine Chemical Incidents

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to spills of oil, chemicals and other hazardous substances in the marine environment. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is also a comprehensive source of information through its library, website and technical publications.

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AERIAL OBSERVATION OF MARINE OIL SPILLS

TECHNICAL INFORMATION PAPER

1

Introduction

Aerial reconnaissance is an important element of an effective response to most oil spills, for assessing the location and extent of oil contamination and verifying predictions of the movement and fate of oil slicks at sea. Aerial surveillance provides information facilitating deployment and control of operations at sea, the timely protection of sites along threatened coastlines and the preparation of resources for shoreline clean-up.

This Technical Information Paper presents advice and guidance on conducting effective aerial reconnaissance.

Strategy for aerial observation

At the outset of an incident, reports from reconnaissance flights are often vital to establish the nature and scale of the pollution. Where appropriate, arrangements for flights should be made as a high priority in the initial stages of a response. The strategy for aerial observation and contact details of appropriate agencies and aircraft operators should be key entries in relevant contingency plans.

Following initial mobilisation, subsequent flights should be made regularly (*Figure 1*). These are commonly timed at the beginning or end of each day, so that the results can be used at decision meetings to plan response operations. The flights, including their time-tabling and flight paths, should be coordinated to avoid unnecessary duplication between agencies. As the pollution situation is brought under control the need for flights will reduce and come to an end.

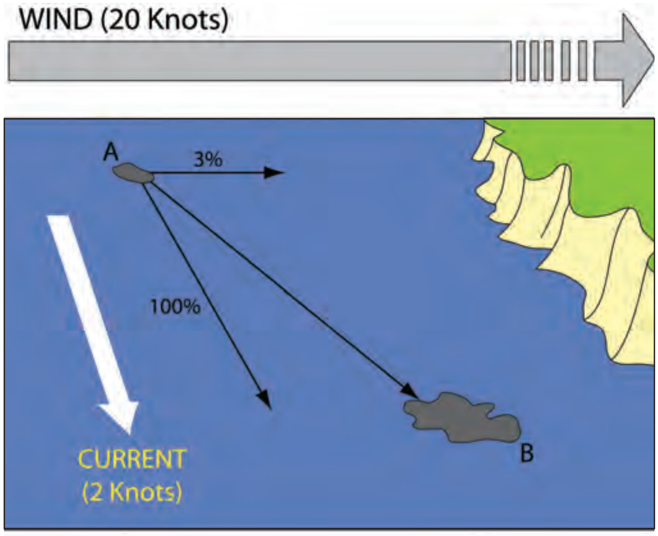
Safety considerations are paramount and the aircraft pilot should be consulted on all aspects of the reconnaissance operation prior to departure. Those taking part in a flight should be regularly and thoroughly briefed beforehand on the safety features of the aircraft and procedures to be followed in the event of an emergency. Suitable personal protective equipment, such as life jackets, should be available and used.

When selecting the most appropriate aircraft, consideration needs to be given to the location of the spill, the nearest airstrip, access to fuel and the distance to be covered in a reconnaissance flight. Any aircraft used for aerial observation must feature good all-round visibility and carry suitable navigational aids. For example, for fixed-wing aircraft, better visibility is afforded by high-mounted wings (*Figure 2*). Over near-shore waters the flexibility of helicopters is an advantage, for instance in surveying an intricate coastline with cliffs, coves and islands. However, over the open sea, there is less need for rapid changes in flying speed, direction and altitude, and the speed and range of fixed-wing aircraft are more advantageous. Aircraft selection should take into account the operating speed, for if this is too fast the ability to observe and record oil will be reduced, and if it is too slow the flying distance will be limited. For surveys over the open sea, the extra margin of safety afforded by a twin or multi-engine aircraft is essential and may, in any case, be required by government regulations.

Figure 1: Aerial observation will allow the nature and scale of the pollution to be rapidly determined. However, thorough preparation is required to gain the full benefit of flying time.

The type and size of an aircraft will limit the number of people able to take part in a flight. For small fixed-wing aircraft, and helicopters in particular, the number of passengers can substantially affect fuel consumption and thus the endurance of the aircraft. If there are two or more observers on a surveillance flight, they should work closely together to compare and confirm sightings. The lead observer directing the pilot should be experienced in aerial surveillance and be able to reliably detect, recognise and record oil pollution at sea. There should be a consistency of at least one observer throughout a series of flights, so that variations in reports reflect changes in the state of oil pollution and not differences between the perceptions of the observers.

▲ *Figure 2: Twin engine fixed-wing aircraft with high wings are ideal platforms for aerial observation of oil at sea. Helicopters may be preferable for observation closer to shore due to their greater manoeuvrability and slower speeds.*

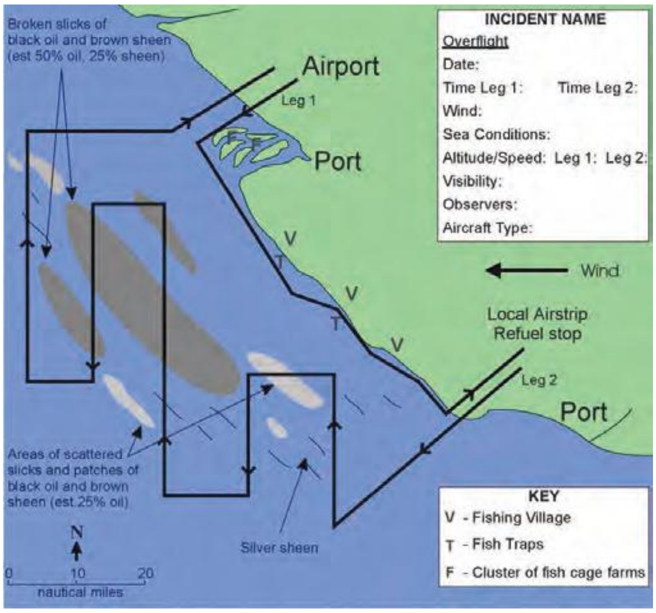


▲ *Figure 3: Influence of wind and current on the movement of oil at sea.*

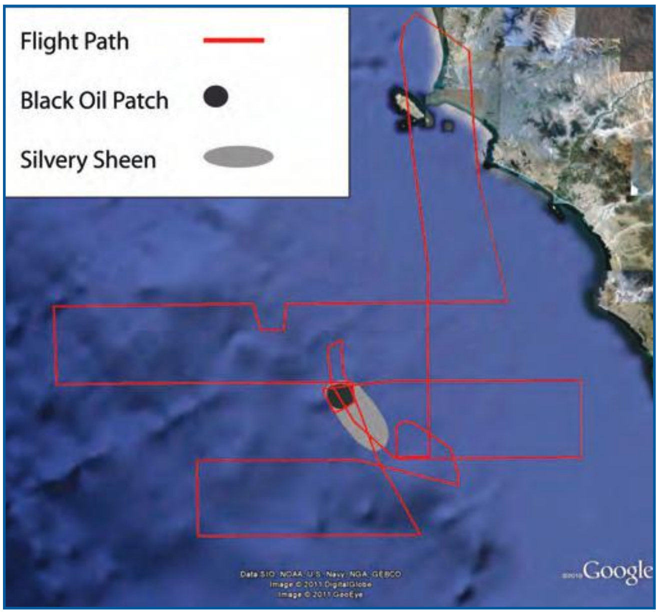
Preparations for aerial observation

Flights should be planned to start and finish with sufficient light to afford observation of the sea surface or shoreline. Weather conditions such as fog, mist, low cloud, snow and heavy rain can also affect surveillance and may mean flying is impractical.

A flight plan should be prepared in advance and agreed with the pilot and relevant authorities as appropriate, prior to boarding. This should take account of any available information that may reduce the search area as much as possible, such as the last known sightings and the expected trajectory of the oil. In addition any flight restrictions should be noted, some of which may be specifically imposed as a result of the spill. For example, it may be prohibited to fly over the shipping casualty, foreign or military airspace or



▲ *Figure 4: An example map showing the flightpath and extent of observed oil. A range of other features may also be observed and recorded during a reconnaissance flight. These might include response and clean-up activities at sea and on shore, the location of sensitive environmental resources such as wildlife and special habitats, together with commercial interests including amenity areas, industrial sites and mariculture facilities. Drawing the flightpath on the map serves to show which areas have been surveyed. The ladder search pattern shown above was adapted to meet expected oil distribution, visibility and light conditions.*



▲ *Figure 5: The flight path from an incident in South America mapped onto Google Earth. A basic ladder search from the north was undertaken to locate the oil. The aircraft then circled around the oil to allow closer observation with a subsequent continuation of the ladder search further south to determine the full extent of the slick.*

certain environmentally sensitive areas where wildlife may be disturbed (e.g. breeding colonies of birds or seals).

Observations can be recorded on a laptop or tablet computer with relevant maps downloaded from online mapping websites or using electronic shipping charts. A linked portable GPS (Global Positioning System) receiver can be used to mark waypoints to identify the location of observed oil and other notable features. As a back-up to any computer based system, extracts or copies of paper maps and charts of an appropriate scale should be obtained for annotation during the flight. Some basic data may be usefully highlighted, such as the location of the spill source and pertinent coastal features. It may be useful to draw a grid onto the paper map so that any position can be easily identified by grid reference or alternatively by reference to the distance and bearing of a radio beacon.

The task of predicting the position of the oil is simplified if data on winds and currents is available since both contribute to the movement of floating oil. It has been found empirically that floating oil will move downwind at about 3% of the wind velocity. In the presence of surface water currents, an additional movement of the oil at 100% of the current velocity will be superimposed on any wind-driven motion. Close to land, the strength and direction of any tidal currents must be considered when predicting oil movement, whereas further out to sea the contribution of other ocean currents predominate over the cyclic nature of tidal movement. Thus, with knowledge of the prevailing winds and currents, it is possible to predict the speed and direction of movement of floating oil from a known position, as illustrated in Figure 3. Computer based oil spill trajectory models of varying sophistication will plot anticipated trajectories. However, the accuracy of both computer models and simple manual calculations depends on the accuracy of the hydrographic data used and the reliability of forecasts of wind speed and direction.

In view of the errors inherent in oil movement forecasting, it is usually necessary to plan a systematic aerial search to ascertain the presence or absence of oil over a large sea area. A 'ladder search' is frequently the most economical method of surveying an area (*Figures 4 & 5*). When planning a search, due attention must be paid to visibility and altitude, the likely flight duration and fuel availability, together with any other advice the pilot may give. Floating oil has a tendency to become elongated and aligned parallel to the direction of the wind in long and narrow 'windrows' typically 30–50 metres apart. It is advisable to arrange a ladder search across the direction of the prevailing wind to increase the chances of oil detection. The distance between the 'rungs' of the ladder search will be determined by the visibility during the flight.

▲ *Figure 6: Features and landmarks (such as promontories and lighthouses) provide clear reference points when surveying a coastline.*

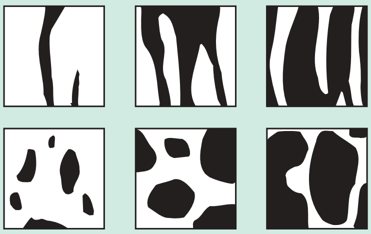
▲ *Figure 7: Communication between the aircraft crew and all observers is important to confirm sightings and to discuss changes in the flight plan in the light of observations.*

Other considerations are haze and light reflection off the sea, which can affect visibility of the oil. Spotting oil is often easiest with the sun behind the observer and it may prove more profitable to fly a search pattern in a different direction to the one originally planned. Sunglasses with polarising lenses can assist the detection of oil at sea under certain light conditions.

Recording and reporting

Despite making careful predictions and planning a systematic ladder search, the actual pollution observed during the flight may still be different to the situation envisaged. It is important, therefore, for contingencies to be borne in mind and adjustments made during the flight, to maximise the chances of finding the oil and plotting its full extent, while still trying to maintain a logical and efficient flight plan.

The search altitude is generally determined by the prevailing visibility. Over open sea areas, in clear weather 1,000–1,500 feet (300–450 metres) frequently proves to be optimal for maximising the scanned area without losing visual clarity. However, it is necessary to drop to half this height or lower in order to confirm any sightings of floating oil or to analyse its appearance. For helicopters, when used closer to shore, and in the absence of any restrictions imposed by the pilot or by the nature of the coastline, a flight speed of 80–90 knots and an altitude of 400–500 feet (120–150 metres) often proves a useful starting point. Further adjustment may

Feature	Data	Comment
Location and extent	Latitude and longitude (preferably by GPS) for location of slicks GPS readings for centre or edges of large slicks	It is important to retain a sense of scale so that what is observed on the water is not exaggerated when being recorded. It is worth establishing a mental picture of distance on the outward leg of a flight by observing and noting recognisable land features. When observing large areas affected by oil, the presence of any ships is useful in gauging the scale of slicks. Regular reference to GPS readings is useful to confirm estimates made visually.
Colour	For oil slicks: Black, Brown, Orange For sheen: Silver, Iridescent (rainbow)	Colour offers an important indication of oil thickness. For oil slicks, a brown or orange colour indicates likely presence of water-in-oil emulsion. In terms of oil spill response, sheen may be disregarded as it represents a negligible quantity of oil, cannot be recovered or otherwise dealt with to any significant degree by existing response techniques, and is likely to dissipate readily and naturally. Depending on the circumstances, sheen may often be omitted from the final report prepared after the flight.
Character	Windrow, Slick, Patch, Streak	Observers should avoid too many descriptive phrases and should apply their selected terms consistently throughout.
Features	Leading Edge	If the thick oil characterising the leading edge of a slick can be identified, it should be denoted by a heavier line on maps and referenced in accompanying reports.
Coverage	 25% 50% 75%	For response efforts to be focused on the most significant areas of oil pollution, it is important to have information on the relative and heaviest concentrations. To avoid distorted views it is necessary to look vertically down on the oil when assessing the distribution. It is difficult to make an accurate assessment of the % coverage and it is advisable not to try to be too precise with the estimation. The diagrams may be used as a reference guide. More experienced observers may be able to interpolate intermediate coverage.

The adoption of common terms can also provide an indication of the amount of oil present in a given area. In combination, the estimate of % coverage together with selected terms, provides a consistent and flexible method of describing the amount of oil in an area to a degree of accuracy sufficient for response decisions to be made.

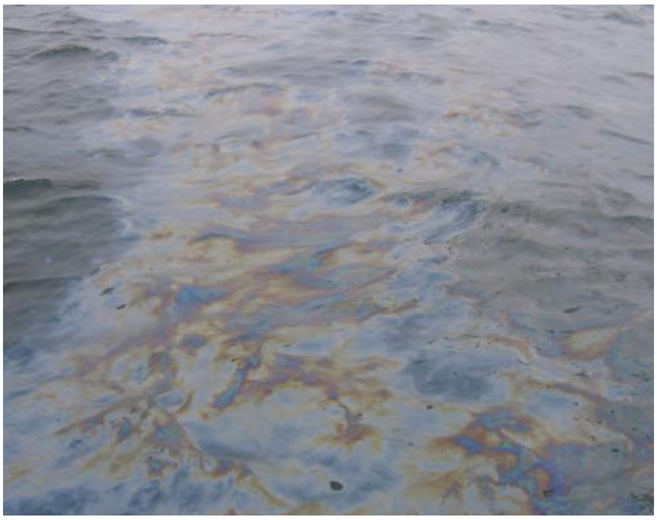
Traces	Scattered	Patchy	Broken	Continuous
<10%	25%	50%	75%	>90%

Table 1: Main features that should be recorded during a surveillance flight.

then be made as appropriate during the course of the flight.

Portable GPS receivers or GPS fitted within the aircraft enable observers to keep track of the geographic position of the aircraft, so that progress may be monitored allowing any changes that might be necessary in the light of the circumstances noted during the flight. Features and landmarks along the coast may be compared against charts when surveying a shoreline but over open water, away from any obvious reference points, it is easy to become disorientated (*Figure 6*). As a back-up, observers may have the opportunity of consulting aircraft instrumentation to ascertain speed and direction. It is worth ensuring beforehand that reading these instruments will present no difficulty.

Throughout the flight, communication with fellow observers and the pilot is important to monitor progress, confirm observations and to discuss and agree any desired and appropriate adjustments to the flight (*Figure 7*). Instruction from the pilot on the use of headsets should be sought prior to take-off to avoid disruption of the communications with other aircraft and the traffic control authorities.



Figures 8 & 9: Large patches of sheen from a spill of intermediate fuel oil (IFO 180) observed from an aircraft (left) and later the same day at close quarters from a vessel (right). The patches contain areas of thin layers of oil spreading to areas of iridescent sheen and thence to silver sheen.

Figure 10: A band of black oil is observed from left to right of the picture. The wind, blowing across the oil, is pushing this band away from the observer resulting in perpendicular windrows of varied sheen.

Figure 11: Very large broken slicks of heavy fuel oil - note the absence of sheen.

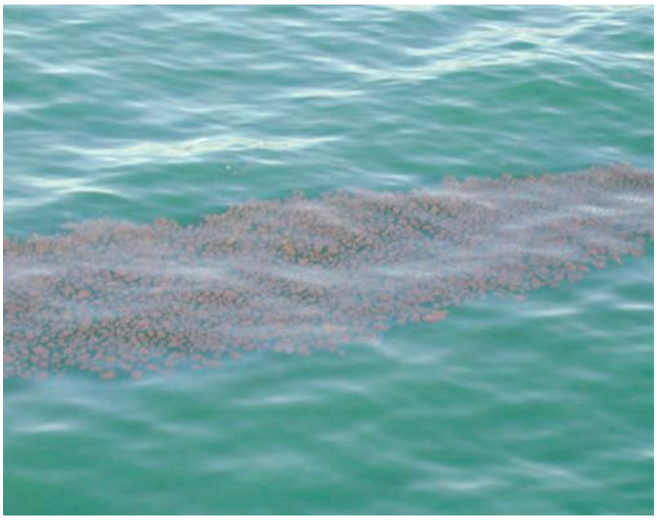


Figure 12: Part of a large slick of brown/orange emulsified heavy fuel oil (IFO 600). After 3–4 weeks at sea the slick started to fragment and after further time has eventually broken up to a large number of small plates and tarballs.

Figure 13: Heavy fuel oil spilled as a result of the catastrophic failure of a bulk carrier. The cargo has mixed with the oil making realistic estimations of the volume of spilled oil difficult to determine.

▲ Figure 14: Cloud cover resembling patches of black floating oil.

▲ Figure 15: Heavy fuel oil arriving at the shoreline. Benthic seagrass and seabed rock formations can confuse estimations of the amount of oil.

▲ Figure 16: Patches of fringing coral reef may lead to mistaken reports of oil.

▲ Figure 17: Sediment plumes disturbed by currents in a shallow area, resembling patches of emulsified light crude oil.

▲ Figure 18: Freshwater run-off from a narrow creek meeting turbid brackish water giving the appearance of significant local pollution.

▲ Figure 19: Emulsified heavy fuel oil held against the shore by wind and waves. The thickness of the oil is difficult to estimate as the extent to which the oil is pooling in crevasses between the rocks cannot be readily determined from the air.

▲ *Figure 20: It is helpful to include vessels or other features in a photograph to give an idea of the scale of the pollution.*

▲ *Figure 21: Light reflection off the sea can sometimes be a problem when taking aerial photographs; UV and polarising filters may help to sharpen the visual definition of oil.*

Digital photographs provide an invaluable record of oil pollution. Whenever possible, features such as ships and the coastline should be included to give an idea of scale (*Figure 20*). Relatively fast shutter speeds (1/500th second) are recommended to avoid blurring from the motion and vibration of the aircraft. UV and polarising filters are often useful to cut down glare and can sometimes assist in sharpening the visual definition of oil on the water, although some polarising filters produce colour distortions through aircraft windows made of plastics (*Figure 21*). Cameras with in-built GPS are useful to maintain a log of photographs taken. Digital images can be rapidly disseminated to a wide audience to assist command and control of the response.

The observations and conclusions on the extent of oiling should be reported promptly after the flight and should provide a clear depiction of the nature and extent of oil pollution at sea and close to the shore. By comparing records from previous flights, an understanding may also be gained on how the situation has developed over time. The nature of the information collected and the way it needs to be recorded and presented will vary depending on the scale of the incident and the level of detail needed to meet the intended purpose of the surveillance flight. The main features of the observed oil that should be recorded are provided in Table 1 (page 5). Working sketches and annotations will need to be formalised either by hand or electronically, to produce a final map for presentation. The original sketches and notes should be retained for subsequent reference.

Video cameras can provide an additional tool for recording observations, but filming by observers may prove difficult in turbulence and during aircraft manoeuvring. The use of hand-held cameras is also constrained by the limited field of view through the eyepiece which reduces the ability of the observer to quickly scan the sea surface. An additional observer for video recording is therefore preferable. If available, video cameras built-in to an aircraft may be alternatively utilised for recording.

Hand-held video cameras allow the addition of commentary, which if not added in sufficient detail with suitable location references, may make later co-ordination of the video with other observations difficult – especially if extended footage has been produced and editing time is unavailable. Video is best used to supplement rather than replace briefings made by experienced observers.

Appearance of oil

Crude and fuel oils spilled at sea undergo marked changes in appearance over time as a result of weathering processes. It is important for observers to be familiar with these processes

Oil Type	Appearance	Approximate thickness	Approximate volume (m^3/km^2)
Oil sheen	Silver	>0.0001 mm	0.1
Oil sheen	Iridescent (rainbow)	>0.0003 mm	0.3
Crude and fuel oil	Brown to black	>0.1 mm	100
Water-in-oil emulsions	Brown/orange	>1 mm	1,000

▲ *Table 2: A guide to the relation between the appearance, thickness and volume of floating oil. Whilst the figures for the thicknesses and volumes listed are indicative only, they serve to show that even large areas of sheen contain relatively small amounts of oil. Actions should therefore focus on areas of black or brown oil and emulsion to maximise the effectiveness of the response.*

so that the presence of spilled oil can be reliably detected and its nature accurately reported.*

Most oils spread rapidly over wide areas of the sea surface. Although the oil may initially form a continuous slick this usually breaks up into fragments and windrows due to circulation currents and turbulence (*Figures 8–12*). As the oil spreads and the thickness reduces, its appearance changes from the black or dark brown colouration of thick oil patches to iridescent and silver sheen at the edges of the slick (*Figures 8 & 9*). Sheens consist of very thin films of oil and whilst these areas can be widespread they represent a negligible quantity of oil (*Table 2*). In contrast, some crude oils and heavy fuel oils are exceptionally viscous and tend not to spread appreciably, but remain in coherent patches surrounded by little or no sheen. A common feature of spills of crude oil and some heavy fuel oils is the rapid formation of water-in-oil emulsions which are often characterised by a brown/orange colour and cohesive slicks (*Figure 12*).

Large amounts of debris in the water or spilled cargo (*Figure 13*) may mix with the oil to mask its appearance. Furthermore, from the air it is difficult to distinguish between oil and a variety of other phenomena commonly confused with oil (*Figures 14–18*). Phenomena that most often lead to mistaken reports of oil include: cloud shadows, ripples, differences in the colour of two adjacent water masses, suspended sediments, floating or suspended organic matter, floating seaweed, algal/plankton blooms, seagrass and coral patches in shallow water, and sewage and industrial discharges.

Quantification of shoreline oiling from the air presents additional problems (*Figure 19*). The extent to which oil has penetrated shoreline substrates, pooled in rocky crevasses, entered mangrove stands etc. cannot be ascertained from the air. Furthermore, many shoreline features, for example vegetation or changes in rock strata, viewed from a distance bear a close resemblance to oil.**

Initial sightings of suspected oil should be verified by over-flying at a sufficiently low altitude to allow positive identification. In instances where doubt exists, aerial observations should be confirmed by closer inspection from a boat (*Figures 8 & 9*) or on foot.

Quantifying oil volumes

An accurate assessment of the quantity of oil observed at sea may not be possible due to the difficulties of gauging thickness and coverage. However, by considering certain factors it may be possible to estimate the volume of oil in a slick to an order of magnitude so that the required scale of the response can be planned. Because of the uncertainties involved, all such estimates should be viewed with considerable caution.

Oils with a low viscosity spread very rapidly and so oil layers quickly reach an average thickness of about 0.1mm. However, the thickness of the oil layer can vary considerably within a slick or patch of oil, from less than 0.001mm to more than 1mm. For more viscous oils the oil thickness may remain well in excess of 0.1mm. The appearance of the oil can give some indication of its thickness (*Table 2*). Some oils form an emulsion by the inclusion of tiny droplets of water, which increases their volume. A reliable estimate of the water content is not possible without laboratory analysis, but figures of 50–75% are typical. The thickness of emulsion can vary considerably depending on the oil type, the sea conditions and whether the emulsion is free-floating or held against a barrier such as a boom or the shoreline. A figure of 1mm may be used as a guide, but thicknesses of 1cm and significantly greater can sometimes be encountered. Gauging the thickness of emulsion and of other viscous oils is particularly difficult because of their limited spreading. When the sea surface is rough, it can also be difficult or impossible to see less buoyant oil types, particularly if weathered, as they can be swamped by waves, and remain just sub-surface for much of the time. In cold water some oils with high pour points will solidify into unpredictable shapes and the appearance of the floating portions may disguise the total volume of oil present. The presence of ice floes and snow may obscure large amounts or all of the oil and will confuse the picture yet further (*Figure 22*).

Figure 22: Spills in icy waters are difficult to quantify.

In order to estimate the amount of floating oil it is necessary not only to determine thickness but also the coverage of the various types of oil pollution observed (*Table 1*). Due account needs to be taken of the patchy incidence of floating oil so that an estimate may be made of the actual area of coverage relative to the total sea area affected. The extent of the affected sea area needs to be determined during the flight. Portable GPS receivers are again useful to accurately record the limits of the main areas. If GPS equipment is not available, the extent of oil must be established by a timed overflight at constant speed.

** Please refer to the separate Technical Information Paper on the Fate of Marine Oil Spills.*

*** Please refer to the separate Technical Information Paper on Recognition of Oil on Shorelines.*

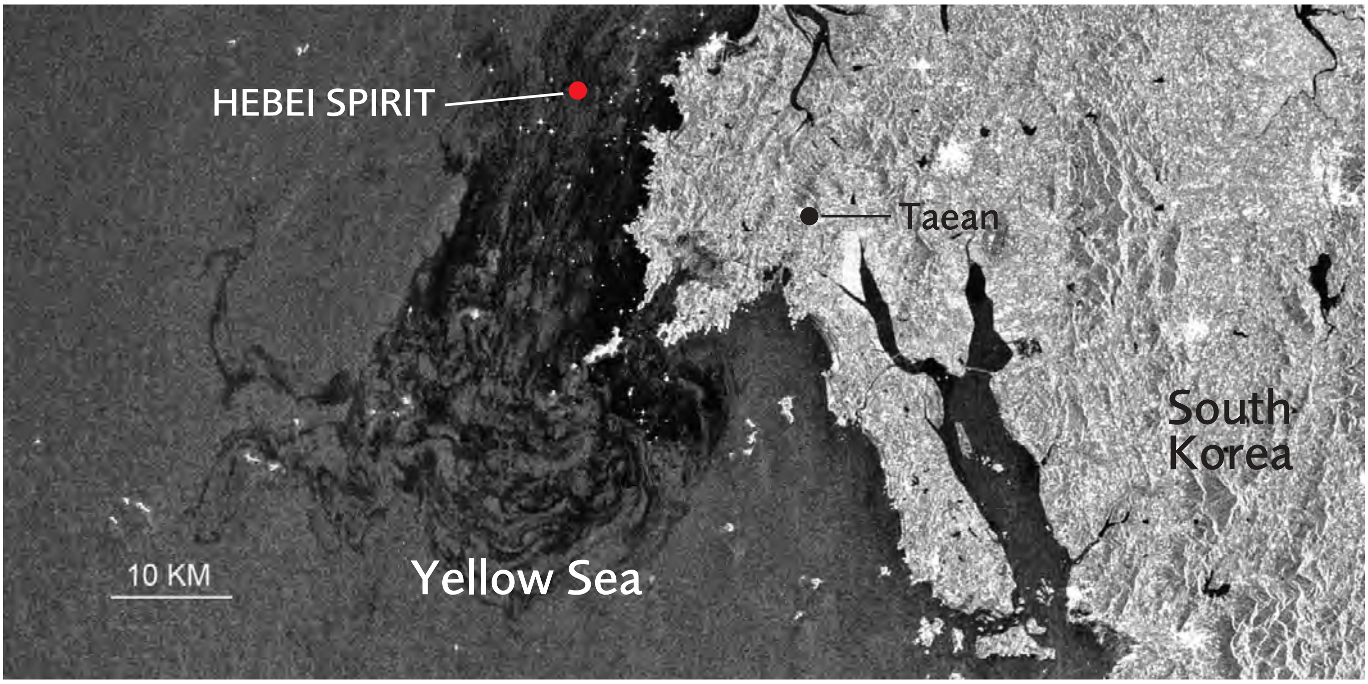


Figure 23: An Advanced Synthetic Aperture Radar (ASAR) satellite image of the eastern Yellow Sea, taken approximately 3.5 days after the release of crude oil from the tanker HEBEI SPIRIT, following a collision off Taean county in South Korea. The oil is moving in a generally southerly direction with the wind and current to spread over a wide area. The image was acquired by the Envisat satellite on 11th December 2007 and is kindly provided by European Space Agency (ESA). All rights reserved.

The following example provides an illustration of the process of estimating oil quantities.

During aerial reconnaissance flown at a constant speed of 250 km/hr, crude oil emulsion and silver sheen were observed floating within a sea area, the length and width of which required respectively 65 seconds and 35 seconds to overfly. The percentage cover of emulsion patches was estimated at 10% and the percentage cover of sheen at 90%. From this information it can be calculated that the length of the contaminated area of sea is:

$$\frac{65 \text{ (seconds)} \times 250 \text{ (km/hr)}}{3600 \text{ (seconds in one hour)}} = 4.5 \text{ km}$$

Similarly, the width of the sea area measured is:

$$\frac{35 \times 250}{3600} = 2.4 \text{ km}$$

This gives a total area of approximately 11 square kilometres or 3.2 square nautical miles.

For the example given: the volume of emulsion can be calculated as 10% (coverage) of 11 (km^2) x 1,000 (approximate volume in m^3 per km^2 from Table 2). Since 50-75% of this emulsion would be water, the volume of oil present would amount to approximately 275-550m^3. A similar calculation for the volume of sheen yields 90% of 11 x 0.1, which is equivalent to approximately 1 m^3 of oil.

This example also serves to demonstrate that although sheen may cover a relatively large area of sea surface, it makes a negligible contribution to the volume of oil present. Consequently, for accurate reporting, an observer must be able to distinguish between sheen and thicker patches of oil.

Remote sensing

Cameras relying on visible light are widely used to record the distribution of oil on the sea but can be supplemented by airborne remote sensing equipment which detects radiation outside the visible spectrum and provides additional information about the oil. Airborne remote sensing systems are routinely used to detect, monitor and identify the source of marine discharges but can also be used to monitor accidental oil spills. These sensors work by detecting different properties of the sea surface which are modified by the presence of oil. The most commonly employed combinations of sensors include Side-Looking Airborne Radar (SLAR), downward-looking thermal Infra-Red (IR) and Ultra-Violet (UV) imaging systems. Other systems such as Forward Looking Infra-Red (FLIR), Microwave Radiometers (MWR), Laser Fluorosensors (LF) and Compact Airborne Spectrographic Imagers (CASI) may provide additional information. All sensors require highly trained personnel to operate them and interpret the results, particularly as discharges other than oil or natural phenomena may give similar results. While advances in technology have reduced the size of equipment, many remote sensing systems are bulky and can only be used from dedicated aircraft into which they are installed. However, handheld FLIR cameras are available which can provide a portable remote sensing system that is not limited to dedicated aircraft.

UV, thermal IR, FLIR, MWR, and CASI are passive sensors, measuring emitted or reflected radiation. With the possible exception of MWR, they are unable to penetrate cloud cover, fog, haze or rain. Their use is consequently limited to clear weather periods. SLAR and LF incorporate an active source of radiation and rely on sophisticated electronic analysis of the return signal to detect oil and, in the case of LF, provide some indication of the type of oil. MWR can provide information on the thickness of oil on the sea surface but are unable to do so if the oil has emulsified. MWR and LF imaging systems are research tools and more often sensors relying on this technology can only provide information on oil along a narrow track immediately beneath the aircraft. MWR, LF and IR sensors can all be used at night in clear skies. Radar systems can penetrate cloud and fog, day or night and can operate under most conditions although they are less effective in both calm conditions and strong winds.

A combination of different devices is usually adopted to overcome the limitations of individual sensors and to provide better information about the extent and nature of the oil. Combined SLAR and IR/UV systems have been used fairly widely during oil spills. SLAR can be flown at sufficient altitude to provide a rapid sweep over a wide area, up to 20 nautical miles either side of the aircraft. However, SLAR is unable to distinguish between very thin layers of sheen and thicker oil patches, and the images thus need to be interpreted with caution. Aircraft equipped with a combination of SLAR and IR can define the total extent of the slick using SLAR and then once the oil has been located, provide qualitative information on slick thickness and the areas of heavier pollution with images from the IR sensors. In daylight an IR/UV sensor combination can fulfil a similar function although the range is limited compared to SLAR. The UV sensor detects all the oil covered area, irrespective of thickness, whilst the thermal IR sensor is capable, under appropriate conditions, of delineating the relatively thick layers.

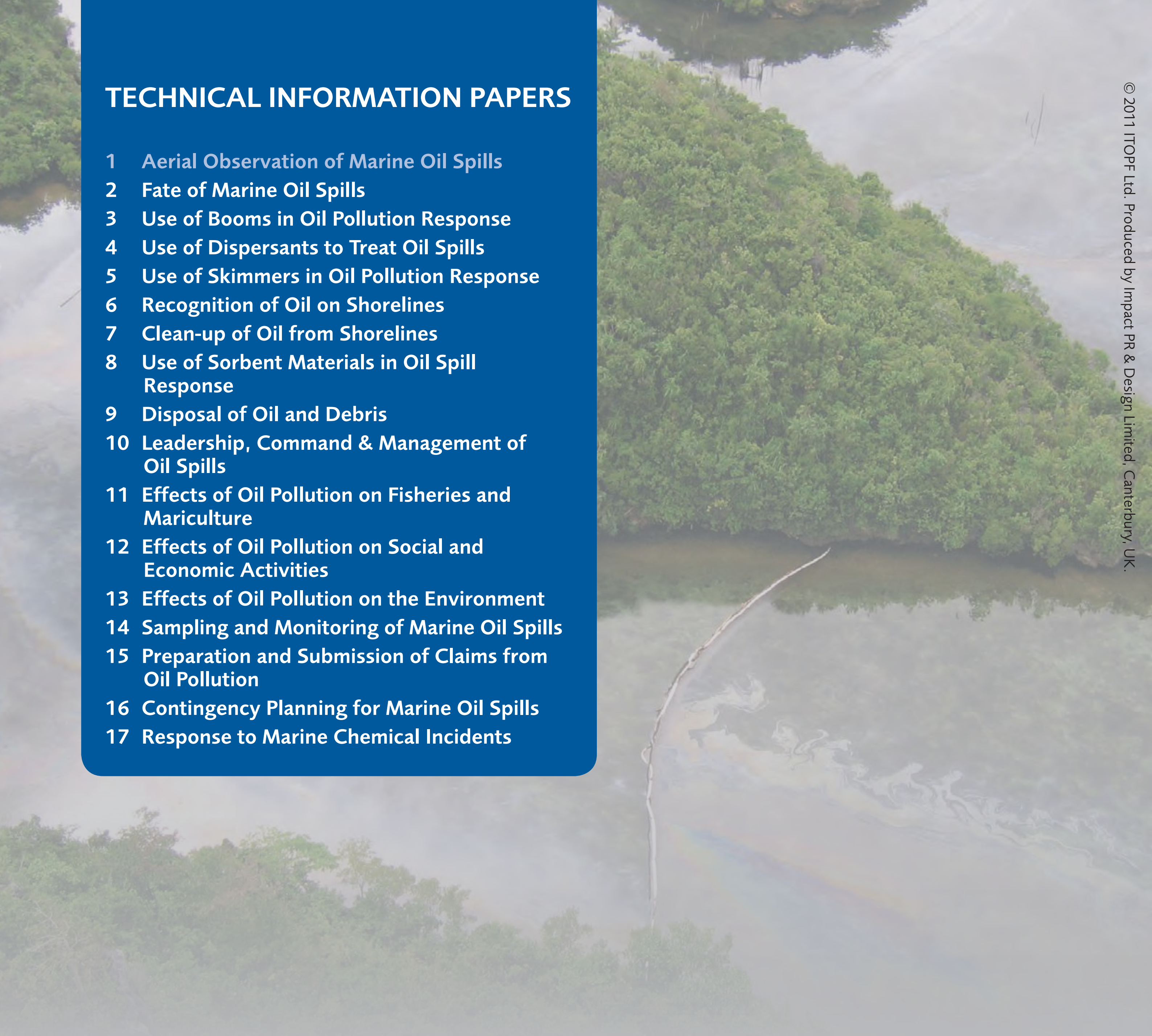
Signals from all types of sensor are usually displayed and recorded on equipment onboard the aircraft. For the resulting images to be used effectively in the management of the response operations, they would need to be relayed to the command centre, correctly interpreted and then presented in a concise and understandable format. In order that the results from remote sensing systems are correctly interpreted it is usually advisable to confirm the findings with visual observations.

Satellite-based remote sensors can also detect oil on water and because such images cover extensive sea areas, they can provide a comprehensive picture of the overall extent of pollution (*Figure 23*). The sensors used include those operating in the visible and infrared regions of the spectrum and synthetic aperture radar (SAR). Optical observation of oil requires daylight clear skies, thereby severely limiting the application of such systems. SAR is not limited by the presence of cloud and since it does not rely on reflected light also remains operational at night. However, radar imagery often includes a number of anomalous features, or false positives, that can be mistaken for oil, such as sea ice, algae blooms, wind shadows and rain squalls and so requires expert interpretation. A further limitation of all satellite imagery is that the frequency with which a satellite passes over the same areas ranges from a few days to weeks depending on the particular orbit. This delay can be partially overcome by interrogation of more than one satellite platform and, where possible, by selectively positioning the angle of a satellite's antenna. In addition, the systems on board usually have to be instructed to acquire the imagery from the area of interest, requiring an element of forward planning.

Once acquired, imagery is transmitted from a ground receiving station for the interpretation necessary to eliminate any false positives. However, for many satellites this inherent delay is minimal allowing a near real time service. Consequently, satellite imagery may provide an effective operational tool in the management of spill response.

Key points

- An initial assessment of a spill is essential to determine the extent of pollution to allow responders to define the clean-up strategy. This is best done from the air.
- Aerial observations can allow the movement of oil, its appearance and estimated volume to be determined.
- Thorough preparation prior to boarding an aircraft will ensure the maximum benefit is obtained from the flight.
- The correct interpretation of oil observations can be hindered by unrelated phenomena and difficulties in estimating oil thickness.
- Remote sensing equipment can supplement visual observation but should be used with caution because these systems also detect other features which may be confused with oil.



TECHNICAL INFORMATION PAPERS

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this leaflet may be reproduced with the prior express permission of ITOPF. For further information please contact:

ITOPF

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999 E-mail: central@itopf.com
Fax: +44 (0)20 7566 6950 Web: www.itopf.com

FATE OF MARINE OIL SPILLS

TECHNICAL INFORMATION PAPER

2

Introduction

When oil is spilled into the sea it undergoes a number of physical and chemical changes, some of which lead to its removal from the sea surface, while others cause it to persist. The fate of spilled oil in the marine environment depends upon factors such as the quantity spilled, the oil's initial physical and chemical characteristics, the prevailing climatic and sea conditions and whether the oil remains at sea or is washed ashore.

An understanding of the processes involved and how they interact to alter the nature, composition and behaviour of oil with time is fundamental to all aspects of oil spill response. It may, for example, be possible to predict with confidence that oil will not reach vulnerable resources due to natural dissipation, so that clean-up operations will not be necessary. When an active response is required, the type of oil and its probable behaviour will determine which response options are likely to be most effective.

This paper describes the combined effects of the various natural processes acting on spilled oil, collectively known as 'weathering'. Factors which determine whether or not the oil is likely to persist in the marine environment are considered together with the implications for response operations. The fate of oil spilled in the marine environment has important implications for all aspects of a response and, consequently, this paper should be read in conjunction with others in this series of Technical Information Papers.

Properties of oil

Crude oils of different origin vary widely in their physical and chemical properties, whereas many refined products tend to have well-defined properties irrespective of the crude oil from which they are derived. Intermediate and heavy fuel oils, which contain varying proportions of the residues of the refining process blended with lighter refined products, also vary considerably in their properties.

The main physical properties that affect the behaviour and the persistence of an oil spilled at sea are specific gravity, distillation characteristics, vapour pressure, viscosity and pour point. All are dependent on chemical composition, such as the proportion of volatile components and the content of asphaltenes, resins and waxes.

The **specific gravity or relative density** of an oil is its density in relation to pure water, which has a specific gravity of 1. Most oils are less dense or lighter than sea water which typically has a specific gravity of about 1.025. The American Petroleum Institute gravity scale, °API, is commonly used to describe the specific gravity of crude oils and petroleum products as follows:

$$°API = \frac{141.5}{\text{specific gravity}} - 131.5$$

In addition to determining whether or not the oil will float, the specific gravity can also give a general indication of other properties of the oil. For example, oils with a low specific gravity (high °API) tend to contain a high proportion of volatile components and to be of low viscosity.

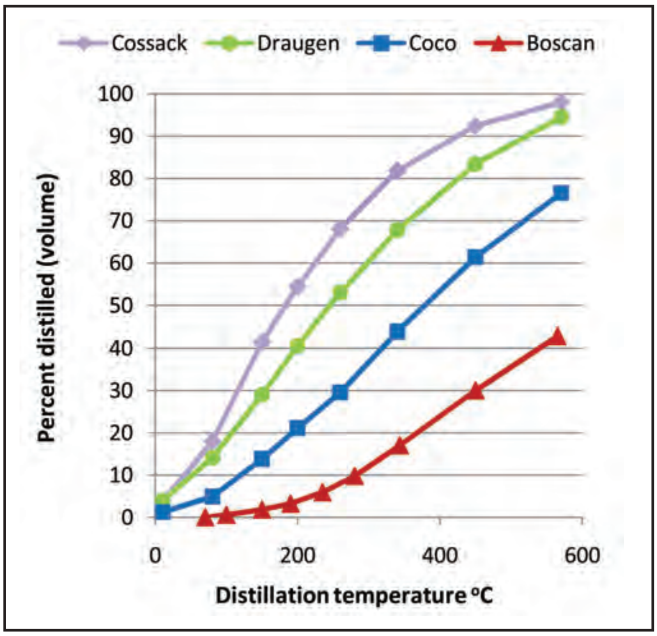


Figure 1: Distillation curves for four crude oils. Oil remaining above the maximum temperature shown is primarily residue. Data from crude oil assays.

The **distillation characteristics** of an oil describe its volatility. In the distillation process, as the temperature of an oil is raised, different components reach their boiling point in succession, evaporate and are then cooled and condense. The distillation characteristics are expressed as the proportions of the parent oil that distil within given temperature ranges (*Figure 1*). Some oils contain bituminous, waxy or asphaltenic residues, which do not readily distil even at high temperatures and are also likely to persist in

	Group 1	Group 2	Group 3	Group 4
	Arabian Super Light	Brent	Cabinda	Merey
Origin	Saudi Arabia	UK	Angola	Venezuela
°API	50.7	37.9	32.5	17.3
SG at 15°C	0.79	0.83	0.86	0.96
Wax content	12%	No data	10.4%	10%
Asphaltenes	7%	0.5	0.16	9%
Pour point	-39°C	-3°C	12°C	-21°C

Table 1: Physical characteristics of four typical crude oils. The colours and groupings correspond to the classifications in Table 2 (page 8).

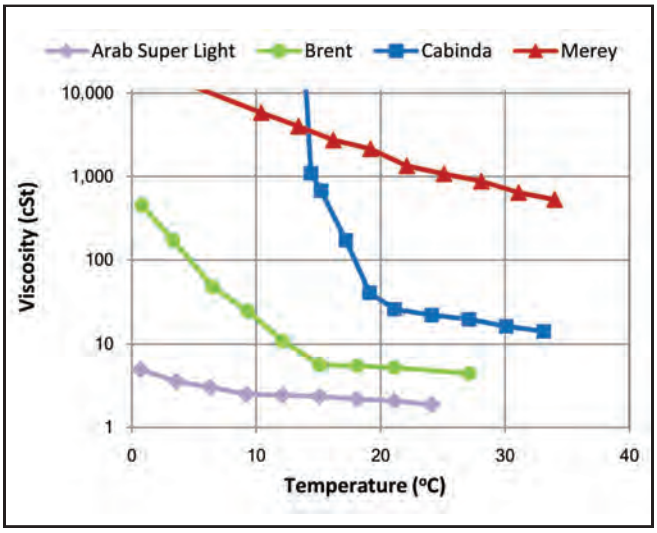


Figure 2: Viscosity/temperature relationship for the four crude oils in Table 1.

the marine environment for extended periods (e.g. Boscan crude in *Figure 1*).

The **vapour pressure** provides a further indication of the volatility of an oil, usually quoted as Reid Vapour Pressure measured at 100°F (37.8°C). A vapour pressure greater than 3 kPa (23mmHg) is the criteria for evaporation to occur under most conditions. Above 100 kPa (760mmHg), the substance behaves like a gas. Gasoline, for example, has a vapour pressure of between 40–80 kPa (300–600mmHg). Cossack crude has a Reid Vapour Pressure of 44 kPa and is very volatile with a high proportion of components boiling at low temperatures whereas Boscan crude is far less volatile with a Reid Vapour Pressure of just 1.7 kPa.

The **viscosity** of an oil is its resistance to flow. High viscosity oils flow less easily than those of lower viscosity. All oils become more viscous (i.e. flow less readily) as the temperature falls, some more than others depending on their composition. The temperature-viscosity relationships for four crude oils are shown in Figure 2. Units of kinematic viscosity* are used in this paper, expressed as centistokes (cSt = $mm^2\ s^{-1}$).

The **pour point** is the temperature below which an oil no longer flows and is a function of its wax and asphaltene content. On cooling, an oil will reach a temperature, termed

Figure 3: Oils spilled into the sea at temperatures below their pour point form semi-solid fragments. This image shows Nile Blend crude, pour point +33°C, in sea water of 28°C. Such oils are highly persistent and may travel great distances.

the **cloud point**, when the wax components begin to form crystalline structures. Crystal formation increasingly hinders the flow of the oil until on further cooling the pour point is reached, flow ceases and the oil changes from a liquid to a semi-solid (*Figure 3*). An example of this behaviour is shown for Cabinda crude oil in Figure 2. As this oil cools from 30°C the viscosity rises slowly but once below its cloud point of 20°C it begins to thicken exponentially. At the pour point of 12°C the viscosity has increased sufficiently to prevent flow.

Weathering processes

The individual processes discussed in the following section act together to bring about the weathering of a spilled oil (*Figure 4*). However, the relative importance of each process varies with time. This is illustrated in Figure 6 for a spill of a typical medium crude oil under moderate sea conditions. In addition to these processes, an oil slick will drift according to the wind and currents as described in the separate paper on Aerial Observation of Marine Oil Spills.

Spreading

As soon as oil is spilled, it immediately starts to spread over the sea surface. The speed at which this takes place depends to a great extent on the viscosity of the oil and the volume spilled. Fluid, low viscosity oils spread much faster than those with high viscosity. Liquid oils initially spread as a coherent slick but quickly begin to break up. As the oil spreads and the thickness reduces, its appearance changes from the black or dark brown colouration of thick oil patches to iridescent and silver sheen at the edges of the slick (*Figure 5*). Rather than spreading as thin layers, semi-solid or highly viscous oils fragment into patches which move apart and may sometimes be centimetres thick. In open water, wind circulation patterns tend to cause oil to form narrow bands or 'windrows' parallel to the wind direction and, over time,

** kinematic viscosity = dynamic viscosity ÷ density. Dynamic viscosity is measured in centipoise (cP) or SI equivalent milliPascals per second (mPa s)*

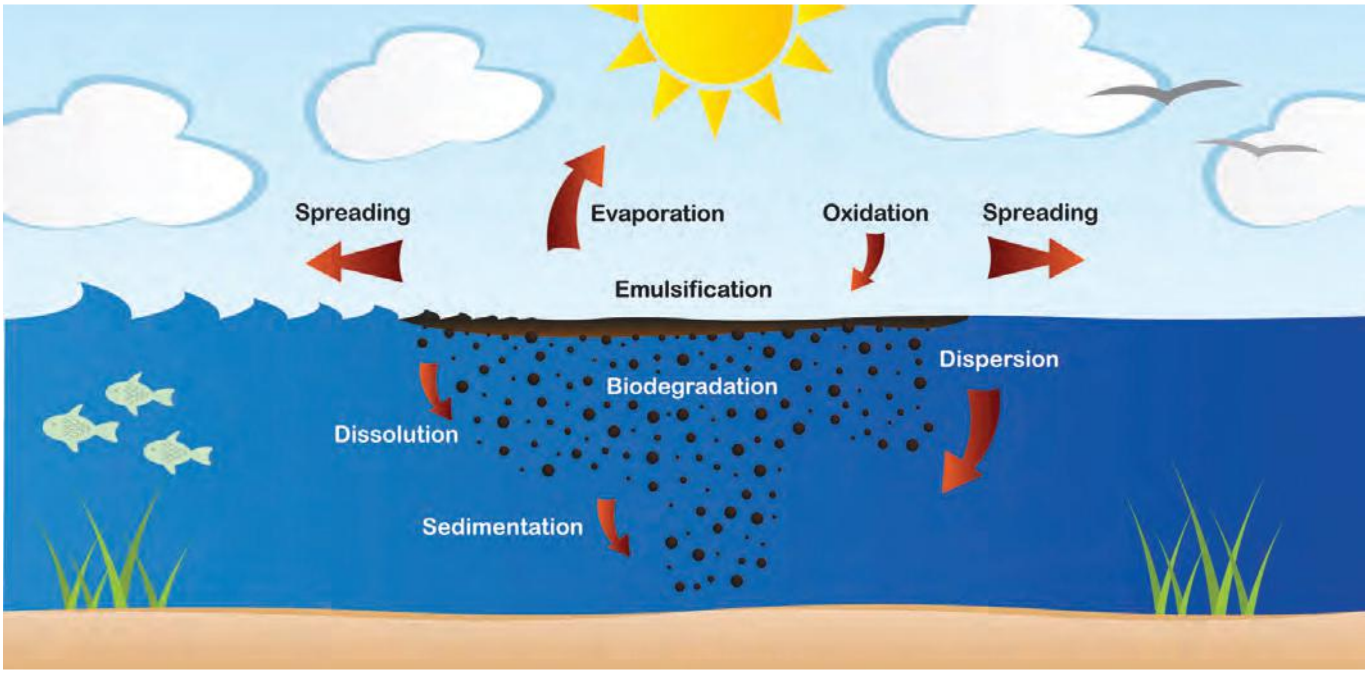


Figure 4: Weathering processes acting on oil at sea. Once oil strands on the shoreline some of these processes will no longer apply.

the oil properties become less important in determining slick movement.

The rate at which oil spreads or fragments is also affected by waves, turbulence, tidal streams and currents – the stronger the combined forces, the faster the process. There are many examples of oil spreading over several square kilometres in just a few hours and over several hundreds of square kilometres within a few days. Except in the case of small spills of low viscosity oils, spreading is not uniform and large variations of oil thickness can occur, from less than a micrometre to several millimetres or more.

Evaporation

The more volatile components of an oil will evaporate to the atmosphere. The rate of evaporation depends on ambient temperatures and wind speed. In general those oil components with a boiling point below 200°C will evaporate within a period of 24 hours in temperate conditions. The greater the proportion of components with low boiling points, as shown by the oil's distillation characteristics, the greater the degree of evaporation. In Figure 1, for example, for Cossack crude, 55% of the crude is formed of components boiling below 200°C whereas for Boscan crude it is just 4%.

Figure 5: When medium and light oils spread unhindered, very thin films eventually form. These appear as iridescent (rainbow) and silver sheens, which dissipate rapidly.

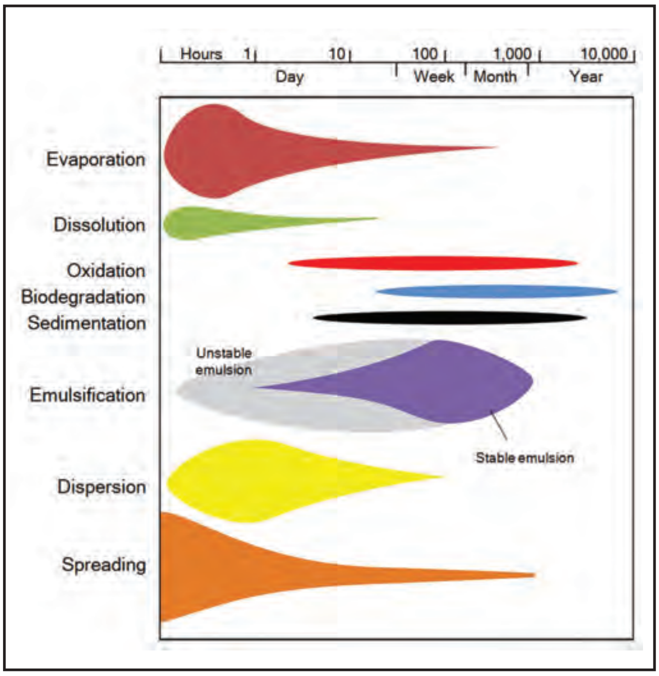
The initial spreading rate of the oil also affects the rate of evaporation since the larger the surface area, the faster light components will evaporate. Rough seas, high wind speeds and warm temperatures also increase evaporation.

Residues of the oil remaining after evaporation have increased density and viscosity, which affects subsequent weathering processes as well as clean-up techniques.

Spills of refined products, such as kerosene and gasoline, may evaporate completely within a few hours and light crudes, such as Cossack, can lose more than 50% of their volume during the first day. When such extremely volatile oils are spilled in confined areas, there may be a risk of fire and explosion or human health hazards. In contrast, heavy fuel oils undergo little, if any, evaporation and pose minimal risk of explosion. Nevertheless, heavy fuel oils can pose a fire risk. If debris is ignited in a pool of oil in calm conditions, it can form a wick sufficient to sustain a vigorous fuel oil fire.

Dispersion

The rate of dispersion is largely dependent upon the nature of the oil and the sea state, proceeding most rapidly with low viscosity oils in the presence of breaking waves. Waves and turbulence at the sea surface can cause all or part of a slick to break up into droplets of varying sizes which become mixed into the upper layers of the water column. Smaller droplets remain in suspension while the larger ones rise back to the surface where they either coalesce with other droplets to reform a slick or spread out in a very thin film. For those



▲ *Figure 6: A schematic representation of the fate of a typical Group 2/3 crude oil spill showing changes in the relative importance of weathering processes with time - the width of each band indicates the importance of the process (after a diagram courtesy of SINTEF).*

droplets smaller than about 70μm in diameter, the speed with which they rise towards the surface is balanced by the turbulence of the sea so that they are held in suspension. This dispersed oil mixes into ever greater volumes of sea water, resulting in the rapid and very substantial reduction of the oil concentration. The increased surface area presented by dispersed oil also promotes processes such as biodegradation, dissolution and sedimentation.

Oils that remain fluid and spread unhindered by other weathering processes may disperse completely within a few days in moderate sea conditions. The application of dispersants can speed up this natural process. Conversely, viscous oils tend to form thick fragments on the water surface that show little tendency to disperse, even with the addition of dispersants.

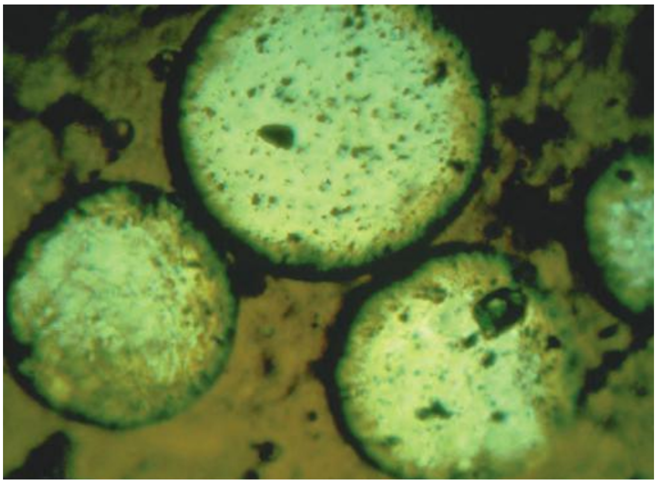
Emulsification

Many oils take up water and form water-in-oil emulsions. This can increase the volume of pollutant by a factor of up to five times. Emulsions form most readily for oils which, when spilled, have a combined Nickel/Vanadium concentration greater than 15ppm or an asphaltene content in excess of 0.5%. The presence of these compounds and sea states typically greater than Beaufort Force 3 (wind speed 3–5ms^{-1} or 7–10 knots) determine the rate at which emulsions form. Viscous oils, such as heavy fuel oils, tend to take up water more slowly than more fluid oils. As the emulsion develops, the movement of the oil in the waves causes the droplets of water which have been taken up in the oil to decrease in size (*Figure* 7), making the emulsion progressively more viscous. At the same time, the asphaltene compounds can precipitate from the oil to coat the water droplets increasing the stability of the emulsion. As the amount of water incorporated increases, the density of the emulsion approaches that of sea water but, without the addition of solid particulates, is unlikely to surpass it. Stable emulsions may contain as much as 70% – 80% water, are often semi-solid, and have a strong red/brown, orange or yellow colour (*Figure 8*). They are highly persistent and may remain emulsified indefinitely. Less stable emulsions may separate into oil and water if heated by sunlight under calm conditions or when stranded on shorelines.

Formation of water-in-oil emulsions reduces the rate of other weathering processes and is the main reason for the persistence of light and medium crude oils on the sea surface and shoreline. Although stable water-in-oil emulsions behave similarly to viscous oils, differences in their compositions have implications for effective response options.

Dissolution

The rate and extent to which an oil dissolves depends upon its composition, spreading, the water temperature, turbulence and degree of dispersion. The heavy components of crude oil are virtually insoluble in sea water whereas lighter compounds, particularly aromatic hydrocarbons such as benzene and toluene, are slightly soluble. However, these compounds are also the most volatile and are lost



▲ *Figure 7: A greatly magnified image (x1,000) of a water-in-oil emulsion showing individual water droplets surrounded by oil.*

▲ *Figure 8: Recovery of emulsified heavy fuel oil showing a typical red/brown colour. Analysis showed the water content of the emulsion to be as much as 50%.*

very rapidly by evaporation, typically 10 to 1,000 times faster than they dissolve. As a result, concentrations of dissolved hydrocarbons in sea water rarely exceed 1 ppm and dissolution does not make a significant contribution to the removal of oil from the sea surface.

Photo-oxidation

Hydrocarbons can react with oxygen, which may either lead to the formation of soluble products or persistent tars. Oxidation is promoted by sunlight and, although it occurs for the entire duration of the spill, its overall effect on dissipation is minor compared to that of other weathering processes. Even under intense sunlight, thin oil films break down only slowly, and usually at less than 0.1% per day. Thick layers of very viscous oils or water-in-oil emulsions tend to oxidise to persistent residues rather than degrade, as higher molecular weight compounds are formed that create a protective surface layer. This can be seen in tarballs stranding on shorelines which usually consist of a solid outer crust of oxidised oil and sediment particles, surrounding a softer, less weathered interior.

Sedimentation and sinking

Dispersed oil droplets can interact with sediment particles and organic matter suspended in the water column so that the droplets become dense enough to sink slowly to the sea bed. Shallow coastal areas and the waters of river mouths and estuaries are often laden with suspended solids that can bind with dispersed oil droplets, thereby providing favourable conditions for sedimentation of oily particles. In brackish water, where fresh water from rivers lowers the salinity of sea water and therefore its specific gravity, neutrally buoyant droplets of oil may sink. Oil may also be ingested by planktonic organisms and incorporated into faecal pellets which subsequently drop to the seabed. In rare instances, oil can become entrained with high levels of suspended solids during storm conditions and fall to the seabed. Similarly, wind-blown sand may sometimes be deposited on top of floating oil and cause it to sink.

Most oils have sufficiently low specific gravities to remain afloat unless they interact with and attach to more dense materials. However, some heavy crude oils, most heavy fuel oils and water-in-oil emulsions have specific gravities close to that of sea water and even minimal interaction with sediment can be sufficient to cause sinking. Only a very few residual oils have specific gravities greater than sea water (>1.025), thereby causing them to sink once spilled.

Some oils can sink following a fire, which not only consumes the lighter components but also results in the formation of heavier pyrogenic products as a consequence of the associated high temperatures. This is a consideration if deliberate in-situ burning is contemplated as a response technique.

In rough seas, dense oils can be over-washed and spend a considerable amount of time just below the surface, making observation of oil from the air very difficult. This phenomenon is sometimes confused with oil sinking but when conditions become calm, the oil resurfaces.

▲ *Figure 9: Manual recovery of sunken heavy fuel oil.*

Sedimentation is one of the key long term processes leading to the accumulation of spilled oil in the marine environment. However, sinking of bulk oil is only rarely observed other than in shallow water, close to shore, primarily as a result of shoreline interaction (*Figure 9*).

Shoreline interaction

The interaction of stranded oil with shorelines depends primarily on the levels of energy to which the shoreline is exposed and the nature and size of the shoreline substrate.

Sediment interaction leading to sinking most often results from oil stranding on sand shorelines. On exposed sand beaches, seasonal cycles of sediment build-up (accretion) and erosion may cause oil layers to be successively buried and uncovered. Even on less exposed sand beaches, stranded oil can become covered by wind-blown sand. Once oil has mixed with sand, it will sink if it is washed back into near-shore waters by tidal rise and fall or storms. A repetitive cycle often occurs whereby the oil/sand mixture is washed off the beach into near-shore waters and the coarser sand particles are released allowing the oil to float back to the surface. This oil then becomes stranded again to mix with the sand and the cycle repeats itself. A sheen emanating from a sand beach may be an indication that this process is occurring.

The interaction of the oil with very fine (<4 microns) mineral particles (fines) within the shoreline leads to the formation of mineral- or clay-oil flocculates. Dependent on the viscosity of the oil, sufficient water movement can cause oil droplets to form to which the fines are electrostatically attracted. The fines surrounding the droplet prevent coalescence to larger droplets and adherence to larger sediment substrates, for example, sand or pebbles. The resulting stable flocculates are close to neutrally buoyant and small enough to be held in suspension by turbulence as water washes over the beach as a result of tides or storms. They can eventually become widely dispersed in coastal currents and, over a period of time, can account for the removal of much of the oil from sheltered (low energy) shorelines, where wave action and currents are too weak for other processes, for example sediment abrasion, to occur.

Muddy sediments and marshes are common on sheltered shorelines. Under most circumstances the oil does not penetrate into these fine sediments and remains on the surface. However, 'bioturbation', the reworking of sediments by burrowing animals, sometimes allows less viscous oils to penetrate a little way into the sediment through migration of the oil down worm holes, plant stems and the like. Oil can also become incorporated into these fine-grained sediments during severe storm conditions when the fine mud particles are suspended in the water column and become mixed with oil. As conditions calm, the mud settles and the oil can become locked into the sediment. In these sheltered locations the sediment may remain undisturbed for lengthy periods. Since oxygen levels in the sediment are low, very little degradation will occur.

On sheltered shingle or pebble shorelines, high viscosity oils, if not removed during clean-up operations, can form 'asphalt pavements', primarily as a result of oxidation of the surface oil layer (*Figure 10*). Floating oil can penetrate these open substrates more readily and is then protected from removal by the sea and other weathering processes by the substrate itself. Asphalt pavements can persist for several decades if left undisturbed.

Biodegradation

Sea water contains a range of marine micro-organisms capable of metabolising oil compounds. They include bacteria, moulds, yeasts, fungi, unicellular algae and protozoa, which can utilise oil as a source of carbon and energy. Such organisms are distributed widely throughout the world's oceans although they are more abundant in areas with natural seeps of oil or chronically polluted coastal waters, typically those close to urban centres which receive industrial discharges and untreated sewage.

The main factors affecting the rate and extent of biodegradation are the characteristics of the oil, the availability of oxygen and nutrients (principally compounds of nitrogen and phosphorus) and temperature. A number of intermediate compounds are produced as the hydrocarbons are broken down but the eventual products of biodegradation are carbon dioxide and water.

▲ *Figure 10: As part of an experiment following a release of crude oil, an area of affected shoreline was deliberately left untouched. This patch of oil, approximately 1m², remains after more than 15 years as asphalt pavement.*

Each type of micro-organism involved in the process tends to degrade a specific group of hydrocarbons and thus a wide range of micro-organisms, acting together or in succession, are needed for degradation to continue. As degradation proceeds, a complex community of micro-organisms develops. The micro-organisms necessary for biodegradation are present in relatively small numbers away from coasts in the open sea but multiply rapidly when oil is available and degradation will continue until the process is limited by nutrient or oxygen deficiency. In addition, although micro-organisms are capable of degrading many of the compounds in crude oil, some large and complex molecules are resistant to attack and these residues tend to include the compounds which give oil its black colour.

Products intended to enhance the rate of biodegradation are available. The efficacy of such materials is questionable since it is unlikely nutrients will be in short supply, especially in coastal waters and little can be done to increase oxygen levels or the water temperature.

The micro-organisms live in the water, from which they obtain oxygen and essential nutrients and, consequently, biodegradation can only take place at an oil/water interface. At sea, the creation of oil droplets, either through natural or chemical dispersion, increases the interfacial area available for biological activity, so enhancing degradation. In contrast, oil stranded in thick layers on shorelines or above the high water mark will have a limited surface area and very restricted contact with water. Under these conditions biodegradation will proceed extremely slowly, causing the oil to persist for many years if not removed.

The variety of factors influencing biodegradation makes it difficult to predict the rate at which an oil may be removed. Although biodegradation is clearly not capable of removing bulk oil accumulations, it is one of the main long term mechanisms for the natural removal of the final traces of oil from shorelines that are frequently over-washed by tidal or wind-driven sea movement.

Combined processes

The combined effect of the processes described previously is summarised in Figure 13. All come into play as soon as oil is spilled, although their relative importance varies with time, as shown in Figure 6. Spreading, evaporation, dispersion, emulsification and dissolution are most important during the early stages of a spill, while photo-oxidation, sedimentation and biodegradation are longer-term processes that determine the ultimate fate of oil. Dispersion and emulsification are competing processes, with dispersion removing oil from the sea surface, while emulsification causes the volume of pollutant to increase and to persist. The factors that determine whether the oil will disperse or emulsify include: the release conditions (rate and amount spilled; surface or underwater

Group 1 oils

A: °API > 45 (Specific gravity < 0.8)
B: Pour point °C
C: Viscosity @ 10–20°C: less than 3 CSt
D: % boiling below 200°C: greater than 50%
E: % boiling above 370°C: between 20 and 0%

	A	B	C	D	E
Aasgard	49	-28	2 @ 10°C	58	14
Arabian Super Light	51	-39	2 @ 20°C		
Cossack	48	-18	2 @ 20°C	51	18
Curlew	47	-13	2 @ 20°C	57	17
F3 Condensate	54	<-63	1 @ 10°C	81	0
Gippsland	52	-13	1.5 @ 20°C	63	8
Hidra	52	-62	2.5 @ 10°C	60	11
Terengganu condensate	73	-36	0.5 @ 20°C	>95	0
Wollybutt	49	-53	2@ 20°C	55	4
Gasoline	58		0.5 @ 15°C	100	0
Kerosene	45	-55	2 @ 15°C	50	0
Naptha	55		0.5 @ 15°C	100	0

Group 2 oils

A: °API 35–45 (Specific gravity 0.8–0.85)
B: Pour point °C
C: Viscosity @ 10–20°C: between 4 Cst and semi-solid
D: % boiling below 200°C: between 20 and 50%
E: % boiling above 370°C: between 15 and 50%

Low pour point <6°C	A	B	C	D	E
Arabian Extra Light	38	-30	3 @ 15°C	26	39
Azeri	37	-3	8 @ 20°C	29	46
Brent	38	-3	7 @ 10°C	37	33
Draugen	40	-15	4 @ 20°C	37	32
Dukhan	41	-49	9 @ 15°C	36	33
Liverpool Bay	45	-21	4 @ 20°C	42	28
Sokol (Sakhalin)	37	-27	4 @ 20°C	45	21
Rio Negro	35	-5	23 @ 10°C	29	41
Umm Shaif	37	-24	10 @ 10°C	34	31
Zakum	40	-24	6@ 10°C	36	33
Marine Gas oil (MGO)	37	-3	5 @ 15°C		
High pour point >5°C					
Amna	36	19	Semi-solid	25	30
Beatrice	38	18	32 @ 15°C	25	35
Bintulu	37	19	Semi-solid	24	34
Escravos	34	10	9 @ 15°C	35	15
Sarir	38	24	Semi-solid	24	39
Statfjord	40	6	7 @ 10°C	38	32

Note: High pour point oils only behave as Group 2 at ambient temperatures above their pour point. Below this treat as Group 4 oils.

Group 3 oils

A: °API 17.5–35 (Specific gravity 0.85–0.95)
B: Pour point °C
C: Viscosity @ 10–20°C: between 8 CSt and semi solid
D: % boiling below 200°C: between 10 and 35%
E: % boiling above 370°C: between 30 and 65%

Low pour point <6°C	A	B	C	D	E
Alaska North Slope	28	-18	32 @ 15°C	32	41
Arabian Heavy	28	-40	55 @ 15°C	21	56
Arabian Medium	30	-21	25 @ 15°C	22	51
Arabian Light	33	-40	14 @ 15°C	25	45
Bonny Light	35	-11	25 @ 15°C	26	30
Iranian Heavy	31	-36	25 @ 15°C	24	48
Iranian Light	34	-32	15 @ 15°C	26	43
Khafji	28	-57	80 @ 15°C	21	55
Sirri	33	-12	18 @ 10°C	32	38
Thunder Horse	35	-27	10 @ 10°C	32	39
Tia Juana Light	32	-42	500 @ 15°C	24	45
Troll	33	-9	14 @ 10°C	24	35
IFO 180	18–20	10–30	1,500–3,000 @ 15°C		–
High pour point >5°C					
Cabinda	33	12	Semi-solid	18	56
Coco	32	21	Semi-solid	21	46
Gamba	31	23	Semi-solid	11	54
Mandji	30	9	70 @ 15°C	21	53
Minas	35	18	Semi-solid	15	58

Note: High pour point oils only behave as Group 3 at ambient temperatures above their pour point. Below this treat as Group 4 oils.

Group 4 oils

A: °API <17.5 (Specific gravity >0.95) or
B: Pour point >30°C
C: Viscosity @ 10–20°C: between 1500 CSt and semi-solid
D: % boiling below 200°C: less than 25%
E: % boiling above 370°C: greater than 30%

	A	B	C	D	E
Bachaquero 17	16	-29	5,000 @ 15°C	10	60
Boscan	10	15	Semi -solid	4	80
Cinta	33	43	Semi -solid	10	54
Handil	33	35	Semi -solid	23	33
Merey	17	-21	7,000 @ 15°C	7	70
Nile Blend	34	33	Semi-solid	13	59
Pilon	14	-3	Semi-solid	2	92
Shengli	24	21	Semi-solid	9	70
Taching	31	35	Semi-solid	12	49
Tia Juana Pesado	12	-1	Semi-solid	3	78
Widuri	33	46	Semi-solid	7	70
IFO 380	11–15	10–30	5,000–30,000 @ 15°C		

Table 2: Example oils classified according to their °API (American Petroleum Institute gravity). The colours of each group relate to Table 1 and to Figures 1, 2,12 and 13. Generally, persistence when spilled increases with group number.

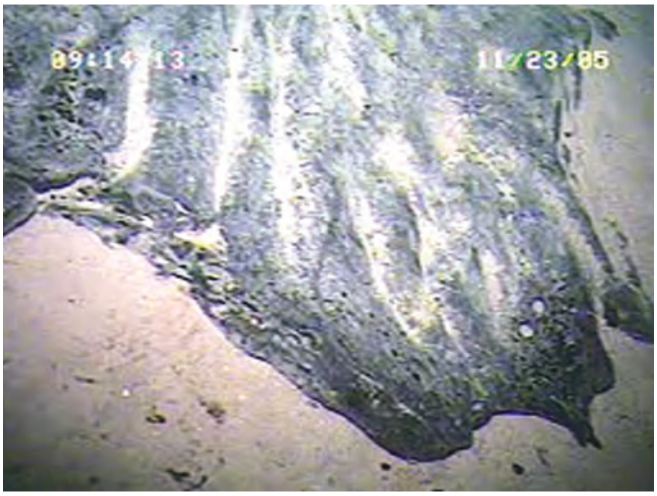


Figure 11: A very heavy fuel oil on the seabed following its release from a damaged barge. The oil had an °API of 4, translating into a specific gravity of 1.04, compared to seawater of 1.025 (image courtesy of NOAA).

release, etc.); the environmental conditions (temperature, sea-state, currents, etc.); and the physical and chemical properties of the oil.

An understanding of the way in which weathering processes interact is important when attempting to forecast the changing characteristics of an oil during the lifetime of a slick at sea. Predictions of potential changes in oil characteristics with time allow an assessment to be made of the likely persistence of spilled oil and thereby the most appropriate response option. In this latter regard, a distinction is frequently made between non-persistent oils, which because of their volatile nature and low viscosity tend to disappear rapidly from the sea surface, and persistent oils, which dissipate more slowly and usually require a clean-up response. Examples of the former are gasoline, naphtha and kerosene, whereas most crude oils, intermediate and heavy fuel oils, and bitumen are classed as persistent.*

An alternative classification allocates commonly transported oils into four groups according to their °API (*Table 2*). The purpose of this is to group oils which are likely to behave in a similar way if spilled at sea. As a general rule, the higher the °API of the oil (and the lower the specific gravity), the less persistent it will be. It is important to appreciate, however, that some apparently light oils behave more like heavy ones due to the presence of waxes. Oils with wax contents greater than about 10% tend to have high pour points and if the ambient temperature is low, the oil will be either a semi-solid or a highly viscous liquid and the natural weathering processes will be slow.

A fifth group is sometimes recognised for oils which have a specific gravity greater than 1 and °API less than 10. Such oils are likely to sink, particularly in brackish water, and are sometimes termed LAPIOs (Low API Oils). This category comprises very heavy fuel oils and residual slurry oils (*Figure 11*).

Figure 12 shows typical increases in viscosity with time after spillage for Groups 2–4 as a result of evaporation and emulsification, demonstrating that emulsification has the largest effect on the increase in viscosity.

Figure 13 shows a simplified schematic of the rate of natural removal of the four oil groups and also takes into account the effect of the formation of water-in-oil emulsions on the volume of pollutant over time. The schematic has been developed on the basis of observations made in the field and is intended to give an impression of how persistence varies according to the physical properties of the oil. The precise behaviour of an individual crude oil will depend on its properties and the circumstances at the time of the spill. Weather and climatic conditions will particularly influence the persistence of a slick. For example, in very rough weather an oil in Group 3 may dissipate within a time scale more typical of a Group 2 oil. Conversely, in cold, calm conditions it may approach the persistence of Group 4 oils. Group 4 oils, including heavy fuel oils which are carried as bunker fuel by many ships, are typically highly viscous and highly persistent, and are among the most problematic to clean-up. Their persistence gives them the potential to travel considerable distances at sea and to cause widespread contamination.

Computer models

A number of computer models are available that forecast the movement or trajectory of an oil spill. Some include weathering predictions showing how spilled oil is likely to change with time under given sets of conditions. These often draw on

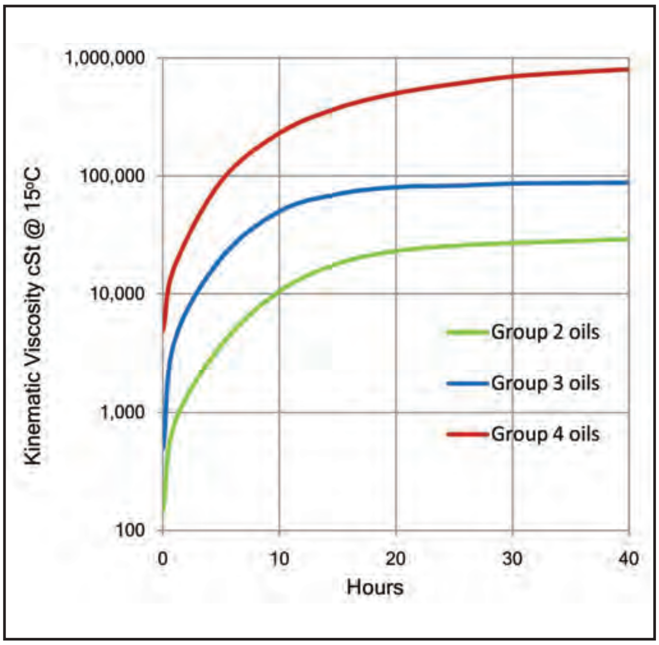


Figure 12: Typical rates of viscosity increase in moderate to rough seas. The viscosity of Group 1 oils never exceeds 100cSt in the marine environment and so is not shown.

** The international liability and compensation regime for tanker spills differentiates between persistent and non-persistent oils, the latter being defined as consisting of hydrocarbon fractions, (a) at least 50% of which, by volume, distils at a temperature of 340°C, and (b) at least 95% of which distils at a temperature of 370°C, when tested by the ASTM Method D 86/78 or any subsequent revision thereof.*

databases of the physical and chemical characteristics of different oils, as well as the results of scientific research and observations of oil behaviour. However, due to the complexity of the weathering processes and uncertainty relating to slick movement, precise predictions of overall fate are still difficult to achieve.

It is therefore important to understand the assumptions upon which weathering and trajectory models are based and to take these into account when using the results. In response operations, for example, model predictions should be verified by observations of actual oil distribution and behaviour. On the other hand, such models provide a useful indication of where such surveys should be focused and the probable fate and behavior of a particular oil. They are also valuable in the context of evaluating optimal clean-up techniques, for training and in the contingency planning process.

Implications for clean-up and contingency planning

The tendency of oil to spread and fragment rapidly, especially in rough sea conditions, will always place constraints on any response technique and should not be underestimated. For instance, ship-borne oil recovery systems, with swath widths of typically only a few metres, will be unable to encounter any significant quantities of oil once it has spread and scattered over several kilometres. In the case of low viscosity oils, this can happen in just a few hours. This is one of the main reasons that oil recovery operations at sea rarely achieve the removal of more than a fraction of a large slick.

The movement of slicks and the changing nature of the oil through weathering can determine whether any response, beyond monitoring the dissipation of the slick, is necessary. Where an active response is called for, the weathering processes will require the suitability of selected clean-up techniques to be re-evaluated and modified as the response progresses and conditions change. For example, dispersants applied at sea reduce in efficiency as the oil spreads and as oil viscosity increases. Depending on the characteristics of the particular oil, many dispersants become significantly less effective as the viscosity approaches 10,000 cSt and most cease to work at all when the viscosity rises much above this value. Oil viscosity can increase very quickly, meaning the time available for using dispersants can be very short. Consequently, dispersant application should be regularly monitored and spraying operations terminated if ineffective (*Figure 14*).

Similarly, if mechanical recovery systems are deployed, the type of skimmers and pumps used may need to be changed as the oil weathers, its viscosity rises and emulsions form. For example, oleophilic (oil attracting) disc skimmers rely on oil adhering to the disc for recovery (*Figure 15*). However, an emulsion acts as a 'shear-thinning' fluid such that when a twisting movement is applied, for example by a spinning disc, the water droplets in the emulsion align all in one direction, reducing viscosity and causing the emulsion to be sliced through rather than adhering to the disc. The same effect occurs with centrifugal pumps, where the pump impellor may spin without efficient movement of the emulsion through the pump. For this reason, positive displacement pumps are recommended for the transfer of emulsions.

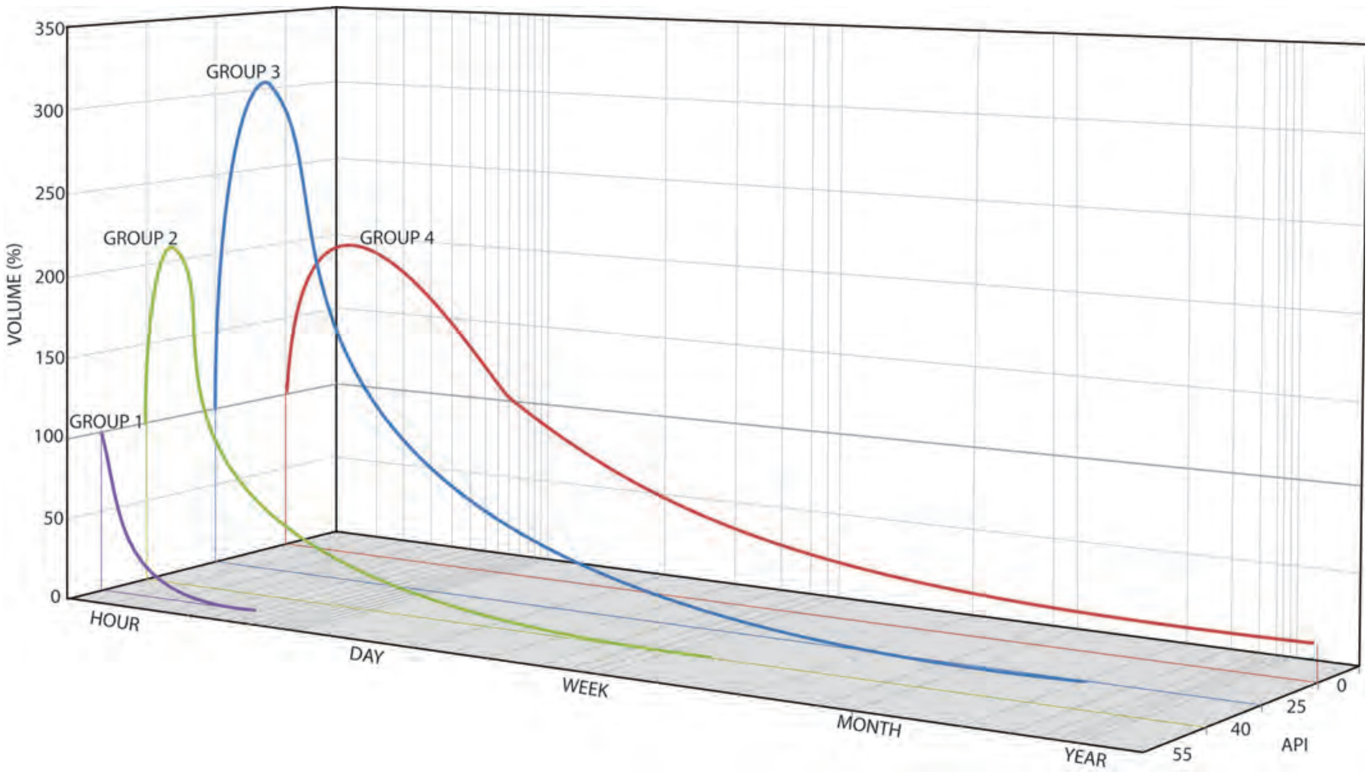


Figure 13: The volume of oil and water-in-oil emulsion remaining on the sea surface shown as a percentage of the original spill volume (100%) for a typical oil from each of the groups shown in Tables 1 and 2. The curves represent an estimated 'average' behaviour for each group. However, the behaviour of a particular crude oil may differ from the general pattern depending on its properties and the environmental conditions at the time of the spill.

▲ *Figure 14: High oil viscosity has resulted in unsuccessful dispersant application, noted by the typical white plume of dispersant around the oil.*

▲ *Figure 15: Disc skimmer working successfully in a freshly spilled light crude oil. However, were the oil to become significantly emulsified, the effectiveness of the recovery operation would reduce due to the inability of the emulsion to adhere to the discs.*

An understanding of the likely fate and behaviour of different oils and the constraints that these impose on clean-up operations is fundamental to preparing effective contingency plans. In addition, information on the prevailing winds and currents throughout the year will indicate the most likely movement of the oil and the sensitive resources that might be affected in a given location. Data on the types of oil handled and transported can enable predictions to be made regarding the probable lifetime of slicks and the quantity and nature of the remaining oil that may require a clean-up response. It will also help to determine the selection of appropriate clean-up techniques and equipment.

For fixed installations such as oil terminals and offshore loading and unloading buoys, where a limited number of oil types are involved and prevailing weather and sea conditions may be well known, fairly accurate predictions can be made. This simplifies the development of an effective contingency plan and permits the appropriate response arrangements to be put in place. In areas of dense ship traffic, with many vessels in transit, or where a wide range of oil types are handled, the plans cannot cover all eventualities. It is therefore even more important that the type and behaviour of the oil spilled is established at the earliest opportunity so that, if a response is required, the most appropriate techniques can be used.

Key points

- Once spilled, oil begins to weather and its physical and chemical characteristics change over time.
- Spreading, evaporation, dispersion and emulsification are important in the early stages of the spill whereas photo-oxidation, sedimentation and biodegradation are long-term processes that determine the ultimate fate of the oil.
- The speed with which these processes occur depends on weather conditions and characteristics of the oil such as specific gravity, volatility, viscosity and pour point.
- Evaporation and dispersion account for the removal of oil from the sea surface, while emulsification leads to its persistence and an increase in the volume of pollutant.
- Interaction with shorelines can lead to oil removal through the formation of clay–oil flocculates or to its persistence in sheltered locations by incorporation in fine sediments or the formation of asphalt pavements when mixed into coarse shingle or pebble beaches.
- A small number of residual oils are sufficiently dense to sink when spilled. However, most oils will float and may sink only if mixed with denser sediment.
- An understanding of the likely fate and behaviour of an oil allows response options to be optimised.

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1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
6 Recognition of Oil on Shorelines
7 Clean-up of Oil from Shorelines
8 Use of Sorbent Materials in Oil Spill Response
9 Disposal of Oil and Debris
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11 Effects of Oil Pollution on Fisheries and Mariculture
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THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999 E-mail: central@itopf.com
Fax: +44 (0)20 7566 6950 Web: www.itopf.com
24hr: +44 (0)7623 984 606

USE OF BOOMS IN OIL POLLUTION RESPONSE

TECHNICAL INFORMATION PAPER

3

Introduction

Booms are routinely used to surround and contain oil spilled at sea and to deflect its passage away from sensitive resources or towards a recovery point. The success of booming operations can be limited by the rapid spread of floating oil and the effects of currents, tides, wind and waves. Effective boom design and a well-planned and coordinated response can reduce these problems, although in some circumstances the use of any boom might be inappropriate.

This paper describes the principles of boom design and the two main modes of operation, namely towing by vessels at sea and mooring in shallow or inshore waters.

Design principles

Booms are floating barriers designed to perform one or more of the following functions:

- **Oil containment and concentration**: surrounding floating oil to prevent its spread over the water surface and increase its thickness to facilitate recovery;
- **Deflection**: diverting the oil to a suitable collection point on the shoreline for subsequent removal, for example by vacuum trucks, pumps, or other recovery methods;
- **Protection**: diverting the oil away from economically important or biologically sensitive sites such as harbour entrances, power station cooling-water intakes, mariculture facilities or nature reserves.

Booms come in a variety of sizes, materials and designs in order to meet the demands of these differing situations and environments. They can range from small, inexpensive, lightweight models for manual deployment in harbours (*Figure 1*), to large, expensive and robust units for offshore use, which may require the use of reels, cranes and sizeable vessels to handle them. Booms are available in a variety of lengths with couplings to allow sections to be combined to the desired overall length. Couplings also provide towing and anchoring points. In addition to reels, a variety of ancillary equipment such as towing bridles, air blowers and anchors may be required.

Figure 1: Fence boom deflecting oil from moorings.

The most important characteristic of a boom is its oil containment or deflection capability, determined by its behaviour in relation to water movement. All booms normally incorporate the following features to enhance this behaviour:

- freeboard to prevent or reduce splash-over;
- sub-surface skirt to prevent or reduce escape of oil under the boom;
- flotation in the form of air, foam or other buoyant material;
- longitudinal tension member (chain or wire) to withstand forces from winds, waves and currents;
- ballast to maintain the vertical aspect of the boom.

The majority of boom designs fall into two broad categories:

Curtain Booms – providing a continuous sub-surface skirt or flexible screen supported by an air or foam-filled flotation chamber usually of circular cross-section (*Figures 2a and 2c*).

Fence Booms – generally with a flat cross-section held vertically in the water by integral or external buoyancy, ballast and bracing struts (*Figure 2b*).

Shore-sealing or beach-sealing booms are also available whereby the skirt is replaced by water-filled chambers allowing the boom to settle on an exposed shoreline at low tide (*Figure 2d*). Fire boom is specifically constructed to withstand the high temperatures generated by burning

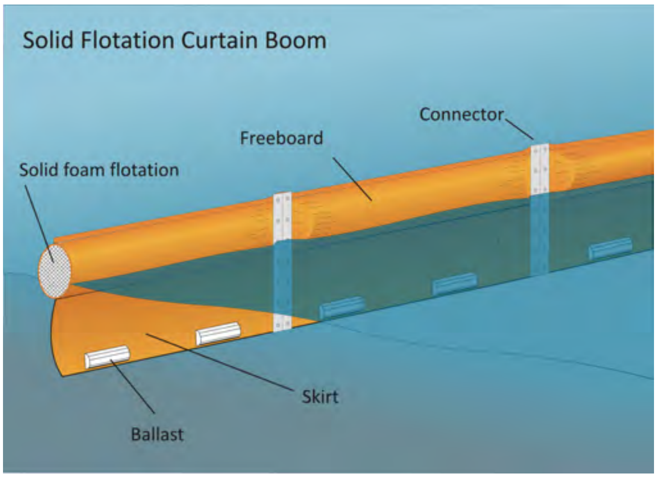


Figure 2a: A solid flotation curtain boom with external ballast.

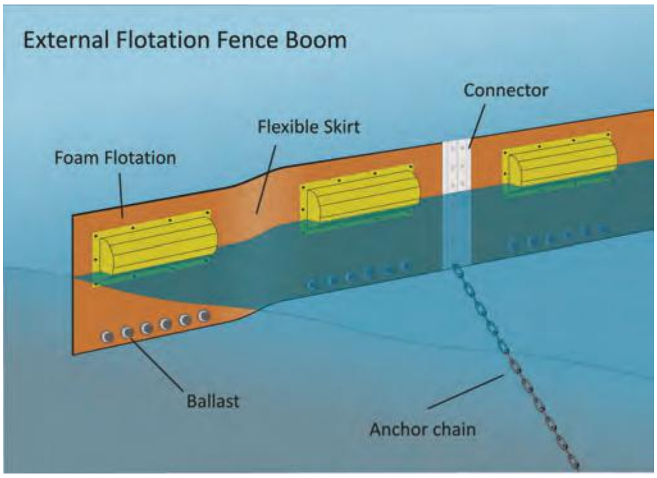


Figure 2b: An external flotation fence boom with external flotation and ballast. Mooring points are located at intervals along its lower length.

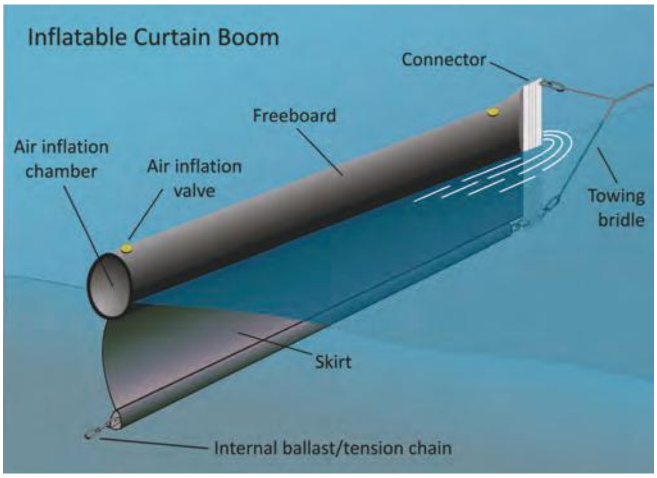


Figure 2c: An inflatable curtain boom with a combined ballast and tension chain fitted in an integral pocket attached to the bottom of the skirt.

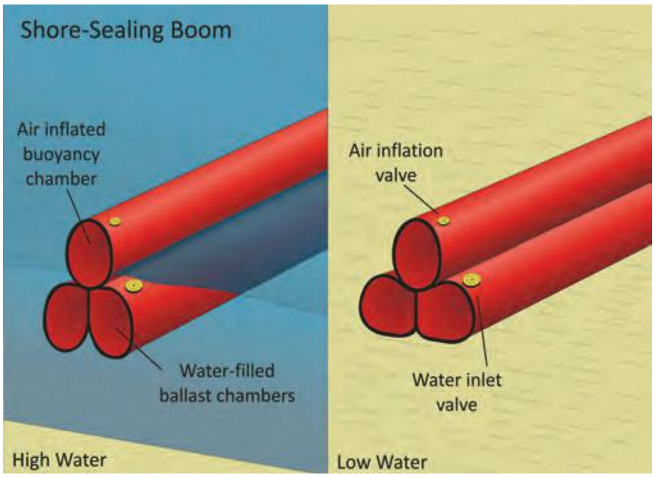


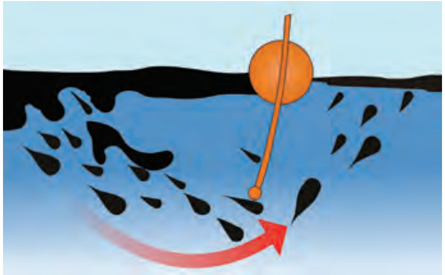
Figure 2d: Intertidal shore-sealing boom. Upper air inflation pocket to allow flotation, lower water filled pockets to provide ballast when floating and to ensure a good seal with the substrate at low tide.

oil and can be of either fence or curtain design with the associated abilities and limitations of these two designs in containing oil.

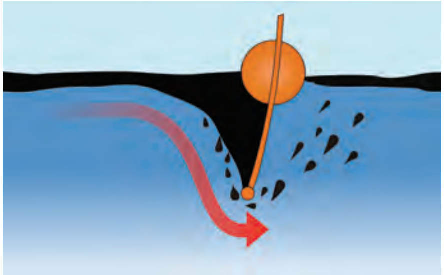
Booms should be sufficiently flexible to follow wave motion yet sufficiently rigid to retain as much oil as possible. Some designs of fence and solid flotation curtain boom exhibit poor wave-following characteristics, causing the freeboard to sink below the surface or the skirt to ride between crests as a wave passes, allowing oil to escape. Consequently, these types of boom should be limited to use in calm waters.

Although boom systems have been developed for use in fast flowing water and others for towing at relatively high speeds, most conventional booms designs are not capable of containing oil against water velocities much in excess of 0.5 ms^{-1} (1 knot) acting at right angles to it. In practice, the escape velocity for most booms is around 0.35 ms^{-1} (0.7 knots) irrespective of skirt depth. The way in which oil escapes, and its relationship to water velocity, is as much a function of oil type as of boom design. Low viscosity oils escape at lower velocities than more viscous oils. With the former, turbulence in the headwave, caused by high currents, shears droplets from the underside of the oil layer that then are carried under the boom, a process termed 'entrainment' (*Figure 3a*). Low viscosity oils are also prone to 'drainage failure' (*Figure 3b*), whereby the high currents cause droplets to break away from the oil accumulating at the boom face, to flow vertically down and under the skirt. More viscous oils are less likely to become entrained in the water and can form thicker layers at the boom face. At a certain critical accumulation thickness, the oil will be swept under the boom (*Figure 3c*).

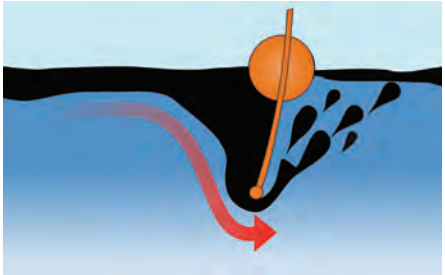
Besides river and tidal currents, wind and waves can generate water movement in excess of the escape velocity, as well as causing splash-over of contained oil (*Figure 3d*). Very high currents may cause the boom to submerge, particularly if insufficient buoyancy is provided (*Figure 3e*), or to plane allowing oil to flow past (*Figures 3f and 4*). Oil escape can also be induced by turbulence along a boom and therefore a uniform profile without projections is desirable.



▲ *Figure 3a: Entrainment.*

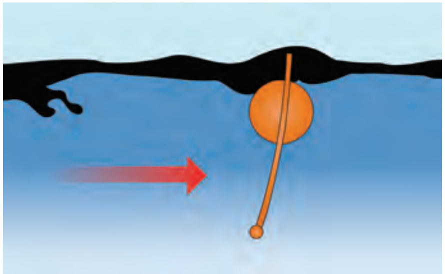


▲ *Figure 3b: Drainage failure.*

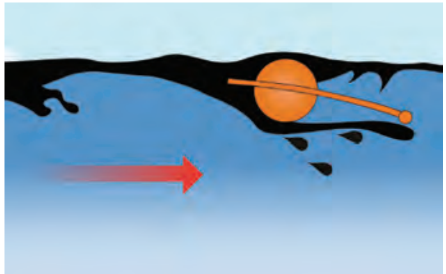


▲ *Figure 3c: Critical accumulation.*

▲ *Figure 3d: Splash-over.*



▲ *Figure 3e: Submergence.*



▲ *Figure 3f: Planing.*

▲ *Figure 3: Boom failure modes. The arrows indicate current direction. (After a diagram in Oil Spill Science and Technology, courtesy Merv Fingas).*

The size and length of boom sections are important considerations. The optimum size of a boom is largely related to the sea state in which it is to be used. As a general rule, the minimum height of freeboard to prevent oil splash-over should be selected. The depth of skirt should be of similar dimensions. Too high a freeboard may cause problems of windage, whereby the freeboard acts as a sail. Increasing the depth of the skirt can make the boom more prone to drainage failure due to the increasing velocity of water passing under the boom. Short sections of boom can be easier to handle and can protect the integrity of the boom as a whole should one section fail, but these advantages must be weighed against the inconvenience and difficulty of connecting sections effectively. Connections interrupt the boom profile and, wherever possible, should not coincide with the point of heaviest oil concentrations. The design of connectors should allow easy fastening and unfastening during deployment and when the boom is in the water.

Many different types of boom connector have been made available from manufacturers. While the prevalence of Unicon or American Society for Testing and Materials (ASTM) standard connectors have reduced the variety, the many designs available can cause difficulties when joining booms from different sources and care should be taken when ordering booms from different suppliers.

Other important characteristics are tensile strength, ease and speed of deployment, reliability, weight and cost (*Table 1*). It is essential that a boom is sufficiently robust and durable for its intended purpose as it will often need to tolerate inexpert handling, twisting, large and heavy floating debris and abrasion from rocks, dock walls or coral (*Figure 5*). Structural strength is required, to withstand the forces of water and wind on a boom, when it is either towed or moored. Ease and speed of deployment, combined with reliability, are clearly very important in a rapidly changing situation and may influence the choice made.

Some low-cost booms are designed for single use, after which they can be incinerated or returned to the manufacturers for recycling. Many of the more expensive, robust booms, if properly deployed and maintained, can be reused time and time again. Booms usually require

▲ *Figure 4: The strong current has caused the boom to plane, allowing any oil to be lost under the skirt.*

Type of Boom		Flotation Method	Storage	Wave Following Property	Moored or Towed?	Ease of Cleaning	Relative Cost	Preferred Use
Curtain Boom		Inflatable	Compact when deflated	Good	Both	Straightforward	High	Inshore or offshore
		Solid foam	Bulky	Reasonable	Moored	Easy / Straight-forward	Mid-range to Low	Sheltered inshore waters e.g. harbours
Fence Boom		External foam floats	Bulky	Poor	Moored	Difficult/Medium; oil can become trapped behind external floatation or in the junctions of the chambers	Low	Sheltered waters (e.g. ports, marinas)
Shore-Sealing Boom		Inflatable upper chamber, lower chambers water filled	Compact when deflated	Good	Moored	Medium; oil can become trapped in junction of the chambers	High	Along sheltered intertidal shores (no breaking waves)

Table 1: Characteristics of common boom types.

cleaning after use and this can prove difficult for some designs (*Figure 6*). Steam cleaning or solvents are usually employed but when using the latter it is important to ensure that the boom fabric is compatible with such chemicals. Proper retrieval, maintenance and storage are important to prolong the life of a boom and to ensure that it is always ready for use at short notice. Some booms, particularly self-inflating models, are prone to damage from abrasion unless retrieved carefully. Emergency repair kits should be kept on hand for dealing with minor damage, which could otherwise make a section or even the whole length of boom unusable. Major damage to boom fabric is often difficult to repair and may necessitate replacement of the whole section. Correct storage of booms is important to minimise long-term degradation of the boom material by high temperatures, UV light rays or mildew, although this is generally less of a problem with more advanced materials such as polyurethane or neoprene. Air flotation booms take up only a small storage area when deflated, whereas solid flotation booms are bulky. This should be considered when transporting booms to site and if storage is at a premium, such as on board a vessel.

Figure 5: A boom can be easily damaged once deployed. Regular attention is required to ensure its effectiveness is maintained throughout the tidal cycle.

Figure 6: Oil trapped behind external floats of fence boom can be particularly difficult to clean.

Forces exerted on booms

To estimate the approximate force F (kg) exerted on a boom with a sub-surface area A (m^2) by a current with velocity V (ms^{-1}) the following formula can be used:

$$F = 100 \times A \times V^2$$

Thus, the approximate force acting on a 100 metre length of boom with a 0.6 metre skirt in a 0.25 ms^{-1} (0.5 knot) current would be:

$$F = 100 \times (0.6 \times 100) \times (0.25)^2 \approx 375 \text{ kg (force)}$$

From the graph in Figure 7, it can be seen that doubling the current velocity would entail a four-fold increase in load. The approximate force exerted by wind directly on the freeboard of the boom can also be considerable. For the purpose of estimating this windage, the above formula can be used on the basis that roughly equivalent pressures are created by a water current and a wind speed 40 times greater. For example, the approximate force on a 100 metre length of boom with a 0.5 metre freeboard in a 7.5 ms^{-1} (15 knots) wind would be:

$$F = 100 \times (0.5 \times 100) \times (7.5/40)^2 \approx 175 \text{ kg (force)}$$

In the above examples the combined forces of current and wind would be approximately 550 kg if they were acting in the same direction on a rigid barrier. In practice, the boom would be positioned at an angle to the flow forming a curve, thereby modifying the magnitude and direction of the forces (also see *Table 2* on page 9). However, these calculations provide a guide to the forces and are an aid to the selection of moorings or towing vessels. When a boom is towed, its velocity through the water should be entered as V in the formula set out in the beginning of this section.

The forces acting on booms from non-breaking waves or swell are usually insubstantial. Provided the boom has the required degree of flexibility, it can follow the surface movement of the water with little consequence. However, when a wave breaks against a boom, the resultant instantaneous loading may cause the boom to tear if the tensional and material strength are insufficient.

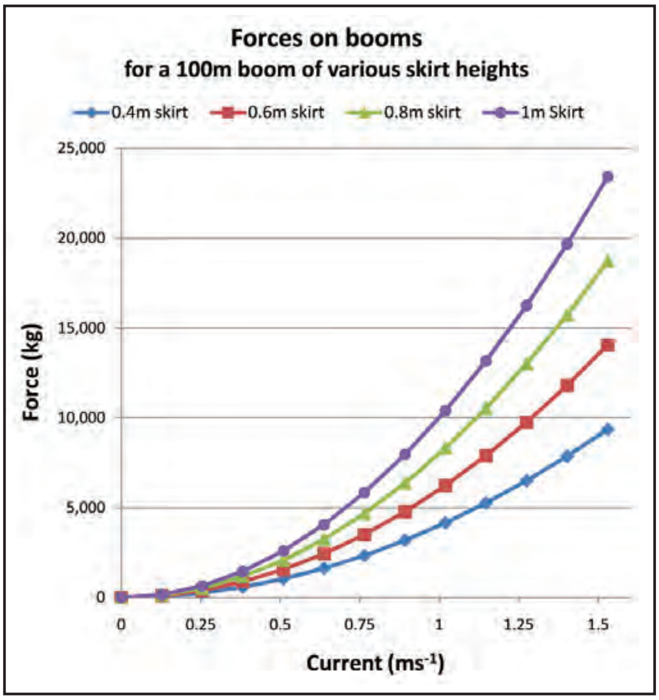


Figure 7: Forces exerted on a 100 metre length of boom of various skirt depths, showing an exponential rise with increasing current.

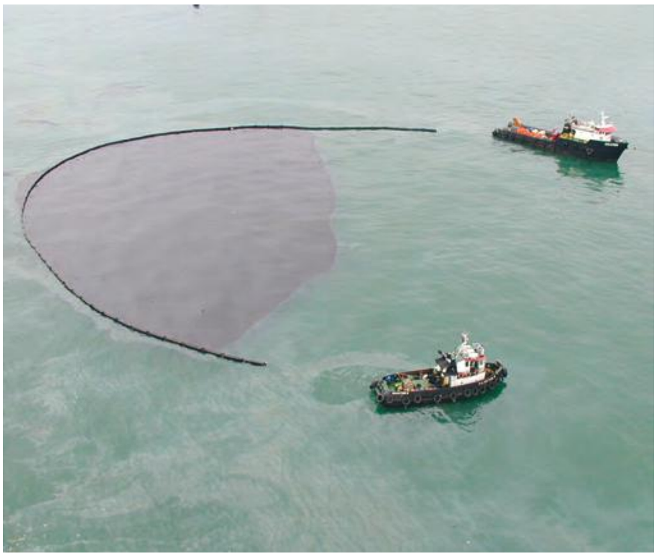
Deployment of booms

The deployment of booms can be a difficult and potentially hazardous operation. Poor weather and rough seas impose limitations on operations and the handling of wet and oily equipment on vessels that are pitching and rolling is demanding and can place personnel at risk. Even in ideal, calm conditions, it is important that operations are well thought out and controlled to minimise these risks and the potential for damage to the boom. A suitable strategy should be developed as part of the contingency planning process. Local conditions, deployment sites, boom types and lengths available, appropriate boom configurations and the availability of work boats and other resources should be fully considered before an incident occurs. In addition, the installation of fixed boom mooring points should be considered where appropriate and their position noted in a contingency plan. Planning is particularly relevant for oil terminals and similar installations where both the source and most likely size of spill can be predicted. Regular boom deployment exercises should be carried out in order that response personnel become fully familiar with operational procedures.

Towed booms

The rapid spread of oil over a large area poses a serious challenge to the success of containment and recovery operations at sea. In an effort to prevent spreading and to contain the oil to maximise the encounter rate for skimmers, long booms in U, V or J configurations may be towed using two vessels (*Figure 8*). For example, a 300 metre towed boom may allow a swath up to 100 metres in width to be swept. Suitable recovery devices and sufficient on-board storage are crucial to the overall success of the operation. Skimmers can be either deployed from one of the towing vessels or from a third vessel behind the boom (*Figure 9*). Combined containment and recovery systems, with skimmers incorporated into the face of the boom, are now rarely deployed due to their ability to recover only a limited range of oils and due to their complexity. The use of skimmers is covered in greater detail in a separate paper.

Oil may more readily escape beneath the inflexible connections between boom sections. Consequently, to minimise the escape of oil, when towing a sectioned boom in either U, V or J configuration, it is important to ensure that there are no connectors at the apex of the boom. With a U configuration, using an odd number of sections of boom will alleviate this problem. To avoid sharp strain or



▲ *Figure 8: Inflatable boom deployed in a U configuration between two vessels to contain a heavy crude oil. Recovery of the oil will bring the operation to a successful conclusion.*

▲ *Figure 9: Curtain boom employed in a V configuration by two towing vessels with a separate skimming vessel at the apex.*

snatching, booms should not be attached directly to towing vessels. Instead, towing lines of sufficient length should be used between boom ends and the towing vessel with lines of 50 metres or more typically appropriate for towing a 300 metre length of boom.

Boom performance is best judged by observation. Oil lost under the boom will appear as globules or droplets rising behind the boom. Sheens may be present even with good boom performance. Vortex formations behind the boom imply that it is being towed too fast.

To maximise performance, vessels should be able to maintain both the correct configuration of the towed booms and the desired very low speeds through the water, i.e. at less than the escape velocity. This means that each of the two towing vessels will require at least half the total power necessary to tow the boom at the maximum speed consistent with oil retention and should be able to manoeuver sufficiently at slow speeds. As a guide, each rated horse-power of an inboard engine corresponds to the ability to provide a pull of 20 kg force. Twin propulsion units, bow and stern thrusters and variable pitch propellers are valuable. In addition, an open and low aft deck working area with winch, lifting gear or a boom reel are necessary when handling bulky and heavy booms. However, experience has shown that the exposed nature of the deck on such vessels can make conditions hazardous for crew in heavy sea conditions.

The ideal towing point aboard the vessel will need to be found by experiment and may need to be altered according to the course and wind direction. For example, a single screw vessel towing from the stern will have difficulty manoeuvering, and towing from a forward point of the ship is preferable. Good communication between the two towing

▲ *Figure 10: Single ship collection system employing a short length of curtain boom deployed from an oil recovery catamaran, in heavily emulsified crude oil.*

▲ *Figure 11: Whilst sufficiently flexible to be able to follow the motion of the waves, the boom has risen from the water where it attaches to the hull, potentially allowing oil to escape from the apex.*

▲ *Figure 12: Inflatable boom moored around a partially sunken wreck to contain any potential leakage of bunker fuel.*

▲ *Figure 13: Curtain boom deployed in front of a power station cooling-water intake.*

vessels must be maintained so that both move at the same speed and in a controlled and coordinated manner. Aircraft equipped with air-to-sea communications could also be used to coordinate the movement and activities of vessels and direct them to the thickest areas of oil.

A single vessel may perform the multiple roles of oil containment, collection, separation and storage. Either a flexible boom attached to an outrigger (*Figure 10*) or a rigid sweeping arm can be used to contain and enable collection of the oil. With all vessel-based containment and recovery systems, oil can be lost from boom that is rigidly attached to the vessel in swell (*Figure 11*). Single vessel systems are more flexible than the more complex multi-ship approach, although the oil encounter width or swath is limited, being similar to the vessel's beam. If the swath is too great, the set-up can become cumbersome and prone to damage in rough weather. This limitation on the swath may be less significant when floating oil has been driven into narrow windrows.

The limitations on boom performance, combined with additional constraints on the use of skimmers, mean containment and recovery operations at sea will, in most cases, be only partially successful.

Moored booms

In rare circumstances it can be appropriate to anchor booms to contain spilled oil close to a source such as a leaking vessel (*Figure 12*). However, waters may be too exposed and currents too strong for moored booms to be effective and anchoring booms in deeper water may be difficult. In addition, placing booms close to the source may create a fire hazard and interfere with attempts to stem the flow of oil or to salve the vessel. Even in calm conditions, large instantaneous discharges of oil can easily swamp a boom, rendering it ineffective. This is especially true for light oils, which will normally dissipate naturally and more effectively without booming.

More frequently, booms are deployed close to shore to protect sensitive areas such as estuaries, marshes, mangroves, amenity areas and water intakes (*Figure 13*). In practice, it may not be possible to protect all such sites. Careful planning should therefore be devoted to identifying first those areas that can be boomed effectively, and second, placing these in order of priority.

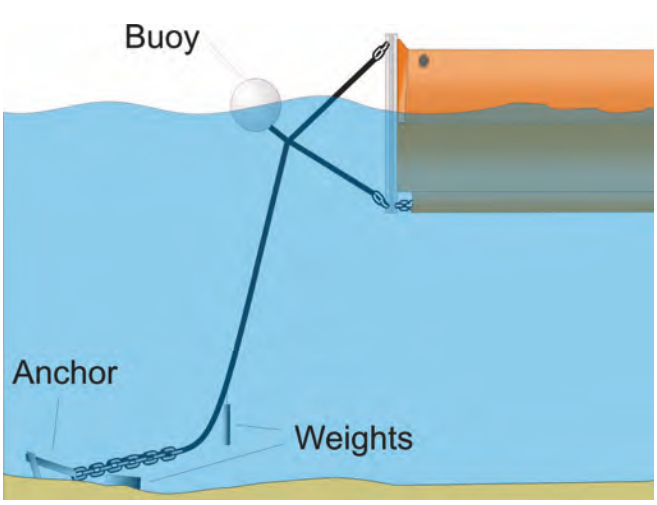
An aerial survey can be valuable in identifying potentially suitable sites for using booms, including access points. In selecting a location and method of deployment it may be necessary to compromise between conflicting requirements. For instance, although it may be desirable to protect a complete river, the estuary may be too wide or the currents too strong to achieve this, particularly if there is appreciable tidal influence. Strong outflow from rivers or estuaries may negate the need to deploy booms against oil approaching from the sea.

Where necessary, a more suitable location may have to be sought further upstream, bearing in mind the need for access to deploy the boom and remove the collected oil. If the oil is not removed at the rate of its arrival at the inshore position, it will accumulate and move out towards the centre of the river where the stronger currents may sweep the oil under the boom.

It is frequently better to use booms to deflect oil to relatively quiet waters (*Figure 14*) where it may be recovered rather than attempt containment. As shown in Table 2, it is feasible to deflect floating oil even in a 1.5 ms^{-1} current (3 knots) where a boom positioned at right angles to the flow would fail to contain any oil. Following this principle, a river can be protected by placing a boom obliquely to the direction of flow. To maintain a navigation channel or to deflect oil from one side of a river to another for ease of collection, two sections of boom can be staggered from opposite banks taking into account reversal of tidal flow.

Correct mooring of the boom is crucial since performance is dependent upon the angle of deflection remaining appropriate to the prevailing current strength. To maintain this angle and prevent the formation of pockets in the boom that will trap oil, frequent anchoring points may be required,

▲ *Figure14: Boom used as a spur to deflect oil to the shore for recovery (© Norwegian Coastal Administration).*



▲ *Figure 15: Typical boom mooring arrangement. The same system would be employed at regular intervals along the boom.*

although the laying of multiple moorings may be impractical in an emergency. The formula to determine forces on page 6 can be used together with Tables 2 and 3 as a guide to the minimum size and number of moorings required to hold a boom in a current of known strength and taking the likely maximum wind effect into account. Whilst a Danforth-type or fluked anchor is effective on sand and mud substrates (*Figure 15*), a fisherman's type or hook anchor is better on rocky bottoms. If time is available, concrete blocks can be cast to give convenient and reliable mooring points, but their weight in air must be at least three times the expected load, to compensate for their buoyancy in sea water. The use of a workboat with lifting gear would be required to handle heavy moorings.

Whichever type of mooring is used, it is important to select the length of the mooring lines to suit the expected water depth, swell and tidal range (*Figure 16*). If the lines are too short the boom will not ride well in the water and the snatching produced in the lines by waves may dislodge the moorings or damage the booms. Conversely, if the lines are too long it will be difficult to control the configuration. A length of heavy chain between the anchor and line greatly improves the holding power of an anchor, and the use of an intermediate buoy between the boom and anchor will help prevent submersion of the end of the boom. Equally, a weight hung from the mooring lines stops them floating on the surface when slack.

Magnetic mooring points allow boom to be attached directly to a ship side. Sliding moorings allow vertical movement of a boom throughout the tidal cycle when attached to a predetermined point such as at a harbour entrance.

When deploying a boom from a shoreline it is often possible to make use of fixed objects on the shore such as trees or rocks. On a featureless shoreline, multiple stakes (*Figure 17*) or a buried object such as a log provides an excellent mooring point. Water-ballasted beach- or shore-sealing booms are most suitable for deployment in this environment as their design enables containment during the tidal cycle. However, care should be taken when positioning these booms prior to ballasting as they are difficult to manhandle on land once filled (*Figure 18*). Such booms are often used in conjunction with curtain boom.

The outcome of the considerations above can be combined into a site specific booming plan, which identifies mooring points, oil collection points, access routes and the length and type of boom for the particular location. Before such plans are incorporated into local contingency plans, they should be subject to practical verification trials under a range of tidal conditions so that there can be confidence that the arrangements will perform as expected.

Current Strength (knots)	Current Strength (m/s)	Max. Angle (degrees)
0.7	0.35	90
1.0	0.5	45
1.5	0.75	28
2.0	1.0	20
2.5	1.25	16
3.0	1.5	13

▲ *Table 2: Maximum deployment angles to flow direction at different current strengths for bottom tension booms to prevent escape of oil Calculations are based on an escape velocity of 0.7 knots (0.35 m/s) at 90°.*

Anchor Weight (kg)	Holding Stength (kg force) Mud	Sand	Clay
15	200	250	300
25	350	400	500
35	600	700	700

▲ *Table 3: Holding strength of Danforth type anchors in loose mud, sand or gravel, and clay.*

Figure 16: Use of an insufficiently long mooring line has caused the boom to become suspended at low tide, allowing oil to pass beneath. Regular adjustment of lines would be required to maintain the boom in an effective position throughout the tidal cycle. Sliding moorings would be more effective in this scenario.

Figure 17: Mooring stakes to hold boom in place on shoreline without trees or other natural anchors.

As winds, currents and tides change, so will the configuration of a boom. Frequent checks and re-adjustment of the moorings will be necessary and contained oil and debris must be removed promptly, since the performance and benefit of the boom will otherwise be severely reduced. In conditions where the air temperature is hot by day and cool by night it is important to allow for the expansion and contraction of air in inflatable booms. This may necessitate releasing air during the day and re-inflating at night. Booms are vulnerable to damage by passing vessels, particularly at night and precautions, such as notifying mariners and marking booms with warning lights, can help to prevent such damage. Brightly coloured booms are more visible in daylight and are better picked out by lights at night.

As well as using booms to intercept or deflect oil they can be used in sheltered areas, where oil has collected naturally, to prevent it moving should conditions change (*Figure 19*). This not only minimises the extent of the contamination but also allows the controlled removal of the trapped oil. Booms can also assist shoreline clean-up by containing oil washed off beaches and rocks, for example by flushing or pressure washing operations. By drawing in the boom, the oil can be concentrated and moved towards collection devices. In some circumstances, simple expendable sorbent booms can be used to collect thin oil films although their use should be tightly controlled. The use of sorbent materials is addressed in a separate paper.

Alternative systems

Bubble barriers have been permanently installed to protect harbours, where currents are relatively low and where floating booms would hinder vessel movement. A rising curtain of bubbles is produced when air is pumped into a perforated

Figure 18: Shoreline sealing boom deployed in an estuary. The lower water ballast chambers allow the boom to sit on the shore at low tide. In this instance, sections of shoreline sealing boom are connected to sections of inflatable curtain boom.

Figure 19: Semi-solid oil held against the shoreline by a section of inflatable boom to facilitate recovery.

▲ *Figure 20: Improvised boom constructed from netting and straw. While not expected to survive more than one tidal cycle, this may nevertheless serve to reduce contamination of the shoreline from incoming floating oil.*

▲ *Figure 21: Barrier constructed from oyster-shells, held in place by stakes and nets.*

pipe located on the sea-bed. The air bubbles create a counter-current on the surface that holds the oil against a water flow of up to 0.35 ms^{-1} (0.7 knots). However, their effectiveness is limited to thin layers of oil in calm conditions as even a slight wind can cause oil to escape. Even simple systems require substantial compressors to provide sufficient air. Regular checks of such systems are essential to ensure that the air holes in the perforated pipes are not blocked by silt or marine organisms.

When purpose-built equipment is unavailable, oil may be contained or collected with improvised systems made with locally available materials. Alternative moored booms can be constructed from wood, oil drums, inflated fire hoses, rubber tyres or fishing nets filled with straw (*Figure 20*). In shallow waters stakes may be driven into the bottom to support screens or mats made from sacking, reeds, bamboo or other such materials (*Figure 21*). In these instances, the boom or barrier may also act as a sorbent to assist recovery of the oil.

On long sandy beaches, sand bars can be built out into shallow water with bulldozers to intercept oil moving along the shoreline or to prevent oil entering narrow estuaries or lagoons. However, such measures should be used with caution as they require considerable effort, can be rapidly washed away by currents or successive tides and could possibly damage the structure or ecology of the beach.

Key points

- Determine priorities for protection in order to maximise effective use of available booms.
- Decide whether selected areas can be protected by either towed or moored booms.
- Obtain as much information as possible on currents, tides and winds.
- Calculate forces likely to be exerted on booms.
- Review available boom designs and select the best for the conditions of expected use.
- Consider reliability, ease, speed of deployment and arrangements for suitable storage, maintenance and repair.
- Select suitable vessels for towing and consider necessary logistics to support operations at sea.
- Identify locations for successful boom deployment and develop and verify booming plans for incorporation in national and local contingency plans.
- Thoroughly train personnel and maintain their skills by practical exercises.
- Appreciate the limitations of booms in containing oil and be aware of the need to improvise as required.

TECHNICAL INFORMATION PAPERS

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ITOPF

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606
E-mail: central@itopf.com
Web: www.itopf.com

USE OF DISPERSANTS TO TREAT OIL SPILLS

TECHNICAL INFORMATION PAPER

4

Introduction

The principal aim of dispersant application is to break up an oil slick into numerous small droplets which become rapidly diluted into the water column and are subsequently degraded by naturally occurring micro-organisms. Used appropriately, dispersants can be an effective response to an oil spill and can minimise or prevent damage to important sensitive resources.

In common with other response techniques, the use of dispersants must be considered carefully, to take into account oil characteristics, sea and weather conditions, environmental sensitivities and national regulations on dispersant use. In some cases, significant environmental and economic benefits can be achieved through the use of dispersants, particularly when other at-sea response techniques are limited by weather conditions or the availability of resources.

This paper provides an overview of the use and limitations of dispersants on floating oil, as one of a range of options available for response to ship-source marine oil spills.

Mechanism of dispersion and dispersant composition

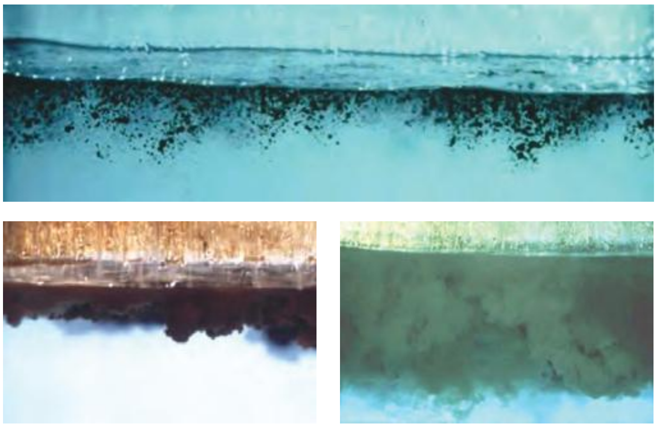
Following a spill of oil onto the sea surface, some of the oil in the resultant slick may disperse naturally into the water column. The extent to which this occurs depends on the type of oil spilt and the mixing energy of the sea. Oils with a lower viscosity are more amenable to natural dispersion than those with a higher viscosity. In general, crude oils will disperse to a greater extent than fuel oils.

Natural dispersion takes place when the mixing energy, provided by the waves and wind, is sufficient to overcome surface tension at the oil/water interface and break the oil slick into droplets of variable sizes (*Figure 1a*). The larger oil droplets will rapidly resurface and coalesce to reform an oil slick. The smaller droplets will remain suspended in the water column, due to wave motion and turbulence, and will be further diluted by subsurface currents.

The process of natural dispersion takes place in moderately rough seas, with breaking waves and winds above 5 m/s (10 knots). For example, severe storm conditions in Shetland, UK, during the grounding of the tanker BRAER in 1993, caused the majority of the 85,000 tonne cargo of Gulfaks crude oil, a very low viscosity oil, to be dispersed naturally, with minimal shoreline impact.

Dispersants are designed to enhance natural dispersion by reducing the surface tension at the oil/water interface, making it easier for wave motion to create many more small oil droplets (*Figures 1b and 1c*). Dispersants are a blend of surfactants (surface active agents) in a solvent. The solvent has two functions: to act as a 'thinner', reducing the viscosity of the surfactant, so that it can be sprayed, and to promote the penetration of the surfactant into the oil slick.

Each surfactant molecule contains an oleophilic part, (attracted to oil) and a hydrophilic part (attracted to water). When sprayed onto oil, the solvent transports and distributes the surfactant through the oil to the oil/water interface where the molecules re-arrange so that the oleophilic part is in the oil and the hydrophilic part is in the water. This reduces the surface tension of the oil/water interface, which, together with wave energy, results in droplets breaking away from the oil slick. Droplets that are sufficiently small to remain suspended in the water column produce a typical coffee-coloured plume seen to spread under the surface (*Figure 1c*).



▲ *Figure 1: Successful dispersion in laboratory conditions. a) Oil without dispersant (natural dispersion), b) Oil with dispersant and c) Oil with dispersant a few seconds later, demonstrating rapid dilution. (Images courtesy of Delft Hydraulics Institute).*

To achieve an effective dispersion, oil droplet size must be in the range of 1μm* to 70μm, with the most stable size being less than 45μm. The speed with which droplets in this size range rise towards the surface is balanced by the turbulence of the sea so that they remain in suspension and the oil and dispersant mixture dilutes rapidly within the top few metres of the water column. The presence of the surfactant molecules at the droplet surface, and the reduced probability of oil droplets coming into contact as they dilute and move apart, minimises the possibility of re-coalescence and reformation of surface slicks.

* *μm = micrometres = 10–6 metres. 1μm = 0.001mm*

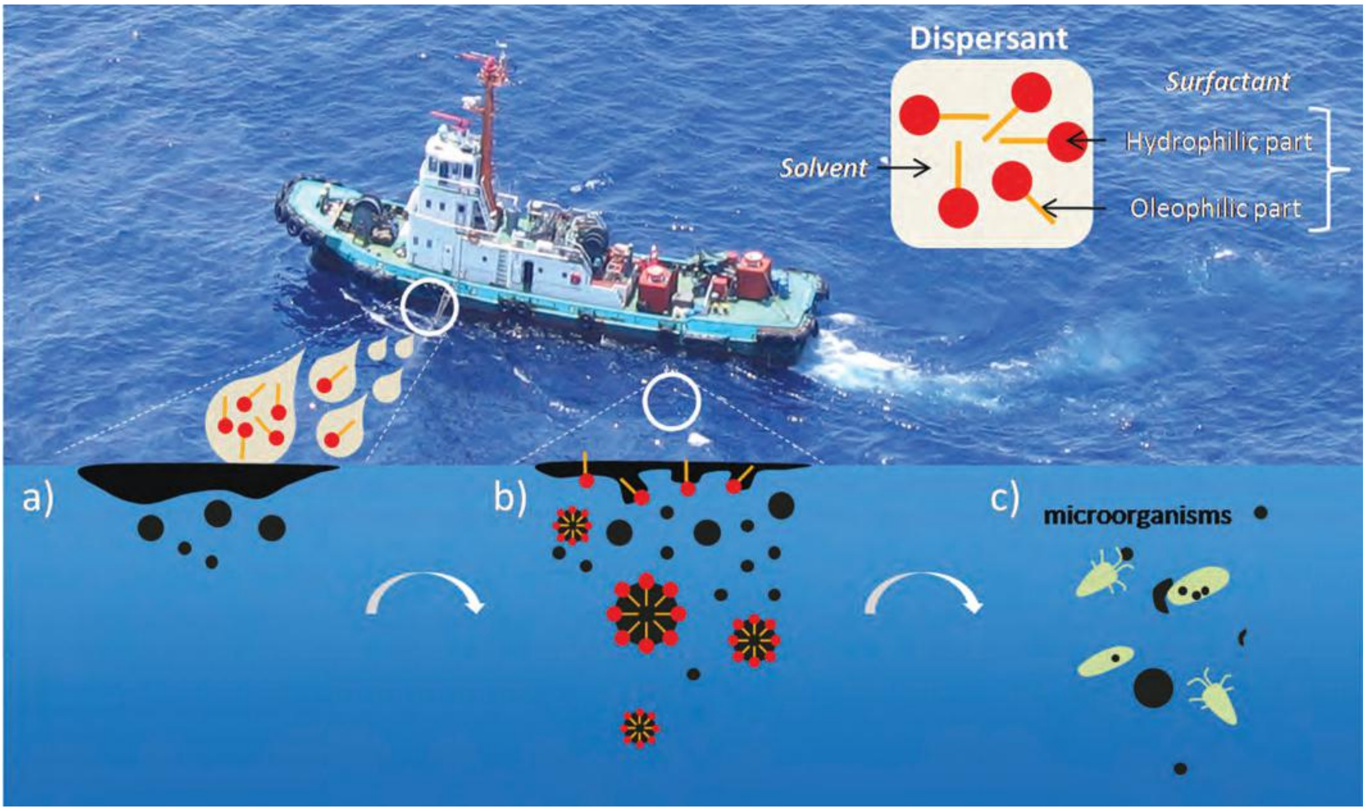


Figure 2: The chemical dispersion process: a) Dispersant containing surfactants and solvent is sprayed onto the oil with the solvent carrying the surfactant into the oil; b) The surfactant molecules migrate to the oil/water interface and reduce surface tension, allowing small oil droplets to break away from the slick; c) The droplets disperse by turbulent mixing and are ultimately degraded by naturally occurring micro-organisms, such as bacteria and fungi. This latter stage may require days or weeks to achieve.

Biodegradation by a range of marine micro-organisms can occur only at the droplet surface because the organisms are present in the water and not in the oil. The production of numerous smaller oil droplets increases the surface area of the oil and therefore the area available for biodegradation. For example, a droplet of 1mm diameter dispersed into 10,000 droplets, all of 45μm diameter, would result in a surface area that is 20 times larger than the surface area of the original droplet. In practice, dispersed droplets are not all the same size but are distributed such that there are very many more smaller droplets than larger ones, greatly increasing the opportunity for biodegradation.

Dispersant classification

Dispersants are classed according to their generation and their type. The first generation of products, introduced in the 1960's, were similar to industrial cleaners and degreasers, with high aquatic toxicity. They are no longer used in oil spill response.

Second generation dispersants, also called Type I dispersants, were designed specifically to treat oil spills at sea by spraying from vessels. They contain a hydrocarbon solvent with a low or no aromatic content and typically 15 to 25% surfactant. They are intended to be applied undiluted (neat), as pre-dilution with sea water renders them ineffective. They also require a high dose rate of between 1:1 and 1:3 (dispersant to oil). While having lower toxicity than the first generation dispersants, they are less effective and may be more toxic than third generation dispersants. In many countries, Type I dispersants are no longer used.

Third generation dispersants contain a blend of two or three surfactants with glycol and light petroleum distillate solvents. The most common surfactants used are non-ionic (fatty acid esters and ethoxylated fatty acid esters) and anionic (sodium alkyl sulphosuccinate). The concentration of surfactant within the solvent lies between 25% and 65% and tends to be higher than with Type I products.

Third generation dispersants can be divided into Type II and III dispersants. Both types are concentrate dispersants. However, Type II dispersants are generally diluted with sea water prior to use, typically at 10% dispersant, but require a high dosage of 2:1 to 1:5 (dispersant/water mix to oil) to be effective. This requirement for dilution limits their use to application from vessels. Type III dispersants are used neat and were developed primarily to allow efficient application from aircraft but may also be used from vessels. Dosage rates range between 1:5 and 1:50 (neat dispersant to oil), with the ideal practical ratio determined as a result of trials during an incident. Third generation, Type III dispersants are now the most commonly available dispersants.

Limitations of dispersants

Dispersant effectiveness is limited by certain physical and chemical parameters, the most important of which are the sea conditions and the oil properties. An awareness of these limitations is important to identify circumstances when dispersant use is appropriate.

Sea conditions

A minimum amount of wave energy is required for the successful use of dispersants at sea. Below this minimum, the dispersed oil droplets may re-surface and reform a slick. Furthermore, in severe sea conditions, the oil may be submerged by breaking waves, preventing direct contact between the dispersant and the oil, and dispersant efficacy will diminish. The results of field trials indicate that a wind speed between 4–12 m/s (8–25 knots, Beaufort Scale 3–6), is optimum.

Dispersants are manufactured primarily for use in seawater with a salinity of around 30-35 parts per thousand (ppt). Performance will decrease rapidly in brackish waters with a salinity below 5–10 ppt, especially when applying pre-diluted dispersant. Similarly, efficiency is also affected when salinity rises above 35 ppt. Efficacy is dramatically reduced in freshwater because the surfactants tend to migrate through the oil layer into the water column instead of stabilising at the oil/water interface. However, some dispersants have been specially formulated for use in freshwater. In a confined freshwater system, such as rivers and lakes, other factors need to be considered, such as whether there is sufficient depth or water exchange to achieve adequate dilution of the dispersed oil.

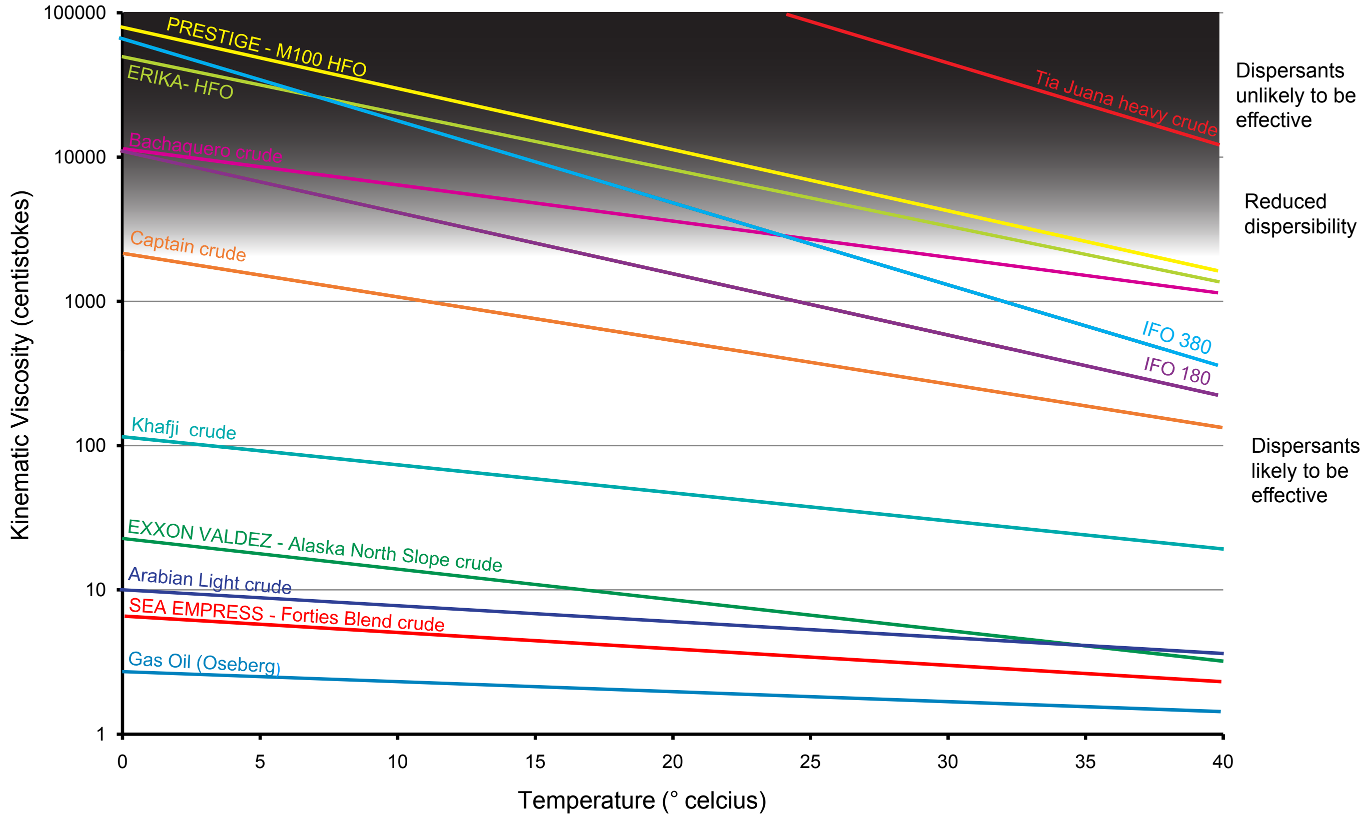
Oil properties

The characteristics of the oil and the manner in which these properties change by weathering at sea, are important when assessing whether the use of dispersants is likely to be successful. The viscosity and pour point of an oil are two properties that provide a good indication of how easily the oil is likely to disperse.

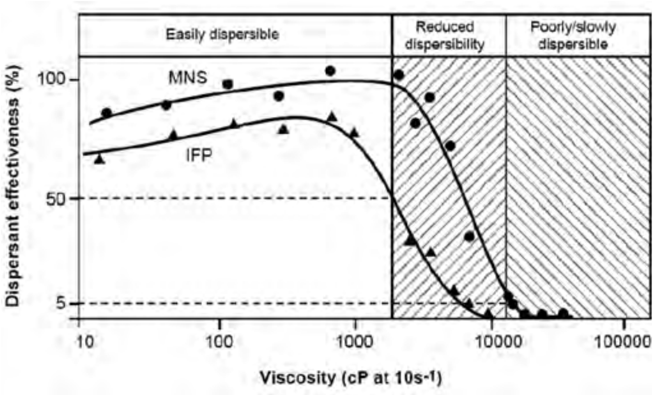
Dispersant effectiveness decreases as oil viscosity increases (*Figures 3 and 4*). Fresh, light-to-medium crude oils (group 2 or 3 oils, as described in the separate ITOPF paper on the Fate of Marine Oil Spills) are generally considered to be readily dispersible at most sea temperatures. The upper limit for dispersion is likely to be reached with heavier oils (Group 4 oils). As a general guide, most dispersants are unlikely to be effective for oils with a viscosity above 5,000–10,000 centistokes (cSt) at the time that they are spilt. The viscosity of spilt oil will increase due to the effects of weathering, primarily evaporation and emulsification. As a consequence, oils that may be dispersible when fresh may not be dispersible subsequently. The changes in oil properties over time caused by weathering mean that the opportunity for the successful application of dispersants is limited. The time available or 'window of opportunity' usually ranges from a few hours to a few days depending on the type of oil involved and the ambient conditions.

Similarly, oils with a pour point that is higher than the ambient temperature are usually transported heated and if spilt will rapidly increase in viscosity as they cool, often becoming semi-solid. As a general rule, oils with a pour point close to, or higher than, the sea surface temperature will not be dispersible.

Oils with a high viscosity, including those with a high pour point, do not disperse easily, either naturally or after the application of dispersants because the mechanical resistance of the oil prevents small droplets from breaking away under



▲ *Figure 3: Relationship between oil viscosity and sea temperature for 10 oils. The graph does not take account of increases in viscosity due to emulsification. Highly viscous oils, including the fuel oils spilt from ERIKA (France, 1999) and PRESTIGE (Spain, 2002), are generally not dispersible. Many crude oils, including those spilt from SEA EMPRESS (Wales, 1996) and EXXON VALDEZ (Alaska, 1989), are, in general, dispersible. Lighter products, such as gasoil, will generally readily disperse (and evaporate) without the use of dispersants.*



▲ *Figure 4: Relationship between dispersant efficacy and oil viscosity for a range of oils and emulsions. Oils with a viscosity between 5,000–10,000 centiPoise become more difficult to disperse and above 10,000cP are generally not dispersible. The two trend lines result from the of use of the differing MNS and IFP test protocols. (Centipoise = Centistokes x density) (Graph courtesy of SINTEF).*

the slick. Furthermore, dispersants are usually ineffective on these oils because they are not able to penetrate the oil before being washed off and lost into the water below, characterised by a white plume (*Figure 5*) that is noticeably in contrast with successful dispersion *(Figure 6*). Dispersant formulations are continually evolving to extend the viscosity range and improve their effectiveness on high viscosity oils. For example, dispersant gels are being developed to prolong contact with the oil to encourage solvent penetration.

Some oils are particularly prone to forming water–in–oil emulsions (especially those that have a relatively high asphaltene content (>0.5%) and a combined nickel/vanadium concentration greater than 15 parts per million (ppm)). However, if the emulsion is not stable, concentrate dispersants may be able to break it, releasing the water and allowing the relatively liquid oil produced to be dispersed by a second application of dispersant. If the emulsion has been successfully broken, patches of reflective pure oil should be observed.

Light products such as diesel, gasoline and kerosene do not readily form emulsions but spread to form very thin films of oil or sheens on the water surface that evaporate or dissipate rapidly without the need to use dispersants. Irrespective of this, the use of dispersants on light products or on sheens derived from a crude or fuel oil is not advised because the dispersant droplets tend to 'punch' through the thin film into the underlying water and cause 'herding' of the oil. The dispersant in the water causes the oil film to draw back immediately, creating an area of clear water that should not be mistaken for dispersion (*Figure 7*). Dispersants formulated for use on mineral oils have been shown to have little or no effect on non-mineral oils, such as palm oil or rapeseed oil.

Dispersant choice

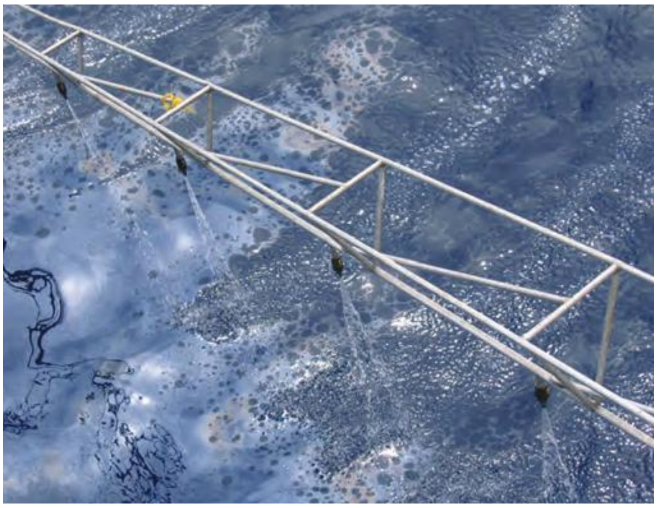
Dispersants are manufactured to different formulations, and their effectiveness varies with oil type. Laboratory tests may be carried out to rank the effectiveness of one dispersant relative to another for a particular oil and some countries require operators of oil production facilities and oil terminals, where the types of oils produced and handled are known, to undertake studies to identify the most effective dispersant for the oils involved. However, caution is advised when extrapolating the results from these studies to predict the amount of oil that will be dispersed at sea, as accurate replication of the conditions at sea is difficult in a laboratory environment. For planning purposes a dosage of 1:20, Type III concentrate dispersant to oil, is commonly used and spraying equipment is often pre-configured to achieve this. This dosage may sometimes be decreased for fresh oils and conversely, increased for viscous or emulsified oils where more than one application may be needed.

Conflicts with other response methods

In a large incident, coordination of all response actions is necessary to ensure dispersant use does not overlap or conflict with other response techniques. For example, oil dispersed into the water column cannot be contained by booms or recovered by skimmers. In addition, oil adheres to many sorbent materials, such as polypropylene, as a result of the relative surface tension of the oil. As the surface tension of oil is modified by dispersants, the effectiveness of

▲ *Figure 5: Ineffective treatment of a heavy fuel oil with dispersant is characterised by a white plume in the water. The oil remains unaffected.*

▲ *Figure 6: Dispersion starting after application to Forties Crude during the SEA EMPRESS spill. (Image courtesy of AEA Technology).*



▲ *Figure 7: Application of dispersant from vessel mounted spray arms onto sheen, causing herding of the oil, rather than dispersion.*

▲ *Figure 8: Application of dispersant using fire monitors on a tug, showing uneven spread of dispersant and the effect of wind.*

sorbent materials can be significantly reduced by the use of dispersants. Oleophilic skimmers will be similarly affected when used alongside dispersants.

Application methods

Dispersants can be applied from vessels or aircraft to oil spilt on open water. Large multi-engine aircraft offer advantages of payload for application to major off-shore spills but, along with vessels, helicopters and light aircraft, may be suitable for treating smaller spills closer to the shore.

It is important that spray systems deliver dispersant droplets of the correct size. Droplets need to be large enough to overcome the effects of wind drift and evaporative loss but not so large that they punch through the oil rather than migrate to the oil/water interface. The optimum dispersant droplet size is between 600 and 800μm in diameter.

Dispersant sprayed onto water or sheen will be ineffective and a waste of costly resources. Consequently, the thickest part of the oil slick should be rapidly targeted, before weathering of the oil or changes in the sea conditions render dispersants ineffective.

Vessel spraying

Dispersants sprayed from vessels are usually applied through a set of nozzles mounted on spray arms (*Figure 7*). Diesel or electric pumps transfer the dispersant from a storage tank to the spray arm, fitted with a set of nozzles calibrated to produce a uniform spray pattern of droplets along the length of the arm. Spray units can be portable or permanently installed on a vessel and systems are available to deliver the dispersant either undiluted or diluted with sea water.

Spray arms operate more effectively if mounted as far forward on the vessel as possible, to avoid the bow wave pushing the oil beyond the width of the spray pattern, or the spray swath. Mounting the spray arms on the bow allows the vessel to travel faster and, because freeboard is often greater at the bow, also allows the spray arms to be made longer. This optimises the encounter rate, i.e. the amount of oil that can be treated, with a limited dispersant payload. However, if the arms are too long they risk damage when

▲ *Figure 9: An Air Tractor spraying from an under-wing spray boom onto crude oil spilt from an offshore platform. (Image courtesy of Mark Hamilton Photography).*

▲ *Figure 10: Application of dispersant from a multi-engined aircraft. Here, application in shallow waters was considered beneficial.*

Figure 11: A helicopter, with an under-slung spray system, approaching a fresh spill of fuel oil. To be effective, application from a lower altitude would be necessary. (Image courtesy of Indian Coastguard).

the vessel rolls in swell.

Fire hoses or fire monitors (*Figure 8*) are sometimes used to apply concentrate dispersants diluted in the water stream. However, optimum dilution of the dispersant is difficult to achieve because of the very high flow rates and it is difficult to apply the dispersant as a uniform spray of droplets. The high pressure of the water jet also risks forcing the dispersant through the oil. Thus, fire monitors are likely to lead to wastage of dispersant and ineffective application unless specially modified for the purpose.

Vessels offer advantages for dispersant spraying because they are usually readily available, easy to load and can apply dispersant fairly accurately to specific areas of a slick. They have cost advantages over aircraft and may be able to carry larger payloads. Nevertheless, they also have severe limitations, particularly for larger spills, because of the low treatment rate and the difficulty of locating the heaviest concentrations of oil from the bridge of a vessel, although this latter problem can be partially overcome by directing the operation from a spotter aircraft.

Aerial spraying

The application of dispersants from aircraft offers the advantages of rapid response, high treatment rates and optimum dispersant use. In broad terms, three categories of fixed-wing aircraft are used: those designed for agricultural or pest control operations (*Figure 9*), which require minor modification for dispersant application, those that have been adapted specifically for the application of dispersant and cargo aircraft with modular tanks (*Figure 10*). Some helicopters have been adapted with fixed spray arms whilst others are able to carry under-slung bucket spray systems, usually without the need for major modifications (*Figure 11*). Helicopters can potentially reload dispersants from a vessel or offshore oil platform for operations offshore.

The ideal aircraft for a given incident will be determined primarily by the size and location of the spill, although local availability will be the crucial factor. Aircraft should be capable of operating safely at low altitudes (typically 15–30 metres for larger aircraft) and at relatively slow speeds (25–75 m/s) and should be highly manoeuvrable. Fuel consumption, payload, distance between the spill and the operating base, turn-around times and the ability to operate from short or improvised landing strips are all important considerations when selecting suitable aircraft.

Type III dispersants are most suitable for aerial spraying as the low dosage (typically 1:20 dispersant to oil) makes best use of the limited payload. Aircraft spraying systems consist of a pump that draws dispersant at a controlled rate from a tank into spray arms fitted to the aircraft. The dispersant is discharged either through pressure nozzles or from wind driven rotating units spaced at regular intervals along the spray arm, which are designed to produce dispersant droplets of the optimum size. Both types of discharge unit can be used on most light aircraft and helicopters but larger aircraft use pressure nozzles.

Shoreline application

Once bulk oil has been recovered from affected shorelines, dispersants are sometimes used as cleaning agents, to remove the remaining oil from hard surfaces such as rocks, sea walls and other man-made structures. They are generally applied from hand-operated backpack systems and brushed vigorously into the oil before flushing with seawater. The dispersed oil cannot be collected and, for this reason, where dispersant use on shorelines is approved, it is usually restricted to areas of low environmental concern but high amenity value. Shoreline cleaners, specifically formulated for the task, may also be used. However, these products work in a different way from dispersants as it is intended that the oil released should be collected. Degreasers are often carried on board ships to deal with engine room cleaning but most are more toxic than dispersant and should not be used as a dispersant at sea or as shoreline cleaners.

Application rate

To calculate the appropriate application rate, the ratio of dispersant to oil required for effective dispersion must be determined. This can range from 1:1 for Type I dispersants to 1:50 for Type III dispersants, depending on the application method, the type of dispersant, the oil type and the prevailing conditions. The application rate can be calculated in two steps, as follows:

1. Estimation of the volume of oil to be treated based on observations and assumptions concerning the average thickness and the area of the slick.
2. Calculation of the quantity of dispersant needed to achieve the required dosage (dispersant : oil ratio)

It has been found that although there are substantial variations in the thickness of the oil within a slick, most fresh crude oils spread within a few hours, so that overall the average thickness is 0.1mm (10^{-4}m). This thickness is often used as the basis upon which to plan operations and gives the volume of oil in one hectare (10,000 square metres, $10^4 m^2$) as:

$10^{-4} m \times 10^4 m^2 = 1 m^3$ or 1,000 litres

Further advice on estimating oil quantities is provided in the separate ITOPF paper on Aerial Observation of Oil.

For a dosage of 1:20, the quantity of dispersant required would be:

Dispersant quantity = 1000 litres of oil / 20 = 50 litres.

Therefore, the application rate would be 50 litres/hectare (4.5 imperial gallons/acre). The discharge rate can be calculated by multiplying the application rate (litre/m^2) by the speed of the aircraft or vessel (m/s) and the spray swath (m).

For example, to achieve an application rate of 50 litres/hectare (0.005 litre/m^2) from an aircraft travelling at a speed of 45 m/s (90 knots) with a swath of 15 metres, the discharge rate required would be:

Discharge rate = 0.005 litres/m^2 x 15 m x 45 m/s = 3.37 litres/s (or about 200 litres/minute).

Thus, to achieve a dose rate of 1:20 and disperse a slick of 0.1mm thickness, the discharge rate of the spray system pump would need to be 200 litres per minute. The same calculation can be made to determine the discharge rate for vessel application.

The significant variation in oil thickness within a slick means that, in practice, it is impossible to evaluate the optimum dosage precisely. The practical and most efficient solution is to target the thickest parts of the slick. Application rates of the order of 50 litres per hectare, as calculated above, have been found to be appropriate in many situations, but adjustment may be required to compensate for different types of oil and environmental conditions that may further affect the thickness of the slick. The application rate can be adjusted by changing the discharge rate of the pumps or the speed of the vessel or aircraft. In addition, estimates of the volume of dispersant required to treat a slick should take into account the accuracy with which the heaviest accumulations of oil can be targeted, with some allowance for overspray.

Logistics and control

Dispersant application is a specialised operation that requires trained operators and thorough preparation to ensure that all the logistics are in place. For operations to be most effective, it is desirable to use spotter aircraft to guide and co-ordinate spraying vessels and aircraft. The crew of the spotter aircraft should be able to identify the heavier concentrations of oil or the slicks posing the greatest threat. They will need to have good communication with the crews of spraying aircraft or vessels in order to guide them to the target, and with spraying aircraft, to identify the points at which spraying should start and stop in order to minimise overspray and wastage of dispersant. During the spraying operation itself, spotter aircraft can also be used to judge the accuracy of the application and the effectiveness of the treatment. These functions are particularly important when directing large multi-engine spraying aircraft that can rapidly apply large volumes of dispersant. At the low altitude necessary for effective application, the crew will experience difficulties in distinguishing between oil, sheen and water, especially if the slick is fragmented.

To ensure safety, aircraft exclusion zones need to be in force during aerial spraying operations. Relief crews may be necessary, as flying over the sea at low altitude can be extremely demanding. Periodic checks of the aircraft are also recommended to ensure that the dispersant does not contaminate lubricants, particularly in the tail rotor of helicopters, or attack any exposed rubber components of aircraft flight control systems. It is advisable to wash down the aircraft frequently with fresh water to remove both dispersant and salt water spray.

Good organisation on the ground is needed to enable spraying operations to continue for the maximum available time during daylight hours. This may require routine maintenance of aircraft and spraying equipment to be carried out during hours of darkness. It is unlikely that a single payload will be sufficient to treat a slick, especially if the release is continuous, and additional supplies of dispersant need to be sourced and conveniently located in order to re-supply vessels or aircraft with minimum delay. Similarly, thought should be given to the provision of fuel, particularly for aircraft, and to the equipment necessary to load vessels or aircraft, such as high capacity pumps and road tankers.

For long-term storage of dispersants, plastic drums, tanks or $1m^3$ Intermediate Bulk Containers (IBCs) (*Figure 12*) are preferable. Provided that they are not exposed to direct sunlight, dispersants stored unopened should last for many years. However, once opened, the dispersant should be tested periodically for its effectiveness. Recommendations from manufacturers include an annual visual inspection together with a check of the main physical characteristics such as density, viscosity and flash point of the product. If these physical parameters have changed significantly

Figure 12: Use of $1m^3$ Intermediate Bulk Containers (IBCs) allows straightforward storage and handling of dispersant. (Image courtesy USCG).

or the expiry date has passed, a laboratory dispersant effectiveness test should be conducted. Dispersants of different types, ages or brands should not be mixed in the same tank or storage container as this may alter the viscosity of the dispersant or cause some components to precipitate or coagulate. Dispersants should not be stored after they have been diluted with sea water. A temperature between -15°C and 30°C is optimum for storage of most dispersants and manufacturers recommend that temperature fluctuations are minimised during storage. In very cold air temperatures, some dispersants may become too viscous to pass through the spray nozzles.

Monitoring dispersant effectiveness

The effectiveness of chemical dispersion should be monitored continually and the response terminated as soon as the dispersant is no longer effective. Visual observation of effectiveness is key but may be impaired in poor weather conditions, in waters with a high sediment load, when dispersing pale-coloured oils, and in poor light. Clearly, spraying and visual monitoring at night is impractical.

For the application of dispersants to be worthwhile, the oil needs to be dispersed relatively quickly after being spilt to reduce the risk of the oil reaching the shoreline and sensitive resources. A change in appearance should be visible from the air shortly after spraying. No change in the appearance of the oil, no reduction in the oil coverage, or if the dispersant runs off the oil to create a milky white plume in the water (*Figure 5*), all indicate the dispersant is not working. Equally, if the oil has spread over a wide area or has become widely fragmented, application of dispersant may not remove sufficient amounts of oil from the water surface to achieve a significant reduction in pollution damage.

Effectiveness can also be monitored using 'real-time' data on the concentration of dispersed oil in the water column with ultra-violet fluorometry (UVF). One or more fluorometers (*Figure 13*) are towed behind a sampling boat at depths of more than a metre under the slick to measure the variation

Figure 13: Preparing a towed fluorimeter to measure dispersant effectiveness at sea. (Image courtesy USCG).

in oil concentrations. Dispersion is demonstrated by a significant increase in the concentration of oil detected by the sensor relative to the concentration measured prior to dispersant application (*Figure 14*). However, UVF cannot provide a quantitative measurement of the amount of oil dispersed into the water column and should be used in combination with visual observations to decide whether a worthwhile response can be achieved.

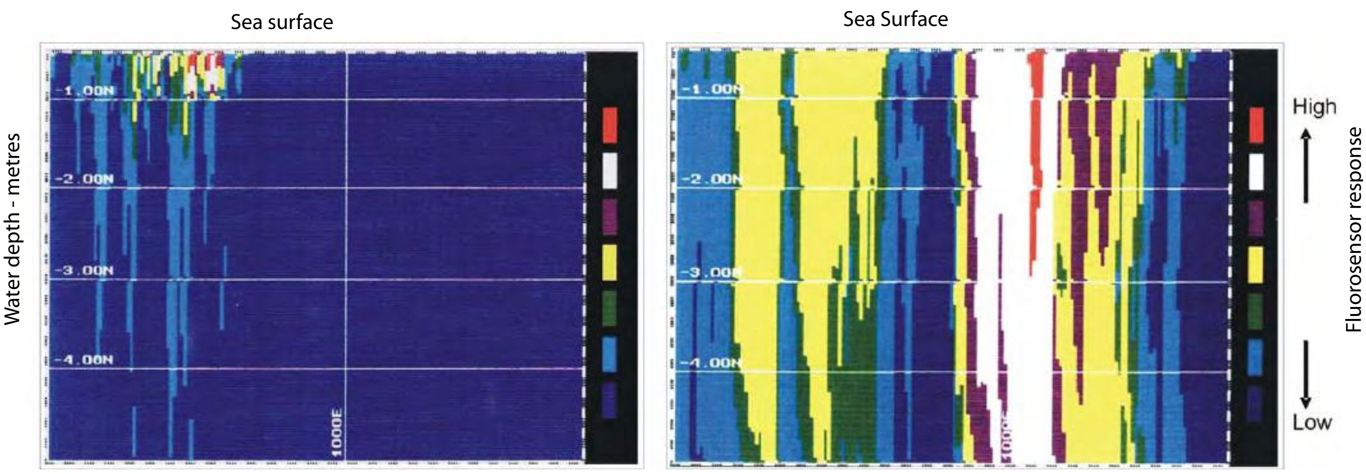


Figure 14: Fluorometer response to oil from 0.5 to 5 metres water depth under an surface slick before (left) and a few minutes after dispersant application (right). Oil rapidly disperses and dilutes after treatment. (Illustrations courtesy of AEA Technology).

▲ *Figure 15: Dispersant use can help protect vulnerable sea birds by rapidly removing oil from the sea surface.*

▲ *Figure 16: Dispersant use in sensitive areas such as coral reefs is not advocated except in special circumstances and after careful consideration of the potential environmental consequences of its use.*

Environmental considerations

Dispersant use can be controversial, at times generating widespread debate in the media and public forums. Its use may be viewed as a way of minimising potential impacts on sensitive resources by preventing or reducing shoreline contamination, but is also sometimes seen as adding another pollutant to the environment. Despite improvements in dispersant formulations, the toxicity of the dispersant/oil mixture to marine fauna and flora is often the major environmental concern. In some countries, the ease with which dispersants biodegrade is a concern and studies are on-going. Approval processes for dispersant use in many countries are designed to take both effectiveness and toxicity into account. Products approved in one country may not be approved in another and, where available, the relevant national list should be consulted prior to their use.

After application of dispersant in open water, elevated oil concentrations are normally only observed in the upper layers of the water column (<10 metres) but are rapidly reduced by dilution, through water movement. Studies on crude oils have shown that immediately after dispersant application, oil concentrations in the range of 30 to 50 ppm can be expected in the water just below the slick, diminishing to 1 to 10 ppm in the uppermost 10 metres or so of the water column after a few hours. The exposure for marine organisms is thus 'acute' rather than 'chronic' and the limited exposure time reduces the likelihood of long-term adverse effects. However, spraying dispersants in shallow water is not advised, unless sufficient water exchange can ensure adequate dilution of the dispersed oil plume.

An estimation of the dilution potential is a useful basis for making the decision on whether or not dispersants should be used to protect certain resources without risking undue damage to others. Relevant factors to take into account when estimating peak concentrations and their duration include water depth, oil quantity per unit area, the distance between the application site and sensitive areas, as well as the direction and speed of currents.

By removing oil from the water surface, dispersants minimise the risk of sea birds becoming oiled (*Figure 15*) and contamination of sensitive shorelines such as salt marshes, mangroves and tourist beaches. However, oil removed from the surface is transferred to the water column and it is the risk of damage caused by dispersed oil that has to be balanced against the advantages of its removal from the surface. In the case of many free swimming fish species, their ability to detect and avoid oil in the water column will help to reduce their potential exposure. However, corals (*Figure 16*), sea grass and fish spawning areas may be highly sensitive to dispersed oil and the use of dispersants is not recommended if these resources could be affected. Similarly, the use of dispersants is not advocated in the vicinity of fish cages, shellfish beds or other shallow water fisheries due to the increased risk of tainting of stock. The use of dispersants close to industrial water intakes is not advisable due to the increased risk of oil entering water intakes.

The decision whether or not to use dispersants is seldom clear-cut and a balance has to be struck between the advantages and limitations of different response options (including reliance on natural processes), cost-effectiveness and conflicting priorities for protecting different resources from pollution damage. In many instances, a balanced assessment of the net environmental and economic benefits will be necessary, in consultation with national authorities, prior to application. The time available to use dispersants is likely to be limited both by the weathering of the oil and its movement towards sensitive resources. To avoid delays at the time of a spill, the decision on whether dispersants can be used and if so, the precise circumstances under which they may be used need to be agreed during the process of developing contingency arrangements for spill response.

Contingency planning

Factors to be considered during the contingency planning process include the types of oil likely to be involved in a spill, the effectiveness of the dispersant on these oils, the sensitive resources in the area and the logistic support. Logistics relate mainly to the location and availability of dispersants, spraying equipment, vessels, aircraft, airstrips and refuelling capability, as well as to customs clearance for any international support that might be required in a major incident. Sensitivity maps are particularly useful to indicate when and where dispersants may or may not be used, as they can denote seasonal influences on sensitivity. For example, migratory birds will be present at certain times of the year and limitations on dispersant use in shallow waters may be overridden to allow application to reduce the risk of the birds encountering floating oil (*Figure 17*). Thought also needs to be given to sources of funding for maintenance of an effective dispersant response capability. The outcome of these discussions should be documented clearly in a contingency plan.

In many countries, national regulations require dispersant use to be approved by the competent national authority. For responders, an awareness of dispersant use policy is important as conflicts may arise and fines may be imposed if dispersants are used without prior consent or regard for national regulations. Some countries maintain a list of dispersants that have been approved for use on the basis of efficacy and toxicity testing. The competent authority may also grant pre-approvals to oil handling facilities or ports allowing them to use dispersants without further consultation, provided that certain criteria have been met.

Training and exercises are an essential part of planning for dispersant use, as indeed they are for all aspects of spill response. Operational crews should receive comprehensive training on dispersant application and safety. Practical exercises to mobilise resources and deploy spraying equipment should be held regularly.

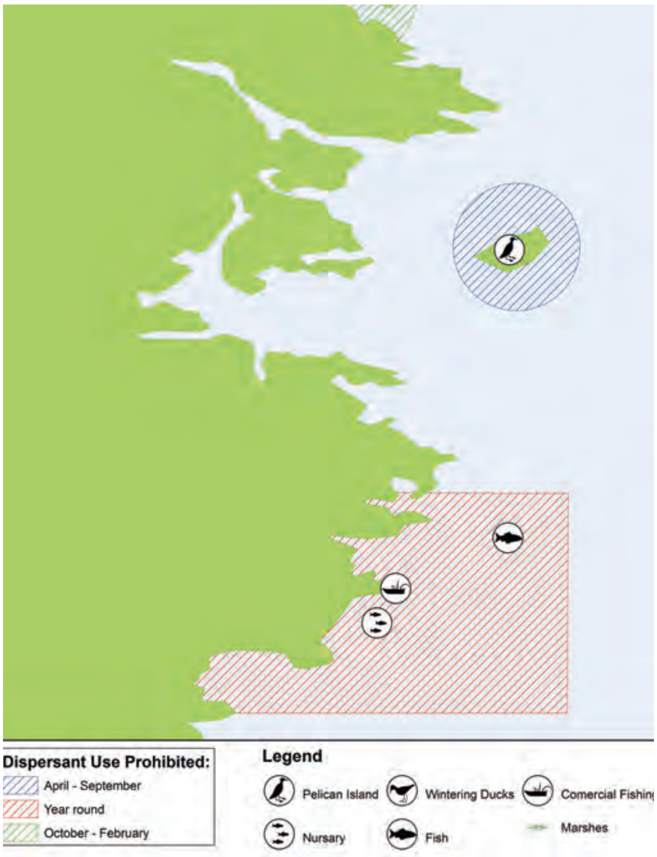


Figure 17: Sensitivity maps are often used in contingency plans to delineate where and when dispersants can be used. In the example, dispersant use is prohibited in the red area because of year-round commercial fishing, but is pre-approved seasonally for treating oil around a bird colony at Pelican Island (blue). Use in shallow water, close to the mainland may be allowed in special circumstances, for example to protect the mangroves or marsh which are both highly sensitive to stranded oil.

Key points

- Dispersants enhance the natural break-up of oil, removing it from the water surface into the water column as numerous small droplets to be rapidly diluted and ultimately biodegraded.
- Most dispersants are unable to disperse very viscous oils and stable emulsions.
- Spraying dispersant on oil sheen is an ineffective and ill advised use of resources.
- For most crude oils and some fuel oils spilt at sea, a brief opportunity exists in which dispersant use will be effective and a fast, well-planned response is essential.
- While vessels are suitable for dealing with small oil spills close to port, large, multi-engine aircraft offer a potentially more effective response for major spills offshore.
- In the open sea, observations show that concentrations of dispersed oil in the water column decrease within hours to levels below those likely to cause long-term adverse effects to marine organisms.
- Dispersants can rapidly and effectively minimise pollution damage to animals present at the surface, such as sea birds and to sensitive coastal resources, such as mangroves.
- Dispersant application should be avoided where the dispersed oil plume may cause damage to sensitive resources such as coral, shellfish beds or industrial water intakes.
- A well prepared and practised contingency plan, and a clear policy for agreed dispersant use, significantly increases the likelihood of an effective dispersant operation.

TECHNICAL INFORMATION PAPERS

1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
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14 Sampling and Monitoring of Marine Oil Spills
15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
17 Response to Marine Chemical Incidents

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ITOPF

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com

USE OF SKIMMERS IN OIL POLLUTION RESPONSE

TECHNICAL INFORMATION PAPER

5

Introduction

A number of options are available to respond to marine oil spills. The primary technique adopted by many government authorities is mechanical recovery of oil from the sea surface. This is usually achieved by use of booms to concentrate spilt oil, allowing a skimmer to selectively recover and pump the oil to storage. Many different types of skimmer exist with designs optimised to deal with different scales of operation, oil types and environmental conditions.

This paper describes the fundamental requirements for the successful use of skimmers in the situations most likely to be encountered during an oil spill and should be read in conjunction with other ITOPF papers in this series, in particular, on the use of booms, shoreline clean-up techniques and the disposal of oil.

Overview

The ultimate aim of any recovery operation is to collect as much oil as is reasonably and economically possible. A successful recovery system must overcome the interrelated problems of encountering significant quantities of oil and its subsequent containment, concentration, recovery, pumping and storage. The recovery and pumping elements of the overall operation are frequently combined in a skimmer. All skimmers are designed to recover oil in preference to water but designs vary considerably according to the intended use, for example, at sea, in sheltered waters or onshore. Skimmers for use on water include some form of flotation or support arrangement while more complicated designs may be self-propelled and may have several recovery elements, integral storage tanks and oil/water separation facilities (*Figure 1*).

A number of factors should be considered when selecting skimmers, the most important of which are the viscosity and adhesive properties of the spilt oil (including any change in these properties due to 'weathering' over time), together with the sea state and levels of debris. In relatively predictable situations, such as at fixed facilities, for example, marine terminals and refineries, the type of oil handled may be known and a specific skimmer can be selected. Conversely, a versatile skimmer, that may be required to address a variety of situations and oils, may be preferable, for example as part of a national stockpile. However, no single skimmer can cope with every situation that may be encountered as a result of an oil spill and a selection of skimmers may be required, particularly as the oil weathers (*Table 1*).

The intended use and expected operational conditions should then be identified, for example whether the skimmer is to form an integral part of a vessel-mounted, offshore recovery system or is to be deployed manually in a port or on a shoreline. Once these are established, other criteria such as size, robustness and ease of operation, handling and maintenance can be evaluated.

Cover image courtesy Ro-Clean Desmi/Danish Navy.

▲ *Figure 1: A self-propelled weir skimmer for use in ports and nearshore waters. The bow doors open to enhance the swath and allow entry of floating oil. Recovered oil is pumped to an internal storage tank.*

Oil recovery mechanisms and skimmer design

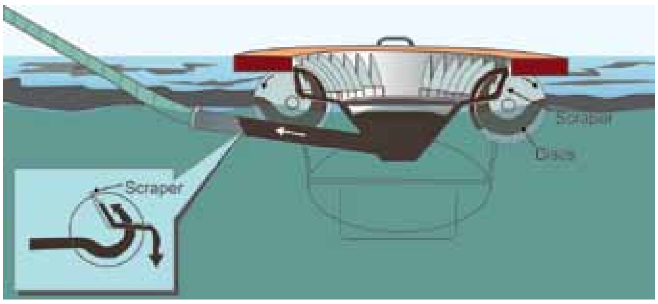
The recovery element of a skimmer diverts or skims the oil from the sea surface, where it flows to the inlet side of a pumping system for transfer to storage. The mechanisms through which oil is removed from the water surface include oleophilic systems relying on adhesion of oil to a moving surface, suction systems, weir systems relying on gravity, and systems that physically lift the oil with mechanical scoops, belts or grabs.

Oleophilic skimmers

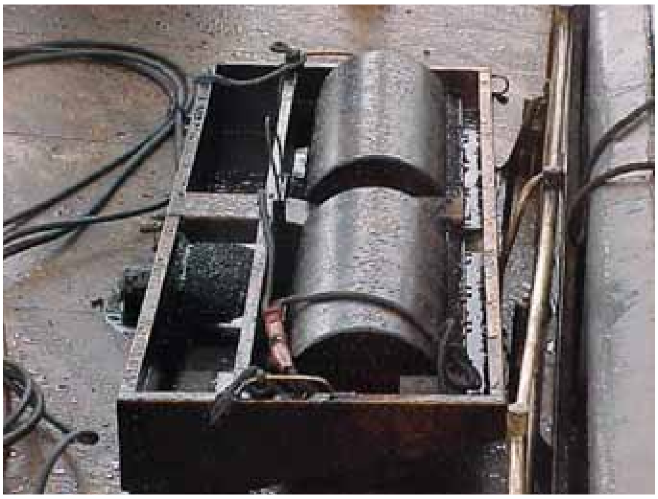
Oleophilic skimmers employ materials that have an affinity for oil in preference to water. The oil adheres to the surface of the material, commonly taking the shape of a disc (*Figures 2 and 3*), drum (*Figure 4*), belt, brush (*Figure 5*) or rope-mop (*Figures 6 and 7*) which, as they rotate, lift the oil from the water surface. Once clear of the water the oil is scraped or squeezed off the oleophilic material and allowed to drop into a sump from where it is pumped to storage. Oleophilic skimmers usually achieve the highest ratio of recovered

Skimmer		Recovery rate	Oils	Sea state	Debris	Ancillaries
Oleophilic	**Disc**	Dependent on number and size of discs. Tests show grooved discs can be highly effective.	Most effective in medium viscosity oils.	In low waves and current can be highly selective with little entrained water. However, can be swamped in choppy waters.	Can be clogged by debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
Oleophilic	**Rope mop**	Dependent on number and velocity of ropes. Generally low throughput.	Most effective in medium oils although can be effective in heavy oil.	Very little or no entrained water. Can operate in choppy waters.	Able to tolerate significant debris, ice and other obstructions.	Small units have built in power supply and storage. Larger units require separate ancillaries.
Oleophilic	**Drum**	Dependent on number and size of drums. Tests show grooved drums are more effective.	Most effective in medium viscosity oils.	In low waves and current can be highly selective with little entrained water. However, can be swamped in choppy waters.	Can be clogged by debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
Oleophilic	**Brush**	Throughput dependent on number and velocity of brushes. Generally mid-range.	Different brush sizes for light, medium and heavy oils.	Relatively little free or entrained water collected. Some designs can operate in choppy waters, others would be swamped in waves.	Effective in small debris but can be clogged by large debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
Oleophilic	**Belt**	Low to mid-range.	Most effective in medium to heavy oils.	Can be highly selective with little entrained water. Can operate in choppy waters.	Effective in small debris but can be clogged by large debris.	Can deliver oil directly to storage at the top of the belt. Ancillaries required to discharge from a vessel to shore.
Non-Oleophilic	**Vacuum/ suction**	Dependent upon vacuum pump. Generally low to mid range	Most effective in light to medium oils.	Used in calm waters. Small waves will result in collection of excessive water. Addition of a weir more selective.	Can be clogged by debris.	Vacuum trucks and trailers are generally self-contained with necessary power supply, pump and storage.
Non-Oleophilic	**Weir**	Dependent upon pump capacity, oil type etc. Can be significant.	Effective in light to heavy oils. Very heavy oils may not flow to the weir.	Can be highly selective in calm water with little entrained oil. Can be easily swamped with increase in entrained water.	Can be clogged by debris although some pumps can cope with small debris.	Separate power pack, hydraulic and discharge hoses, pump and storage. Some skimmers have built-in pumps.
Non-Oleophilic	**Belt**	Low to medium.	Most effective in heavy oils.	Can be highly selective with little entrained water. Can operate in choppy waters.	Effective in small debris. Clogged by large debris.	As for oleophilic belt skimmer.
Non-Oleophilic	**Drum**	Mid range.	Effective with heavy oils.	Can be highly selective in calm water with little entrained oil. However, can be swamped in waves.	As for weir skimmer.	As for weir skimmer.

Table 1: Generic characteristics of commonly encountered skimmer types. The choice of skimmer for effective operations will depend on the oil spilt. As the oil weathers, the effectiveness of a particular type may change, requiring an alternative design for continued recovery. The recovery rate assumes the skimmer would be in a homogenous slick of oil that has not spread or scattered widely.



Figures 2 and 3: Small oleophilic disc skimmer, suitable for oils of medium viscosity. Oil adheres to the rotating discs to be scraped off into a sump for pumping to storage. Requires a suitable pump and hydraulic power supply.



▲ *Figure 4: Oleophilic drum skimmer, suitable for oils of medium viscosity. Operates in a similar manner to a disc skimmer in that oil adheres to the rotating drums to be scraped off into a sump for pumping to storage.*

▲ *Figure 5: Free floating brush skimmer. Oil adheres to the rotating brush sets and is lifted from the water surface. A comb removes the oil from the brushes to storage. A propeller behind the brush draws floating oil towards the skimmer to enhance the encounter rate and throughput (Image courtesy Lamor).*

▲ ▸ *Figures 6 and 7: Horizontal and vertical oleophilic rope skimmers. Interwoven sorbent loops form a continuous mop which floats on the surface to which the oil adheres. The mop is pulled back to a roller and the oil squeezed to a storage tank. Rope mop skimmers are useful to recover oil from among debris, ice and other obstructions.*

oil in relation to free or entrained water, also known as the recovery efficiency. They are most effective with medium viscosity oils between 100 and 2,000 centistokes. Low viscosity oil products, such as diesel or kerosene, generally do not accumulate on the oleophilic surfaces in sufficiently thick layers for high recovery rates to be attained. Higher viscosity oils, such as heavy bunker oil, are excessively sticky and can prove difficult to remove. In contrast, water-in-oil emulsions can be almost non-adhesive and can be difficult to recover with some designs of oleophilic skimmers, for example disc skimmers will cut through emulsion, instead of enabling its recovery. Oleophilic materials are usually made from some form of polymer, although metal surfaces have also been shown to be effective. Discs and drums with grooved surfaces have been shown to result in higher recovery rates than smooth surfaces*.

Suction skimmers

In terms of operational theory, the simplest design is a suction device, whereby oil is recovered by pumps or air suction systems directly from the water surface. In particular, vacuum trucks or trailers, that combine the elements of recovery, storage, transport and oil/water separation, are often readily available locally to a spill site, either commercially or from municipal or agricultural organisations and, as such, are ideally suited to recovery of oil on or near the shoreline (*Figure 8*). Smaller, more portable devices

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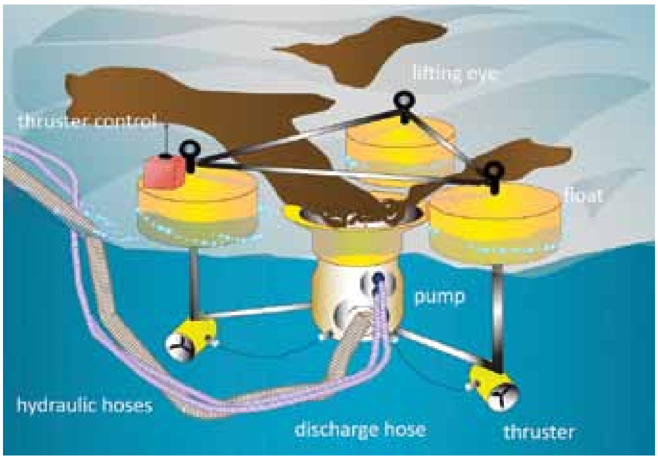
** Source: Optimisation of Oleophilic Skimmer Recovery Surfaces: Field Testing at the Ohmsett Facility, V. Broje, A. Keller, Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, 36 pp., June 2006.*

Figure 8: The widespread availability of vacuum systems make these devices ideally suited to recovery of oil on or near the shoreline.

Figure 9: Portable vacuum systems can facilitate the recovery of oil on sand beaches and rocky shorelines. The compact system allows work in areas that are otherwise difficult to reach, although storage is limited.

Figure 10: Workers placing a hose attached to a vacuum pump directly into the oil. In this instance, the small weir attachment has been removed to allow the viscous fuel oil to flow into the hose, with a consequent potential increase in entrained water.

Figure 11: Fixed weir skimmer attached to a vacuum pump. A number of small inlets at the edge of the head allow oil to be selectively recovered. For use in calm water with minimal debris (Image courtesy Lamor).



Figures 12 and 13: A weir skimmer selectively recovers oil over the top of the central weir sited just below the upper surface of the slick by the force of gravity into a central reservoir where it is pumped to storage.

Figure 14: Improvised weir skimmer constructed from plastic bottles and metal offcuts, attached to a vacuum pump. This device allows rudimentary recovery and can be adjusted by removal or addition of bottles.

Figure 15: A belt skimmer on a large recovery vessel. The belt, constructed from a mesh, allows water to drain through and encourages adhesion of the oil. The oil is lifted on-board and is scraped off to storage.

Figure 16: A belt adaptor added to enhance the capability of the base weir skimmer in highly emulsified fuel oil. The high viscosity of the oil prevented its flow towards and over the lip of the weir. Instead, the toothed belt adaptor 'grabbed' the oil enhancing the efficiency, with the cohesive energy of the oil causing the remaining oil to 'flow' toward the skimmer (Image courtesy Ro-Clean Desmi/Danish Navy).

are also available (*Figure 9*). Placing the suction hose directly into floating or stranded oil, with a mesh screen to inhibit the ingress of debris, provides the simplest method of recovery (*Figure 10*). However, the often indiscriminate nature of this operation may result in very high proportions of water also being collected. Where regulations allow, and the necessary equipment is available, this excess water should be decanted to maximise available storage.

Weir skimmers

Greater selection of oil may sometimes be achieved by the attachment of a device weir to the suction hose (*Figure 11*). Weir skimmers use gravity to selectively drain oil from the surface of the water. By positioning the lip of the weir at, or just slightly below, the interface between the floating oil and water, the oil flows over the weir to be selectively recovered with minimal amounts of water. Advanced types of weir skimmers have adjustable weirs and accurate vertical positioning of the weir is usually achieved by a self-levelling arrangement (*Figures 12 and 13*). Alternatively, weir skimmers can be very simple, rudimentary devices (*Figure 14*), although the level of entrained water may be higher. No weir skimmer is effective in steep waves, although swell alone does not generally interfere with skimmer operation. To overcome friction losses along transfer hoses, some weir skimmers have an on-board pump so that the recovered oil is pushed along the hose rather than relying on suction.

Other skimmer types

Other skimmer designs have been adapted to cope better with waves and rougher seas. Upward rotating belts, for instance, can be partially lowered beneath the oil/water interface to reduce the influence of surface waves. The oil is then scraped off the belt as it rises above the surface and drops into a storage tank or other containers. Belts may be constructed from an oleophilic material, as previously described, relying on the adhesion of the oil to individual elements of a rotating brush (*Figure 5*), chain link or mesh (*Figure 15*). Others use buckets or paddles on the belt to aid lifting of the oil from the water surface. Some belt designs may incorporate a combination of such features. Conversely, downward rotating belts push the oil down into the water and then capture it when it re-surfaces within a quiescent collection area behind the belt.

The localised water currents induced by rotating discs, belts and drums may be sufficient to allow oils of light to moderate viscosity to flow naturally towards a skimmer once recovery commences. Designs utilising toothed discs or belts to 'grab' the oil may enhance flow of more viscous oils and draw the oil into the skimmer. Some weir skimmer designs incorporate interchangeable adaptors to prolong their use as the oil weathers and its viscosity increases (*Figure 16*). One design intended for recovery of very heavy oils comprises a rotating drum or cylindrical mesh which allows the oil to be retained within the mesh while water drains through

▲ *Figure 17: Mechanical drum skimmer deployed in a port area. Teeth on the rotating drum draw the oil towards the device where it is recovered into the drum and pumped to storage. The drum is constructed from a mesh to minimise recovery of water.*

(*Figure 17*). However, the very high viscosity of some oils or emulsions can eventually prevent flow towards the device and continued recovery will be possible only if some form of propulsion is provided to allow the skimmer to move to the oil or if the oil is pushed towards the skimmer.

Several skimmer systems have been designed for operation in fast-flowing waters or at higher towing speeds. The approach typically followed is to increase the area behind the collecting aperture, causing the velocity of the water and oil to slow upon entry to the skimmer and the oil to surface for collection. In order to be effective, such systems must be able to cope with large volumes of fast-flowing water and overcome the turbulence created.

Limitations of oil recovery

As with many oil spill response techniques, successful mechanical recovery is limited by factors such as adverse weather conditions, oil viscosity and the effects of currents and waves. The spreading and fragmentation of a slick limit the amount of oil available to be recovered within a given timeframe, termed the encounter rate. Similarly, the ability of a system to recover oil selectively may be a significant concern if storage capacity is limited. A further limiting factor may be the pump capacity, affecting the distance over which the oil can to be moved to storage. An indication of the potential performance of a recovery system is given by test performance criteria such as throughput efficiency, recovery efficiency and oil recovery rate but each of these is fundamentally constrained by the encounter rate.

Encounter rate

The encounter rate has two components: the area of the water surface 'swept' by the skimming system, which is itself a combination of the swath, i.e. the width over which the oil is collected and the speed of advance of the recovery system; and the degree to which slicks have spread and fragmented. At sea, large slicks of freshly spilt oil may be recovered in suitable conditions without containment, provided the oil remains sufficiently thick, coherent and homogeneous (*Figure 18*). In such situations, the capability of a skimmer may be limited only by its recovery capacity and by suitable and sufficient storage. As a consequence, the prompt mobilisation of resources is an important factor in ensuring skimmers are able to work most effectively in freshly spilt oil.

The primary reason the recovery rates published by manufacturers of skimmers are often unobtainable is the inherent tendency for oil to spread, fragment and weather once spilt (*Figures 19 and 20*). Experience from numerous spills has consistently shown that oil cannot be expected to remain sufficiently concentrated to sustain recovery rates achieved under test conditions. Test results may therefore be misleading and should be used for comparative purposes only.

Once the oil has spread, the effectiveness of a recovery system becomes more dependent on the rate at which oil is encountered. The speed of the recovery vessel, its effective swath, as well as the thickness and extent of scattering of the oil, all determine this rate. These latter factors are determined by the spreading rate, the time elapsed, weather conditions, the oil type and the degree of emulsification, over which little control is possible. However, the swath and operating speed can be varied dependent on certain limitations. For example, the encounter rate is often enhanced with the aid of a boom, allowing a wider swath and concentrating and retaining the floating oil for subsequent recovery. Deployment strategies for booms will therefore largely determine the operating practices for many skimmers. In particular, where a recovery system is static in relation to water movement, the performance of most skimmers is impaired due to the tendency for floating oil to escape confinement by booms in currents exceeding 0.35-0.5 ms-1 (0.7–1 knot). This limitation is partly overcome in certain types of self-propelled skimmers where a belt or sorbent mop array is rotated, usually between catamaran hulls, so that its velocity relative to the floating oil is effectively reduced or is zero when the vessel is underway. This may have the added benefit of minimising turbulence in the oil and thereby reducing the potential for emulsification.

To some extent, the need for a large swath is offset by the tendency of the oil to form windrows at sea, whereby the oil becomes concentrated into narrow bands aligned with the wind direction. Any such oil may be collected using a recovery device with a relatively narrow swath and, ideally, direction from a spotter aircraft. The increased oil concentration and thickness within the windrows and the fact that the water between the windrows is relatively free of oil, means an encounter rate can be achieved that is comparable to a device with a larger swath.

In confined areas, such as ports, marinas, inland waterways or close to shore, the encounter rate may be more affected by the presence of obstacles, such as vessel hulls, pilings and other port infrastructure, rocks or debris and by the oil entering shallow water or stranding onshore. Oil trapped in sufficient thicknesses against natural barriers, such as

Figure 18: A recovery vessel in a large and homogeneous slick of thick oil, allowing highly effective use of resources.

Figure 19: As the oil spreads and starts to fragment, the encounter rate decreases, necessitating greater effort to recover.

Figure 20: After some weeks at sea, the oil has fragmented and weathered into small plates, a metre or less in diameter (ringed), and tarballs over a large area, causing the overall efficiency to drop significantly. At this point in the response, recovery vessels should have been demobilised as continued operations may not be considered effective.

seawalls and other features of the shoreline, may be readily recovered but if the oil moves around, the ability of skimmers to follow the oil may be restricted.

As the volume of oil remaining on the sea surface decreases, either as a result of evaporation, dispersion or other weathering processes, or because the majority has been collected, the encounter rate will similarly decrease and a point will arise when a decision to demobilise resources should be taken.

Performance criteria

A number of performance criteria can be established by testing skimmer systems within the confines of experimental tanks. An important determinant of a system's overall performance is the recovery efficiency, i.e. measuring the selectivity with which oil is recovered in preference to water. This is expressed as the ratio of the quantity of oil recovered to the total quantity of oil and water collected.

Throughput efficiency compares the quantity of oil collected with that encountered and hence highlights the losses that occur from the containment barrier and the recovery device itself. The throughput efficiency tends to decrease with increasing operating speeds and worsening sea states, notably increasing wave height and, more importantly, decreasing wavelength and choppy seas. In other words, at higher speeds, a trade-off exists between a reduced throughput efficiency and a greater encounter rate.

Waves lead to the loss of oil from a boom, either as a result of splash-over or due to poor wave-following characteristics so that bridging occurs between crests. Similarly, the failure of a skimming device, particularly weir skimmers, to remain at the optimum oil/water interface often results in the intake of large quantities of water. In addition, turbulence caused by the skimmer movement relative to any waves can lead to loss of oil under the skimmer. Ideally, a recovery device should be small with a low mass so as to faithfully follow wave movements. Devices that are rigidly attached or built into a vessel and so unable to move independently are less effective in higher sea states because they can move out of phase with the water surface. On the other hand, even a heavy swell is unlikely to be detrimental providing the wavelength is sufficiently long.

A further parameter of interest is the oil recovery rate; the quantity of oil the skimmer recovers per unit time, for example m^3/h. The oil recovery rate is the product of the encounter rate and the throughput efficiency provided that all parts of the system (particularly pumps and storage) have the capacity to handle this flow rate. The maximum pump capacity, adjusted for typical oil viscosity and head loss, is often taken as the sole indicator of a skimmer's capacity and is also known as the 'nameplate rate'. While this is clearly important, other elements, such as how much oil the system has failed to collect and the amount of water collected with the oil, should also be considered. The overall performance of a system should be judged from a combination of pump capacity, oil recovery rate and recovery efficiency, which together define the rate at which oil can be recovered, and the amount of associated free water.

Oil viscosity

The viscosity of the oil is a primary limitation on the efficiency of most recovery devices. Oils with high pour points, including some heavy crudes and fuel oils, generally do not flow easily. If the ambient temperature is below the pour point, the oil will become semi-solid and, hence, will be difficult to recover, since it will not readily flow towards the skimmer.

Viscosity is also affected by the tendency of many oils to form water-in-oil emulsions, leading to an increase in the overall volume of pollutant by three to four times or more. As emulsions form, the viscosity also rises dramatically and viscosities of the order of 100,000 centistokes (cSt) and greater are common. In some situations, the injection and thorough mixing of demulsifying agents or chemical emulsion breakers can be used as a means of reducing this problem, thereby facilitating pumping while at the same time minimising the storage volume required.

The problems arising from increasing viscosity over time due to weathering of the oil necessitate continued re-evaluation of response strategies, including the use of the most applicable skimmer and pumping arrangement. For example, oleophilic skimmers may be able to operate efficiently in oil that has been freshly spilt and has not undergone significant weathering. However, with the increase in viscosity and possible inclusion of debris, recovery then becomes less effective, necessitating their replacement, possibly by weir skimmers using screw pumps with debris cutters (see front cover). However, any skimmer may ultimately become ineffective, necessitating the use of grabs (mechanical clam shell buckets) or excavators (*Figure 21*). Fishing or other vessels equipped with cranes, to handle nets and catch, can often be readily adapted to use grabs. However, while grabs and excavators are often readily available, their use is slow and, unless carefully operated, can incorporate large amounts of associated water. One of the simplest and most effective approaches to the recovery of these highly viscous and semi-solid oils is the use of manual scoops deployed from small fishing boats (*Figure 22*). Holes drilled in the scoops allow water to escape and the oil is transferred into drums or one tonne bags on board.

▲ *Figure 21: Use of an excavator to recover highly viscous fuel oil. The concentration of recovered oil was maximised by instructing the operator to hold the bucket above the water surface for a short period, to allow entrained water to run off. This reduced the subsequent disposal costs at the expense of recovery efficiency.*

▲ *Figure 22: A fisherman using a mesh scoop to recover small clumps of highly viscous fuel oil.*

Pumps, hoses and power supplies

The pumping phase often determines the overall performance of a skimmer because all pumps lose efficiency, albeit at different rates, as oil viscosity increases. In general, positive displacement pumps are more suitable for handling recovered oil. Centrifugal pumps are both limited in the viscosity of the oil they can handle and tend to promote the formation of water-in-oil emulsions. Some specialised pumps, including those designed to pump concrete or slurry and those based on an Archimedes screw principle, have a very high viscosity tolerance but the internal resistances of discharge hoses may then become a limiting factor.

Generally, the amount of water recovered with the oil should be kept to a minimum, in order to optimise storage and reduce subsequent processing costs. However, with high viscosity oils, recovery of free or entrained water may provide

▲ *Figure 23: Burst hose as a result of excessive internal pressure from pumping highly viscous oil (Image courtesy NOFO).*

an initial benefit in that the back pressure encountered from the resistance of the oil while pumping and the power required to pump over a specified distance can be reduced. This will reduce wear and tear on components (*Figure 23*). Skimmers that recover large amounts of water by virtue of their design may be advantageous in such situations, provided that sufficient storage is available or the water can be decanted subsequently. Steam heating to reduce blockages of pumps and hoses may also assist flow. Significant drops in pump inlet pressure have been demonstrated through the use of an annular water injection ring, where the injected water acts as a lubricating medium between the oil and hose wall (*Table 2*). Where available, the use of shorter and/or larger diameter discharge hoses may also serve to improve pumping efficiency.

Transfer hoses and hydraulic hoses should be fitted with flotation devices to prevent drag on the skimmer that may cause the skimmer to float at an incorrect attitude. Floats also ensure that the hoses are more readily visible to minimise fouling and the risk of entanglement with the vessel's propeller. All hoses, including hydraulic hoses, can prove troublesome to handle when oily and should be fitted with simple but effective couplings. A selection of adapters can prove useful for matching hoses of different diameters and joining different connectors.

Many skimmers are designed with a dedicated power pack for the pumping and, where necessary, for the recovery components of the system. Diesel power packs, for example, can be used directly or to drive electric, hydraulic or pneumatic systems. All but petrol engines can be built to comply with safety regulations imposed in refineries, tank farms and other restricted areas where there may be a risk of fire and explosion. In pumping high viscosity oils, power packs may need to operate at full capacity and so it is important that power supplies are chosen to match the full range of pump capabilities.

Storage

Storage of recovered oil and oily water is often a significant limiting factor of the overall operation. For many vessels, on-board storage will be limited, especially for many vessels of opportunity (*Figure 24*) and may be rapidly overwhelmed for any system where large volumes of oil are encountered. An oil/water separator can be used to concentrate recovered oil and maximise the use of limited space. Simple gravity separation in settling tanks is usually adequate. However, the ability to discharge separated water may be limited by local regulations. Vessels with large internal storage capabilities (*Figure 25*), or with suitable oil/water separation facilities, are able to spend more time at sea recovering oil but, by necessity, are larger and consequently may not be sufficiently manoeuvrable in many situations encountered, particularly close to shore.

The logistics of a recovery operation may be enhanced by providing dedicated storage barges or tankers to receive recovered oil at sea. Alternatively, purpose-built floating temporary storage, for example, inflatable barges (*Figure 26*), may be employed. However, the potential for such craft to be overwhelmed in rough sea conditions when loaded should be considered. Dracones, bladders or other enclosed storage should be used with caution due to the potential difficulties with subsequent emptying and cleaning. Ultimately, recovered oil will require discharge to shore and suitable tank or other storage units close to available jetties with appropriate offloading equipment should be identified. Where vessels are not equipped with heated storage tanks, the use of portable heating coils may facilitate subsequent flow through pipe work and hoses to shore, thereby minimising the turnaround time for vessels to return to sea and resume recovery operations (*Figure 27*).

Similarly, the local storage of oil recovered on or near the shore may be a limiting factor and transfer directly to road tankers for onward transport is often preferable. As noted, industrial or farm vacuum tankers are useful in combining many of the individual elements of the oil recovery operation. Alternatively, portable storage tanks, skips or lined pits, placed above the high water mark, can provide intermediate solutions (*Figure 28*). For the latter, local permits may be required prior to construction. The ability to decant separated water should be included in the site plan.

Equipment	Discharge pressure (psi)	Flow rate (m^3m/hr)
Pump alone	181	4.5 – 5.9
Pump with water injection	7 – 9	46.7 – 58.2

▲ *Table 2: Improvements in pumping ability through use of water injection at the pump inlet and outlet, showing a 95% reduction in the discharge pressure and a 10-fold increase in flow rate. Oil with a viscosity of 210,000 cSt was pumped along a 92 metre hose, using a variety of screw pumps. (Source: Floating Heavy Oil Recovery – Current State Analysis, US Coast Guard, Research and Development Centre/David Cooper, SAIC Canada, 27 July 2006.)*

▲ *Figure 24: A workboat with limited recovered oil storage on deck.*

Figure 25: Highly viscous recovered oil in a storage tank on board a recovery vessel (Image courtesy NOFO).

Figure 26: A drum skimmer recovering oil to an inflatable storage barge.

Figure 27: Portable heating coil used to assist with discharge of viscous oil from recovery vessels to shore.

Figure 28: Emulsified fuel oil recovered from the shoreline by skimmers and pumps into temporary storage tanks placed at the top of a cliff.

Deployment of skimmers

Recovery at sea

When planning a response, consideration should be given to the entire suite of logistic requirements necessary to support a recovery operation at sea. Surveillance aircraft are required to locate areas of thickest oil and direct recovery vessels for optimum effectiveness. Suitable vessels from which to deploy booms and skimmers need to be made available as rapidly as possible, before the oil has spread and slicks become too fragmented for recovery to be feasible. Coordination from the air calls for aircraft equipped with air-to-sea communications for direct contact with recovery vessels, allowing a rapid response to shifting conditions. Sufficient storage capacity at sea is necessary to match the anticipated rate of recovery and, as discussed above, arrangements need to be in place ashore to receive recovered oil. The difficulties of ensuring that all these components are in place quickly enough means that only very rarely is more than ten percent of spilt oil recovered at sea and much lower percentages are the norm, despite the involvement of significant numbers of response vessels in many incidents.

To concentrate floating oil at sea, booms can be towed in U, V or J configurations typically using two vessels. The recovery device is either deployed from one vessel (*Figure 29*), or towed as part of the boom array (*Figure 30*). The skimmer should be kept in the maximum thickness of oil but contact between the skimmer and the boom should be avoided to protect the boom from abrasion and other mechanical damage. Wave reflection against large skimmers can interfere with the oil flow to the recovery element. Skilful handling of the equipment is called for, along with continuous adjustments as conditions change. The expertise necessary to tow booms at the slow speeds required is gained through spill experience and regular exercises. In practice, maintaining the required configuration of multi-vessel recovery systems

Figure 29: Boom towed in a U configuration with a skimmer deployed from the main recovery vessel.

Figure 30: A belt skimming vessel deployed with boom and towing vessels in a V configuration.

Figure 31: A single ship recovery system comprising inflatable boom attached to an outrigger and a high capacity free-floating weir skimmer mounted on a Coastguard vessel. The high freeboard allows deployment on the leeside in calmer waters (Image courtesy USCG).

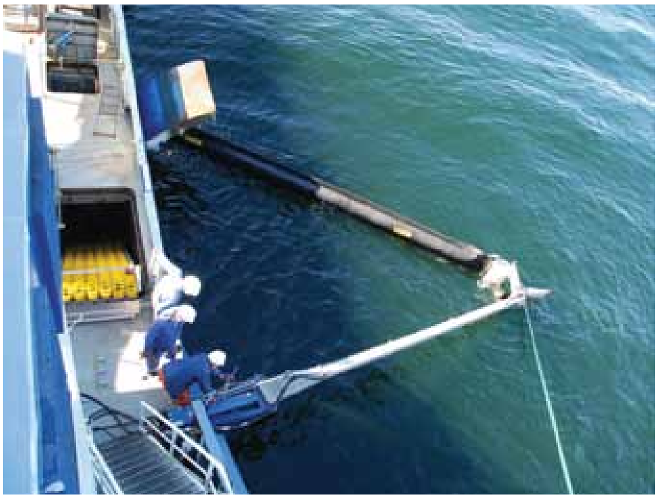


Figure 32: An in-built single ship recovery system. Boom stored in a compartment at the side of the vessel is deployed through an opening by an on-board crane. The opening also allows entrained oil to be recovered by the in-board skimmer, here comprising six sets of brushes in a conveyor arrangement (Image courtesy Lamor).

can be problematic, primarily due to difficulties in coordination between the vessels involved. An alternative solution is to combine oil concentration, recovery and storage functions in a single-ship system using a flexible or rigid sweeping arrangement.

Flexible systems employ a boom attached to an outrigger (*Figure 31*). However, if the swath is too wide, the set-up can become prone to damage in rough weather or large swell and manoeuvrability can be restricted, severely affecting vessel handling. In such systems, the skimmer is positioned at the apex of the boom where oil is highly concentrated and may be free floating or built into the side of a vessel with a suitable opening to allow the ingress of oil (*Figure 32*). Rigid systems comprise a solid floating barrier or sweeping arm deployed from a vessel by crane or hydraulic arms (*Figure 33*). The skimmer, usually a weir or brush depending on the oil to be recovered, is built into the arm, close to the vessel to facilitate recovery. The comparative ease of deployment and straightforward design are strong factors contributing to the success of rigid sweeping systems.

Flexible or rigid systems can be used from specially designed vessels or from vessels of opportunity with suitable fittings. Ideally, the vessel used as a working platform should have suitable handling gear and sufficient manoeuvrability to quickly assume and maintain a selected position against winds and currents. The large open decks of Anchor Handling Tug Supply (AHTS) vessels or Platform Supply Vessels (PSV) are convenient for the storage, handling, deployment, maintenance and cleaning of equipment. However, experience has shown that the exposed decks of such vessels are hazardous for crew in heavy seas. Other vessel types with low freeboard can experience similar problems with large amounts of water and oil washing on-board in heavy swell conditions (*Figure 33*).

Certain types of vessels have been shown to be particularly effective for the recovery of large volumes of floating oil. In particular, the large storage capacities of dredgers, coastal

Figure 33: Rigid sweeping arm attached via hydraulic crane to the recovery vessel. The low freeboard and large swell encountered made conditions on deck hazardous for the vessel crew (Image courtesy WSA Cuxhaven).

Figure 34: Self-propelled weir skimmer recovering oil at a sheltered rocky inlet. The shallow draft of the vessel allows work close to shore. Operators assist by moving oil towards the mouth of the weir.

Figure 35: Self-propelled vessel, normally used to recover debris in a port. Here, the low temperature and relatively high pour point of the oil caused the oil to become semi-solid, necessitating recovery by scoops and grabs into a floating skip.

tankers and bunker barges allow for longer periods at sea before discharge is required. The relatively high freeboard of these and other types of vessels can assist in allowing recovery on the lee side (*Figure 31*), although deploying equipment from a height can introduce problems of windage. Handling of recovered oil will be assisted by the high-capacity pumps with which such vessels are typically equipped and the fact that storage tanks are often fitted with heating coils. For dredgers, the use of dredge pipes or buckets directly in the oil may be feasible in limited circumstances and the non-selective nature and large pipe diameters of these systems reduce the potential for debris and highly emulsified oil to cause blockages.

Recovery nearshore and onshore

Self-propelled skimmers can be used to good effect in the calmer waters of ports, harbours and sheltered areas (*Figures 34 and 35*), where they may also serve some secondary function, for example as debris collectors. These vessels are often an integral part of response arrangements for oil terminals and refineries where the pollution risk and oil type may be appreciated and understood and planning a response may be relatively straightforward. Purpose-built, self-propelled skimmers are comparatively expensive but are effective in confined areas, particularly where access from the shore is impractical.

For portable skimmers, the use of shallow-draught vessels may provide optimal work platforms close to shore (*Figure 6*). In such cases portable storage tanks or Intermediate Bulk Containers (IBCs) may be placed on-board to receive the oil. However, care should be taken to ensure that the volumes of oil stored, together with the presence of power packs and other equipment, do not affect vessel stability.

In common with other floating materials, oil accumulates in certain places along the shore under the influence of wind and water movement. Such natural collection points can assist recovery operations (*Figure 10*), provided the skimmers are capable of dealing with the debris that is usually present, often in large amounts, in these areas. Oleophilic rope-mop skimmers, which are less constrained by debris than other types of skimmer, may be most effective (*Figure 6*). Recovery can be enhanced with the aid of booms to further concentrate the oil and to reduce the possibility of remobilisation on changing wind or currents. Rope-mop skimmers can also be deployed effectively inside a boom to collect small quantities of oil along its length.

Where possible, it is usually easier to operate skimmers from the shore, particularly if road access, hard standing or a flat working area is available close to the point where the oil is to be recovered. Skimmers can be operated from cranes on dock walls and jetties (*Figure 7*) or, if the oil is sufficiently thick, some types of pump can even be placed directly into the oil.

Once the working site has been identified, a simple site plan can streamline the handling of recovered oil and reduce working hazards. Careful thought must be given to providing operators with the necessary logistical support, including fuel, provisions, shelter and communication with the incident command centre.

Where oil has stranded on mud or sand shores, conditions may allow the oil to be concentrated in trenches for recovery, most commonly by vacuum devices (*Figure 8*). Oil pooled between rocks or in crevices may be similarly recovered. On hard-packed sand beaches, recovery may be accelerated by tractor-mounted oleophilic drums or other devices to collect tarballs (*Figure 36*). Other specialised skimmers may be effective in specific situations onshore. However, in the majority of instances, other techniques, including manual recovery, will be more appropriate.

Recovery of oil in rivers and lakes will be subject to similar limitations, particularly of access and currents. However, the recovery of oil in ice presents a number of specific problems, not least that oil may be trapped within the ice itself. Devices to crush the ice allowing recovery are the subject of on-going research. A fundamental problem with this approach, however, is that typically the concentration of oil in the recovered oily ice is very low and, in such instances, better recovery rates may be achieved following a period of thaw. The use of rope-mop skimmers may allow free floating oil to be recovered between drift ice, although the machinery runs the risk of seizing-up in the cold.

Management of recovery operations

Experience from past spills suggests that the most successful recovery operations have generally involved a well-prepared organisation with all logistics in place, well trained crews and the ability to mobilise rapidly. In all cases, the effectiveness of the overall response organisation is as important as the performance of the equipment. The successful deployment of a system requires that all the components of containment, recovery and storage are monitored continuously and that the system remains sufficiently manoeuvrable to follow changes in the distribution of the oil.

All recovery operations require supervision to ensure that oil is reaching the skimmer and debris is not accumulating or entering the device to reduce efficiency or cause damage. Many skimmers are fitted with debris screens which can frequently become blocked by oil or debris. To maintain a high performance, the skimming speed should be adjusted to suit conditions and to match the rate at which oil is arriving at the collection site. If only small amounts of oil are present, skimming should be carried out at intervals to avoid excessive collection of water and, where possible, the oil concentrated using booms.

Generally, skimmers and related equipment such as power packs are robust but, inevitably, breakdowns occur through damage, clogging with debris, incorrect use or wear and tear. Repair will usually require specialised knowledge, access to replacement parts and appropriate tools. The use of suitably trained operational personnel, with an understanding of equipment limitations and the ability to strip down machines and to rebuild them as required will reduce delays. If equipment is subject to a routine maintenance programme, it is more likely to be immediately serviceable when drawn from a stockpile and the risk of breakdowns in the field reduced. Such a programme might comprise a fixed schedule to include replacement of wearing surfaces after a given period in service, topping up or replacing lubricants and starting-up equipment to check for faults.

The application of dispersants in tandem with skimming operations is to be strongly discouraged since the underlying principles of the two methods are mutually exclusive and oil dispersed into the water column cannot be recovered using surface skimmers. Furthermore, dispersants change the surface properties of the oil and, when applied in proximity to oleophilic skimmers in particular, can render such devices ineffective. Similarly, broadcasting sorbent materials, particularly in a loose form or as pads, onto the sea surface in conjunction with skimming operations is likely to lead to blockages of recovery systems.

Recovery operations at night may be feasible in specific locations such as ports, where oil has been previously identified and contained and where adequate lighting is available. However, attempts to locate oil and recover oil at sea at night are unlikely to be effective and may be unsafe for personnel involved.

A record of daily activity, detailing the use of recovery resources, the amounts of oil recovered and any damage or repairs made, will allow progress to be monitored within the command centre and will assist with the formulation of subsequent claims for compensation. For larger recovery vessels, this information may be routinely incorporated into ships' logs that are usually required by maritime authorities.

Demobilisation of skimmers and associated resources should be undertaken as the effectiveness of the operation

▲ *Figure 36: Tractor-mounted oleophilic drum skimmer, used to collect fresh tarballs on a hard-packed sand beach (Image courtesy Le Floch Dépollution).*

diminishes, i.e. as the encounter or oil recovery rates reduce and become negligible. After use, skimmers and ancillary equipment should be cleaned and over-hauled to identify and rectify any wear and damage (*Figure 37*). Steam lances or solvents can be used to remove oil, but cleaning chemicals should not be used on oleophilic discs or sorbent mops as the oleophilic properties of these skimming devices may be adversely affected. When equipment is returned to storage it should be protected from damage and damp, salty atmospheres causing corrosion. Sorbent mops, rubber belts and plastic materials incorporated in skimmers will perish if exposed to direct sunlight for long periods. Storage of equipment should allow ready access to encourage regular inspections, maintenance and testing, particularly as its use is likely to be infrequent.

Figure 37: A weir skimmer brought ashore after recovery of heavy oil. Following demobilisation, equipment should be cleaned and overhauled in readiness for future use.

Key points

- The merits of recovery options at sea and nearshore should be assessed against prevailing conditions such as sea state, wind, currents and the location of sensitive areas.
- The type of oil to be recovered, its viscosity at ambient temperatures and any change with time will dictate the type of skimmer that will be most effective.
- The criteria of capacity, reliability, robustness, field performance, weight, handling, versatility, power source, maintenance and cost should be considered when selecting the most appropriate skimmer.
- Vacuum trucks and other suction systems are often readily available for recovery of thick layers of oil on or near the shore.
- Effective coordination of oil recovery operations at sea is enhanced by use of aircraft to monitor the oil and the progress of the clean-up and to direct recovery vessels to the thickest patches of oil for optimum effectiveness.
- Skimmer performance should be continuously monitored to ensure optimum efficiency.
- The logistics of pumping, storing and disposing of recovered oil must be addressed to ensure delays in recovery are kept to a minimum.
- Regular inspections and testing of equipment should be arranged to maintain personnel training standards and rectify any equipment faults.

TECHNICAL INFORMATION PAPERS

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this paper may be reproduced with the prior express permission of ITOPF. For further information please contact:

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606
E-mail: central@itopf.com
Web: www.itopf.com

RECOGNITION OF OIL ON SHORELINES

TECHNICAL INFORMATION PAPER

6

Introduction

The arrival of oil on the shore may be the first indication of an oil pollution incident. Depending on the quantity and type of oil involved, a clean-up response may have to be organised to remove the oil and to prevent it remobilising and affecting sensitive areas nearby. A reliable early report and estimate of the extent of the pollution can prove invaluable in determining the appropriate scale of the clean-up operation and organising adequate manpower and equipment to meet the task. Estimating the amount of stranded oil with accuracy is difficult and even identifying the type of oil can be a problem, particularly if the oil has weathered extensively.

In cases of large spills, the source of stranded oil may be obvious, but the question of identification frequently arises when a small amount of oil is involved and compensation is sought for damage or clean-up costs. The purpose of this paper is to assist the reader in recognising both the type and quantity of oil on differing shorelines.

Types of oil

It would be impractical to list all the different oils carried by sea which could pollute shorelines, in part because stranded oil can be a mixture of several types. It is therefore more useful to describe the most common types of oil in relation to their likely source.

Accidental spills from oil tankers can involve either crude oil and/or a product refined from crude oil. Crude oil is typically a black liquid when fresh (*Figure 1*). However as the oil weathers over time, the properties of the oil change. For example, as the lighter components evaporate, the viscosity increases. At the same time, many crude oils can take up water and form viscous water-in-oil emulsions which may be brown, red or orange in colour (*Figure 2*). Under hot sunny conditions, stranded emulsions can release water and can revert back to black oil.

Refined fuel oils are carried either as cargo in tankers or as fuel in bunker tanks of a wide variety of vessels. Freshly spilt fuel oil may be a black liquid, similar in appearance to fresh crude oil but with a characteristic smell (*Figure 3*). Fuel oil may also form stable emulsions that can be highly persistent (*Figures 4 and 5*).

Following an incident involving a tanker, both crude oil and fuel oil may be spilt and washed ashore either separately or as a mixture. Differentiating between the two may not be straightforward, particularly as the residue of both oils mixed with sand can assume a non-sticky consistency (*Figure 6*). Chemical analysis may assist in identifying the oil.

Other refined petroleum products shipped in bulk, for example petrol or kerosene, are relatively volatile and are unlikely to persist when spilt because of their rapid spreading and high evaporation rates. Lubricating oils used in vessel engines are relatively non-volatile and are an exception. Such oils may resemble car engine oil and have a tendency to form discrete lenses or discs when deposited on sand. Other oils can take the same form when spilt (*Figure 7*).

▲ *Figure 1: Fresh crude oil and debris on a sand beach. The oil is typically black and of low to medium viscosity.*

Lubricating oils, greases and hydraulic fluids accumulate as waste oil in ship bilges. If the correct oil/water separation and monitoring procedures have not been followed, or associated equipment has malfunctioned, discharges of oily bilge water from a vessel can give rise to pollution.

Oil also reaches the sea through urban run-off into rivers, discharges from land-based industries and effluents from municipal sewers. However, the concentration of oil in these discharges is seldom high enough to cause gross contamination of the seashore although sometimes brown bands or oily sheen may be seen in the tide marks left by waves on a sandy beach.

Some oils encountered on a shoreline may not be mineral in origin as animal fats and vegetable oils are also shipped in bulk. When spilt on water these non-mineral oils may float and behave in a way similar to petroleum oils. Several oils in this category have characteristic rancid smells distinct from petroleum and may be translucent, white or vivid yellow/red in appearance, dependent upon the extent of processing. The emulsions may also be yellow/red or grey/white in

▲ Figure 2: Emulsified crude oil. The inclusion of water within the oil has caused a typical change in colour to deep orange. (Image courtesy NOAA).

▲ Figure 3: Fresh fuel oil, in this instance relatively fluid and black in colour.

▲ Figure 4: Emulsified heavy fuel oil, highly viscous and brown in colour.

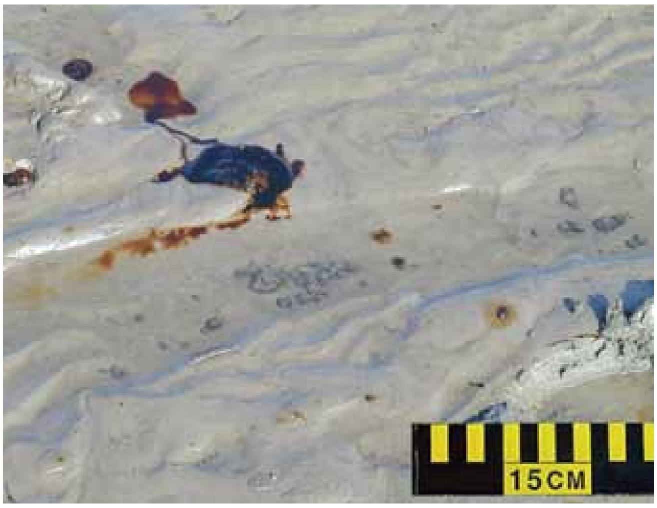
▲ Figure 5: Close-up image of emulsified heavy fuel oil, showing the highly viscous consistency. The high levels of water in the oil reduce the ability of the oil to adhere to underlying substrate.

▲ Figure 6: Weathered oil on a sand beach.

▲ Figure 7: A translucent base oil, used in the manufacture of lubricating oils, has formed lenses on the water surface. This oil was difficult to quantify due to its lack of colour.

▲ *Figure 8: Grey water-in-oil emulsion of palm oil on a rocky shoreline.*

▲ *Figure 9: Tarballs scattered on a sand beach.*



▲ *Figure 10: A fresh tarball.*

▲ *Figure 11: Sheen emanating from a pebble beach.*

colour (*Figure 8*). Examples of non-mineral oils are palm oil, rapeseed oil and olive oil.

Appearance and persistence of oil on shorelines

An understanding of the locations where floating debris collects is useful when predicting where oil may accumulate naturally. Small coves and inlets, as well as under jetties, piers and other man-made structures, are examples of locations from where trapped oil can remobilise and subsequently contaminate other areas.

The appearance, persistence and impact of stranded oil depends to a large extent on the type of coastline, which can vary from exposed rocky shores through pebble and sand beaches to sheltered muddy marshes. Oil pollution is seldom uniform in either thickness or coverage. Contamination can range from pools of liquid oil (*Figures 3 and 4*) through varying degrees of coverage to widely scattered tarballs (*Figures 9 and 10*) or sheen (*Figure 11*). Winds, waves and currents often cause oil to be deposited ashore in streaks or patches rather than as a continuous layer. On tidal shores the affected zone can be comparatively wide, particularly on flat, sheltered beaches, but elsewhere the pollution is often confined to a narrow band close to the high water mark.

Oil stranded on sand beaches may be rapidly covered with further layers of sand by subsequent tides or wind. Excavation or digging may reveal one or several layers of oil that have become buried by clean sand (*Figures 12*).

Liquid oils with a low viscosity may soak into sand, dependent upon the composition, grain size and moisture content of the substrate. For example, wet quartz sand composed of small grains will absorb less oil than coarse, dry shell sand. Penetration into larger beach substrate such as pebble, shingle or shells can reach substantial depths (*Figure 13*).

The rate of weathering processes such as evaporation, oxidation and biodegradation determines the persistence of stranded oil. However, the most active processes of oil

▲ *Figure 12: Layers of oil buried between clean sand by wave action.*

▲ *Figure 13: Heavy oiling with penetration into a shingle beach.*

▲ *Figure 14: Light oil staining of a stone jetty. This may be easily confused with algae growth.*

▲ *Figure 15: Heavy oiling of a sea wall following a storm tide.*

removal from shorelines are usually abrasion and natural dispersion as mineral- or clay-oil-flocculates, accelerated by elevated temperatures and exposure to wave action. In the longer term, the rate of weathering processes such as biodegradation and oxidation determines the persistence of stranded oil.

Tarballs, which are otherwise very resistant to weathering, may soften in strong sunlight and become more amenable to degradation. Alternatively, thin layers of oil on solid surfaces, such as rock or harbour walls, can become more difficult to remove as they may adhere strongly to these surfaces under intense sunlight (*Figures 14 and 15*). Wave action can eventually reduce even the most persistent lumps of oil to smaller fragments which are more readily degraded by chemical and biological processes. On sheltered shores less wave energy is available and, as a consequence, the oil may persist for longer periods. If oil becomes buried in soft sediment it is protected from wave action as well as from degradation due to the lack of oxygen. Significant breakdown will only resume if the buried oil is exposed again by erosion or by tilling or other actions. The factors that affect the persistence of stranded oil are described in the separate paper on the Fate of Marine Oil Spills.

A number of naturally occurring features and processes can be confused with oil, examples of which are shown in Figures 16–24. Silvery or multi-coloured sheens of biological origin covering the surface of rock pools give the appearance of oil but are often the result of biological processes, e.g. bacterial degradation (*Figure 16*). Similar effects are associated with peat outcrops in marshy areas. Sometimes reports of shore pollution prove to be unconnected with oil upon inspection; algae or lichen on rocks (*Figure 17*) and stranded seaweed (*Figure 18*) or other matter of vegetable origin (*Figure 19*) are good examples. In addition, charred wood particles, coal dust (*Figure 20*), black sand (*Figure 21*), pumice or other black rock (*Figure 22*) and wet sediment or roots (*Figure 23*), can be deceptive. On some beaches it is possible to dig down to an oxygen-free or anoxic layer, often grey or black in colour with a sulphurous smell of rotting vegetation. This is a natural feature and should not be mistaken for oil (*Figure 24*).

▲ Figure 16:Natural sheen produced by rotting seagrass.

▲ Figure 17: Lichen on a rocky shoreline.

▲ Figure 18: Stranded sea vegetation resembling light oiling from a distance.

▲ Figure 19: Black vegetable matter.

▲ Figure 20: Coal dust resembling oil on a sandy beach.

▲ Figure 21: Layers of black sand and yellow sand give the impression of contamination of the shoreline by weathered oil (compare with Figure 6).

▲ *Figure 22: Black rock resembling oil contamination.*

▲ *Figure 23: Dark, wet mangrove roots may be confused with oiled mangrove roots (inset).*

▲ *Figure 24: Anoxic sediment is a natural feature and should not be mistaken for oiling.*

Describing and quantifying stranded oil

A rough assessment of the quantity of oil present across a stretch of coastline is needed for the purposes of initiating a shoreline clean-up operation and monitoring its progress. The distribution of oil along a shoreline can vary significantly and the task of estimating the quantity of stranded oil can lead to errors unless it is approached with care and consistency. The assessment is largely a visual one and will be more difficult or impossible if the oil is hidden from view, for example by layers of sand brought on-shore by subsequent tides (*Figure 12*) or a covering of snow (*Figure 25*). Oil stranded on debris or seaweed laden shores (*Figures 26 and 27*), in mangroves (*Figure 28*) or on other types of vegetation (*Figure 2*), on rocky shores (*Figure 4*), on sea defences (*Figure 29*) or under jetties or quays will also be difficult to accurately quantify without further investigation.

Where the oil is visible the problem can be addressed in two stages:

Extent of contamination

Firstly, the overall extent of the contamination along a coastline can be estimated and marked on a chart or map. In the case of a major spill, aerial surveillance is usually the most efficient and convenient way of gaining a general impression. A helicopter is preferable as fixed wing aircraft usually travel too fast for a detailed coastal inspection at low altitude. Please refer to the separate paper on the Aerial Observation of Marine Oil Spills for more information on conducting aerial surveys.

Aerial surveillance should always be combined with spot checks on foot (*Figure 30*) because, as previously discussed, many shoreline features viewed from a distance bear a close resemblance to oil. Careful attention should be given

▲ *Figure 25: A covering of snow may obscure the presence of oil.*

▲ *Figure 26: Oil stranding on a coastline covered in debris can be difficult to quantify as the oil may be hidden from view.*

▲ *Figure 27: Oil stranding on a coastline covered in seaweed can be similarly difficult to quantify.*

▲ *Figure 28: Oil can get caught up in the complex root system of mangrove forests.*

▲ *Figure 29: Oil may become trapped between sea defences, such as these tetrapods, concealing the true amount that has arrived on shore.*

▲ *Figure 30: Walking the shoreline or 'ground-truthing' allows a more accurate quantification of the extent of contamination.*

to identifying locations where the character of the shoreline changes or where the degree of oil coverage appears to change. Examination of the oil to evaluate its consistency and smell may assist with identification.

In addition to a description of the oil itself, reports of shore pollution should include *inter alia* the location, date and time of the observations, the extent and parts of the shore affected by oil, the type of substrate, the key shoreline features and the identity of the observer.

The use of GPS and photographs are a very useful support to any written description of the location and appearance of oil on shorelines. A reference, such as a ruler or pen, allows the viewer a sense of scale (*Figures 10 and 12*). Photographs also serve as a record against which subsequent changes in the degree of pollution may be compared. When oiled sites are to be visited on more than one occasion, it is useful to take photographs from specific reference points so that they may be compared easily in the future.

Volume of oil

The second stage of quantifying stranded oil involves selecting representative samples of shoreline to calculate the amount of oil present. It is useful to split the shoreline into segments based on the shoreline type and degree of contamination. The sample area of shoreline chosen should be small enough to allow a reliable estimation of oil volume in a reasonable time, yet large enough to be representative of the whole shore section similarly affected.

The dimensions of the section of beach affected by oil should be estimated and, if the degree of contamination is consistent, the average thickness of oil should be relatively easy to measure. Thus, the volumes of oil on the beach in Figure 31 can be roughly estimated as described in the accompanying caption.

If the degree of oiling varies from the low to high tide lines as seen in Figures 32 and 33, then a representative strip of beach, for example one metre wide, running from the top of the beach to the water's edge should be surveyed. The volume of oil on the beach can then be estimated by visually determining the oil thickness in a representative number of locations within the strip and multiplying by the area of the strip to obtain a figure for the volume of oil. Multiplying by the length of the entire beach provides an estimate of the total volume of oil, as described in the captions accompanying the figures. This exercise has to be repeated on other sections where the nature of the shoreline or the degree of oil coverage may be different.

Quantifying stranded oil in this way only yields an approximate figure due to several unavoidable sources of error. On a sandy beach the affected area can be calculated relatively easily, but the possibility of oil penetrating into the beach substrate should be remembered (*Figures 12 & 13*). Oil penetration is likely to be greater as the grain size of the beach substrate increases and, therefore, the larger the grain size, the more difficult it can be to estimate the volume of oil on the shoreline.

The volume of oil that has penetrated may be very difficult to estimate (*Figure 34*), but when sand is uniformly saturated, a useful rule-of-thumb is that the pure oil content will be approximately one tenth of the depth of oily sand. For example, if oil has penetrated uniformly to a depth of 5cm, the volume of oil below the surface would be approximately $0.005m^3/m^2$ or 5 litres/m^2. Furthermore, when calculating oil volumes the degree of emulsification needs to be taken into account. Stable water-in-oil emulsions typically contain 40 – 80% water, i.e. the volume of 'pure' oil may be as little as a fifth of the observed volume of pollutant. Consequently, if the oil observed in Figure 31 was an emulsion containing 70% water, the volume of pure oil would be approximately $2.7m^3$ along the length of the beach, rather than $9m^3$. However, when organising shoreline clean-up it is the overall volume of pollutant, i.e. in this example, $9m^3$, that is significant.

If, in some situations, use of the relatively time-consuming methods outlined above prove to be impractical, alternative qualitative methods may be employed to estimate the percentage coverage. For example, the degree of pollution may be described as 'light', 'moderate', or 'heavy', or estimated by use of similar terms, against standard references (*Figure 35*), or by comparing the oiled shoreline with the photographs on page 10 in this paper. Individual or scattered occurrences of weathered oil may be described according to their size.

Often the most compelling reason for quantifying stranded oil is to facilitate clean-up. Therefore, the total amount of oily material, as opposed to the amount of oil spilt, is the most relevant figure as any debris, sand or water mixed with the oil will also require removal. However, on sandy beaches it is worth noting that removal of oil-saturated sand may involve a quantity of material of up to ten times greater than the quantity of oil on the beach. This may lead to problems with beach erosion, temporary storage and final disposal of the collected material. Please see the separate paper on the Clean-up of Oil from Shorelines for further advice on this issue.

Quantifying shoreline oiling has been formalised in some countries in the process known as SCAT (Shoreline Clean-up Assessment Team or Technique). During a SCAT survey, suitably trained personnel methodically record geo-referenced observations on prepared forms using specific and standard terminology, for example, as shown in Figure 35. Such descriptions and definitions allow a comparison over time and between different sites and observers to build a spatial image of the nature and extent of shoreline oiling.

The information gathered from quantifying and describing the oil can be used during various stages of the response, including: decision making and planning of response operations, monitoring, termination and any subsequent damage assessment. An understanding of the full nature and extent of shoreline oiling is important to allow the comparison and prioritisation of oiled sites. This will assist with planning of the resources, manpower and time required for shoreline clean-up, based on the size of the affected area and the volume of oil and/or oiled material.

Heavy oiling

Figure 31: Heavy oiling of a 300 metre long sand beach.

Volume of oil may be calculated as follows:

Average oil thickness is roughly 1cm

Width of oil band is roughly 3 metres from high to low tide lines

300m x 0.01m x 3m = 9m³ total
or
9,000 litres/(300m x 3m) = 10 litres / m²
or
Approximately 30 litres of oil per metre strip down the beach

Moderate oiling

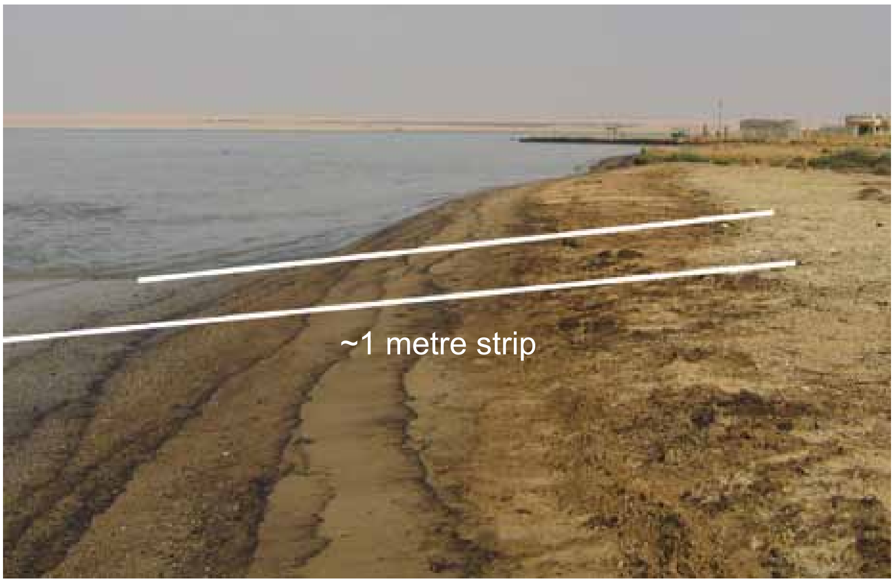
Figure 32: Moderate, broken oiling of a 500 metre long sand beach.

Volume of oil may be calculated as follows:

Average oil thickness is roughly 1mm

Width of oil band is roughly 5 metres from high to low tide lines

500m x 0.001m x 5m = 2.5m³ total
or
2,500 litres/(500m x 5m) = 1 litre per m²
or
Approximately 5 litres of oil per metre strip down the beach



Light oiling

Figure 33: Light, uneven oiling of a 200 metre long sand beach.

Volume of oil may be calculated as follows:

Average oil thickness is again roughly 1mm but in this instance covering approximately 10% of the width of the beach from high to the low tide lines

Width of oil band is roughly 5 metres

200m x 0.001m x 5m x 10% = 0.1m³ (100 litres) total
or
100 litres/(200m x 5m) = 0.1 litre / m²
or
Less than 0.5 litre of oil per metre strip down the beach

Figure 34: Locating and quantifying the extent of buried oil can be a difficult task.

Sampling Guidelines

Oil pollution causing damage to resources or necessitating shoreline clean-up may lead to claims for compensation. Evidence will be required to link the damage or costs incurred to the source of the pollution. Sometimes the link is easy to demonstrate, but on occasions chemical analysis of oil taken from the suspected source and the polluted site is necessary. As chemical analysis is relatively costly, it would be prudent to take and store a number of different samples but only to analyse key samples if a dispute arises.

Where sampling is undertaken for the purpose of environmental damage assessment, it is important to compare the results of chemical analysis for polluted areas with those of reference samples taken from similar, yet unaffected environments in the vicinity of the incident. Please refer to the separate paper on Sampling and Monitoring of Marine Oil Spills for more details.

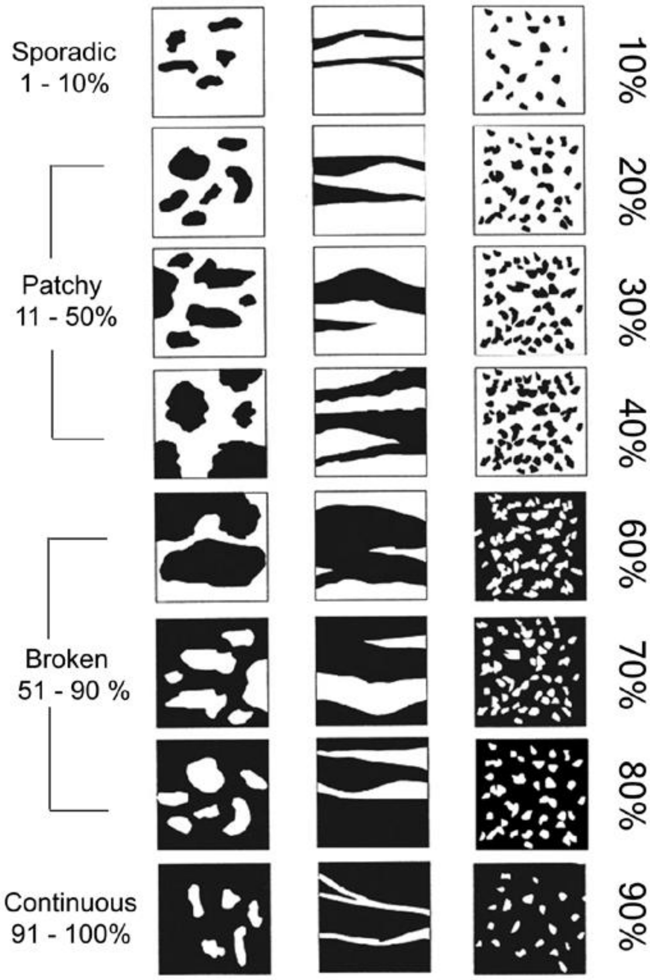
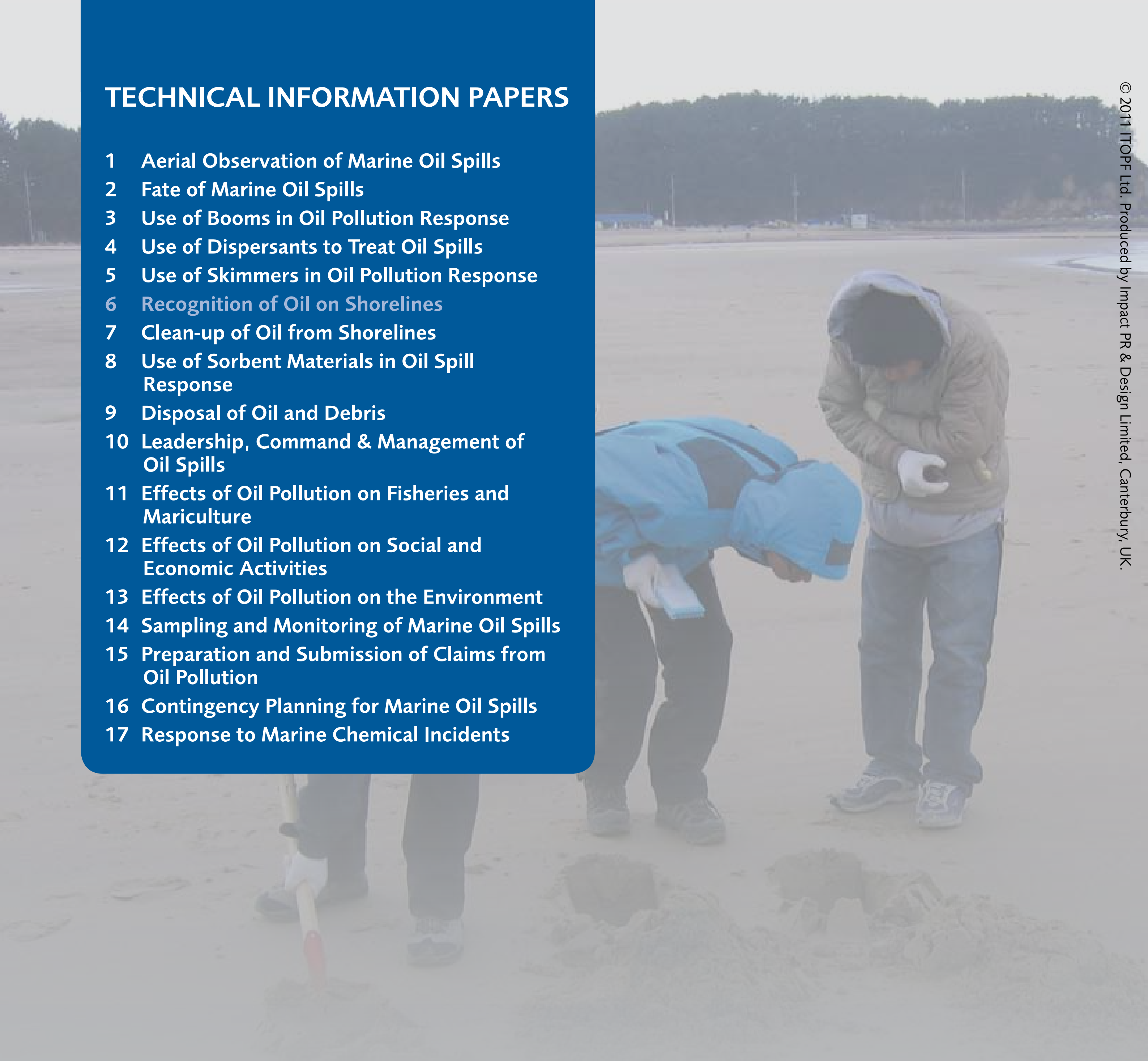


Figure 35: Indicative percentage coverings of oil to allow comparative, qualitative estimates of contamination. (Adapted from Owens, E.H. & Sergy, G.A.. 2000. The SCAT manual. A field guide to the documentation and description of oiled shorelines. 2nd edition. Environment Canada, Edmonton, Alberta, Canada).

Key points

- Considering the possible sources of oil on shorelines and noting the physical appearance and smell will often give clues as to its identity.
- Many features on a shoreline resemble oil and may be misinterpreted; a closer examination of reports of oil pollution is therefore advisable.
- Useful estimates of the quantities of stranded oil can be achieved with simple techniques, but precise calculations are impossible.
- Collation of information on the location, type and estimated quantity of oil, as well as shoreline type, is essential when planning an appropriate response.



TECHNICAL INFORMATION PAPERS

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this paper may be reproduced with the prior express permission of ITOPF. For further information please contact:

ITOPF

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com

CLEAN-UP OF OIL FROM SHORELINES

TECHNICAL INFORMATION PAPER

7

Introduction

ITOPF statistics demonstrate that the majority of ship-source oil spills occur close to the coast. Since activities to combat floating oil at sea are typically limited by time, weather or other constraints, actions taken to prevent oil reaching shorelines may only be partially successful. When oil does reach the shoreline, considerable effort may be required to clean affected areas. It is therefore essential that comprehensive and well rehearsed arrangements for shoreline clean-up are included in contingency plans.

The techniques available for shoreline clean-up are relatively straightforward and do not normally require specialised equipment. However, inappropriate techniques and inadequate organisation can aggravate the damage caused by the oil itself.

This paper describes commonly used shoreline clean-up techniques and provides advice on which are best suited to each stage of operations for a range of different shoreline types.

Overall strategy

The selection of the most appropriate clean-up techniques requires a rapid evaluation of the degree and type of contamination, together with the length, nature and accessibility of the affected coastline. In deciding priority actions, the competing demands on the marine environment need to be considered. For example, amenity use may demand quick and effective methods for the removal of the oil but these may not be compatible with environmental considerations that may call for less aggressive, slower techniques. In such situations, a balance has to be struck between these potentially conflicting interests, for the response as a whole and on a site-by-site basis.

Clean-up operations are often considered in three stages:

- **Stage 1 – Emergency phase**: Collection of oil floating close to the shoreline and pooled, bulk oil ashore;
- **Stage 2 – Project phase**: Removal of stranded oil and oiled shoreline material;
- **Stage 3 – Polishing phase**: Final clean-up of light contamination and removal of oil stains, if required.

During the initial stage, resources will be mobilised with little notice in order to respond as rapidly as possible, for example to minimise the ability of the oil to move along the shoreline and cause additional damage or to affect wildlife. Moving to the second stage may allow resources to be contracted with greater deliberation and possibly placing work out to tender. While termed the project phase and often the most protracted part of shoreline clean-up, Stage 2 should be viewed as one component of the overall response to the emergency generated by the spill of oil and should not be perceived as longer term project management.

Depending upon the situation encountered, progression through each of these stages may not be required. In some instances, the entire operation may be completed in one stage, whilst in others, Stages 1 and 2 may be combined. In many situations, once Stage 2 has been completed, any remaining oil may be best left to weather and degrade naturally.

▲ *Figure 1: Manual removal of bulk oil. The use of manpower for the selective recovery of oil from a shoreline minimises the amount of clean material removed.*

In every case, the first priority is to recover oil floating against the shore as quickly as possible, to prevent it moving to previously uncontaminated or cleaned areas (*Figure 1*). The same is true for heavy accumulations of stranded oil that may remobilise on subsequent tides. It may be possible to use booms to hold the oil against the shore while recovery is in progress. However, this strategy may not be applicable on environmentally sensitive shorelines, where it may be preferable to allow the oil to migrate to a less sensitive area or to where it is more easily accessible.

Once potentially mobile oil has been collected, it may then be necessary to compromise between waiting until all the oil remaining at sea has come ashore, to avoid cleaning the same area more than once, or to commence the second stage of operations immediately, although oil can become buried by successive tides, particularly on sand beaches. Often, a solution is to focus on removal of the thickest areas of oil in the most readily accessible areas without attempting to complete this stage of the work immediately.

Experience from many incidents has shown the most costly and time-consuming component of the overall response to a spill of oil is the treatment or disposal of collected waste. As a consequence, unless other overriding factors are present, the clean-up technique chosen should be one that results in the minimum amount of waste collected for removal. This has the added benefit of minimising the quantity of material for subsequent storage, transport and final treatment/disposal, as well as reducing the possibility of shoreline erosion.

For many shoreline types, removal of all traces of oil will be difficult or inadvisable. As a consequence, it is not always obvious when a shoreline, or a particular work site, is sufficiently clean to allow work to terminate. One important factor is the 'use' of the affected area in terms of the relative importance of environmental, social and economic concerns. Seasonal variations in the significance and sensitivity of the location, as well as the degree to which it may be exposed to natural cleaning, are further important considerations, as is the question of cost. As the amount of oil remaining on the shore decreases, so cost becomes more important, because the effort and expenditure required to achieve further cleaning rise disproportionately in relation to the amount of oil removed. An exhaustive final clean-up stage, whereby traces of oil and oil stains are removed is, therefore, usually required only for low-energy, high-amenity areas during, or just prior to, the tourist season.

The criteria for termination of the clean-up are usually discussed jointly and agreed following inspections conducted by a team comprising representatives of the various organisations involved in the response (*Figure 2*). To achieve the required consensus, it is important that the limitations of the shoreline clean-up techniques used are understood and that the objectives of the clean-up are pragmatic and agreed at an early stage, preferably even before the commencement of clean-up operations. Ideally, members of the inspection team would be involved throughout the incident so that the achievements of the cleaning operations can be appreciated in the context of the initial situation.

Clean-up techniques

A number of techniques are available for the clean-up of affected shorelines. Techniques may be applicable to more than one stage of a response. In particular, some techniques in Stage 2 may also be used in the first or third stages. As a result, techniques are grouped as either Stages 1 and 2 or 2 and 3.

Removal of bulk oil and treatment of oiled beach material (Stages 1 and 2)

Pumps, vacuum trucks and skimmers

Floating oil that has accumulated in relatively calm waters, against shorelines accessible by road vehicles, can usually be recovered using pumps, vacuum trucks or, if the water is sufficiently deep, using skimmers. The efficiency of vacuum trucks will vary, depending upon the type and amount of oil spilled and on the pump and tank capacities, but recovery rates of $20m^3$ of oil per day are typical. Efficiency can be improved by reducing the amount of water recovered with the oil through the use of a weir skimmer attached to the suction hose and through the use of boom to concentrate the oil closer to shore (*Figure 3*).

For heavy contamination of tidal sand and fine shingle beaches, the oil can be flushed or swept into trenches dug parallel to the water's edge (termed 'trenching'). Oil collected in the trench can be removed using pumps, vacuum trucks or

Figure 2: Surveys undertaken jointly between the parties involved in a response allow agreement on appropriate clean-up techniques and the point at which clean-up operations can be terminated.

Figure 3: Recovery of fluid bulk oil from the shoreline using a rope mop skimmer and vacuum pumps.

▲ *Figure 4: Agricultural vacuum tankers recovering oil that has been pushed and flushed into trenches.*

▲ *Figure 5: Civil engineering machinery employed to recover oil from a port area. In this situation, the water temperature was below the pour point of the oil, causing the oil to become semi-solid, precluding the use of skimmers.*

▲ *Figure 6: The use of machinery on oiled shorelines can lead to additional contamination. Here, tractors have driven over an area of oil, forcing the oil into the beach.*

tank trailers (*Figure 4*). The trenches usually only survive one tidal cycle and unless fully emptied and cleaned beforehand, remaining oil may become mixed into the substrate. The location of the trenches should be carefully identified to allow re-use during subsequent low tides and to allow for final cleaning of the trenches during later stages of the response.

If calm conditions are likely to prevail for some time, trenches can be dug just below the high water mark to act as a weir to collect the oil. At high tide, or as a result of wind driven rises in the water level, oil concentrated at the water's edge flows into the trench, remaining there after the water recedes and can then be pumped to storage.

Oil recovered by pumps and skimmers will require transfer into temporary storage, for example, drums or portable tanks, which can be emptied by vacuum trucks or pumped into road tankers. In order to optimise transport logistics and subject to local regulations, any free water collected with the oil should be allowed to settle and decanted prior to being transported from the site.

Mechanical collection

Highly viscous oils, heavy emulsions or semi-solid oils below their pour point may be lifted directly from the sea surface in excavator buckets or grabs, into trucks or skips (*Figure 5*). Skilled operation is required to minimise the amount of water collected. If the machinery is to work in the water, care should be exercised with tides and the topography of the seabed if not fully known. On marsh shorelines, a balance will be required between the need to collect bulk oil to prevent its remobilisation to other areas, against the additional damage to the substrate caused by heavy machinery, which may require a long period to restore naturally.

On readily accessible and open shorelines, particularly sand beaches, a variety of non-specialised civil engineering machinery, such as graders, front-end loaders and excavators, could be used to collect and remove stranded oil and contaminated material. For example, the use of road graders on hard-packed sand beaches may allow recovery when the oil has penetrated a little way into the surface. The grader's blade is adjusted to skim just below the beach surface and the oil and sand is drawn into lines parallel to the shoreline to be collected by front-end loaders. Front-end loaders or bulldozers could be used in a similar manner to skim a beach, although inevitably substantially more of the underlying clean sand will be recovered, Additional care has to be exercised because this heavy equipment can also mix the oil into otherwise clean sediment (*Figure 6*).

As a guideline, heavy machinery may recover as much as 400–800m^3 of material in a day. However, as little as 25% of this volume will be oil and oiled material with the remaining 75% being clean, unoiled material. Once collected, the clean and oiled material will become mixed, generating high volumes of oiled waste (*Figure 7*). By way of comparison, a worker typically recovers between 1 and 2m^3 of oiled sand per day with minimal clean material. The oil content of collected material is highly variable but

▲ *Figure 7: Collection directly by heavy machinery has resulted in a high proportion of clean material and very low concentrations of oil in the waste.*

▲ *Figure 8: Manual removal of oil and oiled seaweed into a telescopic bucket. This method allows oiled material to be selected in preference to clean material, minimising the amount of waste.*

▲ *Figure 9: An area of stranded fuel oil manually collected using shovels and placed into bags.*

▲ *Figure 10: Small bags of waste are consolidated into larger one tonne 'big-bags' for ease of transport to disposal.*

generally the average oil content of mechanically collected beach material is typically 1–2% oil, whereas that collected manually is typically 5–10% oil.

Usually, a combination of heavy equipment and manual collection is preferable to recover contaminated beach material. Oiled sand, seaweed or other material recovered manually can be placed into piles, bags or other containers sited at intervals along the beach. Front-end loaders are then utilised to transport the collected material to temporary storage, for example at the top of the beach. Alternatively, oiled material can be shovelled directly into the loader's bucket (*Figure 8*). To prevent oil being spread up the beach, the site should be divided into clean and dirty areas, with the heavy machinery working from the clean side.

Manual collection

The use of manpower to collect oil and heavily contaminated shoreline material is appropriate on all types of shoreline, but is particularly useful on sensitive shores and areas inaccessible to vehicles. A workforce using hand tools can be more selective than techniques solely involving machinery, as the amount of underlying clean material collected can be minimised. Although manual clean-up can be labour intensive, the overall recovery of manually cleaned shorelines tends to be more rapid, as a result of less physical disturbance to the substrate.

Highly viscous oil or emulsion floating at the water's edge can be collected using rakes or scoops into which holes have been drilled to drain excess water, and transferred to suitable containers for subsequent removal from the shoreline. Stranded oils that are heavily emulsified, viscous or mixed with sand may be transferred directly using shovels into plastic bags (*Figure 9*). Subsequent manual handling is simplified if the weight of the bags does not exceed 10–15 kg. To support this weight, bags should be a minimum of 500 gauge material (>125µm); rubble or fertiliser bags are ideal. Double bagging, i.e. using one bag inside another, may be appropriate to reduce the possibility of bags splitting. Lighter gauge bags deteriorate rapidly when left exposed to sunlight, allowing their contents to spill, causing secondary contamination. Woven polypropylene bags, such as those used for the

Figure 11: Smaller bags of oiled waste consolidated into one tonne 'big-bags' are transported onto a landing craft for removal from an isolated shoreline.

Figure 12: Crude oil is scraped along a hard-packed sand beach to be collected in trenches and then recovered by vacuum trucks for onward transport to disposal.

Figure 13: Oil collected on a rocky shoreline temporarily stored in large open-topped bins. Pumps were required to transfer this oil to the top of the cliff and then to road tankers.

transport of sugar and rice, may be useful but can leach oil in sunlight or high temperatures.

The transfer of bags from the shoreline to a staging post at the top of the beach or to temporary storage is necessary to prevent them being washed away and the contents being released. Bags or other containers can be loaded into front-end loaders or onto lorries, quad bikes, trailers, landing craft, etc. Where mechanical handling equipment is available, the smaller bags of waste can be consolidated into larger one tonne bags (known as big-bags, ton-packs or jumbo-bags) (*Figures 10 and 11*). One tonne bags can also be used directly to store oiled sorbent material and other oiled debris. Filled bags should be placed on plastic sheets to minimise secondary contamination by oil that may leach or spill during storage.

Fluid oils on hard-packed sand shores can be pushed by scrapers into trenches for collection (*Figure 12*). On other shores, dustbins, open-topped 200 litre barrels and drums or open 1m^3 Intermediate Bulk Containers (IBCs) can be filled using scoops, buckets or pumps. Again, the containers should be sited above the high-water mark. Once filled, manhandling is difficult and consequently these types of containers should only be used when mechanical handling equipment is available or if the contents can be pumped to further storage (*Figure 13*). Alternatively, a 'human chain' using buckets to transfer oil from the water's edge to temporary storage may be preferable (*Figures 14 and 15*).

Where the situation allows safe working, drums or other containers can sometimes be carried in small boats to store oil recovered close to shorelines. The concerns raised above with respect to handling full open top containers may be even more relevant in such situations.

In exceptional circumstances, fluid oil may be mixed with sorbents, or other material, so that it can be handled as a solid. The sorbent/material/oil mixture can then be collected with forks and rakes, as pumping of the resultant mixture will not be possible. This approach will significantly increase the volume of waste generated and potentially add additional costs for purchase of the sorbent or material. Synthetic sorbents are usually considerably more expensive than locally available natural materials such as straw, coconut or rice matting, bagasse (sugar cane fibre) or ground bark, which could be used as alternatives. Due to the increase in waste, alternative techniques, such as trenching, are preferable and should be explored before mixing is undertaken.

Flushing

Flushing uses high volumes of low-pressure water to wash stranded or buried oil from shorelines. The two most common applications of the technique are the removal of oil trapped within sediments and the removal of oil from sensitive shorelines.

Removal of oil trapped within sediments

Oil can become mixed with substrate (sand, shingle, pebbles, etc.) through natural seepage, burial under clean sediment deposited by tidal movement or following storms, or as a result of clean-up activities. In many instances flushing can be a viable alternative to the removal of contaminated shoreline material, thereby significantly reducing the amount of waste.

Seawater is drawn by portable water pumps (centrifugal self priming 30–60 m^3/h), through inlet filters or screens, and discharged via hoses to lances or nozzles. Plastic pipes, one metre in length, are ideal for use as lances for manual flushing. To release buried oil, the water is injected into the sediment to provide agitation, which brings the oil to the surface. For cobble and pebble beaches, additional water is sometimes introduced along the top of the beach to flood the shoreline and enhance the flow (*Figure 16*).

For flushing above the waterline, the released oil can be channelled into existing natural pools, or into dams, pits or trenches constructed for the purpose, In calm conditions, it may be possible to flush the oil into the sea, where it can be contained within short lengths of lightweight containment or sorbent booms, the latter possibly also serving to recover the oil. Alternatively and depending on the quantity of oil, access and the nature of the shoreline, the oil may be recovered by skimmers, pumps or vacuum trucks. For flushing undertaken below the waterline, the released oil may be collected directly as it surfaces.

Removal of oil from sensitive or inaccessible areas

Flooding a shoreline with water may also serve to flush fluid oils and oiled debris from sensitive shorelines, such as marsh areas and mangroves. Low pressure flushing reduces the potential for physical damage to the shoreline and associated flora and fauna in comparison to other, more intrusive, techniques. These types of shoreline are typically associated with calm waters and so the displaced oil is usually collected from the water surface close to the shore using sorbent booms or containment booms and skimmers.

Flushing may also be employed to assist in the removal of oil from inaccessible areas, for example rocky areas (*Figure 17*), within sea defences, such as tetrapods or rip-rap, and from under jetties or quays supported by piles or columns. Water may be applied by hoses from the land or alternatively from fire hoses or monitors on vessels from the sea side. Vessel propellers can be used to create a current into or under the structure to encourage the outflow of oil for collection.

Surf washing

Surf washing uses natural cleaning processes and is usually employed on exposed sand, shingle, pebble or cobble shorelines. Wave energy in the intertidal surf zone removes oil from contaminated beach material and disperses it through the water column. Surf washing is similar in principle to flushing but relies on the natural energy of the surf to provide the flushing action with much greater volumes of water than could be delivered by pumps. The resulting agitation and abrasion between the sediment particles help to release the oil from within the substrate and can break it up into droplets which are stabilised by very fine particles of sand and mud; a process known as

▲ *Figure 14: Chains of workers handling buckets of oil and filled bags allow the rapid removal of significant amounts of waste from a shoreline.*

▲ *Figure 15: A chain of workers emptying buckets of oil and oiled beach material into a skip used for temporary storage.*

▲ *Figure 16: Oil buried in a sand beach is flushed out using low pressure water supplied through lances and perforated pipes. The substrate is also agitated manually to encourage the oil to separate from the sand. The oil is then recovered by the sorbent boom surrounding the work area.*

▲ *Figure 17: Low-pressure water is used to flush oil from between rocks, to be collected by sorbent material further down the shoreline.*

▲ *Figure 18: Lightly contaminated sand is moved to the intertidal surf zone for washing on subsequent tides.*

▲ *Figure 19: Piled sand is washed by the incoming tide to remobilise trapped oil. (Image courtesy of Bernard Fichaut, Britannia-Brest University).*

▲ *Figure 20: Oiled cobbles transferred to the surf zone for washing.*

'clay-oil flocculation' or 'oil-mineral aggregation'. These flocculates or aggregates are close to neutrally buoyant and disperse widely into the sea.

Techniques described earlier in this paper should be used to remove any bulk oil present on the shoreline first. The remaining light to moderately contaminated beach material to be treated is then transferred from the upper shore into the surf zone at low tide, either manually or using heavy machinery (*Figure 18*). The incoming tide mobilises and redistributes the substrate along the shoreline, releasing the oil in the process (*Figure 19*). The process can be repeated as necessary if the initial washing is insufficient to remove the contamination to the desired level.

Some of the released oil may migrate to the upper tide line, where it can be recovered manually. Alternatively, re-mobilised oil may be collected using sorbents, particularly snares, or narrow-meshed nets, as used in the construction industry to control dust and debris around scaffolding. Nets have been found to be most effective if one end is fixed to the shoreline and the other free to move in the sea.

Surf washing is particularly useful for resolving problems with buried oil without the large scale removal of material for disposal off-site. However, several tidal cycles may be necessary before the beach profile is restored, since vigorous wave action will be required to lift larger stones back up the beach (*Figure 20*). As a consequence, the risk of longer term erosion should be considered prior to moving oiled substrate down to the surf zone.

Techniques used in the latter stages of shoreline clean-up (Stages 2 & 3)

Once bulk oil and heavily oiled shoreline material have been removed or treated, work can turn to cleaning the remaining contaminated areas by one or a combination of the following techniques.

Pressure washing

High pressure washing can be used on most hard substrates and surfaces, but is typically employed when natural cleaning is likely to be insufficient or too slow to satisfy recreational or aesthetic concerns on amenity or highly visible shorelines (*Figure 21*). This technique is often used to remove oil from quay walls in commercial areas. Both hot and cold water can be used depending on equipment availability and oil type, with higher temperatures being required to dislodge more viscous oils.

This is an aggressive technique and although high pressure/cold water (HP/CW) washing may cause less damage than hot water (HP/HW), destruction of much of the marine biota living on the hard surfaces, for example limpets or lichen, is inevitable. Some damage to the surface itself may also occur, especially to older concrete, brickwork or soft rock, particularly when extreme pressures are used.

For HP/HW washing, operating temperatures between 70–95°C are recommended. Higher temperatures are not advised since steam is not as effective as pressurised water. Recommended pressures vary between 50–150 bar with flow rates of 10–20 litres/minute. Depending on the type of oil, its degree of weathering and thickness, a single lance operator can typically clean a smooth flat surface, such as a concrete wall, at an average rate of 1-3 m^2/hour. For rough surfaces and areas with difficult access, the cleaning time can be significantly longer.

Operational logistics can be eased if salt water is used rather than fresh water. However, seawater rapidly degrades internal seals and pistons and more frequent maintenance of the machines will be required. An operation using seawater should not be contemplated unless a ready supply of spare parts is available and a qualified mechanic is on-site for the duration. In addition, a submersible pump, fitted with a filter or screen to avoid marine debris clogging the system, will be required to supply water to the machines. Where possible, a temporary water storage tank should be set up between the water pump and the pressure washer to act as a buffer (*Figure 22*). Where freshwater is readily available, operations can be expected to run with fewer breakdowns and interruptions. If machines are hired in, and unless pre-agreed, using salt water is likely to breach the conditions of hire.

Oil released by pressure washing may be collected with sorbent sheets placed at the base of the surface to be cleaned, serving also to minimise splash-back on to adjacent cleaned work surfaces. In some instances, the released oil may migrate to the water's edge, where it can be contained and recovered in booms. Flushing may assist in directing the released oil to containment areas.

Oil stains remaining on some surfaces after pressure washing usually fade with time and exposure to the weather. However, amenity areas may require further cleaning, particularly during the tourist season. This may be achieved with further pressure washing and/or the targeted use of cleaning chemicals (*Figure 23*). In tropical and sub-tropical environments, hot-water washing may be less effective than in temperate climates, since oil can become baked on to the rock when exposed to the sun.

Pressure washing in conjunction with chemicals

In some cases, the effectiveness of high pressure cleaning

▲ *Figure 21: Pressure washing a cliff face above an amenity beach. The oil was thrown high up the cliff in a storm and without cleaning would be likely to persist for some time.*

▲ *Figure 22: Pressure cleaning a rock ledge in a remote location. Seawater was pumped to the temporary storage tank to be used by the adjacent high pressure machines.*

▲ *Figure 23: A chemical shoreline cleaner applied to an oil stain followed by pressure washing.*

can be increased by pre-treating the oil stains with appropriate chemicals.

Shoreline Cleaning Agents are specifically designed to remove oil from hard surfaces with no dispersion, allowing the released oil to be collected. Manufacturers' recommended application rates should be followed and the resulting mixture flushed off, ideally with cold water at moderate pressure. Only products approved by national regulatory agencies should be used.

Vigorous brushing of **dispersant** into the oil film produces a mixture that can be flushed off, usually with cold water at moderate pressure. The appropriate application rate can be calculated by estimating the oil thickness and using a dose rate of 1:20 concentrate dispersant to oil. For example, an oil film estimated to be one millimetre thick equates to one litre of oil per square metre, necessitating the use of approximately one litre of dispersant for every 20m^2 of oiled surface.

For many oils, the resultant mixture will disperse in nearby water, precluding recovery. Sorbent materials are generally ineffective on dispersed oil. However, in some instances, notably with viscous oils, dispersant acts simply to release the oil from the surface and does not produce a dispersion. Released oil should therefore be recovered to prevent recontamination.

Many intertidal and near-shore species are sensitive to dispersed oil. Consequently, the use of dispersants on shorelines should be restricted to areas of water movement sufficient to allow rapid dilution of the dispersed oil. Legislation may prevent the use of dispersants on shorelines but, where allowed, only regulated products should be used.

In exceptional circumstances, over limited and well-defined areas, sandblasting has been used where it is necessary to remove all traces of oil. Water is used as the carrier medium instead of air to reduce the abrasiveness of the technique. Nevertheless, this can be highly damaging to the underlying surface.

Pebble/cobble washing

Pebbles and cobbles can be washed successfully in the revolving drums of concrete mixer trucks or purpose-built facilities. For mixer trucks with a drum capacity of 7.5–10 m^3, a batch throughput of some 5–6 tonnes/hour has been achieved. Oiled stones are loaded into the mixer together with a solvent, such as odourless kerosene, or a surface washing agent and premixed before adding water. A ratio of 1:50, solvent to oiled substrate, is used as a guide, but this depends on the degree of oiling. After a period of rapid mixing for some 5 minutes, the mixer drum is slowed and filled to capacity with water. After brief mixing, additional water is added while the mixer rotates very slowly, allowing the released oil to be flushed from the mixer into a series of portable tanks in which the oil is allowed to separate and is skimmed off (*Figure 24*). As much of the water as possible should be re-cycled to wash subsequent batches of material.

Thirty to sixty minutes' flushing is usually sufficient to release most oil from a given batch. Although only lightly

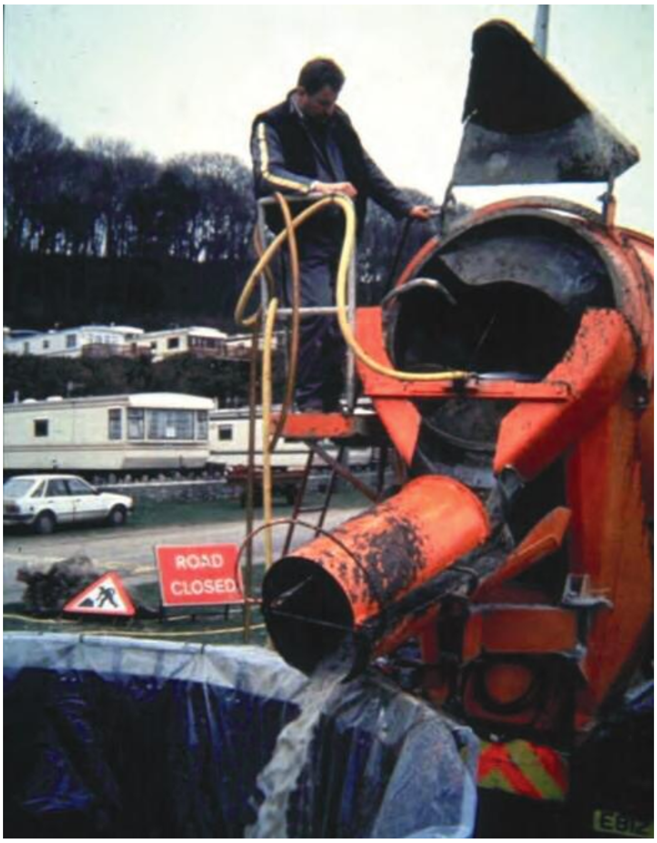


Figure 24: Effluent released from a concrete mixer truck after washing pebbles and small cobbles.

contaminated, the discharged pebbles may still have a slightly greasy feel, which may be addressed by natural cleaning in the surf zone. If sufficient mixing trucks are available, a 'cleaning station' may be established, combining all necessary equipment, such as loaders, pumps and tanks, in one location. This allows the batch process to be optimised so, for example, while one mixer is being loaded, another is washing and flushing and a third discharging cleaned stones.

Experience has found that 'fines', primarily fine sands and clays often associated with pebbles and cobbles, can accumulate in the mixing drum after several batches. These fines may not be sufficiently clean to return to the shoreline and alternative disposal routes may have to be found for this material. In addition, the eventual disposal of the contaminated water has to be considered. When contemplating cobble washing, careful analysis of the cost effectiveness and logistics required to support such an operation is needed.

Variations of cobble washing have included placing oiled pebbles and cobbles in open tanks or hot-water baths. The process is similar but with the mixing provided by an excavator bucket. For small patches of oiled cobbles, especially in inaccessible areas, the same has been achieved manually using suitable containers such as halved oil drums.

Ploughing/harrowing

After removal of bulk oil and heavy contamination from sand or shingle beaches, some light contamination usually remains, for example, where oil has been mixed into the substrate by traffic over the beach. At this stage of the operation, sediments typically have a greasy feel and the use of agricultural equipment to repeatedly plough or harrow the lightly oiled sediments at low water helps to remove this remaining oil from tidal beaches (*Figure 25*). Breaking up the oiled sediments increases the surface area of oil exposed to weathering processes, facilitates clay-oil flocculation or oil-mineral aggregation and keeps the sediments aerated. This allows naturally occurring bacteria and other micro-organisms to degrade the oil more quickly. Small amounts of oil are sometimes released during the tidal cycle and can be recovered using sorbents at high water or from the beach surface as the tide recedes. Reworking shoreline material in this manner can have an impact on sediment dwelling species. However, this technique may be particularly useful when surf washing is impractical.

Sand sieving/beach cleaning machines

Contamination remaining after the clean-up of sand beaches is usually in the form of tarballs or small nodules of oiled sand, 50mm or less in diameter. Machines designed for the routine collection of beach litter and flotsam and jetsam may be used to collect oiled debris, larger clumps of oiled sand and tarballs. Typically, the machines are driven or towed along the beach removing the surface to a preset depth and passing the collected material over a vibrating or rotating screen (*Figure 26*). Depending upon the mesh size, the collected material is passed to a storage bin on the vehicle, while the clean sand is allowed to drop back onto the beach. These machines may not be effective in collecting smaller tarballs or fresh, less viscous oils, when the agglomerates of oil and sand tend to be broken up by the screen vibrations and drop through it.

Smaller scale sieving devices, both mechanical and manual, may be used to remove oiled sand residues and tarballs from lightly contaminated sand that has been collected manually (*Figure 27*). Such an approach is labour intensive and is only likely to find application for high amenity areas, where labour is plentiful, and where the need to minimise the amount of waste collected is paramount. Alternatively, individual tarballs and small residues of oiled sand are occasionally collected by hand, sometimes using hand-held garden sieves, but even for amenity areas of the highest value, such an approach is unlikely to be cost-effective.

Hand wiping

In situations where restricted access to rocky or cobble shorelines prevents the use of pressure washing or other equipment, wiping by hand may be the only option for the active removal of oil. Light to moderate accumulations of oil can be removed by wiping (*Figure 28*). Rags are generally more cost effective than synthetic sorbents. Once used, the soiled materials should be bagged for transport to disposal. Where authorised, the use of cleaning chemicals may be suitable, although this may reduce the effectiveness of sorbent materials. Hand wiping tends to be favoured in countries where labour is plentiful but requires close supervision of the workforce to ensure consistent progress along the shoreline and to minimise secondary contamination.

▲ *Figure 25: Contaminated beach substrate is brought to the surface by ploughing. Oil is then released on the incoming tide for collection at the water's edge.*

▲ *Figure 26: A tractor-towed beach cleaning machine collecting tarballs.*

▲ *Figure 27: Improvised sieve to collect tarballs.*

▲ *Figure 28: Volunteers wiping oiled rocks with rags.*

Bioremediation

Bioremediation is the term used to describe a range of processes that can be used to accelerate the natural biodegradation of oil into simple compounds, such as carbon dioxide, water and biomass. More specifically, biostimulation is the application of nutrients and bioaugmentation or seeding is the addition of microbes specially selected to degrade oil.

Natural biodegradation can be accelerated most usefully when biostimulation is used on land, such as in landfarming. Here the physical, chemical and biological factors that affect bioremediation can be controlled to provide optimum conditions for biodegradation. Use of this process on the shoreline is rarely advocated, as the same level of control is difficult to obtain in the marine environment.

Natural cleaning

In time, most shorelines will clean naturally as the oil weathers and degrades. The key processes of natural removal are abrasion, clay–oil flocculation or mineral–oil aggregation, photo-oxidation and biodegradation. On high-energy, exposed shorelines, the majority of the oil is likely to be removed within a seasonal cycle. With the exception of stains high above the high-water mark, most traces of oil will have disappeared within two or three years. However, in circumstances where the oil has been incorporated into sediment or in fine anaerobic mud, degradation proceeds only very slowly and the oil may persist for many years, for example as an ‘asphalt pavement’.

In many spills, after completion of Stages 1 and 2 of the clean–up operation, final cleaning is left to natural processes as the most efficient and cost-effective solution, particularly if a period of seasonal storms are approaching (*Figure 29*). Where circumstances allow, natural cleaning is the preferred option for a number of sensitive shoreline types, for example, mangroves and marshes, in order to minimise damage from clean-up activities. Surveys of the shoreline are most usefully conducted after winter or tropical storms have passed to determine whether natural cleaning has achieved the desired aims of the response or whether any further cleaning is required.

Shoreline types

Clean-up techniques are described for seven shoreline types:

Ports, harbours and other facilities

Walls and other vertical structures may exhibit a band of oil throughout the tidal range that can be removed by pressure washing from boats or rafts (*Figure 30*). Oil that has migrated under quays, jetties or other structures built on piles or columns can be difficult to remove, particularly when headspace is restricted (*Figure 31*). Wash created by vessels’ propellers may assist removal of bulk oil but fine cleaning may not be possible and the oil can be left to degrade naturally. Wooden structures, particularly where rot is established, may be damaged by more aggressive clean-up techniques. Cleaning of commercially utilised areas of the shoreline is covered in greater detail in the separate paper on The Effects of Oil on Social and Economic Activities.

▲ *Figure 29: In many instances, final clean-up of a shoreline can be left to natural processes.*

▲ *Figure 30: Oiled pilings and dock quay being pressure washed from a small raft. Released oil is collected in the sorbent boom.*

▲ *Figure 31: Access underneath wharves may be difficult and dangerous for clean-up crews due to the lack of headroom and ventilation.*

▲ *Figure 32: Cleaning of rip-rap using high pressure washers.*

▲ *Figure 33: Cleaning of oiled tetrapods is problematic, as oil within the structure is difficult to reach.*

Sea defences

The various designs of sea defences present a particularly difficult problem for clean-up. The oil is likely to penetrate deep into the structure through the spaces between the rocks or concrete tetrapods where it is protected from wave action and weathering processes proceed only slowly. Open forms of rip-rap (*Figure 32*) and tetrapods (*Figure 33*) also collect considerable quantities of debris which act as an oil sorbent, making oil removal even more problematic. If the spill occurs in the winter, the oil can remain trapped within the structure until the summer months, when the oil can become more fluid and leach out. In addition, sea defences are necessarily exposed to the open sea and can be dangerous working environments.

In favourable weather conditions, floating oil may be collected at the base of sea defences from boats. Workers on the structure, and to some extent within it (as far as it is safe to do so), can remove oiled debris and clean boulders and tetrapods with pressure washers or manually with rags and sorbents. Passive cleaning, whereby sorbents are placed along the face of sea defences, allows oil washed out with the movement of tides, swell and wave action to be recovered. In certain situations, this natural action can be augmented by pumping water into the structure to flush out the oil.

	Sea defences	
	Accessible	**Inaccessible**
Stage 1	Skimmers/pumps Vacuum trucks Flushing	Manual Manual & sorbents
Stage 2	Pressure washing Passive cleaning Dismantle (rarely) Natural cleaning	Natural cleaning Hand wiping
Stage 3	Hand wiping Natural cleaning	Natural cleaning

▲ *Table 1: Techniques applicable for cleaning various types of sea defences.*

In very rare circumstances, sea defences may be dismantled to allow the removal of oiled debris and to pressure wash the individual boulders or tetrapods. This might be appropriate if oil is leaching out to threaten contamination of tourist beaches or mariculture facilities but, even then, a balance would normally have to be struck between the threat of contamination and the costs of dismantling and re-assembling the sea defences. The balance is only likely to fall in favour of dismantling if this type of work is routinely conducted, for example, for the maintenance of sea defences, and if the necessary equipment and infrastructure is already in place.

Rocks and boulders

Hard surfaces such as rocks and boulders often become coated with oil through the tidal range, with oil and oiled debris accumulating in rock pools and crevices (*Figure 34*). On exposed coasts, the oil does not usually remain static but is driven along the coast, eventually stranding in sheltered locations. Access to rocky shores is sometimes difficult and particular attention needs to be given to the safety of workers on slippery surfaces, as well as to the hazards of waves and tides. Where access by other means, for example from the sea, is not possible, temporary walkways could be constructed to improve working conditions (*Figure 35*).

In areas of high concentration of wildlife, where significant amounts of oil have stranded, loose sorbent material can be spread over oiled rocks and sometimes brushed into the oil, to act as a mask and reduce contamination of fur or feathers. In some countries, the use of powdered bark is favoured, while in others granular mineral sorbents have been used. The method has been used, for example, to protect seals and penguins at known haul-out sites. The sorbent/oil mixture is not usually collected but remains until removed by the sea, where it becomes widely distributed allowing degradation to take place. However, this technique should be used with caution, as secondary contamination may result from drifting mats of the sorbent/oil mixture and because of the potential cost of the sorbent.

	Rocks and boulders	
	Accessible	**Inaccessible**
Stage 1	Skimmers/pumps Vacuum trucks Flushing	Manual Manual & sorbents
Stage 2	Pressure washing Sorbent materials Natural cleaning	Natural cleaning Hand wiping
Stage 3	Natural cleaning Pressure washing Sand blasting (rarely)	Natural cleaning

Table 2: Techniques applicable for cleaning rocks and boulders.

Cobbles, pebbles and shingle

This type of shoreline is one of the most difficult to clean satisfactorily because the oil can penetrate into the spaces between the stones and deep into the beach. The poor load bearing characteristics of such shorelines inhibit the movement of both vehicles and personnel, so that bulk removal of heavily oiled stones can be problematic. Added to this, the routes available for the disposal of heavily oiled cobbles are more limited than for oiled sand and shingle. However, the removal of heavily oiled shingle on sheltered shorelines may be necessary to prevent the formation of persistent asphalt pavements (*Figure 36*). Where possible, washing oiled stones on site minimises the amount of waste necessitating transport to disposal. Flushing and surf washing techniques are also particularly useful in these environments.

	Cobbles, pebbles and shingle	
	Accessible	**Inaccessible**
Stage 1	Skimmers/pumps Vacuum trucks Flushing	Manual Manual & sorbents
Stage 2	Flushing Surf/cobble washing Mechanical Natural cleaning	Natural cleaning Hand wiping
Stage 3	Natural cleaning Surf/cobble washing Sand blasting (rarely)	Natural cleaning

Table 3: Techniques applicable for cleaning intermediate substrates.

Figure 34: Oil and oiled debris will collect in pools and crevices on rocky shorelines, requiring significant manual clean-up.

▲ *Figure 35: To minimise hazards to workers on rocky shorelines, temporary walkways can be constructed.*

▲ *Figure 36: Collection of oiled shingle into bags.*

Sand beaches

Sand beaches are often regarded as valuable amenity resources, with priority given to cleaning them (*Figure 37*). Recreational beaches usually have good access and, because the depth of oil penetration into the beach for many oils is limited, are generally considered the easiest shoreline type to clean (*Figure 38*). However, oil can become buried in the beach by successive tides and low viscosity oils will penetrate into coarse grained sands. Flushing, surf washing or harrowing techniques may be appropriate to address buried oil.

Temporary roadways may be constructed to allow heavy equipment onto the beach, for example to avoid damage to fragile dune habitats. The wheels or tracks of vehicles working on loose or coarse beaches risk sinking into the sand (*Figure 39*). This may cause stranded oil to be worked further into the beach substrate. Lorries and other vehicles driven onto the beach may become immobilised once loaded.

Concerns are often expressed that excessive removal of sand may result in beach erosion. However, for most exposed beaches, the seasonal cycles of erosion and accretion are so large that the amount of material removed during clean-up operations is usually insignificant in comparison and will normally be replaced naturally. Nevertheless, in order to return a beach to its original use in the shortest possible time, proposals are sometimes made to import clean sand from elsewhere. If this approach is followed, it is essential that, as far as possible, this clean sand should have the same density and grain size as the original material so that it behaves in a similar way. If, for example, a finer grained sand were to be used as replacement there is a risk that it might be washed away.

When sufficient notice is available before the spill reaches the beach, the possibility may exist to move sand above the high water mark. This material can then be replaced after the beach has been cleaned. Flotsam and jetsam may also be removed before any oil arrives so that the amount of oiled debris for disposal is greatly reduced.

▲ *Figure 37: Clean-up of sand beaches may be a priority in the tourist season.*

▲ *Figure 38: Manual collection of emulsified fuel oil from a coarse sand beach.*

	Sand beaches	
	Accessible	**Inaccessible**
Stage 1	Skimmers/pumps Vacuum trucks Manual/mechanical Trenching Flushing	Manual Manual & sorbents
Stage 2	Flushing Surf washing Manual/mechanical	Natural cleaning Manual
Stage 3	Natural cleaning Surf washing Ploughing & harrowing Beach cleaning machines Sand sieving	Natural cleaning

Table 4: Techniques applicable for cleaning sand beaches.

Muddy shores

Whenever possible, it is preferable to allow oil that arrives on this type of shoreline to weather naturally, particularly where it has been washed up on to vegetation. It has been found that, on many occasions, activities intended to clear pollution have resulted in more damage than the oil itself, due to trampling and substrate erosion (*Figures 40 and 41*).

In temperate climates, marsh vegetation often survives a single oil smothering and, in many instances, new plants grow through a covering of oil. Damage to mangroves in tropical regions is less predictable and depends on the species, the nature of the oil (light oils being more toxic than heavy fuel oils) and the porosity of the substrate. Mangroves in coarse sediments appear to be less vulnerable than those growing in fine muds.

Where removal of the oil is essential to prevent its remobilisation and spreading along the shoreline, the oil can be flushed into open water, where it may be contained for subsequent collection. This is best achieved by approaching the shoreline from the water in shallow draught boats or from the land using temporary walkways. Alternatively, if manual collection is used, this should be undertaken under close supervision, to minimise additional damage to plant roots and shoots (*Figure 42*).

If birds and other fauna are threatened, cutting and removal of oiled marsh vegetation might be considered but must be balanced against the risk of longer term damage by trampling. Cutting of mangroves is to be avoided, because recovery times are known to be protracted.

Figure 39: Loaded vehicles can sink into soft substrates. This may cause additional damage and oil to become mixed with otherwise clean sediment.

	Muddy shores	
	Accessible	**Inaccessible**
Stage 1	Skimmers/pumps Vacuum trucks Flushing	Manual Manual & sorbents
Stage 2	Flushing Manual	Natural cleaning Manual
Stage 3	Natural cleaning	Natural cleaning

Table 5: Techniques applicable for cleaning muddy shores.

Corals

Live corals are unlikely to become oiled, since they are rarely exposed at the sea surface. However, should exposed coral become oiled, it is best left undisturbed and to recover naturally. Natural cleaning of coral platforms that dry out at low water can be assisted by low pressure flushing with seawater to minimise exposure of reef communities to oil.

Where recovery of oil is necessary, for example to prevent its remobilisation, this should be undertaken with care to minimise damage to the fragile structures.

Management and organisation

The efficient management of resources engaged in shoreline clean-up is vital to the success of the operation. The responsibility for managing the response to the incident may fall to a team drawn from a number of different organisations or agencies or to a single government agency. In each case, their function is to support the workforce on the shoreline and deal with day-to-day operational issues, logistics, future planning, media relations and financing of the operation.

In deciding which clean-up techniques are to be used, the management team have to consider the interests of all those concerned with the various local uses of the marine environment. Typically, these include interests such as recreation, tourism, fisheries, industry and environmental concerns. The means by which these issues are addressed varies according to national contingency arrangements and from country to country. Often, advisers representing each of these areas of concern are incorporated within the management team. In particular, environmental advisers are a common feature of many management teams, so that cleaning operations avoid doing more harm than good through a lack of a proper understanding of environmental sensitivities.

Proper organisation of the workforce on the shoreline is equally crucial (*Figure 43*). This can be achieved by division of the affected coastline into smaller areas, often relating to natural divisions in shoreline types. A supervisor or beach master should be assigned to take responsibility for the workforce within each area. If manual techniques are to be used, the workforce can be further divided into teams, each with a leader and allocated to clean a part of the shoreline. Tasks should be achievable within a realistic time period, perhaps half a day. The satisfaction of completing the task and observing the progress they have made can assist with motivating workers in what may be harsh conditions. At the same time, the shoreline is cleaned methodically, section by section. Each team would normally comprise 5–10 workers (*Figure 44*) and each supervisor or beach master would be responsible for no more than about 100 people, i.e. approximately 10 teams, within the area. Workers should undergo basic training to ensure that the clean-up is ordered and effective and to raise awareness of any health and safety issues. Facilities to address the catering and sanitary needs of the teams should be established close to the work sites (*Figure 45*).

The potential performance of the workforce is difficult to judge until work has commenced and has been underway for some time. For this reason, deciding how many workers are required on a shoreline is best achieved by establishing a small-scale operation on a representative section of the shoreline and then replicating this approach with the appropriate level of manpower in other areas of the shoreline, once working practices have been optimised. The number of people required will be determined by the demands of the clean-up technique employed and the amount of material that can reasonably be handled within a day. However, the performance of the workforce will also be influenced by their training, motivation and supervision, as well as the shoreline type, accessibility, weather conditions and the levels of contamination. Ideally, the workforce should be drawn from a local organisation with an existing management structure, offering established lines of authority and working relationships. While military command structures meet these criteria and might appear to lend themselves well to this type of operation, they can result in the teams being too large and some modification to the structure may be necessary. Further information may be found in the separate paper on Leadership, Command and Management of Oil Spills.

Figure 40: Intrusive clean-up of an oiled marsh caused considerable additional damage over and above that of the oil itself.

Figure 41: Use of heavy machinery on sensitive areas of the shoreline may cause considerable additional damage. In this case, the need to rapidly recover free-floating oil was a priority.

Figure 42: The need to remove oil in mangroves should be carefully considered, in order to minimise additional damage to the highly sensitive structures.

▲ *Figure 43: A workforce should be clearly briefed, to ensure the objectives and the means of achieving those objectives are clearly understood.*

▲ *Figure 44: The optimum shoreline clean-up team comprises 10 workers, allowing effective supervision and progress with the task.*

▲ *Figure 45: Temporary buildings sited close to a work site provide catering and sanitary facilities for the workers.*

The organisation of equipment and vehicles working on the shoreline is no less important. Segregation of the work site into clean and dirty zones, limiting the number of vehicles within the dirty zone and restricting the movement of those vehicles to within that zone, helps to minimise secondary contamination. Larger capacity trucks, for example those used to transport the collected material to storage or disposal sites, should be kept off the beach, so that dirty and clean areas remain segregated. This also helps to reduce the amount of oil spread onto road surfaces. The types of vehicles selected should be appropriate to the waste transported, to ensure loads are secure and oil cannot leak out.

Road traffic in the vicinity of the work site should be controlled, so that the movement of trucks into and out of the work site is not hindered. The beach may also have to be closed in the interests of public safety, particularly where heavy vehicles are being used.

On tidal shores, the work has to be arranged around the tides, with rest periods and meal breaks preferably being taken at high water. While night time working may be appropriate within a port where adequate lighting can be provided, in other locations, such as open shorelines, it is usually found to be inefficient and potentially unsafe, even when lighting is available.

A record of the quantities of oil and oiled debris removed each day enables progress to be easily monitored, work site by work site, within the command centre. In addition to written reports, the status of each work site and the location of men and equipment can be conveniently recorded and monitored on large scale maps.

Daily records of the men, equipment and materials used at each work site are also essential for the formulation of a subsequent claim for compensation. Further information on this aspect of a response may be found in the separate paper on the Preparation and Submission of Claims from Oil Spills.

Contingency planning

Contingency plans for shoreline clean-up require a high degree of local knowledge and, consequently, the geographical scope is usually limited to a single coastal administrative authority. It is important that plans are prepared by those agencies and organisations with responsibility for cleaning oil from shorelines within the identified length of coast. Not only are staff of these organisations likely to be familiar with local arrangements, but this also helps to ensure that plans are realistic and practical. Beach masters will usually be sourced from the local area and will be familiar with the coastline. However, they will still require training in clean-up techniques and in the management and safety of the workforce. Police and other public agencies may be required to control access to affected areas or to otherwise assist with the response, should a spill occur.

A central location, or series of locations, from which to manage the clean-up should be identified. This should be suitable for accommodation of the management team and equipped with appropriate communication systems. Reliable communications between the management team and individual supervisors along the shoreline will facilitate a coordinated response. If necessary, communications systems suitable for the expected scenarios should be procured.

The temporary storage, transport and eventual disposal of recovered oiled waste should also be considered during the preparation of the contingency plan, as these issues can strongly influence the efficiency of the clean-up. Sources of manpower, equipment and materials, together with their contact details, should be specified in the plan. Contractors who can provide vacuum trucks, front-end loaders, skips or other containers for temporary storage, hot water washing systems and other equipment need to be identified and, ideally, the terms and conditions of hire agreed prior to a spill occurring.

Shoreline sensitivity maps are particularly useful in the early stages of a spill and can be prepared as part of the contingency planning process with information often entered into a Geographical Information System (GIS). These maps should show the location of environmentally sensitive resources and high priority amenity areas, noting seasonal variations in both. Other features may also be recorded, such as shoreline types, vehicle access points, beaches that can support heavy equipment and areas where dispersants should not be used on the shoreline.

Practical exercises of the contingency plan should be conducted periodically, not only to test organisational aspects but also to ensure that the equipment identified in the plan is actually available. Further information on contingency planning can be found in the separate paper on Contingency Planning for Marine Oil Spills.

Key points

- Successful shoreline clean-up depends on the timely availability of personnel, equipment and materials and upon the quality of the organisation established to manage and conduct the operation.
- The objectives and endpoints for shoreline clean-up are best defined and agreed before operations start.
- Early consideration should be given to waste storage, transportation and ultimate disposal, as these can strongly influence operations.
- The shoreline type largely determines the most appropriate clean-up technique to be used.
- Mobile oil should be recovered as soon as possible to prevent its movement elsewhere.
- While heavy equipment can clean beaches quickly, substantial quantities of otherwise clean substrate are also removed, leading to transport, disposal and potential erosion problems. Slower manual techniques are often better.
- Environmentally sensitive shorelines, such as marshes, sheltered mud flats, mangroves and corals, are often best left for natural cleansing processes to take place.
- For non-amenity areas, once Stages 1 and 2 of the response are completed, any remaining oil may be left to weather and degrade naturally.
- Both manpower and equipment should be identified in the local contingency plan and regularly mobilised in practical exercises to test their effectiveness.

TECHNICAL INFORMATION PAPERS

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2 Fate of Marine Oil Spills
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4 Use of Dispersants to Treat Oil Spills
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15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
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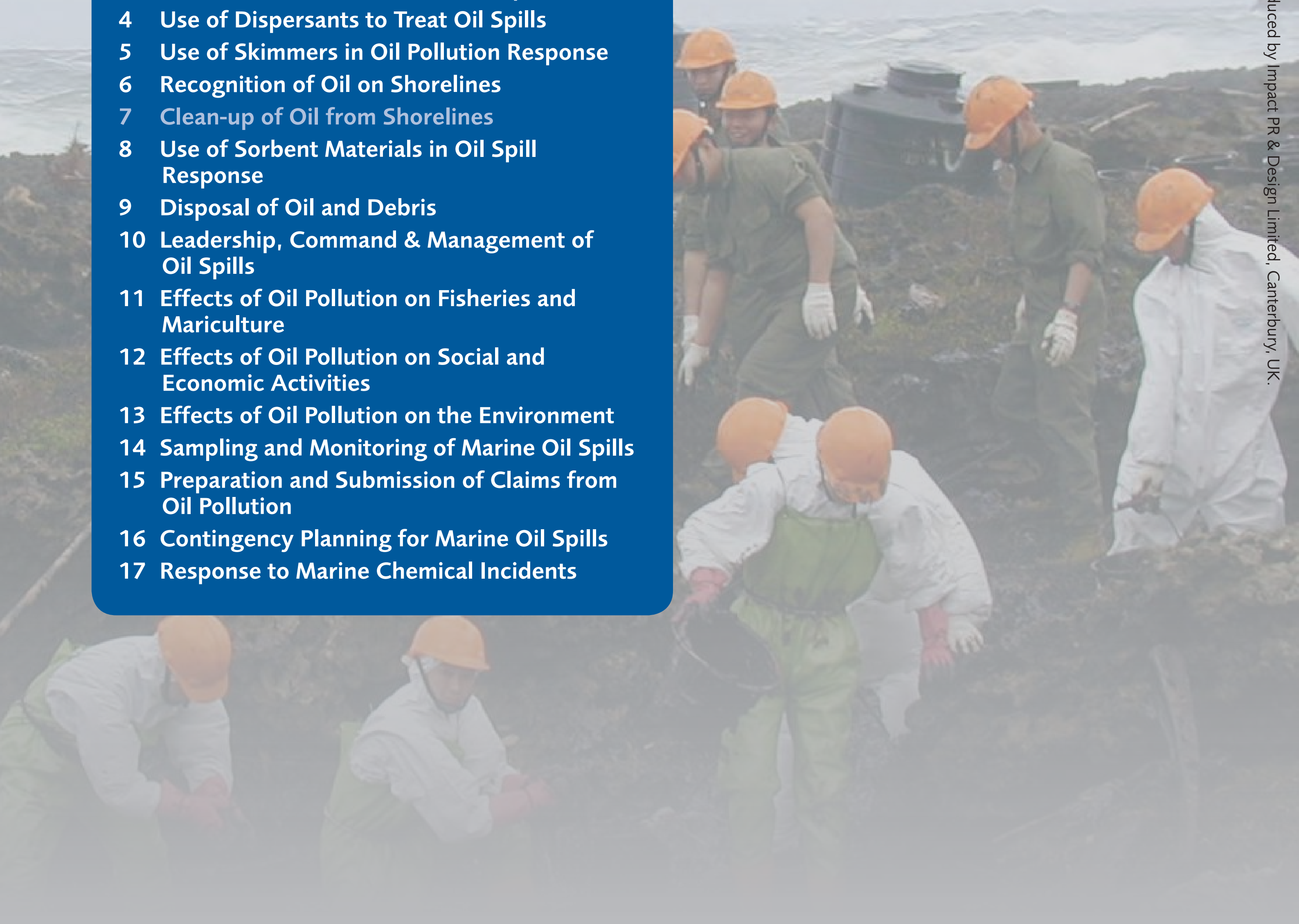


ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this paper may be reproduced with the prior express permission of ITOPF. For further information please contact:

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606
E-mail: central@itopf.com
Web: www.itopf.com

USE OF SORBENT MATERIALS IN OIL SPILL RESPONSE

TECHNICAL INFORMATION PAPER

8

Introduction

Sorbent materials can provide a useful resource in a response to a spill of oil, allowing oil to be recovered in situations that are unsuitable for other techniques. However, sorbents should be used in moderation to minimise secondary problems, particularly by creating excessive amounts of waste that can greatly add to the costs of a response.

This paper considers the types of sorbents available and how they may be used beneficially in a response. It should be read in conjunction with other ITOPF papers in this series, particularly on the use of booms, the use of skimmers, shoreline clean-up techniques and the disposal of oil and debris.

Overview

Oil sorbents comprise a wide range of organic, inorganic and synthetic products designed to recover oil in preference to water. Their composition and configuration are dependent upon the material used and their intended application in the response.

While widely used in spill response, sorbents should be employed with caution to minimise inappropriate and excessive use that can present major logistical difficulties associated with secondary contamination, retrieval, storage and disposal. These all contribute significantly to the overall costs of clean-up operations. In particular, synthetic sorbent material should be used in moderation and care taken to ensure it is used to its full capacity to minimise subsequent waste disposal problems.

In general, sorbents are used most effectively during the final stages of shoreline clean-up (*Figure 1*) and for recovering small pools of oil that cannot be easily recovered using other clean-up techniques. Sorbents are not appropriate for use in the open sea and are generally less effective with more viscous oils, such as heavy fuel oil, and with oils that have become weathered and emulsified, although some sorbents have been specifically engineered for viscous oils.

▲ *Figure 1: Polypropylene sorbent boom used to collect oil released during flushing operations.*

How sorbents work

In order for a material to act as a sorbent, it should attract oil preferentially to water, i.e. it should be both oleophilic and hydrophobic. Sorbent materials can act either by adsorption or, less commonly, by absorption. In adsorption, the oil is preferentially attracted to the surface of the material whereas absorbents incorporate the oil, or other liquid to be recovered, into the body of the material. The majority of products available for oil spill response are adsorbents; few are true absorbents.

Absorbents

Liquids diffuse into the matrix of a solid absorbent material by a process similar to capillary action, causing it to swell and combine with the material in such a way that it will not leak out, nor can it be squeezed out under pressure. Absorbents available for pollution response are made from engineered polymers with a high surface area to promote rapid absorption. As they may reduce the surface area of the liquid, absorbents can be used with volatile products. While absorbent materials are, in theory, capable of recovering light fuel oils and some crude oils, the time required for absorption may be longer than is practical or desirable and, as a consequence, they are suited more to the recovery of low viscosity liquids and spilt chemicals, particularly hazardous and noxious substances, as discussed in the separate ITOPF paper on Response to Marine Chemical Incidents. Absorbents are therefore less commonly encountered in oil spill response than adsorbents.

Adsorbents

To minimise confusion, the widely used generic term sorbent is adopted in this paper as its primary focus is the use of adsorbents in oil spill response. The various mechanisms that allow a material to adsorb oil are described below.

Wetting properties

For successful adsorption, oil should wet the material and therefore spread over its surface in preference to water. A liquid will wet a solid if its surface tension is less than the critical surface tension (γ_c) of the solid. Therefore, for a sorbent to fulfil the required criteria, it should have a γ_c value below that of water and above that of oil. The surface tension of seawater is approximately 60–65 mN/m; the value for oil varies depending on the composition but is typically around 20 mN/m. Therefore, for example, PTFE with a γ_c value of 18 mN/m will adsorb neither oil nor water whereas polypropylene with a γ_c value of 29 mN/m makes an ideal oil sorbent.

Many natural and synthetic solids have suitable γ_c values. Inorganic solids that do not have the required value can be modified by various surface treatments, including heating, to produce the desired condition. An example of such a product is exfoliated vermiculite. For a number of materials, notably sorbent foams and loose fibres, the oleophilic properties can be enhanced once they have initially been wetted or primed with oil.

Capillary action

With some materials, adsorption occurs via capillary action. While this is also dependent on the relative surface tensions of the solid and liquid, the viscosity of the oil has an important effect on the rate of penetration into the structure of the sorbent. Oil penetration rates can be fast (a matter of seconds) for low viscosity oils, such as light crudes, or slow (several hours) to negligible for high viscosity oils, such as heavy fuel oil or weathered oils.

Capillary action is particularly important with foam-based sorbents. Foams with fine pores recover low viscosity oils easily but the pores quickly become clogged with thicker oils. Conversely, foams with a coarse cell structure are effective with viscous oils but are unable to effectively retain low viscosity oils.

Cohesion / adhesion

Cohesion refers to the attraction of a material to itself thereby opposing spreading on a solid surface, while adhesion refers to the attraction of one material to another. Sorbents rely on both adhesion of the oil to the sorbent surface and the cohesive properties of oil which allow greater quantities of oil to be retained by the sorbent. If the sorbent is in the form of a hank of loose strands, the cohesion of the oil among the sorbent elements can serve to produce a congealed mass that retards the spreading of the oil making it easier to recover the oil and sorbent mixture. Cohesion is greater for more viscous oils.

Surface area

In addition to the wetting, spreading and capillary characteristics of a particular sorbent material, its sorption rate and capacity are directly related to the exposed surface area. A successful sorbent material should have a high surface area to volume ratio, including external and available internal surfaces.

For viscous oils that are unable to flow rapidly into a sorbent material, the performance will be determined by the available external surface area. For example, loose strands of sorbent have a greater relative external surface area than a boom and so might be expected to have a higher sorption rate and be more effective with viscous oils.

In contrast to absorbents, adsorbent materials should be used on volatile liquids with caution. Spreading of the liquid over the internal and external surface area of an adsorbent material can increase the rate of vapour release, with attendant consequences for combustion and/or human health.

Sorbent materials and forms

Sorbent materials

A wide variety of materials can be used as sorbents. These include organic materials such as bark, peat, sawdust, paper-pulp, bagasse (the waste product from processing sugar cane), cork, chicken feathers, straw (*Figure 2*), wool and human hair; inorganic materials such as vermiculite and pumice; and synthetic material such as polypropylene

Figure 2: Improvised sorbent booms constructed from straw and netting. Such booms are cheap and easy to construct and can provide effective short-term protection when deployed in suitable areas.

Figure 3: Strips of polypropylene enclosed in netting. The loose inhomogeneous structure of the boom may allow oil to readily penetrate into the structure allowing inner surfaces to adsorb oil but the enclosing netting may be easily damaged.

▲ *Figure 4: The surface of a continuous, homogeneous sorbent boom cut away to show only partial use. The inner volume remains unoiled, either because the boom has been deployed for an insufficient period or because the oil is too viscous to penetrate into the structure.*

▲ *Figure 5: Continuous flat sorbents, such as this sheet laid on a shoreline, are characterised by a high surface area to volume ratio. The large scale use of sorbent in this manner should be balanced against the generation of considerable volumes of potentially unoiled waste.*

(*Figures 3, 4 and 5*) and other polymers.

Synthetic sorbents are generally the most effective in recovering oil. In some cases a ratio by weight of oil to sorbent of 40:1 can be achieved compared to 10:1 for organic products and as little as 2:1 for inorganic materials. Despite the limited adsorptive capability, organic and inorganic materials may be attractive as they are often either abundant in nature or are the waste by-product of an industrial process, and can be purchased readily at low cost or are freely available.

The relative effectiveness of different sorbent materials has been tested by a number of organisations to assess how much oil a given weight of a particular sorbent material

	Material	Benefits	Disadvantages
Bulk	• Organic – including bark, peat, sawdust, paper-pulp, cork, chicken feathers, straw, wool and human hair. • Inorganic – vermiculite and pumice • Synthetic – primarily polypropylene	• Often naturally abundant or widely available as waste by-product of industrial processes • Can be low cost • Can serve to protect wildlife at haul-out sites	• Difficult to control, can be spread by the wind • Difficult to retrieve • Oil and sorbent mixture can be difficult to pump • Disposal of oil sorbent mixture more limited than oil alone
Enclosed	• All of the above bulk materials can be enclosed in mesh or nets	• More straightforward to deploy and retrieve than loose sorbent • Enclosed boom has a greater surface area than continuous boom	• Structural strength limited to that of the mesh or net • Organic booms can rapidly become saturated and sink. Oil retention is limited
Continuous	• Synthetic – primarily polypropylene	• Long-term storage • Relatively straightforward to deploy and retrieve • High oil recovery ratio possible if used to full capacity	• Limited efficiency for weathered or more viscous oils • Do not readily decompose limiting disposal options
Fibre	• Synthetic – primarily polypropylene	• Effective on weathered and more viscous oils	• Less effective on fresh light and medium oils

▲ *Table 1: The benefits and disadvantages of available types of adsorbent material.*

▲ *Figure 6: Local villagers constructing snares from strips of polypropylene. The manufacture of sorbent from locally available materials can be cost effective in terms of price as well as efficiency of transport.*

▲ *Figure 7: Snare strung across an estuary to catch floating oil. The open structure and large surface area of the material are particularly suited to the recovery of viscous oils.*

might be expected to retain. Although these test results can be useful in the comparative ranking of the effectiveness of one sorbent material over another, they are performed under laboratory or controlled field conditions and may therefore be misleading. In practice, sorbents are subject to wind, waves and currents and under these natural and unpredictable conditions, their performance is unlikely to match the outcomes reported in such tests.

Forms of sorbent

Sorbents are marketed in various forms according to their composition and their intended use, but can be categorised generally as one of four types: bulk loose material, often as particulate; enclosed in a mesh as pillows or booms; continuous in the form of mats, sheets, booms or rolls; and as loose fibres combined to form snares or sweeps (*Table 1*). Other types of sorbent may be available for specific applications.

Sorbent in bulk

Most of the materials listed above are marketed as loose sorbent and serve a useful purpose to recover small spills of oil on land. Primarily due to the difficulties of controlling their application and retrieval, their use in the marine environment should be limited to specific scenarios described in the section below on the use of sorbents on shorelines.

Enclosed sorbent

Bulk loose sorbent materials are often enclosed in an outer fabric, mesh or netting to form a boom, pillow or sock that is more straightforward to deploy, control and subsequently easier to retrieve than the loose material itself. Enclosed sorbent products vary in shape and volume but booms are the most common (not to be confused with the continuous form of boom described below). Enclosed sorbent is typically produced using readily available organic or inorganic natural materials such as straw (*Figure 2*) but may also comprise individual elements of synthetic material such as polypropylene (*Figure 3*).

Continuous sorbent

Continuous cylindrical sorbent, primarily boom, differs from the enclosed loose material boom described in the previous section by having a greater homogeneity and a lower surface area to volume ratio, meaning oil is less readily able to penetrate to the core of the boom (*Figure 4*). Continuous flat sorbents such as sheets, rolls, mats, pads and webs are characterised by their high surface area to volume ratio (*Figure 5*).

Continuous sorbents are primarily manufactured from synthetic materials with woven, melt-blown, polypropylene being one of the materials most commonly used during spill response. However, sorbents produced from other materials such as polyurethane, nylon and polyethylene may be encountered occasionally.

Loose fibre sorbent

While bulk, enclosed and continuous sorbent products are effective on a wide range of oils, they are less efficient in the recovery of more weathered and high viscosity oils. Bundles or hanks of loose sorbent fibres are available that allow these oils to be recovered through a combination of adhesion to a large surface area and cohesion within the oil itself. Primarily produced from strips of polypropylene, these are usually attached together to form snares also known as 'pom poms' (*Figure 6*). Several individual snares may be attached along a length of rope to form viscous oil sweeps, or 'snare boom' (*Figure 7*). Rope mop skimming machines use a form of sweep in a continuous band often many metres in length to recover and collect oil. Please see the separate ITOPF paper on the Use of Skimmers for further information.

Viscous oil snares have also been used successfully to assist with the detection of sunken and sub-surface oil, either by suspension in the water column from floats and anchors or by sweeping or trawling the seabed attached to a metal frame. The presence of oil in the sea is indicated by oiling of the sorbent, allowing more quantitative methods to focus on identified areas. Further details are given in the separate ITOPF paper on Sampling and Monitoring of Marine Oil Spills.

Criteria for selecting sorbents

In addition to the form in which the sorbent is presented and the ability of a particular material to selectively take up oil, other factors also affect a sorbent's effectiveness.

Buoyancy

For sorbents to be used effectively on floating oil they must have and retain high buoyancy, remaining afloat even when saturated with oil and water. A number of natural organic materials such as straw and sawdust have good initial buoyancy but eventually become waterlogged and sink. However, buoyancy can in some cases be detrimental to the effectiveness of a sorbent. For example, some lighter, less dense materials may remain on top of heavy, viscous oils. In such instances the sorbent material may require manual mixing with the oil to promote saturation and allow effective recovery to proceed.

The buoyancy of foam sorbents is directly related to the ratio of enclosed cells to open cells; the greater the number of open cells, the greater the sorption capability at the expense of buoyancy.

Saturation

Sorbents can quickly become saturated by oil. Even a relatively small slick may quickly overwhelm a sorbent boom and oil may be released from the sorbent to contaminate the resource that it was intended to protect. Once saturated, sorbents cannot recover further oil and should be removed as quickly as possible to avoid any subsequent leaching. The level of saturation can be difficult to identify, often requiring the boom to be cut open. Incomplete saturation is frequently experienced with viscous oils where booms may be recovered and discarded mistakenly, leaving the inner layers unused (*Figure 4*). Such unnecessary wastage can be avoided or decreased by using sorbent boom with a small diameter, reducing the volume of unused material in the centre of the boom, while at the same time maintaining its effectiveness, or by using oil snares.

▲ *Figure 8. Sorbent materials by their nature are bulky products. Storage and transport before, during and after a response to a spill can pose logistical and cost issues.*

Sorbent sheets can become quickly saturated when placed in contact with even small quantities of oil and their use should be restricted to small scale incidents where the amount of oil to be recovered is limited.

Oil retention

One of the key aspects of the overall performance of a sorbent is its ability to retain oil. Some materials rapidly adsorb oil but, unless retrieved in good time, the sorbent may subsequently release much of it as a result of the effects of wind, waves and currents. Similarly, some sorbents release oil when lifted from the water as the weight of recovered liquid can cause the sorbent to sag and deform, squeezing oil from within pores or internal surfaces. Oil retention can be a particular problem when using sorbents with low inherent strength, in particular those constructed from organic materials.

Sorbent materials with fine pores, such as vermiculite and some foams, generally exhibit good oil retention characteristics. The drawback with these materials is their poor performance in the recovery of viscous oils. Snares can become quickly saturated with oil, primarily due to their large surface area. However, they may release oil when they are lifted from the water surface. The rate of release is directly dependent upon the viscosity of the oil, with lighter, less viscous oils dripping off more rapidly.

Strength and durability

The durability of a sorbent is important in those situations where it may be left in-situ for an extended period of time before recovery. Sorbent booms may start to degrade and fall apart within a matter of hours as a result of environmental effects, such as wave action or abrasion on rocks. The strength of some sorbent booms, particularly those composed of enclosed loose material, is dependent on the durability of the retaining netting material, which may break open in adverse environmental conditions. Once damaged, the contents of these booms will be easily lost and may become a secondary source of contamination.

Fermentation

Some organic sorbents can ferment when left in contact with water for an extended period of time. In addition to altering their composition and efficiency in selectively recovering oil, this can give rise to problems with recovery, storage and disposal of the resultant sorbent/liquid mixture.

Cost

The cost of sorbent products varies greatly and is primarily dependent upon the material used. Organic and inorganic materials are comparatively less expensive than synthetic products. However, this low unit cost will require a trade-off to be made to take account of the additional quantities required due to their low relative efficiency. The additional costs of disposal of higher volumes of material should also be considered when selecting the most appropriate product. Despite the high cost of synthetic products, they are often many times more effective and, in some instances, they can be reused.

Availability, storage and transportation

The performance of synthetic sorbents makes their use attractive but they may not always be immediately available at the site of the spill. While organic and inorganic sorbents may be less efficient, they may offer a pragmatic alternative as they are often more widely available. However, the requirement for a number of organic products to be pre-treated before they can be used effectively as sorbents may limit their availability in an emergency response.

Sorbents are bulky by nature (*Figure 8*) and, in large amounts, the space required for storage can be significant. Where storage space is limited and large quantities of sorbents are required, storage may only be possible outside. If this is the case, protection from sunlight will be necessary to prevent degradation by UV light, especially in the case of synthetic sorbents. Storage of organic sorbents should take account of the potential for deterioration in damp conditions and damage as a result of mildew, rodents or insects.

As with storage, transportation of large volumes of sorbents can invoke logistical problems, both from the warehouse to a distribution centre in the general vicinity of the spill and from there into the field where the sorbents are to be used. In particular, flying plane-loads of sorbents to a spill site is unlikely to be cost-effective.

Use of sorbents on or near the shoreline

Sorbents can play a number of useful roles in nearshore and onshore clean-up operations. However, the use of large quantities of sorbents should be avoided where possible to minimise secondary problems associated with disposal (*Figure 9*). Consequently, the large-scale use of sorbents on shorelines should be restricted to those situations where other techniques are not likely to be effective or feasible. Oil on hard sand beaches, for example, can usually be recovered without the extensive use of sorbents by workers equipped with shovels or through the use of trenches. On the other hand, in circumstances where oil is held against a shoreline, inaccessible other than on foot, and where skimmers and pumps cannot be deployed, it is very difficult to handle fluid oil without the aid of sorbents. Nevertheless, many of the concerns relating to availability, transportation and storage of sorbents, both before and after use, still apply.

Anchored close to shore, sorbent boom can be used effectively to catch run-off from shore washing operations, for example during high pressure washing of oiled rocks (see front cover), or in the intertidal zone to collect refloated/remobilised oil. Sometimes referred to as 'passive cleaning', sorbent and snare booms can be very effective in trapping oil mobilised on successive tides from highly sensitive areas, particularly saltmarshes and mangroves, where other response techniques may cause unacceptable additional damage. Similarly, the technique may be used to recover oil released from rock armour and rip- rap over successive tides. The fine-mesh netting material used as dust screen for scaffolding works has also been used in this way successfully to capture viscous oil released from shorelines comprising boulders, cobbles and coarse sand. One end of the netting is secured on the shore while the other is free to move in the sea. Provided environmental conditions are suitable, in particular the water velocity through the boom is not too high, snare boom can also be effective when strung across industrial water intakes to help limit the ingression of floating high viscosity oil (*Figure 7*).

In general, the use of sorbents in conjunction with shoreline washing techniques during the final phase of a clean-up operation is preferable to sorbents being used directly for wiping rocks since this latter technique results in large amounts of material requiring disposal. Nevertheless, sorbents can be useful for the removal of small amounts

▲ *Figure 9: The large-scale use of sorbent to recover oil on a hard sand beach. The use of sorbent material should be appropriate to the scale of contamination, bring an appreciable benefit to the response and not unduly add to the waste requiring disposal.*

▲ *Figure 10: Organic particulate sorbent material such as peat or bark may be applied on rocky shores of importance to wildlife (e.g. penguins and seals), to minimise contamination to fur and feathers as they come ashore.*

▲ *Figure 11: Sorbent pads applied at sea. Considerable effort will be required to subsequently recover the pads to eliminate secondary contamination. Use of containment boom and skimmers may afford a more effective means of recovering the oil than the use of sorbents.*

▲ *Figure 12: Sorbent boom towed in a 'U' formation behind two vessels, with the aim of recovering sheen (very thin oil films) at sea. Saturation of the boom by seawater limits its effectiveness and the lack of skirt on the boom limits the ability to contain oil. Here oil can be seen escaping from the boom.*

of residual oil that would otherwise be difficult to recover with reasonable cost and effort. Contaminated rock pools in particular are candidates for cleaning with sorbents, for example polypropylene snares that are capable of removing both viscous and weathered oils. The use of sorbents to recover sheen is generally not necessary in most climates, as sheen will normally dissipate naturally.

The large-scale use of bulk loose sorbents near-shore or on the shoreline is generally not advocated, primarily because of the difficulties of controlling the application of the material and its subsequent recovery. Nevertheless, situations may arise where recovery is not contemplated and its use may be advantageous. For example, organic products such as peat or bark can be spread on oiled shorelines to adsorb bulk oil and afford a measure of protection to local fauna, especially sensitive marine mammals and birds such as seals or penguins at haul-out sites (*Figure 10*). In some countries, organic and inorganic bulk sorbents are used in the final stages of clean-up in the knowledge that, although the sorbents will not be recovered, the oil/sorbent mixture will be removed over time by natural processes, which also bring about its distribution over a wide area and the gradual breakdown of the oil.

Use of sorbents at sea

The use of sorbents as a primary response tool in a major oil spill response at sea is to be discouraged. In addition to problems of control of the material on the water surface and increased volumes of oily waste requiring disposal (*Figure 11*), the application of sorbents to an oil slick does not ease the problems inherent in at-sea containment and recovery operations. The resultant oil-sorbent mixture will likely hinder the operation of skimmers and will still be subject to the effects of the wind, currents and waves, resulting in the break-up of slicks that will be no easier to control than the original spill.

Application

The use of bulk sorbents at sea raises a number of efficiency and safety issues, as broadcasting loose powder or particulate sorbents over open water has several inherent disadvantages. Any wind is likely to cause the product to be carried away from the slick, causing wastage and additional pollution. Blowers are sometimes used to broadcast bulk loose sorbents over a spill and personnel undertaking such activities need to protect their eyes from dust and should take precautions against accidental inhalation or ingestion. Without suitable mixing of the sorbent material into the oil the sorbent may simply float on top of the oil resulting in poor efficiency. In order to overcome these obstacles, a number of special devices have been designed to discharge powder and particulate sorbents over the side of a ship in a controlled manner. To be of benefit such devices would need to be within easy reach of a spill site, whereas they are not widely available.

Sorbent boom is far easier to deploy than bulk loose sorbent. However, the limitations imposed on the use of containment boom by currents, winds and sea state are even more applicable to sorbent boom. Sorbent booms are relatively light, especially immediately after deployment, and may be lifted by the wind. They therefore require lashing or anchoring and some sorbent booms are available with lashing points provided. In order to combine the advantages of sorbents with conventional containment boom, some manufacturers have produced sorbent booms with a ballasted skirt. For minor spills of oil, for example in marinas or fishing harbours, this product may assist both the containment and the recovery operations. This is marketed as a disposable product unsuitable for reuse, bringing attendant costs of disposal.

Towing sorbent boom to recover thin films of oil or sheen from the water surface (*Figure 12*) is generally considered to be an inefficient use of resources, as sheen will usually evaporate or disperse readily. Furthermore, the effects of waves and turbulence frequently lead to saturation of the sorbent boom by water, severely limiting the recovery of oil. Saturation is more noticeable for boom composed of bulk loose sorbent material and less so for boom containing homogeneous continuous material. In addition, the forces imposed by towing are likely to be too great for most sorbent booms causing them to tear, with the consequent release of sorbent material and loss of any contained oil.

Sorbent sheets and pads are even more susceptible to being blown by the wind than sorbent booms, as they are not designed for lashing or anchoring and it is impractical to do so. The large-scale use of sorbent sheets or pads at sea is not a recommended technique as they can rapidly spread over a wide area and, although their retrieval is more feasible than recovery of bulk sorbent, it relies on slow and inefficient manual recovery. Sheets, pads and other free-floating sorbent materials stranding on beaches can rapidly become buried by successive tidal movement of the substrate and can be difficult to locate subsequently (*Figure 13*).

Figure 13: Sorbent pads stranded on a shoreline at high tide, after deployment at sea. Unless removed quickly, sand movement during subsequent tides will cover the pads, hindering recovery.

Use with other clean-up techniques

Careful management of a response and of response personnel is required to ensure that the clean-up techniques employed do not counteract each other. It is important to remember when using sorbents that the surface tension of both oil and water can be significantly altered by the surface active agents present in dispersants. As a result, the use of dispersants or other spill response chemicals can interfere with the ability of sorbents to function as designed, as they can decrease both the oleophilic and hydrophobic properties, significantly increasing the amount of water and decreasing the amount of oil recovered. Consequently, to be used effectively, sorbents should not be employed alongside dispersants in a response.

Similarly, the use of sorbents is not compatible with the mechanical recovery of oil with skimmers. Bulk loose sorbent, sorbent pads and other forms of loose sorbent can block or severely restrict weirs and pumps, while sorbent boom can restrict the flow of oil into a skimmer.

Recovery

Unless sorbent is recovered from the water surface, it becomes as much a pollutant as the oil itself. Loose particles of bulk sorbent can be blown great distances and may endanger fauna, primarily through ingestion. In particular, its use is not recommended near mariculture facilities as it may be mistakenly identified as fish food.

Recovery of any mixture of oil and sorbent material from the sea surface presents a number of difficulties. The mixture may be more viscous and bulky than the oil alone and only some heavy duty pumps and skimmers would be capable of dealing with such materials. If the material cannot be pumped, storage tanks on board recovery vessels will become redundant, calling for larger on-deck storage.

The use of seine type fishing nets has been attempted in the recovery of bulk loose sorbent/oil mixtures. However, problems encountered with the recovery of oil alone, such as clogging and reflective waves, are equally applicable to this method. The oiled nets will also require recovery, storage and either cleaning or disposal. Recovery options in these situations may be limited to inefficient and labour-intensive scoops or mechanical grabs.

The recovery of sorbent boom, sheets and pads from the water surface is a similarly time-consuming and labour-intensive operation. In particular, the increased weight of saturated sorbent boom can make hauling-in an arduous task.

Use of sorbents in 'housekeeping' and other roles

One of the most common uses of sorbents is to mop up small spills both on land and on board ships but they also find significant application in general 'housekeeping' functions, such as improving the safety of workers and preventing wider contamination. Sorbent mats can be used to minimise slippery conditions on board recovery craft and at equipment decontamination points and also at cleaning stations to separate clean and dirty sides of the operations. Similarly, sorbent mats are frequently placed at the threshold of ships' accommodation or command centres onshore to avoid oil being walked inside. As with all of the above scenarios, the sorbent should be used to capacity before it is discarded in order to avoid wastage.

In the mariculture industry, sorbent sheets have been used successfully to recover floating oil and oil films from the water surface inside fish cages, where the oiled sheets are contained and easily recovered. In relatively calm conditions, sorbent booms can be used to surround the outside of a fish cage or other sensitive resource to reduce the chance of contamination. A range of sorbent materials from loose fibres to inorganic bulk materials have also been used in the construction of filters designed to prevent oil being carried into water intakes supplying seawater to a variety of onshore facilities, such as hatcheries and salt pans.

Figure 14: Oil leaching from a recovered sorbent boom is a source of secondary contamination.

Figure 15: Used sorbent piled in a temporary storage site. Compression will cause recovered oil to be squeezed from the boom and care is needed to avoid secondary contamination.

Figure 16: Recovered sorbent snare hung on a pole to allow oil to run into a container, thereby minimising the amount of free oil in the waste.

Storage, transport and disposal of used sorbents

Temporary storage and transport of oiled material

Once recovered, sorbent used at sea will need to be stored both on-board any collection vessel and then on the shore prior to final disposal. As saturated sorbent, particularly boom, is compressed through the weight of further material placed on top, adsorbed oil may leach out. On-board storage should, therefore, be enclosed to ensure leachate does not contaminate decks or gangways rendering them unsafe, or flow overboard causing recontamination. Oiled sorbent also needs to be unloaded with care to minimise contamination of quays and jetties (*Figure 14*).

Oiled debris and material, including sorbents, landed ashore and collected from the shoreline will usually require temporary storage while the logistics of transport and disposal are organised. In a large spill, the amount of material collected may exceed the capacity of available treatment or disposal facilities in the local area. The excessive use of sorbent materials exacerbates this problem (*Figure 15*) necessitating a larger temporary storage site which in many parts of the world would need to be licensed. Prior to transport, as much free oil as possible is usually removed (*Figure 16*) and, ideally, sorbents are compressed to minimise bulk and optimise transport logistics. Oil and water released as a result of compressing the sorbents must be recovered and temporary storage sites should be bunded to prevent the escape of leachate.

Disposal routes

The disposal options available for oiled sorbent materials are relatively limited when compared with those for recovered fluid oils. Even small amounts of sorbent material present in the waste stream can preclude disposal by certain routes, for example, as a feedstock in refineries.

Reuse

In theory, some types of sorbent can be reused if the oil can be extracted. This can be achieved either by compression using a mangle or wringer (as in rope mop skimmer systems), by centrifuge or by solvent extraction. Compression is generally the more practical option and is feasible for some synthetic products. However, the number of reuse cycles that can be endured before the sorbent material becomes unusable due to tearing, crushing or general deterioration should be considered.

Other factors to consider with the reuse of sorbents are contamination of the waste oil stream from particles of sorbent detached during compression, the rate of decrease in adsorption capacity and the percentage of oil that can be removed with reasonable levels of manpower and equipment. Nevertheless, some sorbents exhibit an increase in sorption capability upon repeated reuse, particularly for more viscous oils.

Incineration

Burning contaminated sorbent may be a viable option if the sorbent material is combustible and does not contain excessive quantities of water. This latter criterion often excludes the burning of used organic sorbents, as they are often less selective in the recovery of oil versus water and may contain too much water. Although incinerators may be available in the country where an incident occurs, their capacity is usually matched to domestic demand and they are likely to be overwhelmed by the sudden influx of the vast amounts of oily waste typical of a major spill. Of the different types of incinerator available, rotary kiln and open hearth furnaces are the most appropriate for large amounts of solid debris. Large pieces of debris, such as oiled sorbent booms, will need to be removed from the waste stream and reduced in size prior to burning.

The high calorific value of synthetic sorbents can make temperature control of the kiln or furnace difficult, and blending the oiled sorbents into a waste stream comprising less combustible materials may be necessary to lower the feed rate. With complete combustion of synthetic and organic sorbents, a significant reduction in the volume of material destined for landfill can be achieved. On the other hand, incineration of inorganic materials will eliminate the oil content but will not significantly reduce the volume for final disposal.

Incineration is normally strictly controlled and high temperature combustion, together with close monitoring of exhaust gases, will be required to ensure that toxic dioxins, PAHs and HCl are not discharged to the atmosphere, particularly in the case of synthetic sorbents. The cost of incineration is often considerably higher than other disposal techniques and this should be taken into account if this method is selected.

Landfill

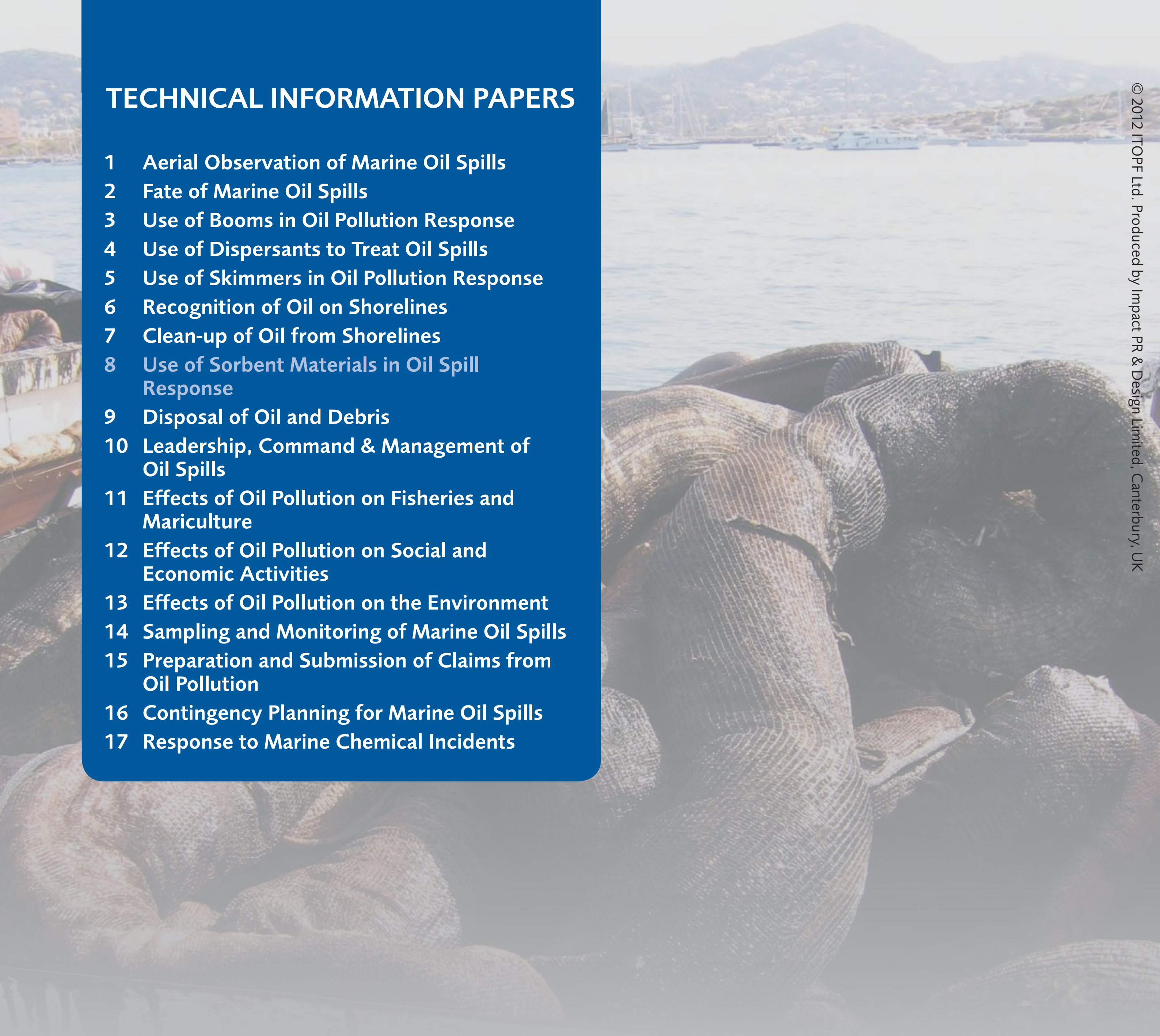
Disposal of sorbent material as landfill is also usually strictly controlled by local or national regulations. In some countries, oiled sorbent material is treated as a hazardous waste and the use of designated hazardous material landfill sites may be required, with consequent increases in the cost of transport and disposal. Modern sites are usually enclosed by an impermeable membrane to prevent run-off. Nevertheless, in parts of the world where such linings are not regularly used, attention should be given to measures to prevent contamination of nearby ground and surface waters.

Biodegradation

Organic sorbent materials generally have the advantage of being biodegradable. Depending on local waste disposal regulations and assuming a relatively low oil content, disposal of organic sorbents by land farming may be permitted. The oiled sorbent is spread over a large area of land and biodegradation is allowed to proceed. Degradation may take a number of years, although faster degradation can often be achieved by aeration using cultivation equipment and the application of fertilisers. Composting of certain organic sorbents may also be a viable disposal route.

Key points

- The large-scale use of sorbents should be strongly discouraged both onshore and at sea because it generates excessive volumes of oily waste for disposal.
- The use of sorbents can nevertheless be appropriate and effective in certain scenarios, primarily during shoreline washing operations or where other techniques are not feasible.
- The use of sorbents in the open sea to recover oil from the water is considered a highly ineffective and inefficient use of resources due to the difficulties of accurately broadcasting the material onto the oil and, more significantly, its subsequent retrieval once oiled.
- Operations utilising clean-up techniques such as dispersants and skimmers conflict with the use of sorbents and careful management of the response is necessary to avoid techniques interfering with each other.
- Sorbents are bulky to store and transport. Storage arrangements must be carefully considered to prevent damage from rodents, insects, mildew, damp, UV radiation or fire.
- Low-cost, locally available organic or inorganic materials may provide a more cost-effective option than stockpiled synthetic sorbents, despite a lower recovery efficiency for the same weight of sorbent material.
- Excessive and inefficient use of sorbent material can lead to secondary contamination and can create significant logistical and financial issues during the temporary storage, transport and disposal of oiled material. Consequently the release of sorbents from stockpiles needs to be controlled and the workforce carefully supervised to avoid these problems.



TECHNICAL INFORMATION PAPERS

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ITOPF

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com

DISPOSAL OF OIL AND DEBRIS

TECHNICAL INFORMATION PAPER

9

Introduction

Most oil spill clean-up operations, particularly those on shore, result in the collection of substantial quantities of oil and oily waste. The storage and disposal of waste is an important aspect of any response operation and adequate provisions for waste management should be clearly highlighted in any oil spill contingency plan. It is essential that arrangements made at the beginning of an incident act to prevent waste issues from compromising the response effort and becoming a costly problem that continues long after the spill clean-up is complete.

This paper explores the various options available for the management of waste material generated as a result of ship-source oil spills in the marine environment.

The waste problem

Experience has shown that the most time-consuming and costly component of a response to an oil spill is often the treatment or disposal of collected waste. The amount of waste generated is dependent on many factors, such as the type and quantity of oil spilt, the extent to which the oil spreads and affects the shoreline and, most importantly, the methods employed to recover the spilt oil and oiled material from the sea surface and the shoreline.

During even relatively minor oil spills, the amount of waste collected can quickly overwhelm existing disposal facilities. To ensure this problem can be readily addressed, methods for dealing with waste should be a key component of any oil spill contingency plan. Decisions on response techniques should take account of the amount of waste likely to be generated, where possible giving preference to those techniques that minimise the amount of waste collected. In addition, especially in the case of shoreline clean-up, firm supervision of the workforce is essential. Nevertheless, even with the use of appropriate and reasonable response methods, the volume of waste generated can sometimes be as much as ten times greater than the volume of oil originally spilt.

Once collected, the effort and expense required to deal with the waste will depend on the storage, transport, treatment and disposal options available and on local regulatory requirements. Decisions on the treatment of waste should be made at the beginning of an incident, based on a realistic estimation of the amount and type of waste likely to be generated. Effective organisation of all parts of the waste handling process is essential to avoid a major and costly problem. As global environmental awareness increases and regulatory requirements concerning waste disposal become stricter, innovative ways of using, recycling or disposing of waste are likely to be needed.

Waste management options

The 'Waste Hierarchy' is a well-established international framework for classifying and prioritising waste management options applicable to all forms of waste and is equally valid as a basis for the management of waste from oil spills. The hierarchy comprises five distinct steps in order of desirability:

Figure 1: Cleaning of oiled sand in-situ by low pressure flushing, with sorbent boom deployed appropriately to capture released oil.

1. **Reduce** the amount of oily waste generated, for example through the use of selective shoreline clean-up techniques that minimise collection of clean material and/or water or through the *in-situ* treatment of oiled material (*Figure 1*). Careful control of consumables, notably the use of sorbent material, will also serve to reduce waste. The separate ITOPF papers on clean-up of oil from shorelines and use of sorbent materials describe appropriate practices in greater detail.
2. **Reuse** the resources used during clean-up, for example by cleaning and reusing oiled equipment and protective clothing where possible (*Figure 2*).
3. **Recycle** liquid oil by incorporation into refinery streams or stabilise oil and oiled material for use in land reclamation or road building projects.
4. **Recovery** of the calorific value of the waste material as fuel for power or heat generation.
5. **Disposal** of waste that cannot be dealt with by one of the above options may be achieved through incineration, landfill or composting.

In reality, waste management decisions are driven by the cost and capacity of the available options that comply with waste disposal regulations in the region where the incident has

Figure 2: Minimisation of waste is an essential consideration in spill response. Personal protective equipment (PPE), including clothing, should be cleaned and reused where possible.

occurred. Where a range of options are technically feasible (*Table 1*), cost effectiveness is likely to be a significant factor in the selection of the disposal route. However, oil spills are often, by their nature, emergencies that require a rapid response, and unless due consideration has been given to waste management during contingency planning, the most practicable and cost-effective disposal options may take precedence over more sustainable waste management options.

Nature of oil and oiled material

As a general rule, spills of persistent oils, such as crude oils, heavier grades of fuel oil and some lubricating oils, are likely to generate considerable quantities of waste. Once spilt, the oil will start to weather with an associated increase in water content and viscosity. Oil collected with minimal delay is more likely to be fluid and relatively free of contamination. Over time, the oil may accumulate debris, either as a result of the break-up of the ship, from lost cargo (*Figure 3*) or debris originating from the shore (*Figure 4*).

Even if the oil is free from solid debris, recovery at sea may involve collection of significant amounts of water due to the recovery methods used, or the formation of a water-in-oil

	Type of material	Separation methods	Disposal options
Liquids	Non-emulsified oils and waste water	• Settling/gravity separation of free water • Recovered water may require further treatment/filtration	• Use of recovered oil as fuel or refinery feedstock • Return treated water to source
Liquids	Emulsified oils	Emulsion broken to release water by: • Heat treatment • Emulsion-breaking chemicals	• Use of recovered oil as fuel or refinery feedstock • Stabilisation and reuse • Incineration
Solids	Oil mixed with sand	• Collection of liquid oil leaching from sand during temporary storage • Extraction of oil from sand by washing with water or solvent • Removal of solid oils or tarballs by sieving	• Use of recovered liquid oil as fuel or refinery feedstock • Return treated water to source • Stabilisation and reuse • Degradation through land farming or composting • Landfill • Incineration
Solids	Oil mixed with cobbles, pebbles or shingle	• Collection of liquid oil leaching from beach material during temporary storage • Extraction of oil from beach material by washing with water or solvent	• Return cleaned stones to source • Stabilisation and reuse • Landfill
Solids	Oil mixed with wood, plastics, seaweed, shellfish and sorbents Oiled fishing equipment and stock – nets, floats and racks	• Collection of liquid oil leaching during temporary storage • Flushing of oil from debris with water • Removal of free water • Compression	• Stabilisation and reuse following removal of plastics and large debris • Degradation through land-farming or composting for oil mixed with seaweed, shellfish or natural sorbents • Landfill • Incineration
Solids	Tarballs	• Separation from sand by sieving	• Stabilisation and reuse • Landfill • Incineration

Table 1: A summary of the main options typically available for separation and disposal of oil and debris.

emulsion (*Figure 5*). Alternatively oils with a pour point above sea temperature may quickly become semi-solid (*Figure 6*), necessitating recovery by scoops or grabs that also tend to recover significant amounts of water. Spills of non-persistent oils tend to evaporate and disperse naturally within a short period of time and are therefore less frequently associated with waste generation issues.

Oil recovered from the shoreline will usually be mixed with substantial amounts of other material, such as sand, pebbles, wood, plastics and seaweed; each material may require a different method of treatment or disposal and separation can be difficult. For example, oily wood may be burnt under controlled conditions, possibly *in situ*, whereas burning oily seaweed is impractical. Oiled materials from response operations, such as adsorbent materials (*Figure 7*), protective clothing (PPE), damaged containment boom, storage sacks (*Figure 8*) and other types of waste receptacles can also contribute significantly to the volume of waste produced following an oil spill, particularly if large numbers of inexperienced workers or volunteers are used. Considerable amounts of waste can also be generated if fishing gear and mariculture facilities are contaminated and cannot be cleaned satisfactorily, or if stock is condemned. These issues are considered in more detail in a separate ITOPF paper on the Effects of Oil on Fisheries and Mariculture.

Transport, storage and preparation for disposal

The large volumes of waste requiring disposal following clean-up can often present major logistical problems during handling and transportation. In order to allow clean-up operations to continue unhindered, it is usually necessary to store the material temporarily to provide a buffer between collection and final treatment and/or disposal. This also allows authorities time to select the appropriate method for dealing with the waste, if not already identified. In the case of waste resulting from shore clean-up, storage at the back of the beach above the high water mark (*Figure 8*) enables the transportation to be undertaken in two stages: from primary storage on the beach to intermediate storage and eventually to final treatment and/or disposal as necessary. This reduces the risk of contamination of roads by restricting the number of vehicles involved in the first stage transfer from the beach.

▲ *Figure 3: Waste plastic from containers lost overboard, mixed with oil and stranded in mangroves.*

▲ *Figure 4: Oil mixed with discarded plastic, domestic rubbish, timber, vegetation and other waste.*

▲ *Figure 5: Emulsified oil stranded on sand. Selective manual recovery serves to minimise the amount of clean substrate removed.*

▲ *Figure 6: Semi-solid oil contained within a boom. The difficulties of pumping the oil can limit the available disposal routes.*

Oily waste must be transported, stored and disposed of in accordance with local regulations. In some countries, licences will be required for temporary disposal sites and by the contractors engaged for the various disposal tasks. Consultation with regulatory and licensing authorities, from the outset of the incident, will assist with this important administrative component of the disposal process.

As far as possible, and provided more than one disposal route is available, the different waste streams should be segregated at the point of collection and stored separately. The loss of control and discipline at any stage of the disposal route can lead to later complications and unnecessary additional costs (*Figure 9*). For example, bulk oil, oily debris and non-oiled materials should be stored in separate areas so that different methods of treatment and disposal can be followed for each category. Provided the bulk oil can be pumped at ambient temperatures, it can be stored in enclosed tanks. However, care should be exercised during the bulk storage of more viscous materials, particularly if the tanks are not fitted with heating coils, as emptying the tanks may be difficult without heating. Large volumes of recovered oil may be stored in tanker vessels, if available, although this may be an expensive option.

Highly viscous oils should be stored in open containers such as barges, skips or drums to facilitate treatment and transfer operations. If waste oil is to be stored for a significant length of time, covered containment is essential to prevent rainwater ingress (*Figure 10*), which may cause the oil to float and overspill. If purpose-built containers are not available, bulk oil from shorelines can be held within compacted earth walls or in simple storage pits lined with heavy gauge polyethylene (or other suitable oil-proof material). Long narrow storage pits approximately 2 metres wide and 1.5 metres deep are preferable to maintain ready access to all parts of the pit (*Figure 11)*. However, the size and number of pits should reflect the volume of waste expected. If there is a possibility of heavy rainfall, allowance should be made for this when filling the pits. Where temporary storage of bulk oil is required in sensitive areas, such as sand dunes, it is important to avoid disturbance of the stabilising vegetation as this could lead to erosion. Wherever dug, pits should be filled in after complete removal of the oil and, as far as possible, the area restored to its original state.

Plastic sacks should be regarded as a means of transporting oily material rather than for storage as they tend to deteriorate and degrade in sunlight, releasing their contents (*Figure*

Figure 7: Partially oiled sorbent boom. The large-scale use of sorbent materials should be avoided in order to minimise waste generation.

Figure 8: Plastic bags containing oiled beach material stored temporarily above the high water mark, on plastic sheeting to contain any leachate.

Figure 9: A well-lined pit containing poorly segregated waste, requiring considerable additional effort to separate and treat.

Figure 10: Recovered oil stored in a barge. A cover is required to prevent rainwater ingress.

12). If the contents are to be treated in some way prior to disposal, it will usually be necessary to empty the bags and dispose of them separately. Irrespective of whether waste is stored in containers, in heaps or piles or by other means, the storage area should be lined and provisions made to catch and treat leachate to prevent secondary contamination of the surrounding area and groundwater (*Figure 13*). Odours resulting from decomposing oiled vegetation, flies and vermin can be a nuisance if temporary sites are located close to populated areas.

Security of temporary waste storage areas should be proportionate to the risks associated with unauthorised access and might range from signage and cordoned–off areas to more impenetrable fencing and 24-hour surveillance. Without adequate security, especially close to urban centres, there is the additional risk of domestic or commercial waste being dumped at temporary storage sites. The time taken to transfer waste to designated final disposal sites should be minimised so as to avoid problems caused by waste being dumped and from secondary contamination.

Where final disposal methods have been identified and capacity allows, transport of waste from the shoreline directly to the site of final disposal negates the need for temporary storage. This avoids double-handling, minimises the build-up of waste and allows the overall response to be completed more quickly and cost effectively.

It is good practice to record the quantities and types of oily waste being collected to allow progress to be monitored within the command centre. Records will also be useful for the formulation of a subsequent claim for compensation.

Minimisation of waste

The problems associated with disposal will be reduced if priority is given to minimising the amount of waste generated during the response. Unless other overriding factors are present, this should be an important factor when considering clean-up techniques.

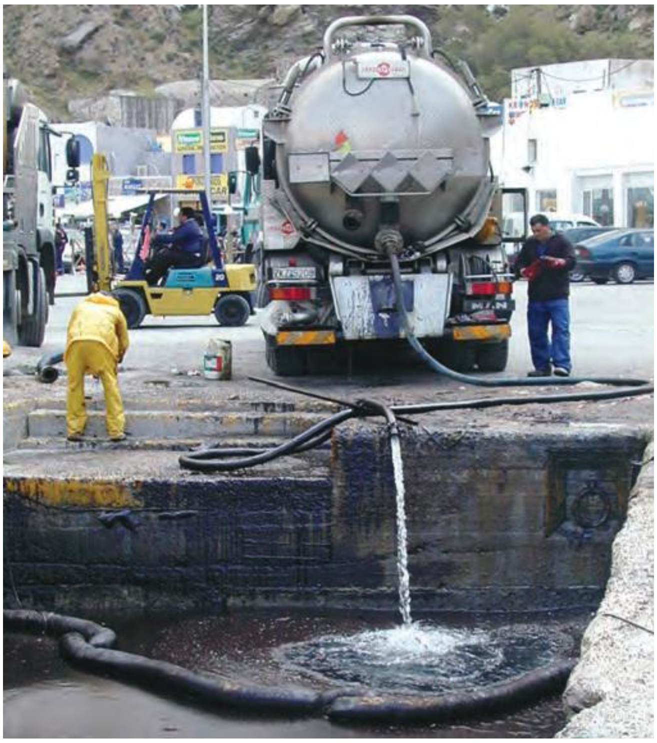
Disposal is often complicated by the amount of debris recovered with the oil. Coastal surveys to identify where debris collects naturally will often indicate where oil is likely to come ashore. Debris can sometimes be removed from these shorelines before the arrival of oil, at nominal cost

▲ *Figure 11: Skip emptying emulsified fuel oil into a lined temporary storage pit.*

▲ *Figure 12: Degradation of plastic sacks by long-term exposure to sunlight can lead to recontamination.*

▲ *Figure 13: Capture and treatment of leachate from oiled sand piled in temporary storage prevents secondary contamination of the surrounding area and groundwater.*

▲ *Figure 14: Removing debris from the shoreline before oil strands will help reduce the quantity of oiled material requiring disposal.*



▲ *Figure 15: Decanting of water into the spill area, after settling and separation of recovered oily water in a vacuum truck.*

▲ *Figure 16: An improvised waste filtration system, where recovered oil is passed through a grilled funnel to filter out debris.*

relative to the cost of its disposal once oiled (*Figure 14*). Alternatively, debris collection areas could be prioritised for protection with boom, to reduce the risk of clean debris becoming oiled.

In an effort to minimise the amount of waste water for final disposal, it may be possible to decant water that has separated from the oil/water mix recovered at sea or nearshore. After the oil has settled and separated in tanks onboard skimming vessels, vacuum trucks (*Figure 15*), or other devices, water may be run off from bottom valves into a boomed area. Concentrating the oil in this way serves to maximise the capacity of temporary storage, thereby reducing interruptions in the recovery operations while additional capacity is arranged. However, it should be noted that in some countries local legislation may prohibit the discharge of any liquid to sea without specific dispensation from the relevant authorities.

It may be possible to recover oil from contaminated beach material *in situ*. For example, oil seeping from collected beach material and debris can be contained within a ditch or bund surrounding the storage area. Oiled beach material may then be flushed with water, sometimes in conjunction with a suitable solvent, such as a citrus-based cleaner, to release the oil. Washing can be carried out using low pressure hoses to loosen and lift off oil from debris contained in a temporary storage pit. The resulting oil/water mixture can then be pumped to subsequent gravity separation. Another approach is to place contaminated material on a grill or wire mesh, with the oil draining into a skip or tank positioned beneath (*Figure 16*). This process can be assisted by washing the waste with water, although significant volumes of oily water can be generated. Separation can also be achieved in a closed system using water or a solvent. Devices have been developed based on a range of equipment, from standard cement mixers for small-scale batch operations to mineral processing equipment for large-scale continuous treatment. Although these large-scale systems have proved successful in specific circumstances, they are slow to achieve satisfactory levels of cleanliness and high levels of fines or tailings in the waste water can be difficult to separate. Consequently, they have not yet found widespread application at oil spill incidents.

The volume of waste can also be reduced by separating oil, in the form of tarballs, from clean sand by selective manual picking where a site might require a high standard of cleanliness, such as on tourist beaches. Sieving devices, both static and mechanical, are also sometimes used to remove oily sand residues and tarballs from lightly contaminated sand (*Figure 17*). While often labour intensive, the cost of cleaning large amounts of oiled beach material on-site could compare favourably with other methods that involve transporting the material some distance from the shoreline and subsequent disposal.

In many incidents, a large percentage of the waste generated is synthetic adsorbent material and a significant proportion of this material is often lightly oiled or not oiled at all (*Figure 7*). Waste problems will be subsequently reduced if adsorbent is used only when other techniques are unsuitable and if care is taken to ensure it is used to its full capacity.

Where oily waste is to be co-disposed with domestic refuse by incineration, agreement on a sliding scale of costs according to the calorific value of the waste can be an incentive to minimise the amount of non-oiled waste collected: the higher the oil content and hence the calorific value, the lower the price of disposal.

Figure 17: Mechanical sieving of tarballs from sand in order to reduce the amount of waste generated.

Figure 18: Stabilisation of oily waste using quicklime.

Treatment and disposal options

A number of options are available for the final treatment and disposal of oil and oily waste and these are summarised in Table 2 and detailed below. The disposal method most appropriate in an incident will depend on several factors, including the nature and consistency of the waste, the availability of suitable sites and facilities, the costs involved, as well as regulatory restrictions.

Recovery of oils

Oily waste may be treated to recover sufficient quantities of oil for eventual processing or blending with fuel oils for subsequent use. This process makes use of the calorific properties of the oil and has the potential to generate financial income from its sale, to offset the costs of disposal. This is often the most cost effective use of recovered oil and should be among the first options to be considered. Possible recipients for processing or blending are refineries, oil recovery contractors specialising in recycling waste oils, power stations and cement works. However, most of these facilities can only accept feedstocks with narrow specification criteria, so the recovered oil must be of a suitable quality. For example, the oil should be pumpable, low in solids and have a salt content of less than 0.1% for processing through a refinery, or less than 0.5% for blending into fuel oil. Assuming that the oil is suitable for recycling, it is likely that the potential refiners or other users will have limited storage or processing capacity and alternative intermediate storage may be required. Vessel slop reception facilities and tanker deballasting stations may be appropriate in this regard but may also have limited capacity.

Oil collected from the sea is likely to be the easiest to prepare for processing since it will usually only require separation from any associated free water. The extraction of water from water-in-oil emulsions is more difficult. Unstable emulsions may be broken by heat treatment at temperatures of up to 80°C, allowing the oil and water to separate by gravity. More stable emulsions may require the use of chemicals known as 'emulsion breakers' or 'demulsifiers'. Both heat treatment and demulsifiers can reduce the viscosity of most oils, rendering them more pumpable.

No single chemical is suitable to break all types of emulsion and on-site trials may be necessary to determine the most effective agent and optimum dose rate. Typical dose rates are in the range of 0.1% to 0.5% of the bulk volume to be treated. Treatment should be undertaken during transfer of the emulsion from the collection device to a tank or from one tank to another to ensure good mixing and to minimise the dose required. The emulsion breaker can be injected into the inlet side of a pump or an in-line static mixer incorporated into a vacuum intake. After separation, the water phase will contain most of the emulsion breaker and up to 0.1% of oil and therefore, care should be exercised when disposing of this mixture.

Stabilisation

Oily sand that does not contain large amounts of driftwood and other debris can be bound with an inorganic substance such as quicklime (calcium oxide) to form an inert product that prevents the oil from leaching out and that can be disposed of under less stringent conditions than untreated oily sand (*Figure 18*). Alternatively, such mixtures may be used for land reclamation and road construction, where high load-bearing properties are not required, such as service roads or roadside embankments. Clearly the suitability of the technique is dependent upon a plentiful supply of stabilising material. Quicklime can usually be sourced from cement works and has the advantage that the heat generated by its reaction with water in the waste reduces the viscosity of the oil, facilitating binding. Other materials such as cement, zeolite, pulverised fuel ash waste and some commercially available products may also be applicable.

The optimum amount of binding agent required is primarily dependent on the water content of the waste rather than the amount of oil and this can be determined by experiment. For quicklime, the amount required is typically between 5 and 30% by weight of the bulk material to be treated. Treatment can be carried out either at a central facility or at the spill site. At a treatment centre, the agent would be mixed with the waste in a continuous process. This method requires the use of expensive equipment such as a continuous drum mixer. Smaller quantities could be treated in a batch process using concrete mixers, although the heat generated by the process and the corrosive nature of the reaction may preclude their use.

Alternatively, waste can be spread out in treatment beds at the final disposal site in layers up to 30cm thick and mixed using a pulverising mixer which incorporates the lime. Following treatment, the waste is either left in place and covered over or sent to landfill. Provided sufficient land is available, this can be a more cost effective method.

On occasion it may be preferable to carry out primary mixing in pits at the site of the spill so that the mixture can be more easily transported, for example in open-top trucks or skips rather than in tank trucks. The final treatment can then be undertaken at a larger reception facility using specialised equipment.

This technique can give rise to a great deal of corrosive dust and if possible the treatment site should be selected in order to minimise its spread to adjacent areas. It is also important that operating personnel wear protective clothing and face masks to protect skin, lungs and eyes. If, after mixing, the material is to be utilised in road construction, compaction using road building equipment is essential.

Incineration

In certain situations, *in-situ* burning of freshly spilt, floating oil can be a successful method of removing large amounts of oil quickly. However, spilt oil tends to lose its volatile components after a short time at sea and typically picks up a high proportion of water. Consequently, burning oil that has stranded on the shore can be difficult without first reducing the water content, particularly if the oil has been at sea for a long period. The direct burning of uncontained oil or oily debris onshore is not recommended, except in very remote areas, as the resultant fire and dense smoke can be difficult to control. When oil is burnt on land in the open, it also tends to spread and be absorbed into the ground. In addition, a tarry residue may remain as it is rarely possible to achieve complete combustion.

These problems can be overcome using an incinerator that destroys the waste by controlled burning at high temperatures. Portable incinerators have been developed for use in remote locations, primarily to burn medical waste. However, local legislation and environmental concerns may prohibit the use of such devices to burn oily waste on the shoreline and they can only accommodate small-scale waste in small batches. On a larger scale, cement factories and industrial kilns are an effective way of incinerating oily waste, subject to technical constraints, such as the removal of large solids, and problems associated with heavy metals, chlorine or sulphur in the waste.

Co-incineration in a cement works is also a cost effective method of disposal, as waste with an adequate calorific value can be used as a substitute for fuel that would otherwise be needed to fire the kiln. In addition, the ash resulting from waste combustion provides aluminium, silica, clay and other minerals typically added in the raw material feed stream

	Benefits	Disadvantages
Re-Processing	• Recycling through use of the calorific properties of the oil • Permanent storage not required	• Oiled waste may require treatment before processing • Facilities and processing capacity are limited • Long term storage of waste may be required whilst awaiting processing
Stabilisation	• National legislation often allows for easier disposal of stabilised oiled material • Recycling through use of stabilised oiled material in construction	• Only appropriate for oiled sand, shingle and pebbles with debris of limited size • Treatment of oiled material requires skilled personnel and suitable reception facilities and equipment
Incineration	• Can be employed for many types of oiled material • Permanent storage not required	• Relatively expensive disposal process • Appropriate facilities and processing capacity are limited • Long term storage of waste may be required
Land-farming or composting	• Enhances natural process of biodegradation	• Suitable sites are increasingly difficult to find • Only applicable to relatively small spills because of the large area of land required • Not all oil components may be degraded • Slow process, requiring periodic tilling and monitoring
Landfill	• Organic waste may biodegrade naturally at a landfill • Can rapidly deal with large amounts of waste	• Restricted application dependent on local legislation • Sites designated for hazardous waste are scarce and can charge high rates • Many types of waste likely to persist for a long time

▲ *Table 2: A summary of the benefits and disadvantages of the options typically available for treatment and disposal of oil and debris.*

▲ *Figure 19: Sacks of oiled waste being fed into the loading chute of a large industrial incinerator for co-disposal with domestic waste.*

▲ *Figure 20: Landfill waste facility. Waste with low oil concentrations can be placed with domestic waste under carefully controlled conditions.*

for cement manufacture. However, the type of oily waste accepted is limited and cement works are often located far from the shoreline, so transportation costs and logistics must be considered.

As a general rule, incinerators used for domestic waste are not suitable for disposal of large amounts of oil, as chlorides from seawater may cause corrosion of the incinerator infrastructure. Co-disposal of low amounts of oily waste with other refuse may be acceptable at some facilities, but the volume of oiled to non-oiled waste will require careful consideration in order to control the incineration temperature (*Figure 19*). Oiled protective clothing, sorbents, netting or other materials that may have a low oil content are often treated in this way. High temperature industrial waste incinerators, while more likely to tolerate salts, are limited in number and may be located in remote parts of the country. They may not have sufficient capacity to deal rapidly with the additional burden created by a large quantity of oily waste. However, this may be an acceptable and effective disposal route if long term storage is available that would allow oily waste to be incorporated into the waste stream gradually.

Pyrolysis, the thermal degradation of waste into gas and solid residues in the absence of oxygen, is another process that has been used during a major incident, although this is a specialised and expensive process for which facilities are limited.

Land-farming and composting

Oil and oily wastes will, given sufficient time, usually break down through biological processes (biodegradation). However, the rate at which this occurs is too slow for it to be a viable short term clean-up option. Biodegradation of oil by microorganisms can only take place at an oil-water interface so that, on land, the oil must be mixed with a moist substrate. The rate of degradation depends upon temperature and the availability of oxygen, nitrogen and phosphorous. Some oil components, such as resins and asphaltenes, are resistant to degradation and may persist for prolonged periods.

Bioremediation is the term used for methods that accelerate the microbial breakdown of oil. One such method is land-farming, whereby the oil and debris are spread over a designated area of land. For many years, oil refineries constructed land-farms to deal with oily wastes but increasingly, legislation is restricting its use and sites suitable for land-farming are becoming difficult to find. Land-farming is only likely to be applicable to relatively small spills because a large area of land is required and because degradation rates are slow. The contaminated material should have a relatively low oil content and, ideally, the land selected should be of low value, located well away from drinking water supplies and should not be permeable. The top soil should first be loosened by means of a harrow and the area bunded to contain any oil run-off. The oily debris is then spread over the surface to a depth of no more than 20cm, the maximum application rate being about 400 tonnes of oil per hectare of land. The oil should be left to weather until it is no longer sticky before being thoroughly mixed with the soil using a plough or rotovator. Mixing should be repeated at intervals to increase aeration and hence the rate of biodegradation. Fertilisers may also be added to enhance biodegradation rates. If land-farming techniques are employed, the use of natural adsorbents, such as straw, peat or bark, during clean-up operations is preferable to synthetic materials as they break down more rapidly. Large items of debris, such as timber and boulders, should be removed. Once most of the oil has degraded, the soil should be capable of supporting a wide variety of plants, including trees and grasses. If crops are grown they should be carefully monitored for heavy metal content.

Another effective means of enhancing degradation is to employ composting techniques, particularly for contaminated seaweed and for natural adsorbent materials. Provided the mixtures contain relatively low levels of oil they can be stacked into heaps to facilitate composting and some success has been achieved by introducing air to accelerate decomposition. Because the heaps retain heat generated during composting, the technique is particularly suitable in colder climates where degradation through land-farming is slow.

The use of commercially available bioremediation agents and fertilisers may be appropriate in certain circumstances, to accelerate natural oil degradation. However, they should be employed with caution to ensure the benefits of their use are cost effective.

Landfill

Disposal of oily waste to specially designated landfill sites is the most commonly used method and although this is now severely restricted by legislation in many countries, it may provide the only realistic option to cope with the quantities of waste generated in a spill. Landfill sites are often licensed under specific conditions and acceptance of waste may be limited to certain types or volumes of waste, or to waste where the concentration of contaminant is below a certain threshold. In some countries, oil-contaminated waste will need to be disposed of in a site designated for hazardous refuse. These sites are typically few in number and may be a considerable distance from affected shorelines.

Where direct disposal is acceptable, the material intended for disposal should have a low oil content to avoid secondary contamination from leachate. The exact content varies according to location. Sites for oily waste disposal should be located well away from fissured or porous strata to avoid the risk of contamination of ground water, particularly if this is abstracted for domestic or industrial use. The co-disposal of oil and domestic waste may be acceptable in some countries (*Figure 20*) as the oil appears to remain firmly adsorbed by all types of domestic waste with little tendency to leach out. The oily waste should be deposited on top of at least 4 metres of domestic refuse, either in surface strips 0.1m thick or in trenches 0.5m deep to allow free drainage of water, and should be covered by a minimum of 2 metres of domestic waste to prevent the emergence of oil to the surface when subjected to compression from site vehicles.

Contingency planning

Contingency plans should review the disposal options available for dealing with different amounts and types of oily material. Plans should be local in scope, as the clean-up and disposal methods adopted will be largely dependent on national and local waste legislation, as well as on the availability of raw materials, equipment and suitable disposal sites close to the spill. Plans should be updated regularly to incorporate changes in legislation that may affect the availability of some disposal options. Contact details of contractors specialising in oil recovery and/or processing and the locations and capacities of refineries, incinerators and other facilities that could accept waste should be included in the Information Directory of the plan.

The risk assessment undertaken as part of the contingency planning process will identify areas where spills are more probable and where oil might come ashore. Sites for the temporary storage of waste, close to these high risk areas, should be identified at an early stage. The problem of final disposal can then be approached in stages to avoid exceeding the capacity of each disposal route. Pre-agreement with landowners and regulatory authorities will simplify the construction of storage sites when a spill occurs. Further guidance is given in the separate ITOPF paper on contingency planning.

Key points

- Disposal of oil and oily waste is a major problem, particularly following shoreline clean-up when there is likely to be a large quantity of associated debris. Therefore consideration of waste disposal during contingency planning is essential.
- Although a variety of techniques have been developed for dealing with oil and oily wastes, many have limited application and capacity. In the event of a major spill, all options need to be considered.
- Decisions on waste treatment are best made at the start of an incident and should be based on realistic expectations of the types and amount of waste likely to be generated.
- In determining potential waste recovery or disposal routes, local waste legislation should be adhered to and relevant authorities consulted.
- The availability of temporary storage should be pre-identified in areas of high spill risk to act as a buffer between the collection of oil at sea or on shore and final disposal.
- Where disposal routes exist for different waste streams, waste should be segregated from the point of collection.
- The feasibility of recovering usable oil should be examined before disposal and consideration given to realising some credit in respect of the calorific value of the waste.
- Techniques which lead to the destruction of the oil are preferable to landfill, although they are likely to be more costly.
- The costs of disposal, including handling and transportation, are likely to be a very significant component of the overall cost of a spill response.

TECHNICAL INFORMATION PAPERS

1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
6 Recognition of Oil on Shorelines
7 Clean-up of Oil from Shorelines
8 Use of Sorbent Materials in Oil Spill Response
9 Disposal of Oil and Debris
10 Leadership, Command & Management of Oil Spills
11 Effects of Oil Pollution on Fisheries and Mariculture
12 Effects of Oil Pollution on Social and Economic Activities
13 Effects of Oil Pollution on the Environment
14 Sampling and Monitoring of Marine Oil Spills
15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
17 Response to Marine Chemical Incidents

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this paper may be reproduced with the prior express permission of ITOPF. For further information please contact:

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606
E-mail: central@itopf.com
Web: www.itopf.com

LEADERSHIP, COMMAND & MANAGEMENT OF MARINE OIL SPILLS

TECHNICAL INFORMATION PAPER

10

Introduction

An effective and successful response to a spill of oil depends to a significant extent upon the quality of the leadership shown by those in command or management. An organisational structure is called for that provides leadership through the difficult decisions and compromises that have to be made at all stages of the response. The organisational structure is also responsible for managing the expectations and widely differing demands of the multitude of governmental and private organisations that can be involved, as well as imparting the confidence necessary to cope with political pressure and the concerns of the public.

This paper considers many of the situations encountered in a response to ship-source pollution and explains how effective leadership, command and management can maximise the success of response operations. Many of the subjects touched on are discussed in greater detail in other ITOPF papers in this series, as listed on the back cover, but in particular, the paper on Contingency Planning for Marine Oil Spills.

Overview

Regardless of the levels of planning and preparedness, oil spills are unforeseen and random events that are capable of upsetting and challenging the normal way of life for those affected. While the immediate effects may include localised damage to environmental and economic resources, as well as disruption of social amenities, the long term consequences are rarely as serious or extensive as may have been feared. The initial stages of an incident involving a spill of oil can develop rapidly and it is important to avoid a loss of confidence by averting any perception of confusion or lack of control, and to establish quickly an effective organisational structure with those in charge identified clearly. If the expectations of a rapid response can be met with assured leadership and definitive action, the concerns raised by those affected can be addressed confidently, thereby reducing the opportunity to undermine the efforts of those in charge and, instead, encouraging the parties to work together.

Each oil pollution incident will differ in size and complexity and a pre-requisite for operational success is to establish an organisational structure that is scaled appropriately to the situation. A small spill, such as the accidental overflow of oil from a tank while bunkering in port, may affect local port infrastructure, the response to which may be dealt with by the port authority according to its own administrative structure. However, the response to a serious incident (*Figure 1*) may require considerably more resources, perhaps from outside of the country, and affect several jurisdictions. In which case, co-ordination and management of the different entities within a well defined and well practiced organisational structure will be vital for a successful response.

To ensure that the organisational structure is effective, the roles and responsibilities of personnel identified in local and national contingency plans should be tested regularly and thoroughly through a series of exercises. In this way, even when an emergency situation gives rise to unforeseen problems, responders will be capable of coping with the pressures of a rapidly changing situation competently.

▲ *Figure 1: When a serious incident occurs, the quality of the leadership, command and management of the response will determine the effectiveness of the response.*

An effective response does not necessarily depend on large amounts of specialist equipment or materials. While the availability of such response resources is central to many operations, a successful outcome will be more easily achieved if the necessary infrastructure, logistical support and leadership are in place. Experience has shown that the response to many incidents can be effective even with the most basic of equipment and resources, provided that the organisational structure is clearly defined and understood and the labour is well managed.

Organisational structure

Governments are responsible for the protection of a country's interests and national authorities are in the best position to establish spill response priorities, some of which may involve conflicting interests. For incidents affecting public areas, this responsibility is often established through competent local or national government departments of the country affected who will lead the response and take the decisions necessary. In some countries, the shipowner is required by legislation to undertake the response, overseen by a government agency with whom decisions can be taken. Spills in private areas, for example within the jurisdiction of ports or terminals, may be dealt with by the facility operator, again with oversight from a government agency.

As a consequence, the organisations involved in a response will depend on the location and severity of the incident. Usually three levels, or tiers, of incident and response are recognised[1]. Allocation of an incident to a specific response tier may be based on the estimated amount of oil spilt or the number of jurisdictions affected. As an incident develops, the oil may spread to affect a wider area, resulting in the need to re-categorise the response at a higher tier or level. Consequently, the organisational structure needs to be sufficiently flexible to accommodate scaling the response up or down according to the circumstances.

Irrespective of the severity of the incident, there are a number of key personnel functions within a response organisation that should be fulfilled, including:

- management of the overall response and of individual operations, for example at sea and on the shoreline;
- planning of future operations based on knowledge of the current and forecast situations, including the availability of resources and local sensitivities;
- providing logistical support to these operations, such as sourcing equipment and ensuring the requirements of the workforce are met; and
- record keeping, financial control and other administrative aspects, for example to facilitate the compilation of claims for the reimbursement of costs.

The organisational structure for discharging these functions varies from country to country. Some utilise existing administrative structures while in others the response organisation is formed at the time of the spill, drawing personnel from a variety of sources as the response develops and the workload of existing members of the response team increases.

Depending on the organisations present within the response structure, different approaches are followed when discharging the functions of spill command or management. In organisations that have a hierarchical command structure, such as armies, navies and some coast guards and marine police forces, a designated commander has authority to control operations through subordinates. In a civilian organisation, a management structure is required that can exercise a similar level of control, which is often achieved by senior management of the organisation providing the equivalent leadership. Organisational structures that combine elements of these two approaches are commonly encountered. An established chain of command or existing management structure within the lead organisation, which has complete responsibility for the entire operation, can help to avoid the confusion that may result from divisions of responsibility.

[1] As described in the separate ITOPF paper on Contingency Planning for Marine Oil Spills.

In practice, a number of organisations and agencies may have interest or responsibility for the marine resources, both on the shore and at sea. In many jurisdictions, responsibility for operations at sea and on the shore are split. Control and operational responsibility for work at sea and at the site of the incident often lies with the navy, coast guard or other marine-based authority, which may direct and conduct aerial and vessel operations and oversee salvage activity. The clean-up of oil that strands along a coastline may be the responsibility of a local or regional authority and, in a major spill, may involve several such organisations. Therefore, a response affecting both the shoreline and open sea areas is likely to necessitate the involvement of civilian, military, public and private entities and these divisions can ultimately define the structure of the response organisation.

Only with suitable preparation can the problems associated with co-ordination and management of this diverse mix of organisations be overcome once an incident has occurred and the response has begun. Involving all interested parties in the decision-making process, whether or not they are technically qualified to do so, usually results in a large and unwieldy spill response organisation. This approach is better suited to the development of contingency plans before an incident has occurred; attempting to introduce this level of consensus-building during an incident can lead to delayed decision making and, potentially, the adoption of inappropriate or conflicting response strategies. An effective organisational structure should result in a coherent unit with all participating organisations working co-operatively towards the shared common goal of minimising the impact of the spill. Such a structure requires a clear hierarchy of command or management, with easily understood roles, responsibilities and associated job titles providing for effective leadership. The structure should be able to accommodate the inclusion of external experts, such as ITOPF, on technical issues, for example oil behaviour, appropriate clean-up techniques, environmental concerns and fisheries, with advice on legal matters, media relations, the reimbursement of costs and other matters sought as required. In a major incident it is essential that the demands of other related operations, particularly search and rescue and salvage, can be also accommodated.

Figure 2: The responsibility for clean-up onshore may lie with different organisations than for clean-up offshore. Here soldiers and civil protection workers recover emulsified fuel oil from the shoreline.

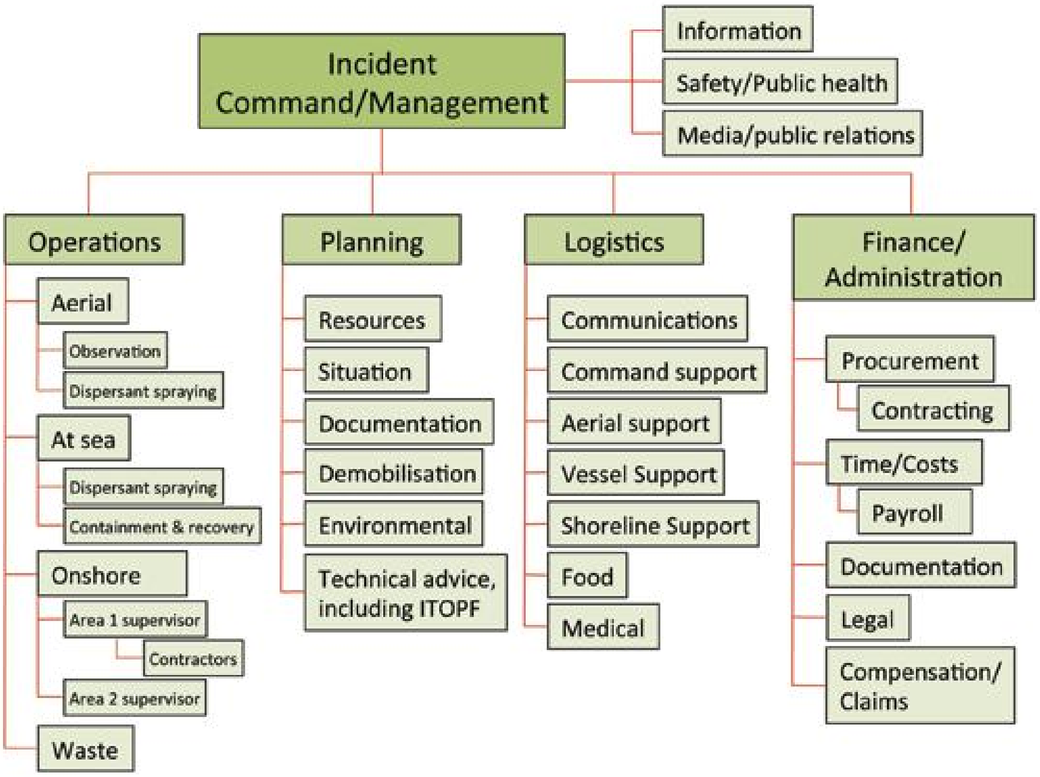


Figure 3a: A function-based organisational structure, with all tasks under a single command and ideally located in a single command centre. In a small incident, some of the tasks may be combined.

Many examples of organisational structures are available, most of which have evolved according to local preferences or prior experience and lessons learnt at incidents and exercises. The generic function and team-based structures (*Figures 3a and b*) are two of the more common examples; the primary difference between them being the division and location of command or management of specific activities.

The Incident Command System (ICS), used most widely in the USA, is an example of a standardised, function-based organisational structure. The ICS is designed specifically to bring together personnel from different organisations and agencies at short notice to work as members of a single structure, within which their roles and responsibilities are well understood. Familiarity with the structure provides a practical means of building a coherent response organisation within a very short timescale. For shipping incidents in the USA, leadership is provided by the Incident Command at the top of the hierarchy, with the response directed by an officer of the United States Coast Guard (USCG) and involving the shipowner and the affected state. Variations of the function-based structure have been adopted in a number of other countries and by some oil industry response organisations.

The alternative team-based structure has been used successfully in the response to oil spills in various parts of the world. The same principles are applied but the approach is less prescriptive and the teams are not separated into individual functions. Instead, positions are established to fulfil different aspects of the response, most commonly at sea and onshore, with support services allocated to each. This has the advantage of promoting self-contained units that can focus on those elements of the response within their remit and can readily accommodate the requirements of the response and the organisations involved. Some specific tasks relevant to all teams are shared. Perceived limitations of both the function- and team-based approaches are explored later in this paper.

Leadership

Irrespective of the structure of the response organisation, the ability of the individual(s) allocated as lead commander(s) or manager(s), will have an important bearing on the progress and outcome of the response. Exemplary leadership is required throughout a response but particularly as an incident develops and difficulties arise, for example when oil affects new areas or response strategies do not provide the expected results and alternative techniques are sought.

The qualities required of a leader would include an ability to:

- command or manage personnel from the diverse range of organisations involved in the response;
- listen and respond to the concerns and suggestions of the various parties involved in the response, including other members of the response team and technical experts;
- assimilate information from a wide range of sources and make timely decisions based on this information;
- set priorities, particularly in situations when conflicting interests may benefit or disadvantage parties, for example when needing to allocate limited resources to a certain area;
- communicate decisions and instructions clearly and authoritatively;
- motivate members of the response team, particularly when required to overcome difficult situations and fatigue;
- recognise the limitations of members of the response team and reallocate tasks accordingly;

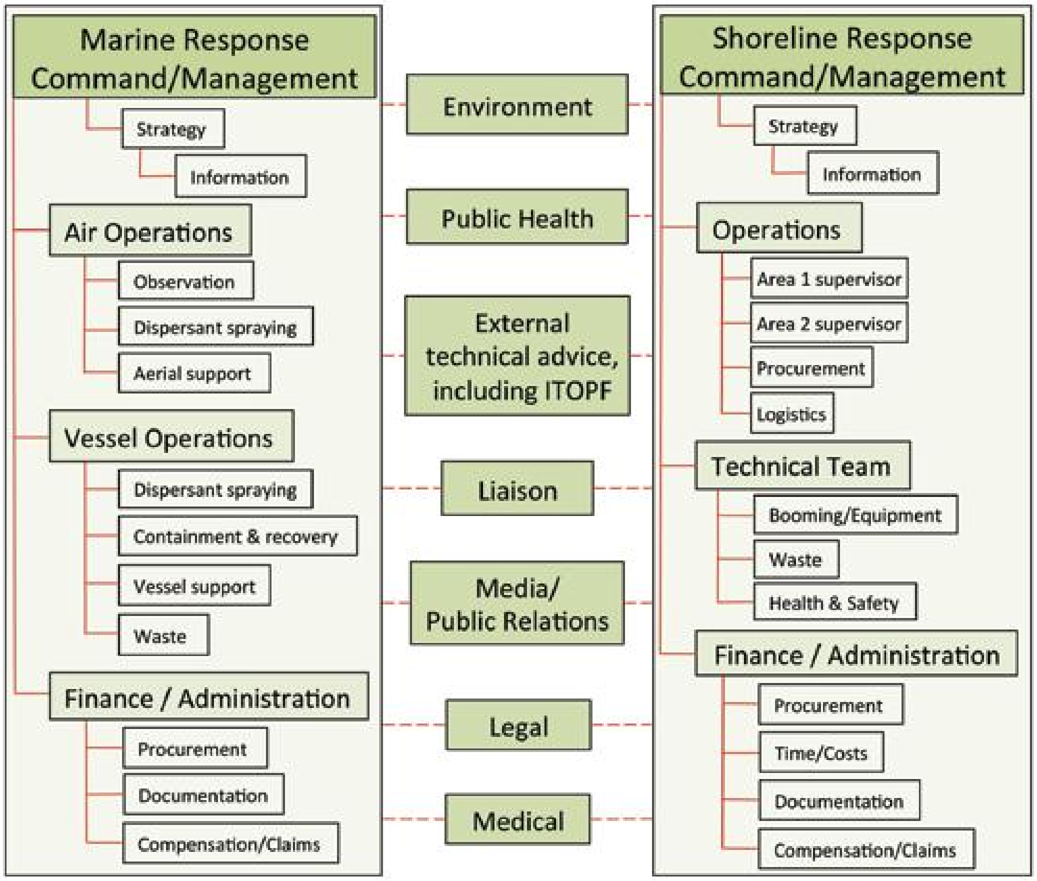


Figure 3b: A team-based organisational structure with two self-contained activities, sharing some functions. This allows marine and shoreline operations to be located at separate command centres, but relies on good communications between the two centres for an effective overall response. In a small incident, some of the tasks may be combined.

- ensure the response is technically reasonable and that pressure placed on the response team, particularly by politicians, the media and public, does not result in unreasonable or dangerous activities;
- appreciate the point at which personnel and resources are no longer required and can be stood down or demobilised, both on site and in the command centre.

Clearly, the task of leader is better suited to an individual with prior relevant experience in a senior command or management position. At the tier one level of response, leadership of the organisational structure may be provided by the harbour master, port captain, terminal superintendent, local authority emergency officer or other such position with the necessary authority. For the more serious, tier two or tier three levels of response, responsibility often rests with an appropriate senior individual from the relevant military or civilian marine-based authority or a related government agency or ministry such as the Ministry of Transport. In other countries, it may be an agency of the Ministry of Environment, the Ministry for Emergency Affairs or a disaster-relief agency. With the team-based structure, the lead commander or manager for each team is likely to come from different organisations and prior experience of working together is an advantage. The issue of seniority is important, as there may be a need to work at a high level with central government, to report to Ministers (or politicians of equivalent rank), to procure resources from other ministries and government departments, and to be able to authorise the allocation of finance to support the response.

Other members of the response team should have the skills necessary to undertake the tasks allocated, for example, a knowledge of aerial operations and the limitations of the aircraft involved or an understanding of contracts and the terminology relevant to specific operations. For operations at specific worksites, individuals with prior experience of managing teams of labour may be necessary, for example, from the construction industry[2].

The long hours and pressures exerted upon members of the response team at all levels can be intense and can lead to extreme fatigue and impaired judgement, particularly during the emergency phase. It is therefore important that, within the constraints of maintaining the pace of the response, members of the response team are allocated deputies or alternates to enable them to take rest periods. The qualifications of the deputy should be similar to the person for whom they deputise and time should be allowed for full hand-over briefings between shifts to ensure continuity.

Role of the shipowner

In countries where governments take the lead in responding to spills, the role of a shipowner may be restricted to crew and salvage matters, or providing technical support and ultimately paying compensation through their Protection and Indemnity

[2] Further information on the management of shoreline clean-up is available in the separate ITOPF paper on Clean-up of Oil from Shorelines.

▲ *Figure 4: Full awareness of the limitation of equipment and of the environments into which they are deployed will help to ensure time and effort is not wasted on actions that can be foreseen not to work. Here, high currents mean the boom will be unable to contain oil.*

(P&I) insurance. In other jurisdictions, legislation may place a requirement on the shipowner to lead the response, with the activities overseen and directed by government.

To ensure that there is clarity, the expectations of government as regards the role of the shipowner should be described in well-publicised regulations. Nonetheless, a successful response relies upon a realistic national contingency plan that establishes a clear organisational structure, showing how the government and the shipowner (or P&I insurer) should interface. In the case of a shipowner-led response, the contingency plan should show how decisions will be made and by whom, as well as indicate which resources are to be provided by each party. Where regulations, contingency plans and logistics are in place to support a shipowner-led response, the necessary infrastructure is also likely to be available, such as spill response contractors and the shipowner's own local organisation or spill management team contracted to manage the response on their behalf. In such instances, excellent communication is necessary between the government agencies and the shipowner's organisation to maximise effectiveness.

Role of ITOPF

ITOPF's technical staff will normally be asked to attend an incident by the shipowner's P&I insurer or occasionally by a government authority, the IOPC Funds or an oil company. However, ITOPF does not represent these organisations or the shipowner but, rather, is provided as a service to support and assist those in charge of the response by the provision of objective technical advice. The role of the technical adviser at the site of a spill will vary according to the circumstances, but normally includes one or more of the following activities:

- advising all parties on the potential fate and effects of the pollutant;
- assisting and advising all parties on the clean-up techniques most appropriate, with the aim of mitigating any damage;
- helping to locate equipment and, in cases where the shipowner is required to mount the response operation, assisting with organising the clean-up and providing the necessary resources;
- undertaking surveys, monitoring the clean-up and advising all parties on the technical merit of the actions;
- investigating any damage to the marine environment and coastal resources, and advising on methods to mitigate losses, including restoration options; and
- advising on the preparation and submission of claims for compensation, as appropriate.

When on site, ITOPF's technical staff endeavour to work closely with all the parties involved in a spill, in order to facilitate technically reasonable response measures. To be able to assist those in charge of the response, the technical adviser needs to interact with the organisation in place to enable them to have an overview of the response and to provide advice as appropriate through the correct channels. This interaction not only helps to maximise the effectiveness of the clean-up, but also facilitates the reimbursement of costs promptly by the organisations paying compensation.

Spill management tasks

The tasks to be accomplished in the management of each stage of the response to a spill are set out in the following section. The term 'management' relates primarily to civilian-type organisations but the principles relate equally to military-type command structures.

Progress through an incident can be broadly separated into seven stages:

- notification of the incident;
- evaluation of its severity;
- determination of appropriate response strategies (*Figure 4*);
- if necessary, mobilisation of resources to implement the strategies chosen;
- reassessment and adjustment of the strategies according to changing situations while coordinating and controlling resources to achieve a successful outcome;
- reduction and termination of operations and waste management;
- review of lessons learnt and recovery of costs.

Notification and evaluation

As soon as notification of a spill is received by a coastal authority, the individuals and organisations identified in the response structure will be alerted. Initially, the information needed to determine the scale of the incident may be insufficient to allow response decisions to be made and resources may be placed on stand-by until the situation becomes clearer.

As information is received, and depending upon the reported size and location of the spill, a judgement can be made about the severity of the incident and the response can be activated according to the appropriate tier. An important decision to be made early in the response is the location of the command centre or centres, which should be central and easily accessible to those within the organisational structure. Each command centre serves as the focal point for the management of the response in the area identified and for liaison with outside interests, including the media. The facilities should include space for the large number of people involved in the management of a major incident and communication systems sufficient to ensure the free flow of information into and out of the command centre. Ideally, this should be in the vicinity of the incident or affected shorelines to allow the ready exchange of information from site and to encourage the management team to visit areas affected and undertake site surveys as time allows. If the spill affects a wide geographical area a number of local operational centres may be necessary, although maintaining central co-ordination will be vital.

Determination of appropriate response strategies

As the members of the response organisation take up their positions, a clear chain of command should be established with the roles and responsibilities of the individual members clearly identified and communicated within the organisation. Information on the state of the casualty, the location of spilt oil, shoreline impact, the weather etc. will be received by the command centre from varied sources. As this information is distributed, recorded and processed by allocated members of the organisation, a coherent picture of the situation will develop and commands to mobilise resources in response to the situation will be issued.

Throughout the response to the spill, but particularly during the initial evaluation stage, knowledge of the prevalent and future weather and sea conditions is important in order to anticipate the risk of oil being carried to sensitive economic and environmental resources. Based on this information, the relevant personnel can be notified, for example, fishing and mariculture operators, tourism facilities, marinas and power stations. Early notification can allow preventive measures to be put in place with minimal delay before the oil arrives. Many other groups, such as wildlife organisations, will also have a keen interest in the response and arrangements to keep them informed should be considered.

Figure 5: While oil has been contained successfully, these efforts may be in vain without a means of recovery from the water surface and temporary storage of the oil.

As the scale and details of the incident become clearer, a number of key response decisions will be required, for example:

- whether to mobilise aircraft for surveillance of the spill and for subsequent monitoring and control of the clean-up operations at sea and onshore;
- which of the available response resources are likely to be most suitable, based on the oil type and environmental considerations;
- where to deploy equipment and personnel taking into account observations of oil movement, the risk to sensitive resources and equipment availability;
- the need for logistical support to enable activities such as transport and temporary storage of recovered oily waste and distribution of fuel for machinery, personal protective equipment (PPE) and food for the workforce; and
- which treatment and disposal routes will be most suitable for the various waste streams, i.e. liquid oil, oiled shoreline substrate, used PPE and sorbent materials.

Adverse weather conditions or excessive currents may mean that no immediate response at sea is feasible and, if coastal sites have already been affected, decisions may focus on the priorities for shoreline clean-up. In a major spill, it is most unlikely that all the economic and environmental resources at risk can be successfully defended, either because of a lack of suitable response equipment or insufficient time to deploy the equipment. As a consequence, decisions may be required as to which sensitive resources should be protected, or affected sites cleaned, in preference to others. For example, boom may be allocated to protect a mangrove stand rather than a sand beach despite the concerns of local hoteliers, as the mangroves will be more sensitive to oil and more difficult to clean. Alternatively, men and equipment may be tasked with recovering bulk oil on the shorelines to prevent remobilisation to other areas in preference to cleaning lightly oiled shorelines, even if they are in amenity areas.

When deciding the most appropriate response options, priority should be given to those techniques that are technically reasonable in the circumstances, that minimise the amount of waste generated, are cost effective and are permitted under national policy and regulations.

Consideration of the advantages and disadvantages of clean-up techniques can assist in minimising the overall impact on the environment and on social and economic activities. Net Environmental Benefit Analysis (NEBA)[3] is a pragmatic scientific approach that can be used to determine which response techniques would allow recovery of the environment more quickly or would provide the greatest protection to sensitive resources in comparison with natural cleaning. By way of example, when considering the application of dispersant to floating oil, the potential impact of the oil on seabird populations might be evaluated against the potentially increased impact of dispersed oil on sub-surface biota. Alternatively, the decision to utilise heavy

[3] *For further information see Choosing Spill Response Options to Minimize Damage. IPIECA Report Series Vol. 10. www.ipieca.org.*

machinery to recover bulk oil and reduce the possibility of the oil remobilising to affect other sensitive areas should be balanced against the potential for long term damage to the substrate.

To ensure the most effective use of response resources, it is important that conflicting and counterproductive response techniques are not undertaken concurrently in the same locality. For example, the use of dispersants (the aim of which is to place oil into the water column) will render booms and skimmers redundant, as they are intended to contain and recover floating oil. Furthermore, dispersants can adversely affect the ability of oil to adhere to sorbent materials and to oleophilic skimmers.

The majority of the individual strategies available in response to a spill of oil are covered in detail in other papers in this ITOPF TIP series[4]. Each paper includes information important to the management of the strategies discussed. A summary of the criteria for the use of the various response techniques, as well as their advantages and disadvantages, is provided in Table 1 for response at sea and Table 2 for response near or on the shoreline.

Mobilisation

Once the initial evaluation has been completed and decisions on response strategies made, appropriate resources can be mobilised. It is important to ensure that the manpower and equipment mobilised are matched to the scale of the spill. For tier one incidents, at the facility or local level, the response team may have sufficient equipment immediately available on site or close by. For tier two spills, affecting the area beyond the immediate source, equipment and materials may be required from other facilities and more distant stockpiles. For tier three incidents, spills of national or international significance, a much more extensive mobilisation of response resources may be required, potentially from other countries. Transport of response resources to the area of the spill may involve considerable logistical effort, for example, chartering cargo aircraft, ferries or other suitable vessels to deliver equipment to islands or otherwise inaccessible locations and contracting road haulage companies. Equipment and personnel arriving from abroad will require quick passage through customs and border security in order for their involvement to have maximum effectiveness. Secure storage and accommodation close to the clean-up area will also be required.

Other parties may be mobilised in addition to those directly involved in response operations, including, for example, salvors, representatives of the ship and cargo owners, the P&I insurer (often represented by a local correspondent with the assistance of local surveyors), oil pollution, fisheries and tourism experts, such as ITOPF, and legal representatives of the various parties involved. For tankers carrying persistent oil, the IOPC Funds secretariat will also follow incidents in the waters of Fund Convention member states. Government authorities may establish a separate salvage unit to oversee the work of salvors on the casualty. Representatives of other government ministries or agencies may also be involved on site, for example, to ensure the safety and marketability of marine products if coastal fisheries and mariculture are likely to be affected.

Not all these parties will be involved directly in the oil spill response and may not have a presence in the command centre as other priorities, such as the welfare of the crew

[4] *Aerial Observation of Marine Oil Spills, Use of Booms in Oil Pollution Response, Use of Dispersants to Treat Oil Spills, Use of Skimmers in Oil Pollution Response, Clean-up of Oil From Shorelines and Use of Sorbent Materials in Oil Spill Response.*

Technique	When suitable	Resources	Benefits	Limitations
Aerial surveillance and monitoring	Necessary in many responses but may be sole activity required if oil is moving away from the shore or is dissipating naturally.	Aircraft – fixed or rotary wing. Remote sensing equipment for advanced surveillance techniques.	Provides the most rapid and straightforward method of obtaining an overview of oil position, volume and movement as well as the extent of shoreline contamination.	Twin engine aircraft required for flying over open water. Experienced observers needed for maximum benefit. Specialised remote sensing equipment may enable surveillance at night or in fog, heavy rain, snow etc.
Containment and recovery	Recovery of floating oil in calm conditions. Best results achieved in large slicks of freshly spilt oil.	Specialised equipment – booms, skimmers, vessels with sufficient and suitable storage and offloading pumps.	In ideal circumstances, a single, suitably equipped vessel can recover a significant amount of oil. Removes pollutant from the sea.	Equipment cannot be deployed in rough weather. Efficiency of skimmers and pumps deceases as oil viscosity rises and as oil spreads and fragments. Often limited by storage availability. Rarely more than 10% of spilt oil recovered.
Dispersants	Floating slicks of oil amenable to dispersion.	Spraying equipment mounted on suitable aircraft or vessels. Stocks of appropriate dispersant.	Can rapidly remove large amounts of oil from the water surface. Can be applied in rougher conditions than would allow containment and recovery.	Efficiency deceases as oil viscosity rises. Largely ineffective on oils with viscosity greater than 5,000 – 10,000 cSt. Limitations on use close to shore or near coral reefs and mariculture facilities.
***In situ* burning of oil**	Floating slicks of freshly spilt oil.	Fire resistant booms, towing vessels, ignition source.	Can rapidly remove large amounts of oil from the water surface.	Minimum thickness of oil required to sustain a burn. Large quantities of smoke produced. Resultant highly viscous residue may sink to the seabed. Weathered oil difficult to burn.

▲ *Table 1: Summary of the primary techniques available for response to oil floating at sea.*

Technique	When suitable	Resources	Benefits	Limitations
Protective booming	In calm water and low currents when floating oil poses a threat to sensitive resources.	Boom, anchors, vessels to deploy, maintain and retrieve boom.	Can deflect oil from sensitive resources.	Will have limited or no effectiveness in currents over ~0.5m/s. Skimmers required to recover contained oil. Requires pre-planning to be most effective.
Use of pumps and skimmers	Recovery of bulk oil in calm water with access from shoreline or shallow draft vessels. Large pools of oil on the shoreline.	Skimmers, pumps, vacuum trucks, temporary storage.	Can recover floating or pooled bulk oil relatively quickly.	Coherent patches of oil required for technique to work effectively. Limited by weather conditions and available storage. Equipment can become blocked by debris.
Mechanical collection	Slicks of high viscosity oil close to the shore or accessible by vessels. Thick patches of oil on the shoreline.	Excavators, bulldozers, shore or vessel based cranes with grabs, storage containers.	Allows recovery of highly viscous oil and recovery of oil stranded on the shoreline.	Can recover a high proportion of water or clean shoreline substrate. Recovery of oil can be slow. Heavy machinery can damage sensitive areas.
Manual collection	Oil stranded on the shoreline. Applicable to recovery of bulk oil and low level contamination.	Access to labour force, personal protective equipment, hand tools, buckets, temporary storage.	Highly selective recovery of oil on many shoreline types.	Can be labour intensive and slow. Requires careful supervision to be most effective and to minimise trampling of sensitive shorelines.
Flushing	Light to moderately contaminated shoreline sediment and oil in sensitive areas.	Pumps, hoses, lances, means of recovery of released oil, e.g. sorbent, skimmers.	Recovery of buried oil without removal of sediment. Removal of oil from sensitive areas with minimal disturbance.	Can produce large amounts of sheen. Care needs to be taken not to undermine root structures on sensitive vegetated shorelines. Otherwise few disadvantages.
Surf washing	Light to moderately contaminated shoreline sediment on exposed shorelines.	Bulldozers, excavators.	Uses natural energy of the surf-zone to clean sediment. Negates removal of sediment from site.	Can produce large amounts of sheen and cause a temporary imbalance of substrate size. Otherwise few disadvantages.
Pressure washing	Light contamination of hard structures e.g. seawalls, rocks.	Pressure washer (preferably adapted for use with seawater), pumps, means of recovery of released oil.	Generally effective for removal of light contamination. Minimal training required to operate.	An aggressive technique that can damage underlying surfaces. High temperatures may affect marine biota.
Pebble washing	Lightly contaminated pebbles and cobbles.	Concrete mixer or other mixing facilities, hot water baths, front loader, storage tanks.	Allows washing of cobbles at, or close to, the affected shoreline. Negates the need to remove sediment from site.	Can be a slow process. Can generate large amounts of oily liquid. 'Fines' (fine clays and sand) can accumulate requiring disposal. Where possible, surf washing is a better method for cleaning this type of substrate.
Ploughing/ harrowing	Light contamination of sand or shingle beaches.	Tractor and towed plough or harrow.	Breaks-up and exposes oiled sediment to washing on subsequent tides. Useful when surf washing is impractical.	Reworking shoreline material can have an impact on sediment dwelling species. Produces sheen.
Sand sieving	Recovery of tarballs and small nodules of oiled sand on sand beaches.	Tractor towed or self-propelled beach cleaning machine, large mesh and excavators, hand sieves.	Driven machines can be an effective way of collecting tarballs over a large area. Minimises collection of clean substrate.	Hand sieving is slow and labour intensive. Small tarballs may fall through mesh. Agglomerates of fresh, lower viscosity oils may break-up and fall through vibrating screens.
Wiping	Light to moderately contaminated rocky or cobble areas with restricted access.	Rags, waste sacks.	Allows cleaning when other techniques cannot be used.	Labour intensive and slow. Requires close supervision to minimise secondary contamination.
Natural cleaning	On exposed shorelines. On sensitive shorelines where other techniques would cause additional damage. Where safety concerns prohibit clean-up.	None. Surveys of the shoreline will allow the progress to be determined.	Allows removal of oil with little human effort. Minimises damage to sensitive areas.	Where possible, removal of bulk oil may be necessary to prevent contamination of nearby areas. Cleaning can be protracted on low-energy shorelines. Most effective during winter storms. May occur too slowly for tourist areas.

Table 2: Summary of the main techniques available for response to oil near and on the shoreline.

or salvage of the vessel and cargo, may require them to be active elsewhere. Nevertheless, the work of these other parties may affect, or be affected by, the clean-up operations. For example, a salvage team may play a vital role in the overall response and regular liaison between salvage and spill response teams will be essential to monitor the risk of further releases of oil from a casualty.

Management of deployed resources

All clean-up activities should be monitored regularly and re-evaluated constantly using information gained from aerial surveillance and personnel on site. Strategic decisions can be reassessed to determine whether the scale of the response remains appropriate to the size and severity of the spill. As the response progresses and operations move from one stage to the next, different response resources and techniques will be required. For example, as the oil weathers, dispersant use may no longer be effective or a change in the type of skimmer to one capable of recovering more viscous oil may be necessary.

Meetings

Regular and frequent operational meetings should be instigated as a priority to review progress, response decisions and logistics requirements (*Figure 6*). Meetings allow the formal introduction of members of the organisation, confirmation of the chain of reporting or command, allocation of identified tasks and the immediate priorities for the response to be established. In a significant spill, a number of different sub-groups may be required. The decisions reached by each sub-group should be passed to the central leadership to ensure coordination among all the groups and to ensure that the decisions take into account other relevant factors. Meetings would usually take place at least daily, preferably early in the morning to discuss reports from aerial observations and in the evening once progress and situation reports from the field have been received.

The initial period of the response, during which the situation may not be fully under control, is often termed the 'emergency phase'. This phase may last from a few days to several weeks, depending, for example, on the period that oil floating at sea threatens sensitive resources. During this period, crucial decisions will be required that will have longer term consequences, thus reinforcing the need for experienced decision makers with appropriate authority.

▲ *Figure 6: Regular meetings of the response team are crucial to ensure all parties are aware of developments and to discuss and plan for future work.*

The emergency phase can be contrasted with the subsequent 'project phase', which is characterised by a clearer understanding of the overall situation and an appreciation of how the response is expected to develop thereby allowing for a greater level of forward planning. Typical indicators that the emergency phase is evolving into the project phase might include:

- the casualty has been stabilised and the threat of further releases of oil has reduced significantly or been eliminated;
- all the oil floating at sea has either stranded onshore, has been carried far offshore, or has evaporated or dissipated; or
- sufficient response resources have been mobilised to address the prioritised concerns and these are working effectively.

Unexpected situations may still arise during the project phase, for example the discovery of oil buried on shorelines, but decisions are often not as time-critical and the results can be predicted with greater confidence. Longer term work could be put out to tender, a process which may be required for contracts of high value in certain jurisdictions. However, even during this more stable phase, it is essential that an air of urgency is retained and that operations do not stagnate, so that local businesses can return to normal and natural recovery of the environment affected can commence as rapidly as possible.

Waste

Waste generated as a result of the response can often present significant problems. In general, the most effective management of oily waste results from a clear strategy to minimise and segregate the various types of waste at source. Careful supervision of the workforce and selection of appropriate clean-up techniques are as important for the management of waste as for the response as a whole. Nevertheless, the amount of waste produced from clean-up operations can be up to ten times the quantity of oil spilt.

Once the response is underway, estimates can be made of the quantity and physical nature of the waste. This information can be used to identify suitable locations for temporary storage of the waste and sufficient transportation to ensure that waste disposal does not disrupt other operations[5].

Demobilisation and termination of operations

Operations shown to be ineffective or to represent an unacceptable risk of additional damage to either environmental or economic resources should be terminated. The costs associated with the response have a strong influence on decisions to terminate clean-up operations and

[5] *Further information is provided in the separate ITOPF paper on Disposal of Oil and Debris.*

should be monitored closely. For instance, the improvement achieved by additional clean-up usually diminishes markedly as work proceeds towards the final stages and at the same time costs can become disproportionately high. Furthermore, organisations that have been engaged in the response from the outset will need to consider the impact that a longer term commitment of their personnel resources will have on their day-to-day operations.

Strong pressure can be placed on those managing the response to adopt non-technical criteria or to retain resources that are excessive or unwarranted when deciding the point at which to terminate a response activity. Oil recovery vessels may be held at sea long after recovery operations might be considered effective, for example after the viscosity of floating oil has increased beyond the capability of available skimmers. On other occasions, thorough cleaning of a sand beach may be undertaken as a result of political pressure, despite the onset of winter storms and the potential for natural cleaning. Nevertheless, if the command structure has clear criteria for deciding when activities should be terminated, these pressures may be more easily resisted.

Joint surveys, undertaken by representatives of the various interested parties, are commonly undertaken in order to facilitate bringing an operation to a successful close. These representatives monitor the progress of the clean-up and decide when pre-agreed end points have been reached and individual worksites can be 'signed off' by regulatory authorities. Equipment can then be demobilised and returned to stores for cleaning and maintenance; any damaged equipment can be repaired or replaced and consumable materials re-ordered as necessary. Finally, temporary waste storage sites and access routes can be restored and other work areas cleaned.

Post spill monitoring

Even after clean-up operations have terminated, there may still be a requirement to monitor areas left to clean naturally, to determine the effects of the oil on sensitive resources over time, or to initiate restoration measures to accelerate natural recovery[6]. These activities generally involve qualified scientists from government agencies, universities, laboratories and other specialised institutions and are often undertaken without the direct involvement of the team leading or managing the response. However, monitoring activities may require the continued presence of organisations involved in the clean-up, for example, landowners or vessel/equipment operators to enable access to high security or remote areas affected.

Review of the response and cost recovery

Many organisations involved in a response will be unfamiliar with the issues associated with an oil spill and can benefit from the lessons learnt by others. The preparation of a detailed report that can be used to record lessons learnt can prove invaluable. The report serves not only as the basis of a review of the response and to update the contingency plan but also to support the preparation of any claims to recover the costs. Although the need for reliable records is essential irrespective of the size of the spill, the volume of paperwork can increase substantially in larger incidents and may make significant demands on the response team. Nevertheless, the quality of the information available for the preparation of an incident report and also to support claims for compensation relies primarily on diligent record keeping[7].

Typical challenges in spill management

In any incident, problems will arise that can place demands on the command or management team or affect the efficiency of the response. A number of issues common to many incidents are described below:

Flexibility of scale

The scale of the response organisation should be readily adaptable to meet the needs of the response, both in terms of addressing the initial size and severity of the incident and in expanding and contracting as the response proceeds. In minor spills, where a small response team may be necessary, and particularly spills at privately operated facilities, many of the management functions can be combined and accomplished by a small number of people. Planning, management, and health and safety of the operation, for example, may all be assigned to the team leader who may have a number of trained assistants able to deal with these tasks rapidly. Reporting to and liaising with government agencies, public and media relations and administrative services might be dealt with by the head office.

Conversely, in a major spill, each of the key functions may require a group of people to complete the necessary tasks. Depending on the nature and location of the incident, functions relating to management of the response may be spread across groups, for example, specific groups responsible for aerial, at-sea and shoreline operations. Similarly, planning functions may involve a number of groups able to keep track of available resources, to prepare for and undertake demobilisation of equipment, and to address environmental concerns. Logistics support groups will ensure appropriate provision of food, safety and medical services (*Figure 7*), as well as the transport of the required personnel, equipment, materials and waste to and from worksites. Additionally, the finance and administration groups will undertake procurement and resource tracking to facilitate the correct payment of bills and the eventual submission of compensation claims.

While highly-structured systems, such as the ICS, can be expanded or reduced to suit the scale of a particular incident, a concern exists that in practice controlling its size can be difficult. This is partly as a result of the system being geared to respond to a worst case scenario and the requirement for the organisations, agencies and contractors identified in the ICS to occupy pre-identified positions within the structure,

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[6] Further information is provided in the separate ITOPF papers on Effects of Oil Pollution on the Environment and Sampling and Monitoring of Marine Oil Spills.

[7] Further information is provided in the separate ITOPF paper on Preparation and Submission of Claims from Oil Pollution.

sometimes resulting in overlapping roles and responsibilities. In the absence of strong leadership many of these positions tend to be filled regardless of the scale of the incident, such that very large numbers of people can be found in the command centre relative to the scale of the response activities at sea or on the shoreline. The ability of these structured systems to incorporate many interests enables a response structure to be rapidly scaled up but it has the inherent disadvantage in that it can also make it difficult to reduce the size of the structure, particularly if each interest has an entitlement to be present. Under the international compensation conventions, the response organisation needs to be proportionate to the size of the incident in order to qualify for reimbursement of associated costs.

Allocating positions within a response organisation

The scarcity of people within a responding organisation with suitable experience and knowledge to direct the response and to provide expert technical advice may be a significant problem. Although training courses and exercises can provide the basic knowledge required, there is no substitute for first-hand experience of the pressures and demands that are associated with emergency spill response. However, the infrequency of spills and the regular reassignment of personnel within some organisations can mean that those who are called upon to deal with a spill may have no comparable experience and so will have to learn as the incident progresses. It is important to acknowledge when a situation is beyond the skills and capability of the response team initially deployed and when to mobilise additional support or to activate a higher tier of response. If necessary, more experienced commanders or managers with stronger leadership skills may also need to be appointed.

Internal communication

Given the customary division of responsibilities between operations at sea and onshore described earlier, a major oil spill will lead to numerous, different organisations working together. Each organisation may have a different management ethos and the individuals concerned may have had little or no contact with each other outside of the incident. This can lead to problems communicating and a potential for confusion among the response team and the wider public. The differences in the separate organisations need to be recognised and addressed as a matter of priority within contingency plans in order to develop an integrated and consistent approach prior to an incident. During a response, procedures should be put in place to promote communication between the various organisations. Exchanging contact details is an obvious first step to achieving this but experience has shown that many communication difficulties can be overcome by ensuring that the space allocated in the command post facilitates discussion between organisations working on related issues. While sometimes noisy, ensuring, for example, that entities concerned with environmental issues are placed together often results in improved interaction and understanding. Quiet areas can be assigned for meetings and interviews.

▲ *Figure 7: The provision of food, warmth and shelter for workers in remote areas can be a challenge for logistics teams.*

In any significant spill, response operations are effectively managed by delegating individual operational functions to specialist teams. However, this division of work can sometimes create artificial barriers to communication and it is essential that this risk is recognised and efforts are made to overcome such barriers. As an illustration, in a function-based structure, such as the ICS, the planning team will require a good understanding of progress on site. Therefore, ensuring that members of the operations team, who are continually in the field, communicate this information to the planning team without delay allows for the timely planning of future operations. Mechanisms for frequent updates between the various teams are built into the comprehensive ICS procedures developed by the USCG and it is important that other organisations adopting the ICS recognise the need to develop similar communication procedures. Nevertheless, the requirement to generate the many forms and other paperwork inherent in this system can sometimes become burdensome and care should be taken to ensure that focus on form filling does not restrict more useful management tasks. In many instances, much benefit can be gained from visits to clean-up sites by all members of the command or management team to allow a better understanding of the work.

With team-based organisational structures, the operational centres for the distinct teams are often established in separate locations. For example, the response at sea may be directed from a naval or coast guard base equipped for communications with vessels and aircraft, whereas the shoreline response is often managed from a local authority building or local hotel etc. The physical distance between sites has the potential to hinder communications between the teams and particular effort will be needed to ensure that those in charge of shoreline operations have information on activities taking place at sea that might affect their priorities, for example:

- planned salvage operations and the risk of further releases of oil;
- information from reconnaissance flights on the movement of floating oil;
- predictions on areas of coastal impact; and
- progress made with operations at sea.

Similarly, the team managing the response at sea should be aware of the effect that their operations could have on the quantity and location of oil stranding on the shoreline. As a consequence, it is vital that efficient lines of communication between the teams are established from the outset and are maintained throughout the incident. One approach is to post liaison officers in each of the operational centres who are charged with ensuring that rapidly changing developments are communicated effectively.

Cross-border spills

Although infrequent, a major incident may result in oil affecting several countries. While each country will have its own response arrangements, a system to deal with joint operations across borders will need to be considered. Different sea sectors may be allocated to each of the countries affected or it may be agreed that one country takes the lead with overall command of joint resources. Close liaison between national organisations is clearly a priority and the adoption of a common language is often found to be helpful. Procedures should be put in place to accelerate the passage of equipment, materials and personnel through border customs and security, for example, by swiftly granting visas where necessary. The ability of vessels and aircraft from one country to operate in the seas or airspace of another will also allow more effective cross-border assistance. Further difficulties can arise when approval schemes for the use of chemicals and other materials are not compatible between the countries involved and when different legal regimes apply, either to the response itself or to compensation arrangements. Regular cross-border exercises and joint contingency plans will assist with the identification of any such inconsistencies and with the development of solutions.

Many of these problems are a particular challenge if response resources are provided by countries further afield and can be a significant barrier to the effectiveness of international aid and assistance, unless addressed properly.

Management of volunteers

One of the most difficult challenges of spill management is to utilise volunteers to good effect. In a major spill, coverage of the incident by newspapers, television, the internet and social media can often attract a large number of volunteers. While this is a potentially valuable and flexible workforce, who may also bring benefits in terms of local knowledge and engendering the trust of local communities, there are a number of issues to be considered when managing this influx of willing helpers. The most appropriate type of work that can be allocated safely and effectively to volunteers and the best method of supervising that work will need to be established early on. Volunteers need to be physically fit, trained to a minimum standard and made aware of safety issues associated with working on the shoreline before they can be used. Volunteers unsuited to manual clean-up work, such as the elderly, could be directed to assist with auxiliary tasks such as providing food for workers. One solution to managing volunteers is to ensure daily registration, at which time safety briefings can be given, PPE issued and work details allocated (*Figure 8*). In general, it is preferable that volunteers are used in the secondary stages of clean-up, once bulk oil removal has been completed by professional responders.

It should also be recognised that volunteer participation in clean-up operations is not cost-free. Although volunteer labour is offered free of charge, their productivity and responsiveness to instruction is unlikely to result in their overall cost-effectiveness matching that of the paid workforce. Comparable costs are still incurred in the provision and subsequent disposal of PPE, feeding and transporting volunteers, as well as providing competent personnel for their supervision. In significant incidents, large numbers of volunteers from beyond the local area may require accommodation and additional assistance. Furthermore, liability insurance may be required to cover the work.

Local fishermen and vessel operators may also volunteer their services to assist with the protection of sensitive resources and recovery of oil close to shore, for example in return for fuel necessary to undertake the work, although their involvement should be coordinated with the wider response at sea.

Volunteers are often directed to assist with wildlife rehabilitation and, while this may be a viable option, the number of volunteers that can be accommodated in this activity may be limited, as the techniques used in cleaning and rehabilitating wildlife become ever more sophisticated. Where employed, volunteers should be trained adequately to prevent injuries to the wildlife and to themselves. Wildlife rehabilitation and volunteer management are both issues that should be addressed in contingency plans.

Wildlife rehabilitation

The priority given to wildlife response differs considerably from one country to another. In some countries, oiled birds are euthanised routinely in order to relieve suffering. In many others, measures for the capture, cleaning, treatment and release of oiled birds and animals are given a high priority and feature prominently in the response. If the treatment and release of oiled wildlife is to be undertaken, there are a number of factors to be considered in the management of this activity, in particular, the availability of suitably qualified

▲ *Figure 8: Volunteers must be properly briefed to ensure they are aware of the objectives of their work and any health and safety issues.*

personnel (including veterinarians) at short notice and their familiarity with established best practice. Suitable treatment centres should be identified early on and, ideally, these will be large open-plan buildings with readily available services such as water and electricity. Local wildlife welfare groups may be able to offer triage facilities, allowing viable birds and animals to be sent to a central treatment centre. In those countries where wildlife issues attract a high priority, there is also likely to be substantial media interest.

As with other elements of the response, costs associated with any wildlife rehabilitation should be in proportion to the scale of the problem for them to be considered reasonable under the international compensation regimes.

Health and safety

Safety of the workforce should be a primary concern[8] with attention drawn to the dangers of slippery and uneven surfaces, liquefied or 'quick' sand, waves, currents, tides etc. Tasks should be allocated according to the ability of the worker, particularly when lifting equipment and waste. Work in extreme heat or cold requires close supervision to prevent dehydration, heat exhaustion or hypothermia. An awareness of poisonous plants, dangerous animals, or unexploded ordnance at a worksite may also be necessary. Working at night can be particularly hazardous and should be restricted to areas with adequate lighting. Clean-up personnel should be allocated appropriate PPE to minimise contact with the oil and chemicals used in the response, and lifejackets for vessel and helicopter operations should be provided. Persons unfamiliar with aerial or marine operations should undergo specific safety briefings. In some jurisdictions, clean-up workers are required by legislation to undergo awareness courses prior to working on-site[9]. Responders working in foreign countries should be aware of specific local risks.

Closure of affected parts of the shoreline or the placement of warning signs may be necessary to limit public access to stranded oil and worksite dangers, for example oil collected in trenches, temporary storage pits and exposed machinery. Interaction with regulatory authorities may also be necessary, for example, spills of lighter oils can give rise to high concentrations of oil vapour that could affect local populations, necessitating specialised air monitoring equipment to assuage concerns. Physical contamination or tainting of seafood can require the temporary closure of fisheries and the involvement of food safety agencies.

▲ *Figure 9: Meetings with members of the public affected may serve to assuage local concerns and improve relations.*

Incidents involving certain types of vessels, for example chemical tankers or container ships, can result in spills of bunker oil and hazardous and noxious substances (HNS)[10]. Even relatively small quantities of HNS may pose a significant risk to human health with attendant implications for local populations Similarly, the response to oil spilt at sea or on the shoreline may not be possible or may be compromised because of the presence of HNS, with frequent monitoring and an appropriate risk assessment required before any response can be initiated.

Given the need for prompt awareness of health and safety issues that could affect the response and the wider public, it is important that the response organisation includes competent individuals or groups to address safety concerns and to ensure that adequate safety and first aid measures are in place.

Media and public relations

In many countries, the media has an important role in an incident, extending beyond the traditional forms of journalism into social media and thus enabling interested members of the public and pressure groups, both locally and globally, to follow and comment on the response. The ease and speed with which information can be circulated means that the wider public may become aware of an incident before the designated national authority has been notified. Similarly, images and video clips taken by amateurs and professionals can be widely disseminated as events occur. This can place immense pressure on the response team, who will see the results of their decisions replayed rapidly and analysed on news channels, websites, blogs and other forms of mass communication.

Under the Civil Liability and Fund Conventions, costs incurred for media and public relations in a response may not be admissible as these activities are not considered to be part of the response. Nevertheless, the response organisation may perceive a benefit in responding constructively to requests from the media and public for information, for example through press briefings and website updates. In so doing, it is important that speculative or unrealistic statements are avoided, for example, understating the size of the spill, premature assertions that oil will not come ashore or stating that the situation is fully under control.

If required, meetings with the public may assist in developing constructive dialogue (*Figure 9*) but should not divert personnel from the response unnecessarily. It is also important to ensure that the response does not become driven

[8] For further information see Oil Spill Responder Safety Guide. IPIECA Report Series Vol. 11. www.ipieca.org

[9] For example the US Hazardous Waste Operations and Emergency Response (HAZWOPER) regulations – www.osha.gov

[10] See the separate ITOPF paper on Response to Marine Chemical Incidents.

or directed by the media and public such that technically unreasonable or unsafe response actions are undertaken.

Media personnel may wish to access affected shorelines and work sites to gain footage and to interview response personnel (*Figure 10*). Controls on site access may be necessary if safety is an issue but, otherwise, media personnel should be briefed but not allowed to interfere with the clean-up activity. Similarly, politicians, other dignitaries and national and international observers may request visits to the command centre and clean-up sites and a dedicated coordinator or guide may be required to ensure minimal disruption.

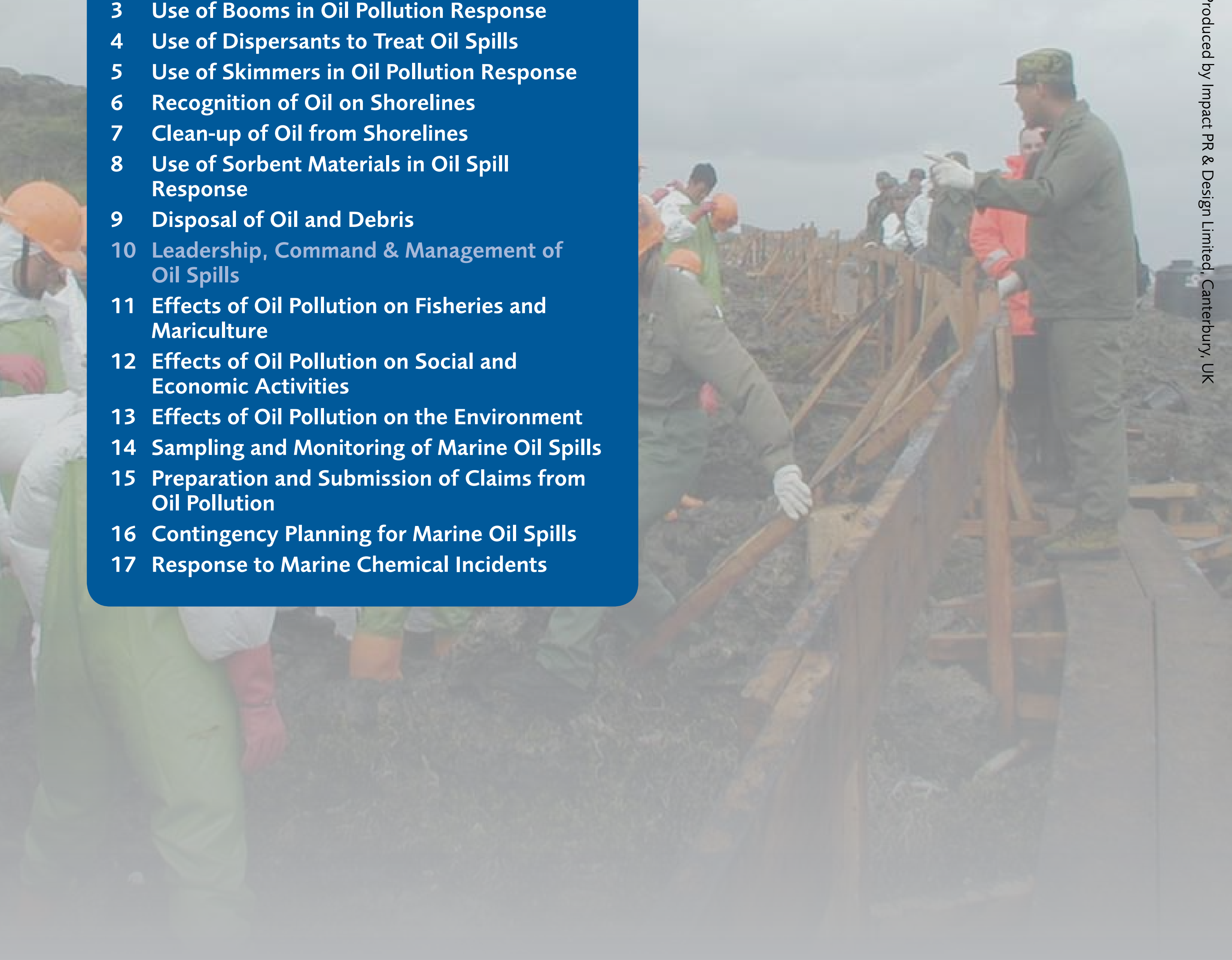
▲ *Figure 10: The media can have an important role but they should not interfere with the response efforts.*

The range of communications media available enables information to be distributed widely and rapidly during an emergency, thereby allowing the public to be kept informed about progress and issues that might affect their use of coastal resources. These communication channels may be an effective means of broadcasting emergency telephone numbers for those affected by the oil, providing information on claims handling procedures, or advising the public where access to affected areas is restricted.

Public awareness, concern and interest in the incident can translate into a willingness to volunteer novel response ideas and to supply equipment and materials from both commercial and non-commercial organisations. As it will be important to monitor and respond to these offers promptly, the extra workload that this generates can place a significant demand on call centres and administrative resources. To address this, dedicated personnel may be necessary to manage and log enquiries, filter information to identify valuable ideas and offers and to pass this information to the relevant section of the response organisation for further action.

Key points

- The key to successful response operations depends on building an organisational structure with effective leadership and management.
- The most appropriate organisational structure for responding to an incident will vary from country to country and it is important to test the structure in place through regular exercises and updating of the contingency plans.
- The organisational structure needs to be capable of being scaled up or down according to the magnitude of the incident.
- A thorough understanding of the roles and responsibilities of each function in the command structure promotes co-ordination and good communication during the response.
- A well organised and managed response instils confidence among the public, press and politicians and reduces the opportunity for others to undermine the efforts.
- A government-led response gives government agencies the greatest control over spill response priorities. For a shipowner-led response to be successful, shipowners' obligations should be clearly identified in national legislation with the appropriate contingency plans and infrastructure in place.
- The response structure should be able to accommodate external experts, advisers, wildlife rehabilitation personnel and other additional functions or personnel as required.
- Clear and open lines of communication between all individuals, teams and groups involved in the response, especially between offshore and shoreline activities if they are located apart, are vital to minimise confusion and delays.
- Mechanisms to manage volunteers, media demands and offers of assistance need to be established, especially in large incidents.



TECHNICAL INFORMATION PAPERS

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this paper may be reproduced with the prior express permission of ITOPF. For further information please contact:

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606
E-mail: central@itopf.com
Web: www.itopf.com

EFFECTS OF OIL POLLUTION ON FISHERIES AND MARICULTURE

TECHNICAL INFORMATION PAPER

11

Introduction

Oil spills can cause serious damage to fishery and mariculture resources through physical contamination, toxic effects on stock and by disrupting business activities. The nature and extent of the impact on seafood production depends on the characteristics of the spilled oil, the circumstances of the incident and the type of fishing activity or business affected. In some cases, effective protective measures and clean-up can prevent or minimise damage.

This paper describes the effects of ship-source oil pollution on fishing and mariculture and provides guidance on response measures and management strategies which may help to reduce the severity of oil spill impacts. Damage to other economic resources is considered in a separate Technical Information Paper.

Damage and loss mechanisms

Fishing (the capture of wild species) and mariculture (the cultivation of captive species) are important industries which can be seriously affected by oil spills in various ways (*Figures 1, 2*). Commercially exploited animals and plants may be harmed as a result of oil toxicity and smothering. Seafood may become physically contaminated or may become tainted, acquiring an objectionable oil-derived taste. Fishing gear and cultivation equipment may be oiled, leading to the risk of catches or stock becoming contaminated or activities being halted until gear is cleaned or replaced. In addition to the losses of individual operators, the interruption of subsistence (*Figure 3*), recreational and commercial fishing activity and the disruption of seafood cultivation cycles can also have important economic consequences. Consumers may become reluctant to purchase seafood products from an affected region and the loss of market confidence can result in economic loss even if there is no actual contamination of the produce.

▲ *Figure 1: Fishing fleets can be affected by spilled oil, either as a result of contamination of vessels and gear or by fishing bans, both of which may force them to remain in port.*

The impact of the spilled oil is determined by its physical and chemical characteristics, in particular the density, viscosity and chemical composition of the oil, and the way these characteristics change with time, or 'weather'. The changes brought about by weathering are themselves largely dependent on the prevailing climatic and sea conditions.

Adult free-swimming fish and wild stocks of commercially important marine animals in the open sea seldom suffer long-term damage from oil spills. This is because oil concentrations in the water column rapidly decline after a spill, only rarely reaching levels sufficient to cause mortality or significant harm, and are usually confined to an area near the source of the spill. In contrast, caged animals and seafood products that are cultivated in fixed locations are potentially at greater risk because they are unable to avoid exposure to oil contaminants on or in the surrounding water.

The greatest impact is likely to be found near-shore, where animals and plants may be physically coated and smothered by oil or directly exposed to toxic components over extended periods of time. For this reason, sedentary species, such as edible seaweeds and shellfish, are particularly sensitive to both smothering and oil toxicity. In addition to mortality, oil may cause more subtle damage to behaviour, feeding, growth or reproductive functions. However, because populations of many marine species normally exhibit significant natural fluctuations, the sub-lethal effects due to an accidental spill of oil can be difficult to isolate.

Damage to seafood may also be caused as a result of measures taken to combat an oil spill. For example, animals and plants that might otherwise be unaffected by floating oil may become tainted through exposure to oil droplets suspended in the water column, particularly if dispersants are used nearby. Aggressive or inappropriate clean-up techniques, such as indiscriminate washing with high pressure and/or hot water, can also adversely affect commercially exploited species and delay natural recovery.

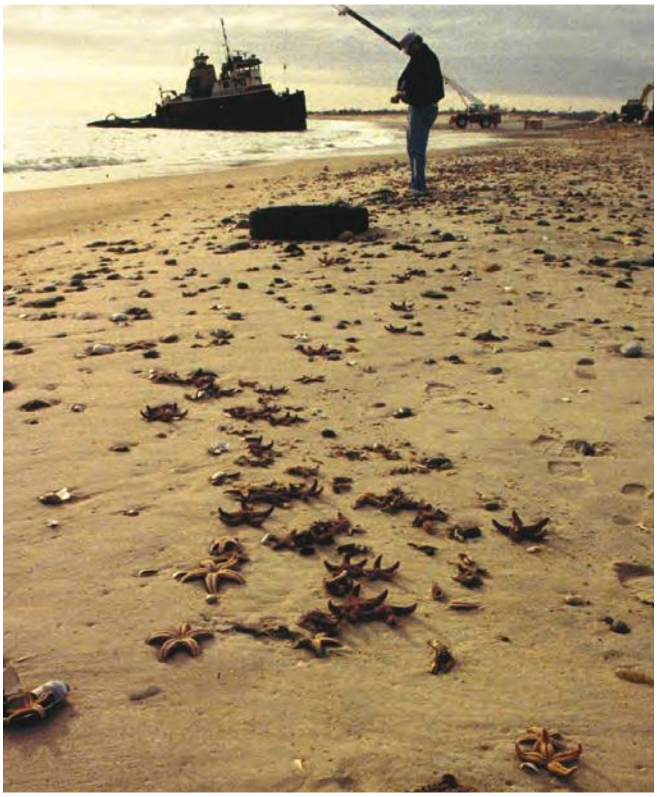
The seasonal cycles of fishing and mariculture vary throughout the year, according to the type of species fished or reared.

▲ *Figure 2: A seaweed farm – fisheries and mariculture are often susceptible to oil spills.*

▲ *Figure 3: Small coastal communities often rely on fishing for income and subsistence and can be severely affected as a result of an oil spill.*

As a consequence, the sensitivity of a species or activity to spilled oil is also seasonally dependent. For example, some of the larger seaweeds grown in Asia are harvested in the spring or early summer and the next generation is not planted out until early autumn. Other faster growing species may have several plantings and harvests throughout the year. The rearing of larvae in onshore tanks supplied with water piped from the sea is similarly seasonal and does not generally extend beyond a few months in any year.

As a consequence, the precise extent and nature of the damage to fisheries or mariculture will depend on a combination of a variety of factors that may arise during a particular oil spill. Neither the spill volume alone, nor any other single factor, provides a reliable indication of the likely damage. Instead, the time of year, the type of oil and how much of the oil reaches these sensitive resources should all be taken into account. One of the most difficult challenges is to distinguish the effects of an oil spill from changes arising from other events, especially natural fluctuations in species levels, variation in fishing effort, including overfishing, climatic effects, for example El Niño, or contamination from industrial or urban sources. In many instances the absence of reliable data to describe the conditions existing prior to the spill, or the levels of productivity previously achieved, serve to compound the difficulty.



▲ *Figure 4: Lobsters, starfish and shellfish affected by a spill of diesel, which dispersed naturally in shallow water during a storm.*

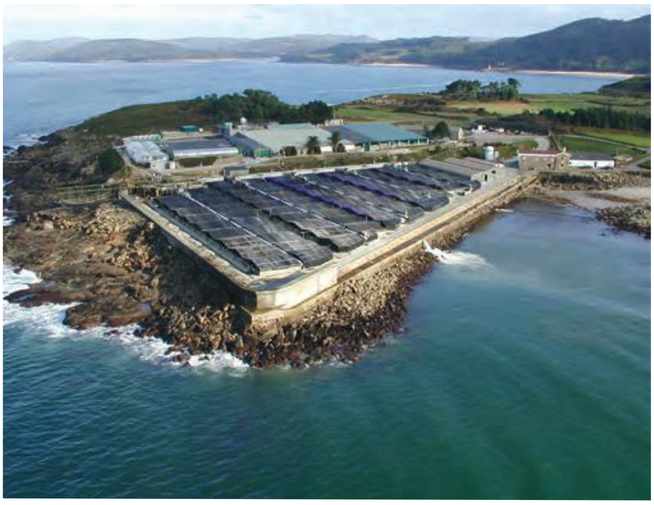
Toxicity

The toxic effects of oil depend on the concentrations of the light aromatic components in the oil and the duration of exposure to these components. Toxicity effects can range from subtle sub-lethal behavioural effects to localised mass mortalities of marine life.

As a generalisation, light crude oils and light refined products, for example petrol or kerosene, contain relatively high proportions of the low molecular weight aromatic compounds that can cause acute toxic effects. Wild stocks occasionally suffer toxic effects following large spills of lighter oils close to the shore, especially in storm conditions or in heavy surf (*Figure 4*). In these circumstances, rather than evaporating rapidly from the sea surface, a relatively large proportion of the lighter toxic components can disperse into the water column and become confined in shallow waters, resulting in sufficiently elevated concentrations to cause narcosis or mortality of marine organisms. Intertidal and shallow sub-tidal benthic fauna, such as bivalve molluscs and crustacea, are particularly vulnerable, but on rare occasions free swimming fish have also been observed to succumb under these conditions.

▲ *Figure 5: Oiled fishing nets and pots may be cleaned, provided they are not too heavily fouled. However, in some instances, replacement may be more economically viable.*

▲ *Figure 6: Fish traps are susceptible to contamination by floating oil.*



▲ *Figure 7: Onshore fish hatcheries require large volumes of clean sea water. Water intakes are usually located below the water surface and may be affected by dispersed oil.*

At lower concentrations, laboratory studies have demonstrated that exposure of test species to the more toxic components of oil can result in impairment of various physiological functions, such as respiration, movement and reproduction, and can increase the likelihood of genetic mutations in eggs and larvae. However, not only is it difficult to detect such sub-lethal effects in the field but the widespread impact on stocks, which might be predicted by extrapolation of the laboratory results to the field, has not been observed. Similarly, despite mortality of eggs and larvae which may occur following a spill, subsequent depletion of adult wild stocks is very rarely recorded. In part, this can be explained by the considerable natural resilience of marine ecosystems to a variety of acute impacts. Marine organisms readily adapt to naturally high mortalities, *inter alia* by the production of vast surpluses of eggs and larvae and recruitment from stock reservoirs outside the affected area.

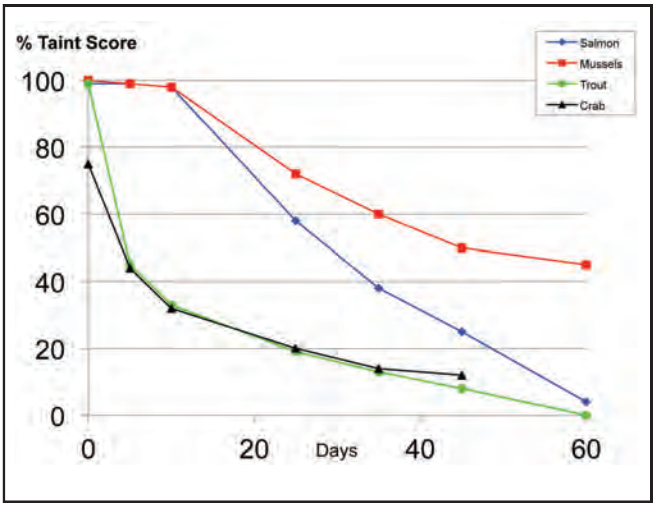
Physical contamination

Oil can foul boats, fishing gear and mariculture facilities and can then be transferred to the catch or produce (*Figure 5*). The rearing and handling of many seafood products in bulk means that it is seldom practical to locate, isolate and remove just the oiled specimens. Flotation equipment, such as buoys and floats, lift nets, cast nets, and fixed traps (*Figure 6*) extending above the sea surface are particularly at risk of contamination by floating oil. Lines, dredges, bottom trawls and the submerged parts of cultivation facilities are usually protected, provided they are not lifted through an oily sea surface or affected by sunken or dispersed oil. Shoreline cultivation facilities, such as intertidal oyster racks (*Figures 16 and 19*) are especially vulnerable. They are usually located in the middle or lower shore, where the natural rise and fall of the tide exposes a band of the shoreline to oil pollution. When fish farming facilities become physically impacted by floating oil, the oiled surfaces may themselves be a source of secondary contamination until they are cleaned.

The cultivation of seaweed, fin fish and many marine animals, such as crustaceans, molluscs, and echinoderms, frequently involves the use of onshore tanks to rear the young to marketable size or to a size and age suitable for transfer to the sea (*Figure 7*). Such facilities are usually supplied with clean sea water drawn through intakes located below the low water mark. These intakes may occasionally be under threat from sunken oil or dispersed oil droplets, which may lead to contamination of pipework and tanks, and the loss of cultivated stock. The presence of oil may significantly add to the stresses already imposed on stock kept in the artificial environment of cages or tanks. If, for example, the stocking density or the water temperature in a fish farm is unusually high, there is a greater risk of mortality, disease or growth retardation, although these may occur irrespective of oil contamination.

Tainting

Taint is commonly defined as an odour or flavour that is foreign to a food product. Oil contamination of seafood can usually be readily detected as a petroleum taste or smell. Bivalve



▲ *Figure 8: Depuration rates (loss of taint) for fish and shellfish after experimental exposure to Forties crude oil (Source: Davis, H.K., Moffat, C.F. & Shepherd, N.J. (2002). Experimental tainting of marine fish by three chemically dispersed petroleum products, with comparisons to the Braer oil spill. Spill Science & Technology Bulletin, Vol 7, Nos.5-6, pp.257-278.)*

molluscs and other filter-feeding, sedentary animals are particularly vulnerable to tainting, since they filter substantial quantities of water and so risk ingesting dispersed oil droplets and oiled particles suspended in the water column. Caged fish, and in particular those with a high fat content, such as salmon, have a greater tendency to accumulate and retain petroleum hydrocarbons in their tissue.

Other factors that influence the presence and persistence of taint include the type of oil, the species affected, the extent and duration of exposure, the hydrographical conditions and the water temperature. Tainting of living tissue is reversible but, whereas the uptake of oil taint is frequently rapid (minutes or hours), the depuration process, whereby contaminants are metabolised and eliminated from the organism, is much slower (weeks) (*Figure 8*). At low ambient temperatures, metabolism, and therefore depuration, may be very slow.

Some of the chemical components in crude oils and oil products which have the potential to cause tainting have been identified, but many remain unknown. Furthermore, although no reliable threshold concentrations have been established, the hydrocarbon concentrations at which tainting can occur are very low. Consequently, it is not possible to determine by chemical analysis alone whether a product is tainted or not. However, the presence or absence of taint can be determined quickly and reliably by sensory testing (also known as organoleptic testing), particularly if a trained panel and well-established testing protocols are employed. Since the levels of contamination that lead to an unpalatable oil taint are very low, it is widely considered, as far as oil contaminants are concerned, that if seafood is judged to be taint-free, it is safe to eat.

Public health concerns

The occurrence of contamination in seafood organisms or products following a major spill can lead to public health

▲ *Figure 9: Seafood is an important protein source for many communities.*

concerns and may give rise to the imposition of fishing restrictions. These concerns stem primarily from the presence of polycyclic aromatic hydrocarbons (PAHs) in the oil. Not all PAHs are of the same potency because of differences in molecular structure that affect their metabolism. Crude oil spills give rise primarily to contamination by low molecular weight PAHs which usually exhibit little or no carcinogenic potential, but are of concern due to their acute toxicity or tainting properties. On the other hand, heavy fuel oils generally contain a greater proportion of high molecular weight PAHs, including those that can be actively carcinogenic. A key factor in PAH mutagenic potency is the formation of reactive metabolites that attach to DNA and can lead to genetic mutations, a particular concern of PAHs of between 3 and 7 benzene rings. Importantly though, because of the physical characteristics of fuel oils and associated emulsions, including their high viscosity and low dispersability, they are less readily incorporated into living tissue, being less bio-available.

Background PAH concentrations in water, sediment and tissues are highly variable and arise from a variety of inputs, including pyrogenic (combustion related), chronic anthropogenic (from human activities) and natural sources. Normal PAH intake through eating seafood varies greatly between individuals and communities according to typical portion size, the frequency with which seafood is eaten and individual body weights. The risk to an individual or community from oil spill-derived carcinogens is therefore dependent on the pattern of consumption of fishery products in any one location (*Figure 9*). Although it is not possible to define a risk-free intake for humans, 'acceptable' levels of PAH in seafood can be developed for specific geographic areas according to the typical level and patterns of consumption. As a consequence, a number of authorities have now adopted Maximum Permitted Levels (MPL) of PAH in marine products. For example, in the European Union the MPL for the PAH Benzo[a]pyrene (BaP) in fish is <2 µg/kg and for bivalve molluscs is <10 µg/kg (*Table 1*).

The US Environmental Protection Agency (US EPA) has identified 16 PAH compounds as 'priority' pollutants which are often targeted for measurement in environmental samples.

Figure 10: Fish for sale – the interruption of commercial fishing activity can have important economic consequences throughout the sales chain, from landing ports to retailers, such as this market stall.

Guidance values have been established based on the sum of these 16 priority PAHs following spills. However, since PAHs form a complex mixture of thousands of compounds, 'total PAH' is often used as a measure of contamination. Total PAH is, however, often difficult to interpret, since it will depend on the nature of the particular components that have been added together to obtain the global figure. For this reason, the identities of the actual PAHs analysed should be specified to allow an evaluation of contamination levels based on a comparison of like-with-like.

The range of relative potency of various PAHs extends over many orders of magnitude. In this respect, BaP is considered a key compound and, because of its presence in cigarette smoke, is the PAH most studied. As a result, a range of guidelines have been developed around the use of BaP as an indicator. As a further step, in order to compare samples from different origins and apply guidelines, Toxic Equivalency Factors (TEF) have been developed whereby the concentrations of individual PAHs are expressed as equivalents of BaP, based upon their relative carcinogenic potency. These values are summed to obtain a Benzo[a] pyrene equivalent figure (BaPE).

Overall human exposure to PAHs from all potential sources is subject to many variables. For example, a wide variety of smoked or barbecued foods also contain the same or similar PAH compounds as might be derived from spilled oil. Leafy vegetables grown close to urban centres may become contaminated by airborne PAHs deposited on the leaves. A further complication for food quality controllers is the fact that seafood quality is also affected by other forms of contamination, such as heavy metals, algal toxins, pathogenic bacteria and viruses. The potential impact of an oil spill on public health therefore has to be viewed in its overall context in order to identify and implement appropriate remedies. Taking into account the amount, frequency and duration of PAH exposure following oil spills, most risk assessment studies have led to the conclusion that there is usually a sufficient safety margin between the levels of PAHs in seafood following an oil spill and those that would lead to a significant threat to public health, even for subsistence consumers.

	Indicator	Guidelines[1]	Target
France - AFSSA[2] (ERIKA 1999)	16 PAH analysed by National Network of Observations (RNO)	∑ < 500 µg/kg DW Sale exclusion>1,000 µg/kg DW	Shellfish
UK FSA[3] (2002)	Benzo[a]anthracene Benzo[a]pyrene Dibenz[a,h]anthracene	∑ < 15 µg/kg WW	All seafood
European Union (2005)	Benzo[a]pyrene (BaP)	< 2 µg/kg WW < 5 µg/kg WW < 10 µg/kg WW	Fish Crustaceans & Cephalopods Shellfish
South Korea (MIFAFF)[4] (HEBEI SPIRIT 2007)	Benzo[a]pyrene equivalent (BaPE)	< 3.35 µg/kg WW	All seafood
US EPA[5] (NEW CARISSA 1999)	BaPE	'Safe' < 10 µg/kg WW 'Unsafe' > 45 µg/kg WW	Shellfish Shellfish
US EPA[5] (KURE 1997)	BaPE	'Safe' < 5 µg/kg WW 'Unsafe' > 34 µg/kg WW	Shellfish Shellfish
US EPA[5] (JULIE N 1996)	BaPE	'Safe' < 16 µg/kg WW 'Unsafe' > 50 µg/kg WW	Lobster Lobster

[1] DW – Dry weight; WW – Wet weight. As a rule of thumb DW = ca. 15% x WW; µg/kg ≡ ppb.
[2] AFSSA: Agence de Sécurité Sanitaire des Aliments.
[3] FSA: Food Standards Agency. This guideline has now been superseded by European Union standards.
[4] MIFAFF: Ministry of Food, Agriculture, Forestry and Fisheries
[5] EPA: Environment Protection Agency. Variation in guidelines limits are primarily due to differing regional diets.

Table 1: Examples of guideline PAH levels used by different authorities to manage seafood safety following oil spills.

Loss of market confidence and business disruption

The disruption of fisheries and mariculture activities and the potential for substantial economic loss are often among the most serious consequences of an oil spill (Figure 10). Public health concerns and the detection of taint are likely to lead to produce being withdrawn from the market. A loss of market confidence may also occur leading to price reductions or outright rejection of seafood products by commercial buyers and consumers. Media coverage of oil contamination, or word-of-mouth, can have implications for the marketability of seafood. However, quantifying financial loss due to loss in market confidence can be difficult, because it depends on reliable data being available to demonstrate both that sales have been lost and that prices have fallen as a direct consequence of the spill.

When it proves impossible to protect fishing gear and cultivation facilities from oil, economic losses are typically suffered until facilities are cleaned and become operational again. Quantifying economic loss due to mortalities of cultivated organisms is often a relatively straightforward process of counting and weighing the affected produce. Lost profit is then calculated from projected harvest weights and the expected market price at the first point of sale, less any saved production costs such as staff wages, feed and fuel. Account also has to be taken of the degree of natural mortality which routinely occurs during cultivation.

Response options and mitigation of pollution damage

When mariculture facilities, structures or nets become contaminated, they can sometimes be cleaned *in situ*, for example, with high pressure washing equipment (*Figure 11*). For more severe contamination, the facilities may have to be dismantled for cleaning. When it is impossible to clean, or cleaning costs are likely to exceed the costs of purchasing new equipment, replacement may be the preferred option (*Figure 12*).

To protect fixed fishing gear and mariculture facilities from contamination, booms and other physical barriers can sometimes be used. However, fishing and cultivation equipment are frequently purposely sited to benefit from migration routes or efficient water exchange and such locations are usually characterised by moderately fast flowing water in which booms are largely ineffective. Fish farms located in calm waters can sometimes be protected with heavy-duty plastic sheeting wrapped around the perimeter of the cages, thereby preventing floating oil from entering the nets or contaminating the floats (*Figure 13*). The sheeting should not extend too far below the water surface and should be weighted at the bottom edge to prevent it from riding up as a result of currents or wave action. In certain situations, sorbent booms can also be deployed around cages.

Although sorbents are not appropriate for the removal of

Figure 11: Mariculture facilities can be cleaned in-situ by pressure washing.

Figure 12: Seaweed cultivation racks heavily contaminated with oil. These could not be cleaned to a satisfactory standard and were therefore dismantled and replaced with new structures.

Figure 13: With sufficient notice, weighted plastic sheeting can be suspended around fish cages in an attempt to prevent contamination by floating oil.

▲ *Figure 14: An oiled abalone farm. Sorbent pads, though inappropriate for bulk oil removal, are often useful for removing sheen from inside fish cages.*

▲ *Figure 15: Fishing restrictions may be imposed to protect public health and to prevent contaminated produce reaching markets after an oil spill.*

bulk oil, they are often useful for removing thin oil films from water surfaces in tanks and cages (*Figure 14*). Sorbent materials have also been used successfully to filter sea water for onshore facilities. In all cases, it is important to replace oiled sorbents to avoid them becoming a source of secondary pollution. Loose particulate sorbent should not be used, as this can be mistaken for feed.

Contamination of equipment by floating oil can sometimes be reduced or prevented by the application of dispersants to slicks at a sufficient distance from facilities and inshore fisheries. The distance necessary to avoid contamination of stock by dispersed oil is dependent upon the strength and direction of prevailing currents and the time required for the dispersed oil to be sufficiently diluted in the water column. As a consequence, dispersant use in the vicinity or up current of mariculture facilities, spawning grounds, nursery areas or water intakes should be undertaken only after consideration of the potential effects.

In addition to standard spill response measures, alternative mitigation strategies include towing floating facilities out of the path of slicks, temporary sinking of specially designed cages to allow oil to pass over, and the transfer of stock to areas unlikely to be affected. The opportunities to use these approaches may be rare for a range of technical, logistical and financial reasons but, in the right circumstances and with sufficient planning, opportunities to avoid contamination and financial loss should not be overlooked.

For shore tanks, ponds or hatcheries, temporary suspension of water intake and re-circulation of the water already within the system may be effective to isolate stock from the threat of oil contamination. Closing sluice gates to prawn ponds, for example, can also afford short-term protection. Suspension of feeding may offer an option to avoid farmed fish and other cultivated stock coming into contact with contaminated feed if food would otherwise be distributed through a surface film of oil. The reduction or suspension of feeding has the additional advantage that the loading of waste products in the re-circulated water is reduced, but care must be taken to ensure that the build-up of noxious waste products in stagnant or re-circulating water does not result in excessive mortality of stock. A balance will be required between the potential damage to stock caused by these mitigating actions and from the oil.

For such mitigation strategies to be effective, it is vital that sensitive fishing and mariculture facilities are identified in contingency plans. Operators should be included in drills and exercises to test their readiness to respond and should be notified promptly in the event of a spill that poses a threat to their facilities, to allow sufficient time for strategies to be put into effect.

In some cases mariculture operators may face the risk of ultimately losing all the stock due to oil spill damage. With sufficient notice it might be possible for operators to harvest stock early, before it becomes oiled. Although the stock may not have reached full marketable size, some of its value could be salvaged. Conversely, normal harvesting might be delayed to allow contaminated stock to become taint-free by natural metabolic processes. However, it may prove difficult to predict a reliable timetable for this process to be completed satisfactorily since depuration rates depend on local conditions and the species involved. In addition, given that depuration rates are likely to be slow, stock may have grown beyond optimal market size, so that alternative and perhaps less lucrative markets may need to be found.

Management strategies

A number of management strategies are available to prevent or minimise the impact of oil pollution. The simplest involves no intervention beyond monitoring the evolution of an oil spill and any threat to seafood quality. Low-key intervention can take the form of guidelines to the seafood industry, for example measures that could be taken to mitigate losses. Where fish are caught by anglers for sport, sufficient protection can sometimes be provided simply by issuing advice against consuming the catch and the temporary adoption of a catch-and-release policy. Stricter measures include retail controls, impoundment of catches and seafood products, activity restrictions and fishery closures (*Figure 15*). Each measure has potential drawbacks and a careful review of the options available is advisable before action is taken. The following four strategies may allow authorities to manage the situation and to confidently allow controls and restrictions to be revoked.

Sampling, monitoring and analysis

The objectives of a well-defined monitoring programme should be to determine the degree, duration and the spatial extent of the oil contamination (*Figure 16*). In principle, in order to introduce a restriction on fishing or sale of products, the sampling and analysis of a relatively small number of samples is often sufficient to confirm the initial presence of contamination or taint and to define the affected area. The minimum number of samples required to obtain reliable results is determined on a case-by-case basis. Monitoring the progressive loss of contamination by sampling at appropriate intervals thereafter allows the point at which levels return to background to be ascertained with some confidence.

The frequency and geographic extent of sampling and testing should be determined by the severity of contamination and the rate at which depuration is observed to occur. One practical approach is to ensure that samples should be taint-free and that levels of PAH are no higher than reference samples collected just outside the affected zone or than found in marine produce freely marketed elsewhere in the country. When two successive sample sets, taken over a short period of time, produce results at acceptable levels, restrictions can be removed or the scope of the ban adjusted as contamination within a distinct area or species is shown to have reduced sufficiently.

It may not be necessary to analyse all the samples taken and some may be retained for later analysis should initial results prove inconclusive or unreliable. Target species will be those of commercial, recreational or subsistence value and which are actually consumed. Carefully selected control samples from nearby areas unaffected by oil pollution are important for reference purposes and to help eliminate the interference from background contamination. In some cases, samples from local seafood markets can provide a benchmark for comparison with samples from oil-polluted areas.

Samples of animal and plant tissue are perishable and must be collected and stored appropriately to preserve their integrity. Clean storage containers should be used (preferably glass) to avoid spoilage and cross-contamination of samples. Chilling or freezing is the most convenient conservation method for counteracting the microbial decomposition of samples in the short term. Collected samples should be sealed, labelled and quickly placed in an insulated container with a suitable refrigerant pack ready for transport to the analytical laboratory or to a freezer facility for longer term storage. It should be recognised that under some analytical protocols even frozen samples become invalid after long periods of storage.

Figure 16: Collecting oyster samples for analysis – the minimum number of samples to obtain reliable results needs to be determined on a case-by-case basis.

Figure 17: Fish and shellfish are usually steamed prior to sensory testing. After cooking, these lobsters have been opened and the white meat will be tested for taint by smell and taste.

Sensory testing

Sensory testing is often the most appropriate method for establishing the presence or lack of tainting and for indicating whether seafood is fit for human consumption (*Figure 17*). Trained taste panels and valid control samples are essential elements in a sensory test protocol. In order to obtain reproducible results and minimise bias, tests should be conducted ‘blind’, that is, the tasters should not know the identity of either control or potentially tainted samples.

Figure 18: Collection of water samples in an enclosed onshore farm. Analysis may indicate the potential for contamination of stock.

Figure 19: Procedures for monitoring the levels of contamination, as with these oysters, should be included in contingency plans to avoid unnecessary fishery closures.

The taint-free threshold can be defined as the point at which a representative number of samples from the polluted area are found to be no more tainted than an equal number of samples from a nearby control area or commercial outlet outside the spill zone. This approach takes account of the fact that there may be variation between individual testers and consumers and that in any population tainted samples may occur for reasons other than an oil spill. The confidence in accepting that the fish or shellfish are clean and safe comes from an adequate time-series of monitoring data showing the progressive reduction in taint following a spill (*Figure 8*).

Chemical analysis

Sensory testing may serve as a useful screening tool. However, the lack of trained taste panels, the greater accessibility and reduced cost of analytical techniques, and the adoption of chemical seafood safety standards by many authorities, means chemical analysis is used more frequently to manage fisheries and mariculture following an oil spill. Most commonly, chemical analysis of PAHs is undertaken using Gas Chromatography linked to Mass Spectrometry (GC/MS). PAH concentrations are then compared with nationally or internationally accepted standards or with levels found in reference samples taken from a local control area.

The selection of samples of seafood organisms for analysis is usually preferable to samples of water and sediment as the organisms effectively 'monitor' the condition of the surrounding water and/or sediment by the processes of accumulating and then depurating contaminants. The water and/or sediment serve as the pathway by which the contaminants reach and become accessible to the organism. As a consequence, in cases where the water column is known to be impacted (for example by visual observation), it is generally preferable to analyse the seafood in order to determine whether or not the contamination has transferred to the organism. Primarily, it is the condition of the seafood, rather than the water or sediment, that is of interest and importance to regulators and consumers. Where the presence of contaminants cannot be ascertained by obvious means, testing of water column samples, particularly from enclosed onshore facilities (*Figure 18*), or of individual indicator species (e.g. mussels) may be necessary to allay fears of contamination to stock.

Managing fishery closures

Fishing and harvesting restrictions can be imposed after an oil spill in order to prevent or minimise contamination of fishing gear and to protect or reassure seafood consumers. Fishermen can agree to a voluntary suspension of fishing activity as a precautionary measure during a period when oil is drifting in their normal fishing area, and thereby avoid repeatedly contaminating fishing gear. Where a voluntary suspension is inappropriate, formal closures or marketing restrictions may be applicable, but it is essential that criteria for reopening and lifting such bans are also considered when restrictions are imposed.

Fishery closures imposed to protect equipment and catches can generally be lifted once the sea surface is visually free of oil and sheen and provided that there is no evidence of sunken oil. Restrictions imposed on the basis of proven tainting or contamination are likely to be more prolonged and require careful monitoring. In most oil spill scenarios, a fisheries and mariculture management protocol will consist of measures such as surveys to confirm the absence of floating sheens or sunken oil, sensory testing to determine the lack of taint and chemical analysis to demonstrate that contamination levels have returned to background or to below Maximum Permitted Levels (MPL). Separately, or more often in combination, these strategies offer scientific credibility and meet the demand to provide adequate safeguards against unpalatable or unsafe seafood reaching consumers.

The criteria for reopening a fishery must be realistic and achievable in terms of the normal seafood quality in the area. Credible decision-making calls for a knowledge of fishery resource management and reliable data on background levels of contamination, both locally and nationally. A good understanding of the physical and chemical characteristics of oil pollutants and how these affect marine plants and animals is also helpful. Seafood consumption patterns and seasonal variations in availability will further help to define the risk to public health and allow regulators to form a considered opinion on risk management.

Seafood quality regulators will have to strike a balance between the need to inform, reassure and protect the public while addressing the risk of raising unnecessary fears. The strategies adopted will reflect the cultural and administrative practices of the country affected and will therefore vary globally. The media can play a valuable role in promoting a rational reaction to temporary restrictions by relaying the results of properly conducted sampling and testing regimes.

Both closure and reopening criteria should form an important part of contingency plans (*Figure 19*). Ultimately, the benefits of a closure need to be balanced against the economic losses that arise from a prolonged disruption of normal fishing and cultivation activity. Paradoxically, oil spill fishery closures can sometimes result in beneficial stock conservation, particularly if the exploited species are non-migratory and the impacts from the oil are minimal.

Key points

- The effects of oil pollution most commonly suffered by the fisheries and mariculture sector are the physical oiling of equipment and contamination of seafood leading to tainting.
- The effects of an oil spill on natural fishery resources and fish populations are extremely difficult to isolate from other factors, such as natural fluctuations in stock, climatic effects, contamination by industrial or urban sources and from over-fishing.
- The effects on commercial and subsistence fisheries can lead to substantial losses.
- The repercussions of contaminated seafood on public perception can be serious unless the issues of market confidence and public health are well managed.
- Arrangements to advise operators as early as possible of the threat of an oil spill to their facilities offers the best opportunity for the use of effective mitigation techniques.
- To maintain confidence in the fisheries sector, management strategies adopted following an oil spill should rely on scientific methods and data to ensure seafood safety and quality.
- In the context of oil pollution, if seafood is taint-free it is widely considered safe to eat because contaminant levels at which humans detect oil taint are so low.
- Effective contingency plans that address fisheries' closures and reopening, as well as oil spill response measures, can prevent or reduce the impact of oil spills on fishing and mariculture.

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ITOPF

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com

EFFECTS OF OIL POLLUTION ON SOCIAL AND ECONOMIC ACTIVITIES

TECHNICAL INFORMATION PAPER

12

Introduction

In addition to the costs incurred in cleaning up oil spills, serious financial losses are sometimes experienced by economic sectors that rely on clean seawater and clean coastal areas. Typically, the greatest economic impacts are felt in commercial fisheries and tourism, although a great number of other sectors can be affected, such as power plants, shipping, salt production or seawater desalination. This paper considers some of the effects of oil spills on a variety of coastal industries and social activities and considers measures which might reduce their impact. Given their particular importance, the effects of oil spills on fisheries and mariculture are considered in a separate Technical Information Paper.

Tourism

Tourism is a key economic sector in most populated coastal areas of the world that can be disrupted by the presence of oil in the water or on the shore, with the most serious consequences likely to arise just before or during the main tourist season *(Figure 1)*. Disruption of traditional coastal activities such as bathing, boating, angling and diving can have a consequent effect for hotels, restaurants and bar owners, as well as sailing schools, camp sites, caravan parks and the many other businesses and individuals who gain their livelihood from tourism. Restaurants serving seafood may additionally experience losses due to reductions in supplies, while those businesses supplying hotels and restaurants may also experience reduced incomes unless they are able to make up losses elsewhere. Much depends on the extent to which such businesses are dependent on the coastline affected.

Some holidaymakers may decide to cancel bookings in the area affected and transfer their holidays to alternative locations. The repercussions of visitors curtailing or cancelling their stay may go beyond losses to commercial businesses, for example, by reduced receipts from car parks operated by local authorities and national parks. Losses may also be incurred by road, rail and sea transport companies that routinely transport holidaymakers to the coastal areas affected.

Affected beaches may have to be closed during clean-up. On beaches that remain open, in addition to the oil itself, the presence of workers and equipment may cause a nuisance. The movement of trucks and heavy machinery to and from affected shorelines may cause further disruption to the local population and may lead to secondary contamination in areas further inland if oil on vehicle tyres is not addressed.

In heavy weather, oil can be carried inshore by airborne spray from waves breaking against a quayside or a rocky shore. Buildings, cars and caravans along a seafront or close to the shore can become spotted with oil and require cleaning and, in some cases, repainting. The cleaning of private shorelines, for example those associated with holiday homes, presents a particular difficulty if the owners are absent and their permission is required to access the shoreline.

Figure 1: Oil spills can lead to severe disruption for the tourist industry.

During an incident, some businesses may be able to find alternative sources of income, for example, by providing food and lodging for those involved in the incident. However, secondary contamination of hotel carpets and fixtures may occur from workers attending the spill, if due care is not taken. A wreck close to the shore can attract substantial numbers of spectators bringing with them the possibility that some businesses – cafés, restaurants, parking, etc – may be able to make up some of their losses.

The physical disturbance to coastal areas and recreational pursuits from a single oil spill is usually comparatively short-lived. Once shorelines are clean, normal trade and activity would be expected to resume, although media attention may cause disproportionate damage to the image of the local tourist industry, aggravating economic losses by contributing to a public perception of prolonged and wide-scale pollution. This could result, for example, in bookings being lost even by hotels and other businesses well outside the affected area. The degradation of the 'brand image' of a region may call for targeted regional advertising campaigns and other promotional activities to counteract negative publicity generated by the spill and restore public confidence.

Aquariums and recreational facilities

Many coastal facilities, such as aquariums, seawater swimming pools and thalassotherapy centres, require a continuous supply of fresh seawater. The water is usually screened to remove debris and sometimes passed through filter beds composed of sand, crushed shells or other materials. While these can provide protection against gross contamination, soluble components of the oil may still get into the water supply, particularly if crude oils or light refined products are spilled.

Operators of these facilities may be able to mitigate the damage from oil in a number of ways. With sufficient warning, the animals in an aquarium might be transported to alternative facilities, but this requires specialist transport and is likely to expose the animals to extreme levels of stress. Depending on the volumes of water required and the degree of oil exposure, filter beds may be constructed using sorbent materials to remove the oil. Alternatively, the water intakes may be closed and water in the system re-circulated with clean seawater brought in by road. In all cases, a balance will be required between potential damage caused by the mitigation activity and that caused by the oil. In addition to the costs of such preventive measures, it is likely that aquariums and other facilities will either be closed or suffer reduced attendance figures for the duration of the incident.

Marinas and fishing harbours

Marinas and fishing vessel harbours are usually enclosed by sea defences to protect moored vessels against adverse sea conditions. The sea defences are often provided by rock armour or tetrapods. If oiled, these can be difficult to clean and, as the oil can penetrate deeply into the structure, they may become a source of secondary pollution. In many instances, a narrow entrance to the marina or harbour allows vessels access to the sea and, with sufficient notice, this could be protected from floating oil by deployment of booms. However, if conditions allow fishing to continue, protection of fishing harbours may be compromised by the passage of vessels entering and leaving the harbour, if not appropriately managed (*Figure 2*).

Vessel cleaning

Once oil has entered a marina or fishing harbour, the hulls of a significant number of vessels, mooring lines and berths can become oiled (*Figure 3*). Oil stains on vessel hulls are typically limited to a band around the waterline. Hulls can usually be cleaned while still in the water if undertaken with minimal delay. Inducing a list in the vessel, thereby exposing the waterline, may allow oil to be removed with rags and one of a range of proprietary vessel cleaning products stocked by yacht chandlers. To avoid secondary pollution, run-off should be recovered, for example by sorbent boom surrounding the work area. Some cleaning materials may damage hull coatings and a small test area should be tried if vessel owners are unfamiliar with the available products. Concerns about product toxicity also mean that the use of cleaning agents may be controlled by local regulations. For more intractable stains, vessels may be slipped or hauled out for cleaning and stronger cleaning agents used. However, some cleaning agents, such as those based on chlorine, ammonia, acetone or ketones, are likely to damage the gel coat of fibre-glass vessels.

The severity of staining depends on a number of factors including the oil characteristics and degree of contamination, the time that the oil is left in place and the type and condition of the hull coating. Older and more porous coatings are likely to be penetrated more easily and therefore stained more heavily than newer ones. Some coatings are finished with a wax polish, which is likely to be removed by the oil, while polymer-based top coats are more resilient.

An area may be established within a marina or harbour where vessels can be cleaned either by their owners or by a contractor engaged specifically for the task. The organisation and logistics required to clean large numbers of vessels

▲ *Figure 2: Successful booming of marina entrances can be compromised if the boom is damaged by vessels entering or leaving.*

▲ *Figure 3: Moored vessels may require cleaning if oil enters a marina or fishing harbour.*

should not be underestimated. Cleaned and oiled vessels should be separated to prevent the risk of re-oiling. If vessels are to be lifted out of the water, the hire of a specialised crane may be required. Additional labour may be needed to handle and clean the vessels and contact with vessel-owners, most of whom are likely to be absent, will be necessary to gain permission for their vessels to be cleaned.

In many marinas, the vessels are moored to floating walkways. If oiled, these can be cleaned with high pressure, hot water equipment. On rare occasions, the walkways may have to be dismantled to allow the floats to be cleaned to prevent secondary pollution.

Ports

Ports can suffer similar problems to marinas and harbours, although on a considerably larger scale, and many port authorities demand that the hulls of commercial vessels are cleaned before the ships are permitted to sail. Specialist cleaning contractors may be required and additional demurrage charges may be incurred while the vessel is cleaned (*Figure 4*). Similarly, vessels sailing through slicks at sea may require cleaning before they are authorised to enter port. Considerable disruption may be caused to normal port operations while vessels undergo cleaning or if vessel movements have to be curtailed. Furthermore, ports typically have large entrances, limiting the effectiveness of booms.

Statistical records show that shipping casualties frequently occur close to the coast and in the approaches to ports. In such cases, the casualty itself may present a hazard to navigation or interfere with the traffic moving in and out of a busy port. Disruption to port operations and potentially to businesses served by the port may necessitate alternative routes for the movement of goods and materials. To minimise disturbance of port activities, work to clean jetties and dock walls should be scheduled around normal port operations. Large vessels, particularly leaving or entering port, should move at slow speed to reduce wash that could disturb booms and other deployed resources, as well as to minimise the spread of floating oil around the port.

The sheltered nature of ports and harbours and the ready availability of spill response equipment in many ports can allow for a rapid and effective response to a spill of oil, particularly if a comprehensive and fully exercised port contingency plan is available. However, removal of oil trapped under wharves and jetties can present serious difficulties because of the numerous piles or columns and difficult and dangerous access (*Figure 5*). A successful approach has been to use fire hoses and the wash from vessels' propellers to deliberately flush the oil out. However, if manual cleaning is required, precautions are needed to ensure the safety of the workforce in the semi-enclosed space under the wharf, especially when tidal fluctuations may further restrict the working head-space. If not addressed, the oil can present a chronic source of secondary pollution as it is flushed out by water movement during berthing operations.

Depending on the nature of the oil spilled, precautions are also required in the enclosed waters of ports and harbours to minimise the risk of fire and explosion. For example, all hot work may need to be stopped after a spill of a volatile oil. Even spills of fuel oils with high flash points warrant additional vigilance, as sparks from hot work can ignite debris, such as rope saturated with oil, which can in turn lead to serious fires with a potential to damage or destroy vessels lying in pooled oil.

Coastal civil engineering & shipbuilding yards

Projects such as sand and aggregate extraction, dredging, land reclamation and coastal construction work can all be put in jeopardy during an oil spill. Typically, the scale of these projects is such that protection using conventional booms is not feasible and disruption is likely to continue until clean-up operations have been completed. Building contracts, in particular, usually have agreed time-lines and penalties may be incurred if these are exceeded due to a spill.

▲ *Figure 4: Specialist clean-up contractors are usually employed to clean larger, commercial vessels.*

▲ *Figure 5: Access underneath wharves may be difficult and dangerous for clean-up crews due to lack of head room and ventilation.*

Port expansion works vary in nature but often involve significant dredging and movement of spoil, the sinking and placement of large pre-fabricated cement structures and rock material, and pouring of cement. Oil passing through or stranding in construction sites risks becoming buried, trapped or otherwise integrated into the sediment or structures and may leach out from hidden spaces on subsequent tides. Contamination of formwork or shuttering into which cement is to be poured may necessitate expert advice from civil engineers before construction can continue. Cleaning of construction sites requires careful supervision to ensure the work is undertaken methodically and safely.

Work on vessels being built or repaired on slipways, such as painting or renewal of antifouling, is likely to be badly affected by contamination by oil, possibly requiring the vessels to be cleaned or the work redone. The external structure of floating dry docks may be contaminated by oil floating within a port. Spills within a floating or land-based dry dock, where oil may be inadvertently released from a vessel during maintenance work or manoeuvring, can be highly disruptive to often tight working schedules and may require considerable effort to clean (*Figure 6*).

Industrial water intakes

Seawater is widely used in a broad range of industries: as a coolant for thermal and nuclear power stations and refineries, as a feedstock and as a coolant for desalination plants, and as a feedstock for salt production. In addition to aquariums and onshore mariculture facilities, seafood processing plants and numerous other users of seawater rely on the ability to draw clean water from the sea. The design of water intakes depends on a variety of factors, such as the volumes of water required and the environmental conditions at a particular site. In quiescent areas with a low tidal range, the intake may be simply a channel at sea level with a sluice to control water flow. Where the location is exposed to waves and a high tidal range, intakes are usually submerged to a depth that exceeds the likely fluctuations in water levels. The possibility that oil will be entrained into the water flow depends on the type of oil, the weather conditions at the time of the spill and the design of the intake itself. Deeply submerged intakes are less likely to be affected, except in storm conditions when dispersed oil may become entrained. Light crude oils are dispersed more easily into the water column than viscous fuel oils and are more likely to present a risk of contamination to submerged intakes. However, in exceptionally severe storm conditions, high density fuel oils may disperse into the water column and even deeply submerged intakes may be at risk.

Many different approaches have been taken to protect industrial water intakes. Some are more effective and offer better protection than others. For example, beach wells draw water through sand which provides a first level of filtration and protection against physical contamination, although soluble components of oil may nevertheless contaminate the water. The protection of intakes at or close to the surface with conventional floating booms and bubble barriers depends on weather conditions and the velocity of the water flow, which should be sufficiently low for these techniques to be effective (*Figure 7*).

Electricity power plants

Electricity power plants use cold seawater circulated through tubes to condense steam from steam turbines. Occasionally following an oil spill, water intakes are shut down as a precaution against damage to machinery and to avoid the more extensive shut-down of the entire plant should condenser tubes and other equipment need to be cleaned. The concern is that the oil will either block the condenser tubes or will interfere with heat transfer so that efficiency of cooling is substantially impaired. The consequences of shutting down a power station are likely to be both far-reaching and severe, as it may become necessary to buy in electricity from other producers to maintain supplies. Consequently, strenuous efforts are usually made to avoid shut-downs.

As well as spill response equipment to protect water intakes, there are normally several levels of defence in place to prevent oil from contaminating the condenser tubes. Debris

▲ *Figure 6: Oil spills in dry docks can occur during routine maintenance operations.*

▲ *Figure 7: Water intakes should be protected to prevent oil affecting heat exchangers that can be difficult to clean and may lead to the shut down of facilities.*

screens, used to remove flotsam and jetsam, can become blocked if the oil is particularly viscous, restricting water flow to the tubes. Additional manpower may be required to avoid blockages by ensuring that the screens are constantly cleaned. Two screens are often run in parallel so that one can be brought out of service for maintenance and cleaning while the other remains in operation. The design of the particular facility may include a sedimentation pond downstream of the debris screens, to allow dense sand particles to drop out before the water enters the plant. Such ponds may provide an opportunity to recover floating oil with skimmers or sorbents and to monitor for signs of oil ingress. While oil droplets entering condenser tubes can adhere to the surfaces as a thin film, in general the oil will be slowly flushed through the system, with only a slight effect on heat transfer. The tubes routinely suffer from the build-up of scale and stiff foam balls are often used to scour tube surfaces. These also work well in removing oil films although they need to be replaced more frequently than when used to minimise scale.

Seawater can also be used to warm Liquefied Natural Gas (LNG) when transforming it from a liquid to a gas prior to distribution in gas pipelines. Water is pumped from the sea surface, where it is warmest, using floating skimmers, to the regasification plant. Floating oil may become entrained in the resultant water flow. Debris screens are unlikely to cope with this type of contamination, with a real risk that oil is distributed through the rest of the plant.

Desalination plants

Two types of desalination plant are in common use: multistage flash distillation (MSF) and reverse osmosis. In MSF desalination plants, brine is heated and passed through a series of stages where the pressure is reduced incrementally with salt-free water vapour evaporating at each stage. The experience with MSF desalination plants has been that a certain level of oil can be tolerated without contamination of the fresh water product or undue effects on heat exchangers. On the other hand, reverse osmosis systems rely on semi-permeable membranes to remove salt from seawater and oil contamination could foul the surface of these very expensive membranes. Some lighter components of the oil may also penetrate to contaminate the product water while more viscous oils are more likely to blind the membrane surface and reduce or block water flow. While it may be possible to successfully clean membranes following mild contamination, it is generally considered that oil would have a seriously deleterious effect on membrane performance.

▲ *Figure 8: The production of salt can be severely affected if an oil spill occurs when water is let into the pans. The brine in the ponds naturally takes on a pink colouration due to the presence of microalgae.*

Salt production

In regions with limited rainfall, salt is often produced by the evaporation of seawater in salt pans along the coast (*Figure 8*) The seawater is collected in shallow ponds and allowed to evaporate in the sun and the wind to produce brine. Insoluble impurities, such as sand and clay, and slightly soluble impurities, such as calcium carbonate, settle to the bottom as evaporation begins. Over a period, the increasingly saline brine is pumped or flows by gravity through a series of ponds until the concentration has increased sufficiently for the salt to crystallise.

Production facilities range from an artisanal scale, with salt pans dug out of mud in salt marshes, to industrial scale with glazed-tile ponds and pumped water supplies. Seawater is generally only drawn into the ponds at high water during spring tides and the flow into the ponds is controlled by sluice gates. In the event of a spill, oil can sometimes be prevented from entering the ponds simply by closing the sluice gates. However, if pollution is prolonged, it may be possible to maintain production by allowing seawater into the ponds through filters constructed from sorbents and shells and by careful monitoring of water quality. While tiled pans can be cleaned relatively easily if oil does get into the ponds, cleaning mud-based ponds can be problematic. The closure of mud ponds over prolonged periods causes them to dry out and leads to the formation of fissures requiring substantial maintenance before salt production can be resumed.

Agriculture

Contamination of crops and farmed animals, although rare, has occurred following a number of marine oil spills. If the spill coincides with high tides and onshore winds, water levels can rise sufficiently to allow oil to strand high up on estuary banks where animals are grazed. In addition, animals such as sheep and cattle may be grazed on the shoreline itself (*Figure 9*) and risk feeding on contaminated feedstuff. In some regions, seaweed stranded after winter storms is collected and used as a fertiliser. Seaweed is cultivated for a number of uses and, as well as a foodstuff, it is used in the production of cosmetics, pharmaceuticals and food additives.

Strong winds and waves can also result in oil being blown ashore in sea spray to contaminate crops and animals. In addition to cleaning the affected animals, supplies of extra feed would be required to replace grazing that has become contaminated. Where oil spills have occurred on navigable rivers and estuaries, livestock, such as ducks and geese, and crops, such as rice irrigated by river water, have also been contaminated. Depending on the severity of contamination, crops may have to be destroyed or additional fertilisers used to enhance the recovery of the soil and to accelerate the natural breakdown of the oil. Clearly, with sufficient notice, livestock can be excluded from polluted shorelines and sluice gates to irrigation channels closed.

Coastal communities, heritage sites and cultural artefacts

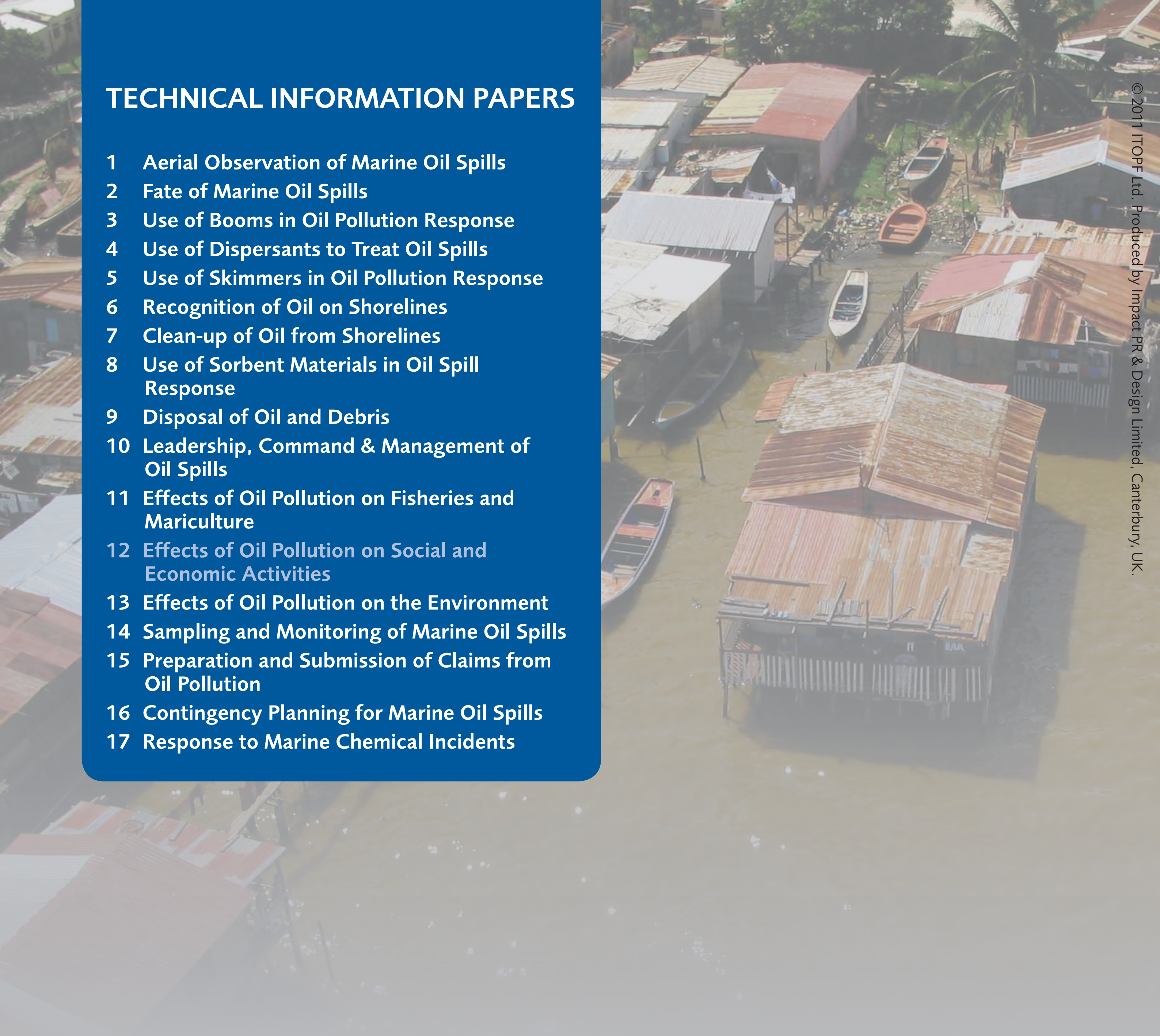
The smell of oil stranded or floating close to the shoreline can be very unpleasant and presents a severe nuisance to people living along the affected coastline. A major spill of a volatile crude oil close to a centre of population is likely to raise health concerns and complaints of breathing difficulties, headaches and nausea. In some parts of the world, coastal communities live on the shoreline or, in some cases, even over the water in accommodation built on stilts. In such cases, the contamination of the shoreline can be more than a nuisance and can interfere with day-to-day life. In extreme cases, the oil may represent a fire hazard and necessitate the evacuation of such communities.

Damage may be caused to cultural artefacts, either through direct contact with oil or as a result of clean-up operations. There may be concerns that human remains buried on shorelines can be disturbed by efforts to clean the shoreline and often the location of such sites is only known to archaeological specialists and local communities. Shoreline clean-up has to be undertaken with great care and under expert supervision. The cleaning of heritage sites requires equivalent care and sensitivity. The surfaces of ancient buildings which have weathered and have become porous or are crumbling and where oil stains have penetrated deeply present enormous difficulties. Specialist restoration techniques may be called for since the aggressive techniques which might be used to clean rock faces on the shoreline would probably cause further damage. Provided that sufficient warning of an approaching slick is given, buildings can be wrapped in polythene sheet to protect the ancient stonework from airborne droplets or oil splashing up from the water's edge.

Figure 9: Livestock on the shoreline may be affected by oil directly or through contaminated foodstuff.

Key points

- A wide range of industries that rely on clean seawater can incur substantial losses following an oil spill. The fisheries and tourism sectors are frequently the most seriously affected.
- In many cases early notification would permit effective contingency arrangements to be put in place to protect marinas and industrial water intakes.
- Although enclosed port waters offer optimum conditions for spill response, the need to minimise disruption to port activities means working around ship movements and can result in extended clean-up operations.
- The consequences of a precautionary shut down of a power station or desalination plant may have far-reaching consequences and may be unnecessary if measures can be put in place to maintain operations.
- Other activities, such as the production of sea salt, coastal engineering and even agriculture have all been adversely affected by oil spills. Where feasible, contingency plans should consider measures that could be used to mitigate impacts.



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THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com

EFFECTS OF OIL POLLUTION ON THE MARINE ENVIRONMENT

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TECHNICAL INFORMATION PAPER

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Introduction

Oil spills can seriously affect the marine environment both as a result of physical smothering and toxic effects. The severity of impact typically depends on the quantity and type of oil spilt, the ambient conditions and the sensitivity of the affected organisms and their habitats to the oil.

This paper describes the effects of ship-source oil spills and resultant clean-up activities on marine flora and fauna, and their habitats. Particular attention is devoted to discussing the complex interactions between oil and biological systems, which have been the subject of diverse studies over many years. Separate ITOPF papers consider the specific effects of oil on fisheries and mariculture and on wider human activity.

Overview

Oil spills can cause a wide range of impacts in the marine environment and are often portrayed by the media as 'environmental disasters' with dire consequences predicted for the survival of marine flora and fauna. In a major incident the short-term environmental impact can be severe, causing serious distress to ecosystems and to the people living near the contaminated coastline, affecting their livelihoods and impairing their quality of life (*Figure 1*). Images of oiled birds following a spill encourage the perception of widespread and permanent environmental damage with the inevitable loss of marine resources. Given the highly charged and emotional reaction usually associated with oil spills, it can be difficult to obtain a balanced view of the realities of spill effects and subsequent recovery.

The impacts of spills have been studied and documented in the scientific and technical literature over several decades. Consequently, the effects of oil pollution are sufficiently well understood to allow for broad indications of the scale and duration of damage for a given incident. A scientific appraisal of typical oil spill effects reveals that, while damage occurs and can be profound at the level of individual organisms, populations are more resilient. In time, natural recovery processes are capable of repairing damage and returning the system to its normal functions. The recovery process can be assisted by removal of the oil through well-conducted clean-up operations, and may sometimes be accelerated with carefully managed restoration measures. Long term damage has been recorded in a few instances. However, in most cases, even after the largest oil spills, the affected habitats and associated marine life can be expected to have broadly recovered within a few seasons.

Mechanisms for oil spill damage

Oil may impact an environment by one or more of the following mechanisms:

- physical smothering with an impact on physiological functions;

Figure 1: Oil stranded on the shoreline adjacent to a fishing village.

- chemical toxicity giving rise to lethal or sub-lethal effects or causing impairment of cellular functions;
- ecological changes, primarily the loss of key organisms from a community and the takeover of habitats by opportunistic species;
- indirect effects, such as the loss of habitat or shelter and the consequent elimination of ecologically important species.

The nature and duration of the effects of an oil spill depend on a wide range of factors. These include: the quantity and type of oil spilt; its behaviour in the marine environment; the location of the spill in terms of ambient conditions and physical characteristics; and the timing, especially in relation to the season and prevalent weather conditions. Other key factors are the biological composition of the affected environment, the ecological importance of the component species and their sensitivity to oil pollution. The selection of appropriate clean-up techniques and the effectiveness with which operations are conducted can also have a significant bearing on the effects of a spill.

The potential effects of a spill are also dependent upon the speed with which the pollutant is diluted or dissipated by natural processes. This determines the geographical extent of the affected area and whether or not sensitive environmental

▲ *Figure 2: Typical effects on marine organisms range across a spectrum from toxicity (especially for light oils and oil products) to smothering (intermediate and heavy fuel oils (IFO and HFO) and weathered residues).*

resources are exposed to elevated concentrations of oil, or its toxic components, for a significant period of time. Of similar importance is the extent to which organisms are vulnerable and sensitive to oil pollution. Vulnerable organisms are those which, because of their positioning in the marine environment, typically at the sea surface or the water's edge, are more likely to come into contact with oil. Sensitive organisms are those that would be acutely affected by exposure to oil or its component chemicals. Less sensitive organisms are more likely to withstand short-term exposure. In a number of countries, shorelines have been mapped and indices attributed to different habitats according to sensitivity. For example, the resultant maps or sensitivity atlases accord mangrove forests or saltmarshes a high index, while sandy beaches generally feature at a low index.

The characteristics of the spilt oil are important in determining the extent of any damage (*Figure 2*). A spill of a large quantity of highly persistent oil, such as a heavy fuel oil (HFO), has the potential to cause widespread damage in the intertidal zones of shorelines through smothering. However, toxic effects are less likely for HFO, or other highly viscous oil that has low water solubility, as the chemical components of the oil have a low biological availability. Oil incorporated within 'asphalt pavement' (a conglomerate of highly weathered oil and shingle) is similarly less bio-available, irrespective of its duration on the shoreline, although indirect damage may occur due to habitat modification.

In contrast, the chemical components of kerosene or other light oils have a higher biological availability and damage through toxicity is more likely. However, rapid dissipation, through evaporation and dispersion, means light oils may be less damaging overall, as long as sensitive resources are sufficiently distant from the spill location. On the other hand, effects can be expected to be greatest and longer lasting in situations where dilution is slowed, such as when the pollutant becomes trapped in muddy sediments or in enclosed areas, for example shallow lagoons with poor water exchange. At exposure levels lower than those sufficient to cause mortality, the presence of toxic components may lead to sub-lethal effects such as impaired feeding or reproduction.

The marine environment is highly complex and natural fluctuations in species composition, abundance and distribution over space and time are a fundamental feature of its normal functioning. Within this environment, marine animals and plants have varying degrees of natural resilience to changes within their habitats. The natural adaptations of organisms to environmental stress, combined with their breeding strategies, provide important mechanisms for coping with the daily and seasonal fluctuations in ambient conditions. This in-built resilience means that some plants and animals are able to withstand a certain level of contamination by oil. Nevertheless, spills are not the only anthropogenic pressure on marine habitats. Widespread over-exploitation of natural resources and chronic urban and industrial pollution also contribute significantly to the degree of variability within marine ecosystems. Against a background of high natural variability, more subtle damage inflicted by an oil spill, such as a downturn in breeding success, productivity or biodiversity, can be difficult to detect.

Recovery of the marine environment

The ability of the marine environment to recover from severe perturbations is a function of its complexity and resilience. Recovery from highly destructive natural phenomena, such as hurricanes and tsunamis, demonstrates how ecosystems can re-establish over time, even after severe disruptions with extensive mortality. While considerable debate exists over the definition of recovery and the point at which an ecosystem can be said to have recovered, there is broad acceptance that natural variability in ecosystems makes a return to the exact pre-spill conditions unlikely. Most definitions of recovery instead focus on the re-establishment of a community of flora and fauna that is characteristic of the habitat and functioning normally in terms of biodiversity and productivity.

This principle can be illustrated by the experience of inappropriate clean-up operations following the loss of the tanker TORREY CANYON off the coast of England in 1967, in which the use of toxic cleaning agents on rocky shorelines led to considerable damage. Although the detailed distribution of particular species present was altered and the effects of the perturbation could be traced over more than two decades, the overall functioning, biodiversity and productivity of the ecosystem was re-established within one to two years. Under the definition proposed above, the rocky shore community could be said to have recovered within the two year period. Nevertheless, the limitations of this definition can be recognised by considering the age distribution of the component organisms. Instead of the full range of ages prior to the incident, from juveniles to mature organisms, the newly recruited plants and animals fell within a narrow age range and consequently the community was, initially, less robust.

Similarly, if a mangrove stand is damaged, either by the effects of a spill or by natural phenomena, such as a tropical storm, in time, the affected area will be re-colonised by juvenile plants from adjacent areas. However, these replacement plants will all be of a similar age and will not provide the same full complement of environmental services until the trees reach maturity. These observations lead to a distinction between effects and damage, where, in some cases, less significant effects (in terms of the normal functioning of an ecosystem), may still be detected after an ecosystem has recovered from pollution damage.

Recovery mechanisms have evolved to deal with the pressures of predation and other causes of mortality. For example, one of the most important reproductive strategies for marine organisms is broadcast spawning, whereby vast numbers of eggs and larvae are released into the plankton and are widely distributed by currents. In most cases, only a few individuals in a million survive through to adulthood. This high fecundity gives rise to the over-production of young stages, thereby ensuring a considerable reservoir not only for the colonisation of new areas and recruitment into areas affected by the spill, but also for the replacement of individuals lost from the population. In contrast, long-lived species that do not reach sexual maturity for many years, and which produce few offspring, are likely to take longer to recover from the effects of a pollution incident.

In most cases recovery typically takes place within a few seasonal cycles and for most habitats within one to three years, mangroves being a notable exception, as shown in Table 1, below.

Habitat	Recovery period
Plankton	Weeks/months
Sand beaches	1 – 2 years
Exposed rocky shores	1 – 3 years
Sheltered rocky shores	1 – 5 years
Saltmarsh	3 – 5 years
Mangroves	10 years and greater

Table 1: Indicative recovery periods after oiling, for various habitats. The period is dependent on many factors including the amount and type of oil spilt. Recovery is defined here as the point at which the habitat is functioning normally.

Marine environments

The following sections consider the different types of damage caused by ship-source oil spills in various environments.

Offshore and coastal waters

Most oils float on the sea surface and are spread over wide areas by waves, wind and currents. Some low viscosity oils may disperse naturally within the top few metres of the water column, particularly in the presence of breaking waves, where they are rapidly diluted. If the release of oil is continuous over time, concentrations of dispersed oil in the upper levels of the water column may be sustained close to the point of release. Notwithstanding this, the impact of spilt oil on species lower in the water column or on the sea bed is low, although damage may arise from sunken wrecks, spills of very heavy (or low °API)* oils or the tarry residues remaining after oil fires.

Plankton

The pelagic zones of seas and oceans support a myriad of simple planktonic organisms, comprising bacteria, plants (phytoplankton) and animals (zooplankton). These include the eggs and larvae of fish and invertebrates, including those which eventually settle on the sea bed or shoreline. Plankton naturally suffer extremely high levels of mortality, primarily through predation, but also through changes in environmental conditions and transport into regions where survival is unsustainable. In contrast, particularly favourable conditions with a plentiful supply of nutrients can lead to plankton blooms whereby populations dramatically increase, notably in spring in temperate climates. Once the input of nutrients subsides or the nutrients are consumed, populations collapse and the dead organisms biodegrade and fall to the sea bed. The ecosystem has evolved to respond to these extremes by copious production within short generation times. As a consequence, plankton typically display extremely patchy distribution both in space and time, ranking them among the most variable of all marine communities.

The sensitivity of planktonic organisms to exposure to oil has been well established and there would appear to be potential for far-reaching impacts. However, the typically massive over-production of young life stages provides a buffer for recruitment from adjacent areas not affected by the spill, sufficient to make up losses of eggs and larval stages, such that significant declines in adult populations following spills have not been observed.

Fish

Despite the susceptibility of juvenile stages of fish to relatively low concentrations of oil in the water column, adult fish are far more resilient and effects on wild stock levels have seldom been detected. Free-swimming fish are thought to actively avoid oil. In exceptional circumstances depletion of the year class for a particular species has been recorded but mass

** American Petroleum Institute gravity.*

▲ *Figure 3: Corralling oiled African penguins (Spheniscus demersus).*

▲ *Figure 4: Penguins benefit more than other bird species from cleaning. Here, rockhopper penguins (Eudyptes moseleyi) are rehabilitated.*

mortalities are rare. Mortalities that have occurred have been associated with very high, localised concentrations of dispersed oil in the water column in storm conditions, with the release of substantial quantities of light oils into breaking surf along a shoreline, or with spills in rivers. The impact of oil spills on exploited fish stocks and cultivated marine products is considered in greater detail in the separate ITOPF paper on the Effects of Oil Pollution on Fisheries and Mariculture.

Seabirds

Seabirds are the most vulnerable open water creatures and in major incidents large numbers may perish. Sea ducks, auks and other species which raft together in flocks on the sea surface are particularly at risk. However, significant mortality in seabird populations can also arise from unrelated causes, such as storms or loss of a food source or habitat. Post-mortem studies may be required to identify the cause of death and whether this can be attributed to a particular incident.

Fouling of plumage is the most obvious effect of oil on birds. The plumage acts to trap warm air against the skin, providing both buoyancy and insulation. When oiled, the delicate structure of the protective layer of feathers and insulating down is disrupted, allowing seawater to come into direct contact with the skin, resulting in loss of body heat and the bird may ultimately succumb to hypothermia. In cold climates, a small oil spot on a bird's plumage may be sufficient to cause mortality. In many species, a layer of fat beneath the bird's skin acts both as a further insulating layer and as an energy reserve. This reserve may be rapidly consumed as the bird attempts to keep itself warm. A bird that is suffering from cold, exhaustion and a loss of buoyancy may drown. Furthermore, oiled plumage reduces the bird's ability to take off and fly in search of food or to escape predators.

Once oiled, a bird's natural instinct is to clean itself by preening which may spread the oil over otherwise clean areas of its body. Oil is very likely to be ingested which can have serious effects, such as congested lungs, intestinal or lung haemorrhages, pneumonia and liver and kidney damage. On return to the nest, oil can be transferred from a bird's plumage to that of its live young or to hatching eggs. Oil contamination of eggs can lead to eggshell thinning, the failure of the egg to hatch and developmental abnormalities.

There is no clear link between the quantity of oil spilt and the likely impact on seabirds. A small spill during the breeding season, or where large populations of seabirds have congregated, can prove more harmful than a larger spill at a different time of year or in another environment. Some species respond to colony depletion by laying more eggs, breeding more frequently or by younger birds joining the breeding group earlier. These processes can assist recovery, although recovery may take several years and also depends on food supply, habitat availability and other factors. While it is common for short and medium term losses to be recorded, the above recovery mechanisms may successfully prevent long-term impacts at a population level. However, in some circumstances there may be a risk that an oil spill could tip a marginal colony into permanent decline.

Cleaning and rehabilitation of oiled birds may be attempted, but for many species typically only a small fraction of treated birds survive the cleaning process. An even smaller proportion of those birds that are released tend to survive in the wild and breed successfully. Penguins are often an exception and are generally more resilient than many other species. When handled properly, the majority are likely to survive cleaning and rejoin breeding populations (*Figures 3 and 4*). Even for penguins it has been found that the breeding success of birds that have been cleaned is less than for those that escaped oiling altogether. Nevertheless, the development and promulgation of bird cleaning best practice is helping to improve outcomes.

Marine mammals and reptiles

Whales, dolphins and other cetaceans may be at risk from floating oil when surfacing to breathe or breach. Harm to nasal tissue and eyes from oil has been postulated. However, where mortalities have been recorded, necropsies have generally concluded death resulted from causes other

▲ *Figure 5: Oil can adversely affect the ability of mammals, such as this seal pup (Arctocephalus australis), to maintain vital physiological functions.*

▲ *Figure 6: A juvenile hawksbill turtle (Eretmochelys imbricate) being cleaned (Image courtesy USCG).*

than oil. While large tropical marine mammals, such as the herbivorous sirenians (manatees and dugongs), might also be expected to be vulnerable, reports of oil pollution damage to these animals are very rare. However, seals, otters and other marine mammals that haul-out or spend time onshore are more likely to encounter and suffer from the effects of oil. Species that rely on fur to regulate their body temperature are the most vulnerable to oil as the animals may die from hypothermia or overheating, depending on the season, if the fur becomes matted with oil (*Figure 5*).

Floating oil may be a threat to marine reptiles, such as turtles, marine iguanas and sea snakes. Turtles in particular are vulnerable during the nesting season. Loss of eggs and hatchlings may occur if oil strands on sand beaches or if nests are disrupted during clean-up operations. Adults can suffer mucus membrane inflammation increasing susceptibility to infection. However, there are many cases where oiled turtles have been successfully cleaned and returned to the sea (*Figure 6*). All species of sea turtle are endangered or threatened through human activities principally due to inadvertent fishing bycatch, deliberate targeting for food and shells and loss of habitat.

Shallow inshore waters

Damage in shallow waters is most often caused by oil becoming mixed into the water column by strong wave action or by the inappropriate use of dispersants too close to the shore. In many circumstances the dilution capacity, for example due to tidal flushing, is sufficient to keep concentrations of oil in the water below harmful levels. On the other hand, where light refined products or light crude oils have become dispersed into shallow water leading to high concentrations of the toxic components of oil, mortality of bottom-dwelling (benthic) animals and those living in the sediment has occurred.

Seagrass

Different species of seagrass are found in temperate and tropical waters. They support a highly diverse and productive ecosystem, sheltering many other organisms. Beds of seagrass reduce water currents, thereby increasing sedimentation, while the root structures stabilise the seabed, protecting coastal zones from erosion. Floating oil is most likely to pass over seagrass beds with no ill effects. However, if oil or its toxic components become mixed into these shallow inshore waters at sufficiently high concentrations, seagrass and associated organisms may be impacted. Clean-up operations in the vicinity of seagrass should be undertaken with care, as the plants can be torn or pulled out by vessel propellers and boom anchors.

Corals

Coral reefs provide an extremely rich and diverse marine ecosystem, are highly productive and offer coastal protection to otherwise exposed shorelines. Corals are highly sensitive organisms that can take a long time to recover from oiling. Dispersed oil presents the greatest risk of damage to coral reefs. This risk is highest where increased turbulence from breaking waves encourages natural dispersion of spilt oil and where dispersants are used. In addition to the coral themselves, the communities which the habitat supports are also sensitive to oil. Consequently, dispersants should not be used in the vicinity of coral reefs. On rare occasions, coral reefs may dry out at spring tides, presenting a risk of smothering from floating oil.

Vessel groundings present a more prevalent source of damage to coral reefs than oil pollution. Other anthropogenic impacts can also induce stress in corals, for example, overfishing or destructive fishing practices, nutrient pollution and increased sedimentation due to deforestation and coastal construction projects.

Shorelines

Shorelines are exposed to the effects of oil more than any other part of the marine environment. However, much of the flora and fauna on the shore are inherently resilient, since they must be able to tolerate the tidal cycle as well as periodic exposure to pounding waves, drying winds, extremes of temperature, variations in salinity through rainfall and other severe stresses. This tolerance also gives many shoreline organisms the ability to withstand and recover from spill effects.

Rocky and sandy shores

Exposure to the scouring effects of wave action and tidal currents means that rocky and sandy shores are the most resilient to the effects of a spill (*Figure 7*). This scouring also usually enables natural and rapid self cleaning to take place. A typical example of an impact on rocky shores in temperate climates is the temporary loss of the common limpet (*Patella vulgata*), a keystone species of marine snail. 'Keystone' species are plants or animals that exert a controlling influence on the ecosystem that is disproportionate to their biomass, and their removal is likely to lead to a dramatic change to that ecosystem. Limpets grazing on micro-algae on rock surfaces limit algal growth and settlement of other fauna. Their loss typically leads to a rapid growth of opportunistic green algae (*Figure 7 inset*). Over time this algal growth is displaced by other algal species and as space becomes available for limpets to re-colonise the rock surface, the ecological balance is gradually restored. On tropical and sub-tropical sandy shores, ghost crabs (*Ocypode sp.*) occupy a similar environmental niche as limpets and high mortality rates are a common feature of shoreline oiling. Despite this, within weeks of shorelines becoming clean, the crabs often re-colonise the beaches in similar numbers as before.

Soft sediment shores

Fine sands and mud are found in areas sheltered from wave action, including estuaries, and tend to be highly biologically productive (*Figure 8*). They often support large populations of migrating birds and indigenous sediment dwelling invertebrates, including bivalves, and are also nursery areas for some species.

While fine sediments are not as readily impacted as other substrates, oil can become incorporated through flocculation with sediment stirred up by storm activity or penetration through worm burrows and open plant stems. Pollutants that do penetrate fine sediments can persist for many years, increasing the likelihood of longer-term effects.

Saltmarshes

The upper fringe of soft sediment shores is often dominated by saltmarsh vegetation comprising woody perennials, succulent annuals and grasses. Saltmarshes are usually associated with temperate climates but occur throughout the world, from sub-polar regions to the tropics. On tropical shores, saltmarshes are often associated with mangroves, occupying the upper and lower intertidal zones respectively. Species composition is determined to a large extent by salinity. For example, in low salinity or brackish waters found in the upper reaches of estuaries, marsh vegetation gives way to reed beds. Plant detritus carried away from marshes also contributes to food webs in estuaries and nearshore waters. Many saltmarshes have been attributed special conservation status under the Ramsar Convention on Wetlands of International Importance, due to their importance as habitats for birds, especially migratory species.

▲ *Figure 7: Rocky shorelines are commonly exposed to wind and waves and may rapidly self-clean. Biota including limpets may be affected by oil. Significant mortality may result in the subsequent abundance of opportunistic flora (algae and seaweed) that would otherwise be kept under control through grazing. Over time, species re-establish and equilibrium will be restored.*

Figure 8: Soft sediments are often found along sheltered, less dynamic shorelines and are usually highly biologically productive. Leaving an oiled marsh to clean naturally should be considered, as clean-up operations have the potential to extend and aggravate the damage. Oil penetrating into the substrate, as shown in the cross-section sample, can remain for years.

The impact of an oil spill on saltmarshes depends on the time of year relative to periods of plant growth. Temperate or cold region marshes are dormant during winter months, while in the Mediterranean growth is slow during high summer temperatures. A single event is unlikely to cause more than temporary effects but longer term damage, possibly over several years, can be inflicted by repeated, chronic oiling or by aggressive clean-up activity, such as trampling, the use of heavy equipment or removal of contaminated substrate. Cleaning of a saltmarsh is difficult without risking additional damage and so it is frequently recommended to leave marshes to clean naturally. However, if burning or cutting vegetation is to be contemplated, this is best done after the vegetation has died back. In general, as long as the roots or bulbs of the plants are not harmed by serious oiling or excessive compaction during the clean-up, seasonal re-growth may be expected to follow.

Mangroves

Mangroves are salt-tolerant trees and shrubs growing at the margins of sheltered tropical and sub-tropical waters. Mangrove stands provide a valuable habitat for crabs, oysters and other invertebrates as well as important nursery areas for fish and shrimp. In addition, the complex root structure traps and stabilises sediment, thus reducing erosion of coastlines and minimising deposition of terrestrial sediments on adjacent seagrass beds and coral reefs.

Their location means that mangroves are highly vulnerable to oil spills. Mangroves are also considered to be extremely sensitive to contamination by oil, dependent to a large extent on the substrate in which the mangroves are growing. Mangroves typically grow in dense muddy anaerobic sediments and rely on oxygen supplied through small pores (lenticels) on aerial roots (*Figure 9*). Heavy oil inundation of the root systems may block this oxygen supply and may cause the mangroves to die. However, in open aerated sediments, which allow relatively free water exchange, the root systems draw oxygen from seawater and so have a higher tolerance to smothering by oil. In the second mechanism, the toxic components of oil, notably in light refined products, interfere with the plants' systems for maintaining the salt balance, thereby affecting their ability to tolerate salt water. Experience has indicated that loss of mangroves due to heavy oil smothering appears to be less likely than mortality due to inundation with lighter products, including some cleaning agents, which can result in localised loss of tree cover.

Organisms living within the mangrove ecosystem can be impacted both by direct effects of the oil and also the longer term loss of habitat. Natural recovery of the complex mangrove ecosystem can take a long time and reinstatement measures may have real potential to accelerate the recovery process in such habitats.

Long term damage

An effective clean-up operation usually includes removal of bulk oil contamination, reducing the geographical extent and duration of pollution damage, and allowing natural recovery to commence. However, aggressive clean-up methods can

▲ *Figure 9: Mangroves are highly vulnerable to oil. Coating of stilt roots or pneumatophores (breathing structures growing vertically through the substrate) can cause blockage of the lenticels (pores) preventing the exchange of gases and leading to asphyxiation.*

cause additional damage and natural cleaning processes may be preferable. Over time, several factors reduce the toxicity of oil so that the contaminated substrate can support new growth (*Figure 10*). For example, oil can be flushed away by rain and tides and as the oil weathers the volatile fractions evaporate, leaving less toxic residual oil.

As the marine environment has such a strong capacity for natural recovery, the impact of an oil spill is usually localised and transitory and there are few documented examples of long term damage. However, under certain specific circumstances, damage may be persistent and impairment of an ecosystem longer-lasting than might typically be expected. The circumstances that tend to lead to acute long term damage are associated with the persistence of oil, particularly where oil has become trapped within the sediment and is protected from normal weathering processes. Examples include sheltered habitats, such as marshes, shingle shorelines and nearshore waters, especially when an oil spill coincides with storm conditions. A storm surge inundating a marsh, with the associated turbulent conditions, is likely to bring fine sediments into suspension and into contact with naturally dispersed oil. Once the storm abates, the oil incorporated within the sediment settles to the marsh floor. Similar circumstances result in oil being incorporated into fine sediments and settling in nearshore waters. In both situations, anaerobic conditions slow any degradation of the oil. On shingle shorelines, the weathering of the mixture of oil and shingle can result in the formation of an asphalt pavement, which may persist for some time. Oil products that are more dense than seawater, such as very heavy oils or fire residues, fall to the seabed where they can remain undisturbed for indeterminate periods and may result in localised smothering of benthic organisms.

Post-spill studies

Research into the effects of oil pollution has followed almost every major incident since the loss of TORREY CANYON. As a result, a very substantial body of knowledge now exists on the likely environmental effects of a spill. Given this level of knowledge it is therefore neither necessary nor appropriate to consider post-spill studies after every spill. However, in order to determine the specific extent, nature and duration of the impact arising from the particular circumstances of an incident, post–spill studies may sometimes be necessary. Since the effects of oil pollution are, for the most part, well understood and predictable, it is important that studies focus on quantification of conspicuous damage rather than attempting to investigate a wide array of hypothetical impacts. The variability exhibited by the marine environment means that the study of an extensive range of potential impacts are very likely to lead to inconclusive results.

The techniques available for chemical analysis of pollutants are continually evolving. Concentrations of the potentially toxic components of oil can now be measured down to levels of parts per trillion (ppt, ng/kg, 1×10^{-12}). One of the most important objectives of damage assessment studies is to establish both a pathway for the observed damage and the qualitative identification of the particular oil contaminant responsible, particularly in chronically polluted environments. This is usually done by Gas Chromatography linked to Mass Spectrometry (GC-MS) analysis.

Figure 10a: Intrusive clean-up of the marsh has caused additional damage over and above that caused by the oil.

Figure 10b: The cleaned marsh after seven weeks with signs of new growth apparent.

Figure 10c: After 22 months, the marsh has full ground cover, albeit with opportunistic species.

Figure 10d: After three years, the marsh has returned to full species diversity.

Figure 10: Natural recovery of a damaged marsh.

Biomarkers are routinely used to screen animals for exposure to the polycyclic aromatic hydrocarbons (PAH) found in crude oil and oil products. For example, measurement of EROD (Ethoxyresorufin-O-deethylase) activity detects enzyme levels in liver tissue, involved both in the metabolism and elimination of toxins and also in the development of cancerous tumours. This technique is sufficiently sensitive to indicate exposure to PAH without detectable body burden and so can provide an early warning of potential damage. However, changes in the levels of activity of this enzyme are also indicative of other causes of stress, such as the presence of other similar toxic materials unrelated to oil. Activity levels also reflect the age and reproductive status of the animal, as well as changes in temperature. It is important, therefore, that such studies take account of these potentially confusing factors.

Studies may be prioritised according to a number of factors. Firstly, the baseline against which effects are to be established: whether by reference to pre-spill data, where this exists; by comparison with equivalent species, communities or ecosystems at reference sites outside the affected area; or by monitoring the recovery of a feature of conspicuous damage, such as the mortality of seabirds or shell fish. Plankton provides a poor subject for investigation. Although both laboratory and field studies have demonstrated mortality and sub-lethal effects upon exposure to oil, variability of the plankton is so high that comparisons between pre- and post-spill situations are likely to be unreliable. Other factors to be considered include the geographical extent of the affected area, the degree of contamination and related levels of exposure (concentration and duration) and the importance of the affected resource, i.e. its rarity or ecological function. Finally, the practical feasibility of conducting the studies should be considered. Feasibility may relate to financial support or simply the practicality of accessing study sites or the risk of disruption to the site during the period of study. Further guidance on designing and conducting post-spill studies can be found in the separate paper on Sampling and Monitoring of Marine Oil Spills.

Restoration, reinstatement and remediation

Restoration, also known as reinstatement or remediation, is the process by which measures are taken to restore the damaged environment to conditions where it is functioning normally more quickly than might be expected from natural recovery processes alone. The terms are often used interchangeably in the context of environmental damage. However, in comparing environmental law in the United States and European Union with the international regime of the 1992 Civil Liability and Fund Conventions (CLC & FC), the interpretation of the terms can be different. Guidance provided by the 1992 Fund Claims Manual** indicates that within the international regime, **reinstatement** measures should have a realistic chance of significantly accelerating natural recovery without adverse consequences for other natural or economic resources. The measures should also be in proportion to the extent and duration of the damage and

** *http://www.iopcfund.org/publications.htm* the benefits likely to be achieved. Damage is considered as the impairment of the marine environment, where impairment in this context can be described as the abnormal functioning or absence of organisms within a biological community, caused by the spill.

The US regulations promulgated under the 1990 Oil Pollution Act (OPA '90) also acknowledge natural recovery as a key mechanism for **restoration** but introduce two concepts: primary and compensatory restoration. Compensatory restoration is intended to compensate for environmental services 'lost' during the period that the environment is undergoing recovery, whereas primary restoration refers to actions taken to restore or accelerate recovery and is equivalent to reinstatement under the international regime. The 2004 EU Environmental Liability Directive (ELD) also includes these concepts in terms of **remediation**. However, the international regime does not recognise the concept of compensatory restoration or remediation.

Figure 11: An area of mangrove, created from planting individual seedlings in a grid pattern.

Following a clean-up operation, further active steps may be justified to restore damaged resources and encourage natural recovery, especially in circumstances where recovery would otherwise be relatively slow. An example of such an approach following an oil spill would be the replanting of saltmarsh or mangrove plants (*Figure 11*). Once the new growth has become established other forms of biological life return and the potential for erosion of the area is minimised.

Designing meaningful reinstatement strategies for fauna is a much greater challenge. Damaged habitats may be protected and recovery of ecosystems may be enhanced, for example, by restricting access and human activity, by placing controls on fishing to reduce competition for a limited food source, as is the case with sand eels and puffins, or by closing beaches used by turtles during the nesting season. In some cases, protection of a natural breeding population at a nearby, un-oiled site may be warranted, for example by predator control, to provide a reservoir from which re-colonisation of the damaged areas can occur. However, many complex biological, ecological and environmental factors are likely to govern the ability of adjacent populations to re-colonise a polluted area.

In reality, the complexity of the marine environment means that there are limits to the extent to which ecological damage can be repaired artificially. In most cases natural recovery is likely to be relatively rapid and will only rarely be outpaced by reinstatement measures.

Key points

- A wide range of highly complex ecosystems exist within the marine environment and substantial fluctuations in abundance and diversity occur as a feature of their normal functioning.
- The marine environment has a strong capacity for natural recovery from severe perturbations caused by natural phenomena as well as oil spills.
- The key mechanisms for environmental damage from oil spills are smothering and toxicity but the severity of the damage depends very much on the type of oil spilt and how quickly it dissipates relative to the location of resources sensitive to oil pollution.
- The most vulnerable organisms are those found on the sea surface or shorelines.
- Saltmarshes and mangroves are the most sensitive shoreline habitats.
- Seabirds are particularly at risk. Some species, and penguins in particular, respond well to cleaning, however, others may not survive for long when released back into the wild after cleaning or may have difficulty breeding successfully.
- Although short-term impacts can be severe, lasting damage is unusual even following the largest incidents. Where observed, long term damage has been restricted to geographically discrete areas where conditions have permitted accumulations of oil to persist.
- Effective planning and execution of response operations both mitigate damage and provide the first step to recovery by the removal of oil.
- Well designed reinstatement measures may sometimes enhance natural recovery processes.

TECHNICAL INFORMATION PAPERS

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ITOPF

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com

SAMPLING AND MONITORING OF MARINE OIL SPILLS

TECHNICAL INFORMATION PAPER

14

Introduction

Following a spill of oil, governments and other organisations often wish to know the extent of contamination of key resources or the impact of the incident on the marine environment. This information is important to determine if prompt action may be required to protect human health or sensitive resources. To facilitate decision-making, monitoring programmes may be undertaken, which will often involve surveys and the collection of samples of oil, water, sediment or biota for chemical analysis.

This paper provides a broad overview of the monitoring and sampling procedures that can be used for qualitative and quantitative monitoring of oil contamination. While qualitative analyses can confirm the source of oil contamination, monitoring programmes are often concerned with the quantitative changes in hydrocarbon levels over time. Guidance on analytical best practice is given and common terminology is explained. However, the techniques and observations required to monitor specific ecological or biological effects and to monitor contaminants in the air are beyond the scope of this paper.

Overview

Following a spill, monitoring can be undertaken in a number of different ways depending upon the objectives of the monitoring programme. Documenting the extent of oil contamination through the use of aerial reconnaissance, boat- or shore-based surveys is usually undertaken as a first step in any monitoring programme. This enables the distribution and extent of the pollution to be identified and, for resources at risk, it may be possible to formulate response strategies for their protection. Delineating the extent of the contamination visually (*Figure 1*) will assist with the design of any monitoring programme and allow sampling stations within and outside the area affected to be identified according to the specific objectives of the monitoring. The rationale for undertaking monitoring after an oil spill varies from incident to incident. Monitoring may not always be necessary, especially if the spill is small and resources are not at risk, or if the effects of the oil on a particular resource are well known. Where monitoring has taken place, it has often been carried out with the following objectives, to:

- authenticate the origin of the oil pollution;
- establish the risk of transfer of contaminants to the human food chain;
- ascertain the effects of the pollution on commercial fish and shellfish to support decision-making regarding the need, or otherwise, to impose fishing restrictions;
- verify the cause and effect; that is, to establish whether or not any environmental effects observed are directly attributable to elevated oil concentrations arising from a particular pollution event;
- measure hydrocarbon concentrations in sediment or water to aid decision-making over the continuation or termination of the response;
- determine the decline of hydrocarbon concentrations in the marine environment and to monitor recovery;
- identify conditions appropriate for initiating and sustaining restoration measures;

Figure 1: Following an oil spill, a monitoring programme may be required to determine the changes in the level of contaminants in the environment.

- demonstrate that damage caused by a spill has been evaluated, that recovery is underway and that concentrations of oil in the marine environment are returning to background levels;
- address monitoring requirements set out under applicable national regulations, such as standards for bathing waters.

The aim of any monitoring programme must be to provide reliable, objective and useful information to answer specific, rational concerns about the presence of oil spilt in the environment. Determining the extent and level of contaminants in the environment over time forms the cornerstone of most monitoring programmes and, for the vast majority of incidents, these are the only parameters that are necessary to measure. Further studies to investigate the potential for environmental impact as a result of oil contamination can be conducted alongside contaminant monitoring, but the methodologies employed to study individual resources or habitats are varied and numerous. As such, this paper focuses on the rationale and methodology for conducting contaminant monitoring to support decision-making during the response.

While it is important that the objectives of any monitoring programme are defined as precisely as possible before work starts, a phased approach may be appropriate to allow for additional objectives to be included, or the initial objectives to be adjusted, depending on the results from an earlier phase of the study.

Three complementary approaches to conducting monitoring programmes are possible:

- comparison of post-spill and pre-spill data;
- comparison of data from contaminated areas and un-contaminated reference sites, and
- monitoring changes over a period of time.

Monitoring forms an important interface between the scientific, legal, operational, and financial aspects of an incident. Results produced systematically may be used to confirm the source of the spill and thus the legal liabilities, to validate the decisions made during the clean-up operation (for example, appropriate methods and optimal termination end points) and to follow environmental recovery. As the outcome of monitoring studies can have a significant bearing on compensation and other financial issues, the most constructive approach to monitoring is one in which all parties work co-operatively. This can be achieved through joint sampling and analysis, through the use of an independent third party, or by one party undertaking the sampling and analysis and sharing the results. Although differences of opinion may arise in the interpretation of the results, each of these approaches reduces the duplication of effort and costs and maximises the opportunity for agreement on the basic facts.

Designing a monitoring programme

An understanding of the fate, behaviour and effects of spilt oil and the potential pathways by which resources may be exposed to hydrocarbons will facilitate consideration of whether or not a monitoring programme is needed and, if so, will assist with its design[1]. The geographical extent of the pollution enables the area of study to be delineated, although these boundaries may need to be redefined in cases of a continual oil release, where remobilisation of stranded oil is a factor, or where the results of the initial sampling and analysis indicate that the area affected is different than first thought. The type of oil spilt and the extent to which natural resources are likely to be exposed are also key parameters to consider when designing a monitoring programme. Taking into account these factors, as well as potential exposure pathways, enables appropriate spatial and temporal parameters to be applied.

When designing a monitoring programme, the first stage is to define the objectives of the study clearly and to determine the information and data necessary to achieve these objectives. The objectives will define the scope and content of the programme and are normally set by a government authority or in response to potential claims against the polluter. In either case, the scope of the study and the plan for its implementation need to be agreed at an early stage and, ideally, cooperatively as explained earlier.

Having agreed the objectives, a detailed monitoring plan can be created that establishes the type of data or information to be acquired and whether samples need to be taken, the distribution of sampling stations and the type, number and volume of samples to be taken at each station. The frequency of sampling, the type of analysis and the overall timeframe of the study will depend on the objectives of the monitoring. For example, if the objective is to establish that oil concentrations in the environment are decreasing to background levels, the study can be considered complete once background levels have been reached or the results show a satisfactory rate of decline. In many ship-source oil

[1] *See the separate ITOPF papers on Fate of Marine Oil Spills, Effects of Oil Pollution on Fisheries and Mariculture, Effects of Oil Pollution on Social and Economic Activities and Effects of Oil Pollution on the Environment.*

Location	Monitoring objective	Monitoring activity
South America	To determine the extent of oil contamination and the need for continued clean-up measures.	Extensive boat and shoreline surveys were conducted to document visually the presence and absence of oil on the water and the extent of shoreline oiling. Oiled sites requiring clean-up were identified and appropriate clean-up techniques recommended. Continual observations made during the clean-up operations and a final inspection once the work had been completed allowed for recommendations to be made regarding appropriate termination of clean-up work.
Europe	To establish the level of oil contamination in sediments at key sites oiled as a result of the incident.	Sediment samples were collected from beaches and shallow waters from key sites known to have been oiled during the incident over a period of 3 months. Samples were analysed for THC and PAHs. The results of the monitoring showed that most of the sediment was relatively unaffected by the oil spill.
Indian Ocean	To ascertain whether drinking water in water wells located on the shoreline had been contaminated as a result of the loss of the cargo of phosphate and bunker fuel.	Samples of water were taken from wells along the contaminated shore and from wells outside of the area and analysed for phosphate, PAHs and heavy metals. Comparison of the average values for water taken from the reference wells and wells in the contaminated area showed no significant difference, allowing the conclusion that the incident had not caused contamination of the local drinking water supply.
Atlantic Ocean	To establish the spatial extent and duration of potential contamination to a fishery.	A sampling programme was instigated to collect species samples from the affected area and from reference sites and over a number of months. Samples were analysed to monitor depuration rates of PAHs and compared with background levels reached.

▲ *Table 1: Examples of monitoring objectives and activities in past oil pollution incidents. The various parameters analysed are discussed later in Box 1.*

spills, little in the way of appropriate pre-spill data exists and there will be few opportunities to obtain true control samples. For this reason, monitoring programmes often rely upon control data collected during an incident from unaffected, reference sites nearby. It is important to ensure that the reference sites selected are representative of the habitat types being studied within the area affected and that they are comparable in terms of biota, topography and physical nature, for example, exposure to currents or wave action. Furthermore, surveys intended to provide quantitative data must take into account the natural variability that typically occurs in any ecosystem. Comparison of a time series of measurements from reference sites and from within the area affected allows naturally occurring variability and seasonal changes to be taken into account.

Table 1 provides examples of monitoring objectives from past oil pollution incidents and provides a summary of the monitoring activities undertaken.

Location and number of monitoring sites

Field surveys can be useful for rapidly collecting geographically-referenced information on the location and extent of the oil. Surveys can also be useful for monitoring qualitatively the effectiveness of shoreline clean-up operations or the progress of natural recovery, especially when carried out at regular intervals. The location and number of sites that should be included in field surveys or sampling stations will depend largely on the variability of impact and the variability and extent of the shoreline affected. Care should always be taken to ensure that the sites chosen are representative of the area being cleaned, the contamination observed or habitat being monitored. However, most oil spill scenarios do not require the use of sophisticated statistical procedures to determine the number of sites to be surveyed or the number of samples to be collected. In reality, compromises and a certain degree of pragmatism are often called for in order to satisfy both the demands of statistical reliability and the practicality of accounting for the full spatial and temporal variation of complex ecosystems within the available timeframe and financial constraints. Furthermore, there are few universal rules regarding the optimum location and number of sampling stations for post-spill monitoring studies. Instead, this will depend on the objectives of the monitoring programme and on a number of case-specific variables such as the:

- quantity and type of oil spilt;
- weathering behaviour of the oil (e.g. spreading, dissolution, etc);
- physical characteristics of the area affected (e.g. sandy, exposed, etc);
- nature and location of sensitive resources;
- means available for sampling and analysis; and
- physical conditions that might constrain sampling (e.g. access or weather).

In the simplest situations, for example where the objective is to establish the source of contamination, probability-based sampling designs are not required. Instead, a very small number of samples taken from the oil slick or contaminated shoreline would usually be accepted by all parties as representative of that contamination.

In some cases, the optimum locations and number of sampling stations can be deduced by overlaying a map of the study area with a grid showing the oil contamination, annotated with GPS co-ordinates. A transect or a series of transects can be useful for defining trends in relation to distance from the pollution source (*Figure 2*) or to other environmental variables, such as tidal height. This systematic approach may be particularly useful for areas of relatively homogenous shoreline, such as wide areas of marsh or sand. In nearshore areas with some complexity in physical characteristics (for example, separate bays), or in spills affecting extensive areas of coastline, the area may be sub-divided into smaller, stratified zones to be monitored individually. In practice, sampling stations should be selected to reflect the distribution of oil and natural environmental gradients, and in this respect it is helpful to draw upon local knowledge when planning the monitoring programme.

Entirely random approaches to sampling are possible, but they are rare when sampling solely for contaminants in a monitoring programme. Although a random approach would enable greater use of statistical inference in the reporting of results, a significantly large number of samples would need to be analysed at much greater cost for little improvement in the data obtained. Instead, in complex cases, a useful compromise can be achieved by making certain elements of the study random, for example, using stratified random sampling, or implementing more sophisticated phased (i.e. cluster) or composite sampling. Setting up an appropriate probability-based sampling design in such cases may call for the services of an environmental statistician. Various approaches to designing the statistical approach for sampling plans are summarised in Table 2.

Timing of the monitoring programme

While there are no definitive deadlines for contaminant monitoring and sampling activities following a spill, the sooner monitoring is started, the sooner short-lived

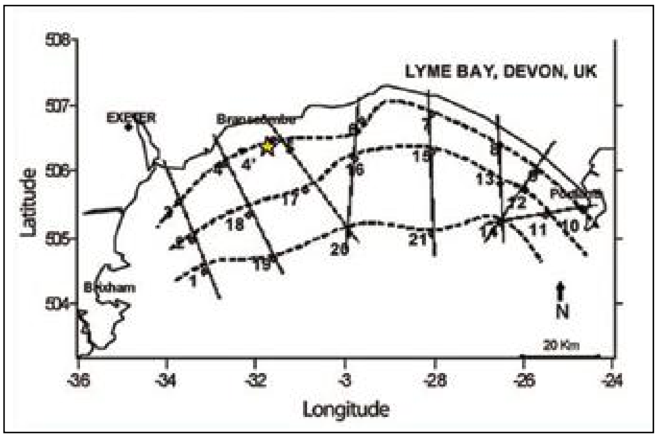


Figure 2: Location of water sampling stations in proximity to a vessel's beached position (yellow star). (Source — Environmental monitoring conducted in Lyme Bay following the grounding of MSC NAPOLI in January 2007, with an assessment of impact. CEFAS Aquatic Environmental Monitoring Report no. 61 — http://cefas.defra.gov.uk).

Sampling design	Main characteristics in relation to post-spill monitoring
Judgemental sampling	Easy to implement, 'common sense' approach, especially good for fingerprinting and consensual, low effort monitoring programmes. An example of non-probability sampling, based on the judgement of the person sampling.
Simple random sampling	Samples are chosen entirely by random from a larger group. Statistically sound, easy to implement in homogenous areas (open waters, long and constant coastlines, fisheries); difficult in areas of varied coastline and varied contaminant levels.
Stratified random sampling	A 'judgemental' variation of simple random sampling where areas are broken up into case-relevant sub groups (or stratum) for random sampling. Good in heterogeneous areas (diverse in character) when sub-groups within an overall group vary.
Systematic (grid) sampling	Appropriate for large areas with little known variation, especially for vessel-based sampling where transects can be made. Statistically troublesome where other variables may be systematically involved (e.g. other contaminant sources).
Cluster sampling	Efficient, multiple-phase approach that allows a second, more detailed study of hot-spot areas identified in first phase (often a grid design).
Composite sampling	Extremely efficient phased approach where large areas can be screened by combining samples for analysis. Not appropriate in areas of highly varied contamination.

▲ *Table 2: Typical statistical approaches to sample station distribution in post-spill monitoring.*

(ephemeral) effects can be detected and the changing extent of contamination recorded. Where sampling is necessary, samples of oil from potential sources should be secured and preserved at the same time as gathering samples from the areas affected to verify the source and collecting samples for ephemeral data (in particular water samples). As many impact assessments are based on model predictions, ephemeral data may be important in order to document the actual concentration to which biota have been exposed to verify the predictions.

The duration of the monitoring programme and frequency of repeat sampling depends on the programme objectives and the inherent characteristics of the specific parameters that are being measured. For example, measurement of total oil concentration in a contaminated environment is a parameter that may require weeks or months of monitoring before background concentrations are re-established. On the other hand, if the objective is to determine the efficacy of a particular response technique, such as the use of dispersants, the immediate implementation of monitoring and rapid processing of results would be crucial to enable a timely decision to be made.

The availability of resources, such as trained staff and suitable sampling vessels, also needs to be taken into account, as well as the logistics and costs involved. The rate at which samples can be safely and correctly taken will depend on the weather, sea state, and the accessibility of sampling sites. Additionally, where ephemeral effects are to be measured, the area of concern may need to be adjusted or the desired intensity of sampling may have to be adapted in order to take samples within the time available. In all cases, the timing and the overall programme design should take into consideration the likely time required for the processing of samples at analytical laboratories and the speed with which the results are required. For example, when investigating whether fisheries could be affected by a spill, the timing of sampling and analysis is likely to be influenced by the need for data to inform decisions on the closure or re-opening of the fishery.

Budgeting for the cost

Responsibility for paying for the monitoring programme depends on the legal regime applicable within the country in which the incident or damage occurs. Regardless of who is to pay, it is good practice to produce a proposal containing an itemised budget early in the process (*Table 3*). Where relevant, this may be discussed with the bodies paying compensation prior to the commencement of the work.

Generally, the overall cost of monitoring should reflect the level of effort involved, the frequency of surveys undertaken, the number of samples or sampling stations, the types of analysis required, and be in proportion to the scale of the issues being addressed. However, because some costs are fixed, for example vessel hire, the final cost per sample is not necessarily affected by the total number of samples taken and there may be opportunities to take more than the minimum number of samples at little additional cost. Nevertheless, because analysis costs tend to be directly related to sample numbers, it is often recommended to analyse only the minimum number of samples and keep the remaining samples in appropriate storage in case they are needed later.

Background	Sampling	Analysis	Logistics
• Case name, dates, location • Names and affiliations of scientific team • Objectives, methods, and procedures	• Period and frequency • Geographic scope • Sample types	• Laboratories undertaking analyses • Analytical plans and related costs • Date commitment for publishing report	• Description and costs of equipment and materials • Costing of any special logistical support • Costing of travel and accommodation needs

▲ *Table 3: Typical components of a budget proposal.*

Use of a phased approach is another strategy to keep monitoring costs in proportion. Compared with an initial phase of sampling that might take place shortly after a spill, later phases are often narrower in scope. Criteria for termination of the monitoring programme need to be considered early on, but contaminant monitoring would usually conclude once a return to background levels has been detected.

Selection of the laboratory

The laboratories tasked with undertaking sample analysis should be selected and agreed by all parties at the programme design stage. The laboratory must have the capacity to deal with the anticipated sample numbers and offer the techniques required to meet the programme objectives. Some of the preliminary enquiries that might be made to establish the suitability of a particular laboratory include:

- Are the laboratory technicians experienced and qualified in the analysis of hydrocarbons?
- Does the laboratory have the requisite equipment, primarily UVF, GC-FID and GC-MS (as described later in this paper)?
- Is the laboratory nationally accredited or internationally recognised?
- What quality assurance and quality control procedures are in place?
- Can oil spill work be given priority over routine activities?
- What are the costs associated with screening the samples and undertaking the analysis?
- How will the results be reported?
- Is the laboratory willing to explain and defend its results in court if required?

Quality control

To maintain a high quality of sampling and analysis, every monitoring plan should incorporate two key elements:

- quality assurance (QA) to ensure that processes and procedures are in place to check that the aspects of the monitoring plan, such as sampling and analysis, are being carried out in the correct manner (an audit of the process); and
- quality control (QC) to ensure that the monitoring plan delivers the planned objectives (a check of the product).

Samples may be divided in a number of ways for quality control purposes and this is decided prior to sample collection:

- split samples: each fully-homogenised sample is divided after being drawn or taken, giving two or more parties the opportunity to undertake independent analyses;
- field duplicate/replicate samples: the same device and procedures are used at the same location to take two or more samples which should be identical. Such samples are used to test sample variance and their identity may not always be made known to the laboratory; or
- laboratory duplicate/replicate samples: split samples given to the same laboratory for analysis, yet described as being two different samples. These can be used to check the precision of laboratory analysis.

Implementing the sampling and monitoring programme

The type and extent of field data and information collected depends on the objectives of the monitoring being carried out. For example, to monitor the effectiveness of dispersant application, in addition to visual observations by trained observers, ultra-violet fluorometry (UVF) can be used to collect data on oil concentrations in the water column[2]. Clearly, to be useful for decision making, the results from field surveys need to be forwarded to the command centre in a timely manner.

Although aerial surveillance is useful for gathering information on the overall geographical extent of oil at sea and on the shoreline, more detailed shoreline surveys aimed at rapidly documenting shoreline oiling provide crucial information to help determine appropriate clean-up techniques. In addition to written notes and sketches, it is common practice for shoreline surveys to document findings using photographs and videos. For both aerial surveillance and shoreline surveys, it is useful to record images using GPS data, thereby allowing straightforward referencing of data and information[3].

Where the properties of the oil and the environmental conditions at the time of the spill indicate that significant quantities of oil may have sunk, underwater surveys may be required to establish whether or not this has occurred and to determine the extent of any areas affected. Such surveys could be achieved through a variety of methods, such as visual assessment, either by divers or a remotely operated vehicle (ROV), acoustic sensors and sonar, or mechanical methods. Mechanical methods in the form of sorbent materials anchored in fixed positions or towed across the seabed (*Figure 3*) have been used to detect the presence of sunken oil in past cases.

[2] See the separate ITOPF paper on Use of Dispersants to Treat Oil Spills.

[3] See the separate ITOPF papers on Aerial Observation of Marine Oil Spills and Recognition of Oil on Shorelines.

▲ *Figure 3: Using sorbents for sub-tidal sampling. The frame, with sorbent attached, is towed along the seabed. The presence of oil on the sorbent when raised allows the geographical extent of sunken oil to be determined.*

Description	Indication of minimum required quantity (per sample)
Pure oil source sample	30–50 ml
Contaminated oil (e.g. emulsified oil, oil from the sea or shore, sandy tarball, etc.)	10–20 g
Debris with oil, oil stained sand	Sufficient quantity that oil content is approx. 10 g
Oiled feather	5–10 feathers depending on oil quantity present
Fish, shellfish (flesh and organs)	Multiple individuals of same species totalling 30 g
Water sample with visible oil	1 litre
Water sample with no visible oil	3–5 litres

▲ *Table 4: Guidelines for the amount of sample typically required for hydrocarbon analysis.*

Regardless of the type of field data and information being collected, protocols, such as SCAT (Shoreline Clean-up Assessment Technique or Team), should be developed to ensure accuracy and consistency in how the data and information are collected. Furthermore, the personnel undertaking the surveys should be appropriately trained. Any field data or information collected should be suitably categorised, stored and archived, enabling it to be linked to the results of any other monitoring studies that may be undertaken.

Sample collection

Sample collection procedures should conform to international best practice and should be described in detail in the monitoring plan. This approach ensures that the sampling teams follow the same protocols in the field and that sufficient information is available to enable the results to be interpreted correctly. If internationally accepted best practice has been followed, it is also more likely that the results can be defended in court, if this becomes necessary. Guidelines for the amount of sample of various types are provided in Table 4.

Source samples

Among the most important samples to obtain early on in a monitoring programme are clean and verified samples of oil from all potential sources (*Figure 4*). When the source is known, such as a ruptured pipe or ship's tank, and accessible, samples can be taken directly by qualified personnel (*Figure 5*). Where the source is not known, samples may need to be taken from several candidate sources. While oil in cargo tanks can generally be sampled from one location, the contents of bunker tanks or bilges are rarely sufficiently homogenous to be sampled from a single point and samples are often taken from multiple depths through the tank, usually top, middle and bottom.

Samples of oil are normally taken when cargo or bunker oil is being loaded onto the ship and these are kept as a matter of standard operating practice in case of commercial dispute. While they may be useful as source samples, it is important to note that there may be quality and chain of custody issues involved in using them, in particular if they have been stored in plastic containers. When the source of the oil is a sunken wreck and access for sampling is not feasible, it may be possible to collect an oil sample as the oil rises to the sea surface, directly above the wreck. If oil removal operations from the wreck are undertaken later, a small amount of recovered oil may be obtained from the salvage team. In cases where it is not possible to obtain a sample from the source, multiple samples of oil from contaminated shorelines can be used as proxy source samples.

▲ *Figure 4: Decanting a bunker fuel source oil sample on board a casualty.*

▲ *Figure 5: Ship-source sampling is a highly technical and potentially dangerous activity that should be carried out by vessel crew, marine surveyors or salvors.*

▲ *Figure 6: Capturing floating oil with a clean sorbent pad.*

Sampling spilt oil

Samples of floating or stranded oil are taken generally for qualitative purposes to confirm the source of the oil, rather than quantitatively to map concentrations. Only small quantities of oil (i.e. 10–20 g) are usually required for analysis. Samples from the water surface can be collected directly with sampling jars or sorbent pads (*Figure 6*). If access is restricted, samples may be collected using a bucket on a rope or by using extension poles. Samples should be taken from the bow of the sampling boat, avoiding any sheens from the sampling vessel's hull and engine exhaust or cooling water.

Occasionally samples of thin oil sheen are required, for which specialist sampling equipment exists, such as fine-mesh sampling nets. Only very small amounts of oil are obtained from sheens and, the thinner the films that are to be sampled, the greater the risk of sample contamination (for example, from the sampling vessel or equipment). For quality control, unused sampling nets or sorbent pads should be provided to the laboratory as references for analysis alongside the sample.

The procedure for sampling oil stranded on shorelines or within an intertidal zone generally involves scraping or gathering the oil into a sample jar (*Figure 7*), taking care to minimise the sand and debris content.

Environmental samples

Sampling and monitoring that is intended to quantify hydrocarbon contamination involves a shift from targeting the spilt oil to sampling the medium that has potentially been contaminated. The initial approach is often to take samples from the water column, as this is the pathway through which the oil migrates to reach shorelines, sediments and biota. Depending on the objectives decided at the outset of the monitoring, evidence of elevated oil concentrations in the water column may provide the trigger for extending the sampling regime to other targets, such as biota. In other cases, an intensive environmental monitoring programme (i.e. contaminant monitoring and biological impact assessment) may be initiated, requiring a suite of water, biota and sediment samples, but this is usually necessary only if the pollution has been extensive and the impacts are potentially significant.

▲ *Figure 7: Sampling stranded oil on the shoreline.*

It is important to ensure consistency throughout the sampling effort and, where possible, to ensure that comparable specimens are targeted. For example, when monitoring shellfish contamination at a number of locations, the same species of shellfish, and ideally at the same stage in their life cycle, should be targeted at all locations in order to allow meaningful, quantitative comparisons.

The volume or mass required for each sample depends on the number and types of analyses planned, the concentration of oil in the sample, the number of participant organisations requiring their own split sample and the number of duplicates or replicates required for quality control purposes. Modern testing procedures require only very small samples for relatively pure oil (*Table 4*).

Water sampling

Water column monitoring may be undertaken by field measurements *in situ* or by manual collection of samples that are preserved and transported to a laboratory for analysis. Field measurements include basic water quality and oil-specific detection, both of which involve portable field sensors that provide real-time output:

- Electronic water quality sensors measure such chemical and physical variables as pH, salinity, conductivity, chemical oxygen demand (COD) or biological oxygen demand (BOD). These do not have direct relevance for oil contaminant monitoring, but they may be useful in related ecological monitoring studies.
- Field sensors, specific to oil spills, such as towed multi-wavelength fluorometers find greater application in response operations than environmental monitoring, for example, to indicate dispersed oil concentrations.

Manual collection of water samples can be undertaken with specialist sampling devices that are lowered to the desired water depth in the closed position (*Figure 8*). Once there, the device is opened to take the sample, then closed for

Figure 8: Decanting water samples from the sample collection device into glass bottles, for split samples.

retrieval to avoid contamination by oil films that may be present on the sea surface. Manual collection for subsequent laboratory analysis remains the mainstream practice for contaminant monitoring.

Sediment sampling

The quantitative measurement of total oil, or the changing composition of oil in sediments as it degrades, often forms part of contaminant monitoring programmes (*Figure 9*). Subtidal sediments are generally sampled from vessels and, because of the low migration rate of oil into these sediment types, shallow grabs are frequently used. Well designed grabs avoid the contents being washed out during retrieval and it is good practice to rinse the grab with an appropriate solvent between collecting samples. Diver-operated corers are sometimes used, particularly if the presence of pre-existing contamination from other sources is suspected.

Sampling intertidal sediments is usually carried out either using surface scrapers or with corers. The results might be used, for example, to aid decisions on when to terminate clean-up operations.

Biota sampling

Sampling procedures for biota are varied and will depend on the organisms and habitats to be included, for example demersal and pelagic species (i.e. those near the seabed or in the water column), benthic species (living on the seabed or in sediments), as well as birds and mammals. Studies should focus on trends within the ecosystem, rather than attempt to document every fluctuation from the norm, and the use of key indicator species has been shown to be the best approach. These species are often either commercially important or by their nature and exposure offer good opportunities to document contamination (for example mussels and other filter feeders). Samples can be either organ-specific (i.e. the same organ from a number of individuals) or whole-organism, with all soft parts homogenised (*Figure 10*).

Biota samples may involve both wild species and farmed species, such as those found in mariculture facilities. Mariculture should be sampled jointly with the facility operator and ideally at representative locations selected by the sampling team. For wild stocks of commercially exploited species, samples may be purchased from fishermen, although this approach has many quality control issues regarding where and when the fish were caught and the risk of cross-contamination. Collecting samples together with fishermen avoids these issues and is perhaps most appropriate in an artisanal fishery where the catch is local and brought ashore on a daily basis.

Birds, mammals or other higher organisms are not typical test subjects in oil contaminant monitoring because the

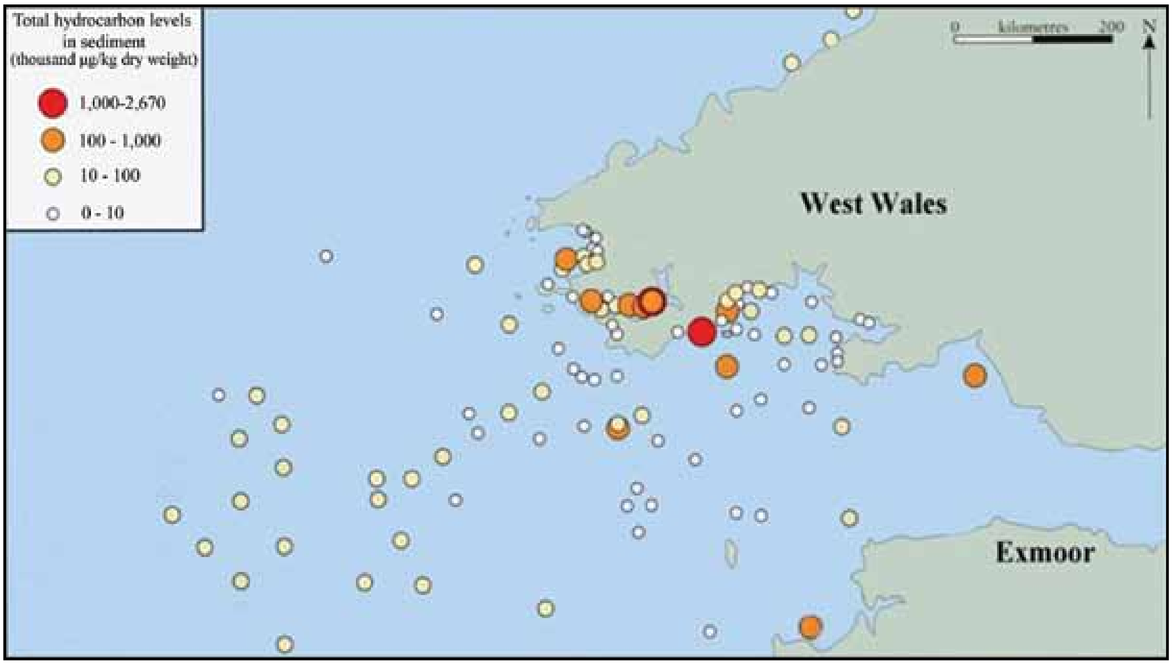


Figure 9: Sample station locations selected for the assessment of seabed sediment contamination by oil after the SEA EMPRESS oil spill in Wales, UK. Following this large spill, it can be seen that sediment contamination some six months after the spill persisted mainly in shallow waters close to the coast. (Source: The Environmental Impact of the SEA EMPRESS Oil Spill; SEA EMPRESS Environmental Evaluation Committee (SEEEC) 1998).

contamination can usually be noted visually and the variability is greater than with lower indicator species, such as mussels. Samples from oiled animals tend to be taken from carcasses or in a non-intrusive manner from live animals, for example oiled feathers or oiled fur.

Handling samples

In many instances, the eventual use of a sample and analysis results are not known at the time the sample is taken. In order to maintain the integrity of the sample so that it can be used later, proper handling and storage protocols should be followed. The handling of samples in the field involves storage, labelling, pre-laboratory stabilisation, packaging, shipping and management of the process. The associated chronological documentation is referred to as the chain of custody.

Storage

Storage is an intrinsic part of sampling, because the material is placed immediately and directly into the storage container in order to minimise cross contamination and degradation. In some cases, the container itself is used as the collection device, such as when floating oil is skimmed or oiled sand is transferred into a glass jar. Ensuring a supply of appropriate containers for storage should be pre-planned. The use of non-specialist containers, such as plastic water bottles, should be avoided unless no other suitable container is available. If there is a risk of contamination from dissolved plastic, the container itself may be analysed and used as reference against the result of the analysis. Many characteristics of appropriate storage containers are provided in Table 4 and Figures 11 and 12.

Labelling

Storage and labelling should be considered in tandem, because the chain of custody effectively begins as soon as the sample is put into a container. A programme of spatial or temporal sampling will require multiple containers and the scope for confusion and inadvertent mixing of containers is great. To avoid this, standard sample labels should be prepared, allowing the user to allocate a unique identifying reference for the sample, together with detailed information on where, when and by whom the sample was taken. If the sample is part of a joint sampling exercise, the name and contact details of a witness to the sampling should be included.

A parallel sample inventory should be maintained, for example, as an electronic spreadsheet, in which the same information is recorded and copies of which can be made available to interested parties and to the analytical laboratory. In addition to recording purely scientific variables, sampling teams should document the names, dates, places and other details surrounding the custody of the samples as they are transferred from one party to another. Protecting the chain of custody ensures that the samples are not exposed to any risk of physical tampering, cross-contamination or any other alteration, whether intentional or not.

Stabilisation

Many samples will remain stable for some time and can be kept in their original sample containers because they are not particularly susceptible to degradation, for example weathered tar balls or pure oil, or because they are cooled or frozen, for example fish tissue samples. Depending on the monitoring protocol, water and sediment samples may need to be stabilised in the field if there is to be a delay in delivery to the laboratory in order to ensure their continued integrity. While samples may be acidified or biocides added, the general practice is to carry out solvent extraction on the same day that the samples are collected. Even when frozen, a risk exists that samples may deteriorate and material may become absorbed onto the walls of containers. Consequently, the permitted storage time for samples may be strictly prescribed under some analytical protocols. Care must also be taken to procure only the purest solvents for extraction. Contaminants in solvents can confuse or mask the detection of compounds of interest, particularly when these compounds are at very low concentrations.

Packing & shipping

Samples are stored primarily in glassware and need to be packed carefully prior to transport to avoid breakage, loss

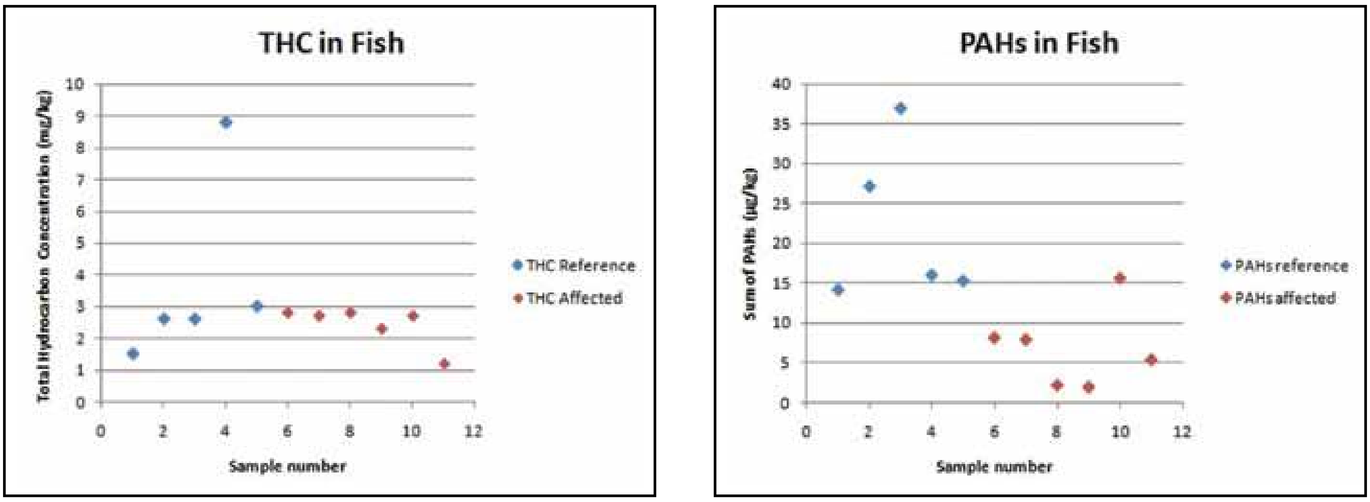


Figure 10: The results of testing carried out to measure total hydrocarbon (THC) and polycyclic aromatic hydrocarbon (PAH) concentrations in fish.

or degradation of samples. Padded boxes with dividers are useful as are hard-shelled cooler boxes if these can be delivered securely to the analytical laboratory. In all cases, good practice includes minimising free water in oil samples, respecting the appropriate temperature for biological material, labelling any outer container with the name of the incident and enclosing an inventory of the samples within the package. As domestic shipping requirements differ from one country to the next, advice should be sought locally. International shipping of samples is generally more complicated and may involve adhering to stringent packaging and labelling rules where the characteristics of the oil, for example the flashpoint, will affect the required packaging and mode of transport.

Analytical techniques for oil contamination

Once a suitable laboratory has been selected and the samples have been collected in the field, work can commence to analyse the samples to determine the source of the oil or the level of contamination. While non-specialists are not expected to undertake analysis, an appreciation of the different analytical techniques and their purpose is useful for those involved with planning and conducting monitoring programmes.

In order to appreciate the rationale for using a particular analytical technique to determine the level of oil contamination in samples, and to confirm the source of particular oil, knowledge of the chemical composition of oil can be helpful, as summarised in Box 1, overleaf.

No single international standard or set of guidelines covers the analysis of oil pollution samples worldwide. However, a number of relevant protocols at international and national levels can be followed during sample analysis, including those published by the:

- American Society for Testing and Materials (ASTM);
- American Petroleum Institute (API);
- US Environmental Protection Agency (EPA);
- Canadian Council of Ministers of the Environment (CCME);
- European Committee for Standardisation (CEN); or
- Euro-Asian Council for Standardisation in Russia (EASC).

On arrival at the laboratory and before the analysis work can commence, the samples should be cleaned to remove extraneous material and to concentrate the hydrocarbon compounds. The most common techniques are solvent-extraction and chromatography. The nature of this preparation step is dependent on the final analytical techniques to be used and the condition of the sample. For example, debris will need to be removed from sediment samples, emulsions will have

▲ *Figure 11: Well labelled bunker samples in wide mouth glass jars (in this case split samples from a single tank).*

▲ *Figure 12: Clear, narrow-mouth bottles (left) or plastic bottles (right) are not ideal containers for monitoring purposes.*

General guidelines	Remarks
Samples should be contained in clean glass jars with Teflon lids or lids lined with clean aluminium foil. Fluid source oils may be collected in stainless steel containers. Solid or semi-solid samples can be transferred with an unused lollipop stick or wooden tongue depressor. Nitrile gloves should be worn (*Figure 7*).	Plastic containers can contaminate the sample. Sample jars should be rinsed first with an appropriate solvent. New sampling sticks must be used for each sample. Gloves avoid the risk of contamination by trace oils from skin during handling.
Use amber bottles or keep samples in the dark during transfer and storage.	Protection against photo-oxidation and degradation for water column samples, in particular.
Use 30 ml or larger sample jars for pure oil and oiled sediments. Wide necks and screw caps are recommended.	Narrow mouth and thin glass are harder to fill and may break during transport.
Do not fill the sample jars with liquid or oily debris completely.	Allow some space for thermal expansion, especially if there is a risk of freezing.
Sample jars should be correctly labelled with a unique reference number, location, time and date, type of sample and other relevant information (e.g. depths).	Prepare standard labels with as much information as possible just before taking the sample. Use permanent pen and cover the label with clear tape to maintain its legibility.
Secure lid to avoid spillage and to prove that no tampering took place along the chain of custody.	Use tape to ensure the lid is secure.
Avoid contamination.	Clean sampling devices between samples with solvent. No smoking! Keep away from boat exhaust or similar.

▲ *Table 4: General guidelines for the storage of samples.*

to be broken (i.e. the water released and decanted), and oil samples extracted, even if apparently pure in appearance (*Figure 13*).

Chromatography is one of the many techniques where a mobile phase (containing the sample to be purified) passes through a stationary phase. Two of the most commonly used techniques to fractionate and separate groups of hydrocarbon molecules are silica column gas chromatography (GC) and high-performance liquid chromatography (HPLC). While GC is available relatively widely, HPLC requires highly sophisticated equipment and very pure solvents and so is less prevalent. However, HPLC provides increased sensitivity and the ability to identify PAHs reliably.

To promote cost effectiveness and to expedite the process overall, samples are usually screened to select those that merit more detailed investigation and so reduce the number of samples for which full analysis is required. The combined technique of gas chromatography and flame ionization detection (GC-FID) is typically employed for screening but UVF spectroscopy and sensory testing may also be used. Sensory testing involves the use of a trained panel of sensory assessors working in a controlled environment to evaluate suspect and control samples for flavour, odour and appearance[4].

[4] *See the separate ITOPF paper on Effects of Oil Pollution on Fisheries and Mariculture.*

Box 1: Oil composition

Oil is a highly complex mixture of compounds ranging from simple low molecular weight hydrocarbon molecules to resins and other dense macromolecules that incorporate metals and other elements. In many oil spill incidents, the focus for the monitoring programme will be to establish the **total hydrocarbon content (THC)**, or synonymously **total petroleum hydrocarbons (TPH)**, which represents the sum of aliphatic and aromatic compounds. THC usually describes the measurable amount of hydrocarbons present in an environmental sample, but it does not provide information on the individual constituents. As the amount of THC measured depends on the extraction methods used and the absorption of infrared light by the extract, the results are dependent upon the method used. When more detail is required as to the nature of the oil contamination within a sample, for example within seafood or for identification of the source of the oil spill, specific hydrocarbon compounds can be analysed individually.

Normal **alkanes** (n-alkanes) are compounds composed of straight chains of carbon atoms and typically comprise a large proportion of fresh crude oil or distillate products. Low molecular weight n-alkanes are sensitive to evaporation and biodegradation. Consequently, weathered oils tend to have a lower proportion of n-alkanes than their fresh counterparts. Iso-alkanes, so called branched-chain compounds, are equally abundant in fresh oils and are also sensitive to biodegradation Some iso-alkane compounds can be useful as indicators of biodegradation.

Alicyclic compounds are cyclic, saturated hydrocarbons that are relatively resistant to biodegradation. The term saturated refers to molecules that are fully hydrogenated and have only single carbon-carbon bonds. Their relative stability makes some of the higher molecular weight alicyclic compounds particularly useful as distinctive features by which to identify individual oils. These compounds are referred to as biomarkers* because they were transformed from biological material during the geological process of oil formation.

Aliphatic hydrocarbons comprise straight, branched or (non-aromatic) cyclic chains of carbon atoms and include both n-alkanes and alicyclic compounds.

Aromatic compounds are unsaturated cyclic hydrocarbons, typically with alternating double and single carbon–carbon bonds and one or more rings of six carbon atoms (benzene rings) and include Volatile Organic Compounds (VOCs) and Polycyclic Aromatic Hydrocarbons (PAHs). VOCs include the low molecular weight compounds, for example benzene and toluene, that evaporate quickly and therefore sample collection and analysis of VOCs is a challenge requiring specialised techniques.

Polycyclic aromatic hydrocarbons (PAH) are toxic and carcinogenic compounds and are therefore a focal point of many environmental monitoring programmes. In particular, 16 PAHs identified by the US EPA (Environment Protection Agency) as ‘priority pollutants’, are commonly measured and are discussed in further detail in the separate ITOPF paper on Effects of Oil Pollution on Fisheries and Mariculture. The variation in PAH mixtures that arise when oil is formed, mean that each oil has its own unique signature or PAH profile. This, combined with a high resistance to weathering, makes PAH an important method for identifying different oils. The study of PAH can also be used to help determine the possible sources of water contamination because the analysis is able to distinguish between pyrogenic (combustion products), petrogenic (originating from crude oil) and biogenic (originating from biological processes) sources of oil.

** In environmental monitoring, the term biomarker can refer, as here, to compounds used in fingerprinting oils or to compounds indicating levels of enzyme activity in animals. For the latter, please see the separate ITOPF paper Effects of Oil Pollution on the Marine Environment.*

Ultra violet fluorescence (UVF)

Ultra violet fluorescence spectroscopy is a qualitative and quantitative analytical method that can be used for detecting the presence of oil either in the water column *in situ* with portable devices, or in samples prepared in the laboratory. The material to be tested is exposed to specific frequencies of UV radiation, which excite aromatic molecules to fluoresce (i.e. emit lower energy light) and are then detected by the spectrometer. The oil-specific composition of PAHs makes UVF a good technique for identifying different oil types (*Figure 14*) and also for determining the THC in a sample. It is also capable of detecting very low concentrations of oil in water, typically down to 1.0 µg/l (i.e. ppb) in the field, 0.1 µg/l in the laboratory and 1.0 mg/kg (i.e. ppm) in sediments provided that calibration with a known source sample is performed. UVF is considered a quick and valuable screening technique but it is not routinely used to confirm a source sample, as this would necessitate the analysis of individual oil compounds such as those highlighted in Box 1. UVF is not appropriate for fingerprint analysis, because non-hydrocarbon molecules present can emit at the same excitation wavelengths and can interfere with PAH signals.

Gas chromatography–flame ionization detection (GC-FID)

GC is an analytical technique involving the separation of the complex mixture of hydrocarbons in oil into component molecular groups. A small liquid sample is injected into a long and narrow metal column which is heated at a controlled rate through a pre-determined temperature range. The column is flushed continuously with a carrier gas, usually helium. Special coatings within the column interact with the vaporized compounds as they pass through, separating the molecules by their chemical properties, such as volatility, resulting in each compound being eluted from the column at different time intervals, or retention times.

A flame ionization detector (FID) is a sensor that responds to ions released from the combustion of molecules eluting from a GC column as they are burned in a hydrogen flame. Lighter molecules pass through the column more quickly than heavier ones, so retention time in the column can be related to molecular weight and, by the introduction of standards, individual hydrocarbons can be identified. The higher the concentration of a particular compound, the stronger the FID signal, which, after computer processing, is displayed as a peak in the resulting chromatogram. GC-FID can be used as a relatively fast combined screening and fingerprinting technique and it is also an appropriate technique for quantitative measurement of hydrocarbons.

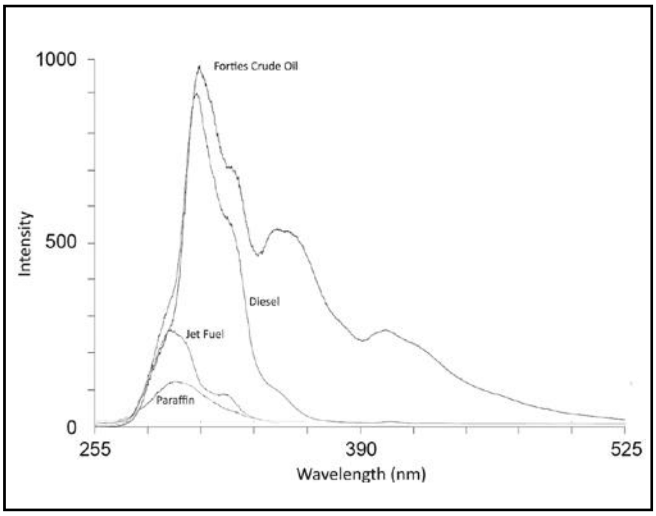
Because each type of oil has its own distribution pattern or fingerprint, many oil samples can be identified by a comparative study of GC-FID chromatograms for spill and source samples. In some cases, GC-FID alone may be sufficient to confirm that two samples do not match (e.g. a spill sample does not match the source sample), especially for relatively fresh oils. When results are inconclusive and there is only a possible match or when there is a need to quantify particular compounds, further study may require the higher resolution of GC-MS.

▲ *Figure 13: Extraction of oil samples using a separation funnel (image courtesy CEFAS).*

Gas Chromatography–Mass Spectrometry (GC-MS)

The coupled GC-MS process consists of a gas chromatograph linked to a mass spectrometer (MS), which detects and analyses each molecule separately, enabling the accurate, high resolution detection and identification of molecules. Mass spectroscopy involves a four-step process of ionisation, fragmentation, magnetic deflection and detection of positive ions. By counting and representing graphically the different ion fragments, the overall structure of the molecule is revealed (*Figure 15*).

Because of its high resolution, GC-MS is a prime technique for the identification of biomarkers, VOCs and specific PAHs. The limits of detection for GC-MS are typically in 0.1 µg/kg but techniques are available that can detect levels down to parts per trillion (i.e. ng/kg), although the relevance of this level of detection in the context of monitoring ship-source marine pollution is open to debate.



▲ *Figure 14: UVF emission spectra for four different types of oils combined. This can be contrasted with the GC-MS chromatograms for the same oils overleaf. (Adapted from CEFAS Aquatic Environmental Report No. 12 – Methods for Analysis for Hydrocarbons and PAH in Marine Samples, 2000).*

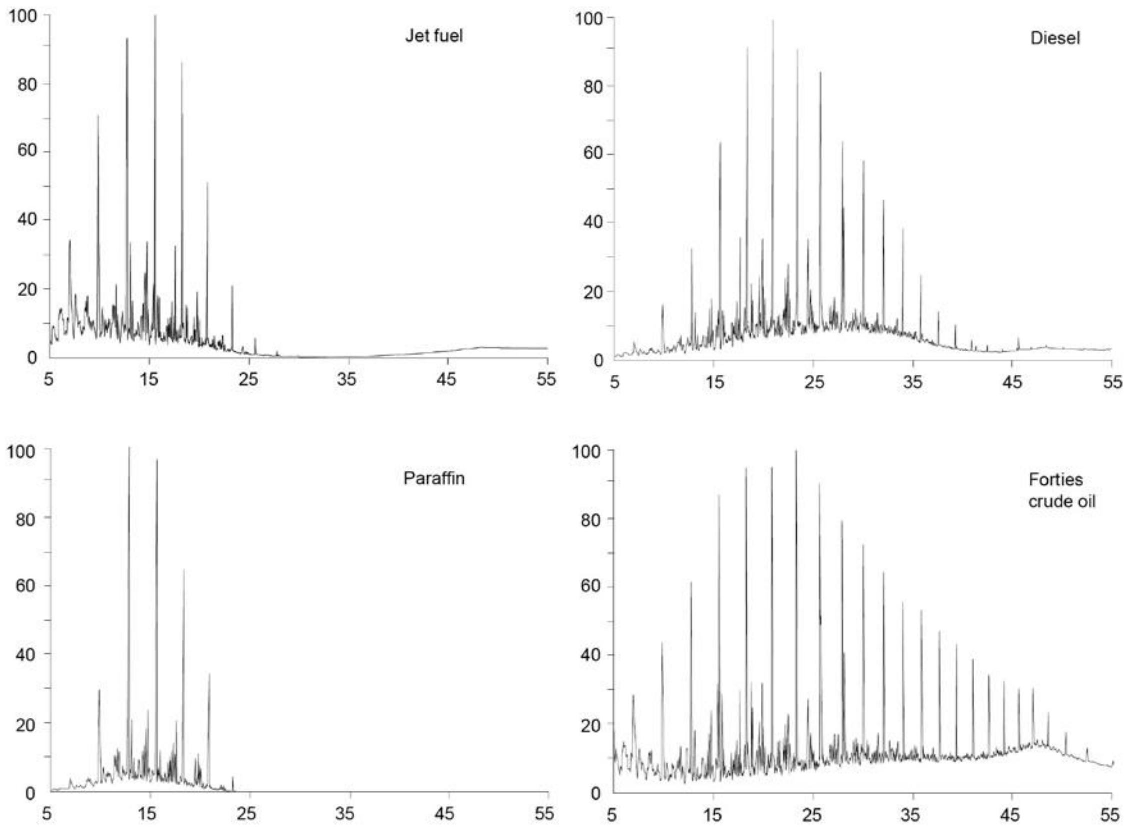


Figure 15: Four typical total ion chromatograms (GC-MS) for a jet fuel, a diesel, paraffin and Forties crude oil. The diesel shows a predominance of light ends. The Forties crude oil shows a dual pattern of both light oil and heavier oil. (Adapted from CEFAS Aquatic Environmental Report No. 12 - Methods for Analysis for Hydrocarbons and PAH in Marine Samples, 2000.)

Selection of analysis technique

Selection of the appropriate technique is determined by the objectives of the monitoring programme (*Table 5*). If the objective is to prove that spill samples were derived from a suspected source, then qualitative analysis using GC-FID screening and GC-MS analysis of biomarkers is the approach most frequently followed. UVF or GC-FID techniques may be used if the monitoring programme is simply concerned with following total hydrocarbon concentrations in environmental samples and recording the return to background levels. GC-MS would usually be used for analysis of biota and particularly the analysis of species intended for human consumption, when measurement of the concentrations of PAH might be required.

Interpretation and reporting of the analysis results

The interpretation of results from the analytical techniques described above requires a thorough knowledge of the methodology used and experience in reviewing the analysis outputs and is, therefore, beyond the scope of non-specialists. Challenges to interpreting the results include the weathering processes to which the oil was subjected prior to being sampled, as well as the presence of other petrogenic and biogenic sources of hydrocarbon compounds commonly found in oil.

The results and conclusions of oil analyses should be interpreted in the context of the observations made on site following the incident. In order to fully understand the extent and pathways of the contamination caused by the oil spill, results of samples from sediments, biota and the water column at different locations need to be interpreted in relation to the background hydrocarbon levels for each location.

In reporting the results of a monitoring programme, it is important to present the details of the sampling and analytical protocols applied. Interpretation of the results should be accompanied by the raw data collected, including, for example, the chromatograms developed.

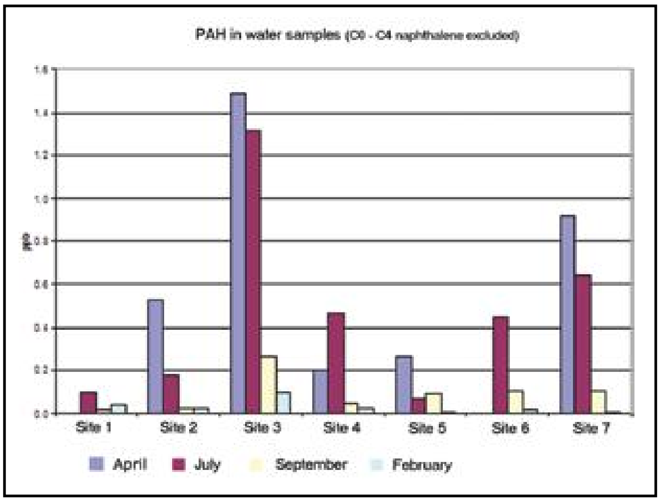
For reporting visual observations and quantitative data where there are relatively few samples analysed, numerical tables, graphs and text descriptions may be adequate (*Figure 16*). However, where oil contamination is distributed across complex geography, numerical tables can be supplemented with maps indicating the degree of contamination observed or results from individual sample stations.

Compounds	UVF	GC-FID	GC-MS
n-alkane		X	X
iso-alkane		X	X
biomarkers		X	X
VOCs		X	X
PAHs	X	X	X
THC	X	X	

Table 5: Analytical techniques used to analyse molecular groups.

Concluding monitoring activities

During the design phase of a monitoring programme, consideration should be given to the expected duration of any field sampling and the criteria used for the termination of the programme. Given the many factors, both occurring naturally and deriving from the response, that will influence the continued presence of oil contamination within the marine environment, it can be difficult to predict a suitable duration for monitoring. As a result, monitoring programmes are often iterative, whereby the results of previous sampling events are used as a basis for determining the requirement and scale of the next sampling event and to aid decision making on when to conclude the monitoring programme.



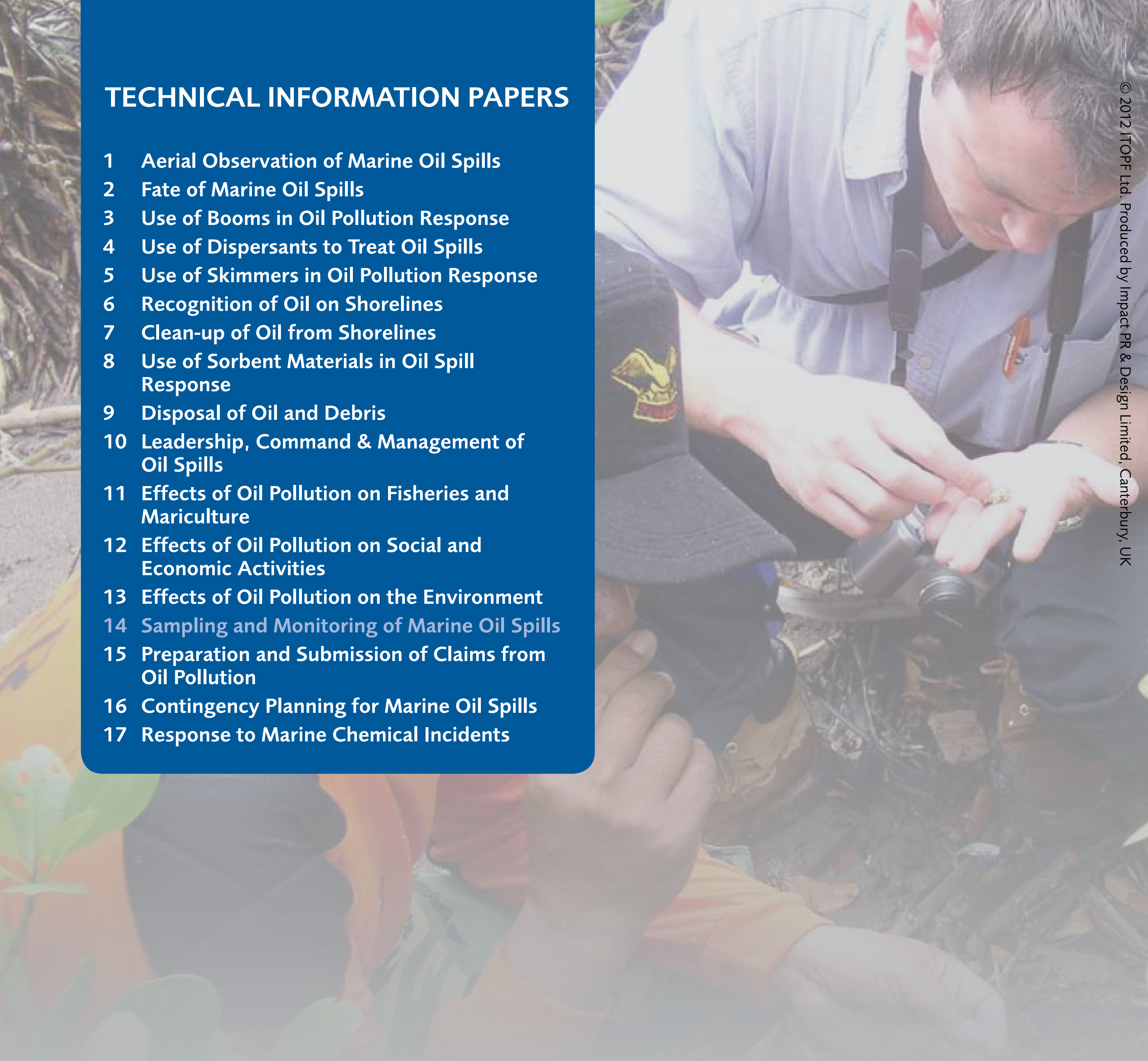
▲ *Figure 16: Results of a study to monitor the return of PAHs to background levels off coastal waters during shoreline clean-up. Sites 1 and 6 are reference sites.*

Monitoring programmes for oil within the environment will not be necessary after all spills and would normally be most appropriate in the case of major incidents, where oil has spread over a wide geographic area and where the oil has either the potential to cause significant environmental damage, presents a risk to seafood safety or where monitoring can assist directly with response activities. It is important that the monitoring is carried out with scientific rigour, objectivity and balance, with the aim of providing reliable information that can be used to assess the scale and extent of the oil contamination. The results of a well executed contaminant sampling and monitoring programme can, in some circumstances, be used in conjunction with, or to justify, a longer term more complex study of environmental impacts.

While there may be political and public pressure to undertake extensive monitoring programmes following an incident, it is rarely necessary or practical to monitor all resources and ecosystems that may or may not have been affected. In ITOPF's experience, well planned and focused monitoring programmes with clear objectives linked directly to the incident are those most likely to be effective.

Key points

- Monitoring may not always be necessary if the spill is small and resources are not at risk, or if the effects of the oil on a particular resource are well known.
- Joint sampling and analysis provides a constructive co-operative approach to monitoring.
- A monitoring programme should clearly define the objectives of the study and the information and data necessary to achieve these objectives.
- The objectives and the specific factors of the incident define the optimum location and number of sampling stations.
- The costs of the programme should be clearly budgeted and, where relevant, discussed with the body paying compensation prior to the start of the work.
- Reference sites selected should be representative of the habitat types affected and being studied.
- Collection of source samples should be a high priority, but may require the involvement of personnel qualified to enter enclosed spaces.
- Proper protocols for handling and storing samples should be followed to ensure their integrity for analysis.
- Results from the analysis of samples taken earlier in the monitoring programme can define the extent and duration of further monitoring.
- The techniques used to analyse samples will depend on the objectives of the monitoring, but screening techniques can be useful to limit the number of samples requiring more sophisticated analysis.



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1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
6 Recognition of Oil on Shorelines
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13 Effects of Oil Pollution on the Environment
14 Sampling and Monitoring of Marine Oil Spills
15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
17 Response to Marine Chemical Incidents

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this paper may be reproduced with the prior express permission of ITOPF. For further information please contact:

ITOPF

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com

PREPARATION AND SUBMISSION OF CLAIMS FROM OIL POLLUTION

TECHNICAL INFORMATION PAPER

15

Introduction

A spill of oil can cause a financial loss for a variety of organisations and individuals. Despite the best efforts of those concerned, the resultant clean-up can be protracted and costly. Oil may arrive on a shoreline causing damage to property and economic loss, particularly affecting local fishing or tourism industries. Those placed at a financial disadvantage as a result of a spill of oil may be eligible for compensation.

This paper provides guidance on the information to be recorded and the documentation or other evidence required to support a claim. The process by which a claim should be compiled and submitted is also outlined. This paper is applicable primarily to spills of oil from ships although many of the points raised will be relevant to spills of oil from other sources.

Overview

The payment of compensation for damage caused as a result of ship-source oil spills is dependent to a large extent upon the legal regime applicable within the country in which the incident or damage occurs. Many countries are signatories to one or more of a number of international compensation regimes designed to expedite payment of claims[1]. For countries that are not signatories to an applicable convention, national law will determine the compensation available[2].

A detailed explanation of the regimes is beyond the scope of this paper. However, in most instances, the vessel's third party liability insurer, usually a Protection & Indemnity (P&I) Club will be the primary source of compensation. For tankers carrying persistent oil, the International Oil Pollution Compensation Funds (IOPC Funds) may be involved in the payment of claims. In other instances, compensation may be available from a national government fund. Irrespective of the expected source of compensation, the submission of claims will usually follow a defined path with the onus of responsibility resting with a claimant to prove their loss. To allow the bodies paying compensation a full understanding of the claim, sufficient and suitable supporting information should be provided.

Detailed information on the preparation and submission of claims can be found in a number of claims manuals appropriate to individual compensation regimes. Specifically, the IOPC Funds' Claims Manual[3], while applying strictly to incidents involving the IOPC Funds, provides guidance helpful to many other jurisdictions, including incidents in non-Fund countries, involving vessels other than tankers, and other marine incidents. This ITOPF paper does not consider in detail the processes by which claims are assessed or settled and is intended to supplement rather than replace theguidance given in the claims manuals. Claims for removal of oil remaining in a casualty or wreck are also not considered.

▲ *Figure 1: In the event of a spill of oil from a ship, compensation for losses incurred may be available from a number of sources, dependent upon the legal regime applicable.*

The assessment process

In many instances, the claims settlement process is undertaken as a series of steps (*Figure 2*). Where a loss is anticipated, notification should be made at the earliest opportunity, supported by information on the quantum of the loss. It is the responsibility of the claimant to provide adequate evidence of their loss and further information and evidence may be requested during the claim assessment process. The assessment may therefore take the form of iterative exchanges between the claimant and those responsible for settling the claim, until the process has been completed. In most cases, agreement on the amount of compensation to be paid is reached on an amicable basis, without the need for legal action and associated costs.

Notification of claims

Delays often occur between a loss being incurred and the claim

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[1] International schemes include the Civil Liability and Fund Conventions applicable to spills of persistent oil from tankers, the Bunkers Convention applicable to spills of bunker oil from ships and the HNS Convention (not yet in force) applicable to spills of non-persistent oil from ships. The Convention on Limitation of Liability for Maritime Claims may also be relevant (see www.imo.org). The definition of persistent oil can be found in the separate ITOPF paper on the Fate of Marine Oil Spills.

[2] for example, the US Oil Pollution Act 1990.

[3] www.iopcfund.org/publications.htm

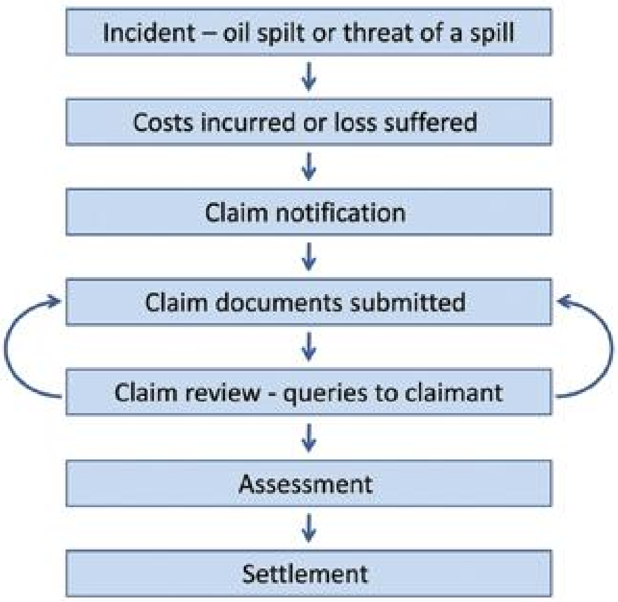


Figure 2: The typical steps by which straightforward claims are settled. Incidents or claims that are complex may involve other steps not shown, for example surveys and iterative assessments.

being submitted. For example, time may be required to compile a claim involving the costs incurred by different organisations or to collate supporting documentation from various sources. It is to the benefit of all parties that formal notification is made by a claimant to the vessel owner, the relevant P&I Club or other insurer of an intention to make a claim, as soon as practicable after losses are incurred. Dependent upon the circumstances of the incident, formal notification to the IOPC Funds or relevant national compensation scheme may also be required. In large-scale incidents, advice on the process for notification of claims may be provided in local media and a claims office may be established locally to facilitate the process.

If appropriate, the body paying compensation will send a representative to site. Often, this representative will be from the insurer's local correspondent or from a local surveying company. In some jurisdictions, other organisations, for example, spill management teams, will be mobilised. The insurer or IOPC Funds may also appoint experts, including ITOPF, to provide advice to those involved in a pollution response and affected by the incident, although it is important to note that advice provided by experts is not binding on those determining compensation.

A clear advantage of early notification of a claim is that advice and assistance from appointed experts can be provided in a timely manner, for example on appropriate clean-up techniques and on measures to mitigate economic losses. Furthermore, surveys can be conducted promptly at the time an alleged loss is occurring. Guidance may also be provided on the admissibility of potential claims, the types of evidence required to support a claim and how a claim should be formulated and submitted, thereby helping to avoid subsequent difficulties in verifying the nature and quantum of the loss and preventing unnecessary delays in the settlement of claims. Additionally, the bodies paying compensation can gain an early indication of potential losses, an important requirement if the total of expected claims has the potential to exceed the amount of compensation available.

Preparation of claims

The type of information required to support a claim depends upon the type of loss, in particular whether the loss is incurred as a result of the cost of responding to the incident or as a result of the effects of the oil on, for example, a tourism or fisheries business (*Figures 3 and 4*). While the quality of the documentation and other information required in support of a claim depends to a large extent upon the measures taken to record and preserve this information at the time the loss is incurred, for claims for economic loss, records of income and profit prior to an incident may also be required. In simple terms, for all claims, answers to the following questions may be required:

who is it about?
what happened?
why did it happen?
when did it take place?
how did it happen?
where did it take place?

As time passes and unless records are meticulous, the

Figures 3 and 4: Claims for the costs of labour intensive clean-up and losses associated with fishing operations require different types of supporting documentation.

availability of information to support claims, verify losses, and answer these questions is likely to diminish. Settlement of a claim may require time and if key personnel are no longer available to answer queries during this period, the records may be the sole source of information. Similarly, unless evidence is preserved correctly, substantiation of a subsequent claim may not be possible, for example if biological samples are not preserved and recorded properly, evidence of damage to mariculture could be compromised.

It is important to note that under the International Conventions, the losses claimed should be technically reasonable. As such, a claim should be based on the actual costs or losses incurred and should not result in an excessive level of profit. Furthermore, a claim for response costs should reflect the activities undertaken to achieve an effective and efficient response.

The preparation of claims for four categories of pollution damage are considered below: clean-up and preventive measures, property damage, economic loss and environmental monitoring, damage and restoration.

Clean-up and preventive measures

For many oil spills, significant costs will be incurred in the initial, emergency phase of a response as a result of deploying resources to protect sensitive areas and to recover the oil. In later phases, many of these same resources, especially personnel, may be used for cleaning damaged property and for undertaking subsequent environmental studies. While this section of the paper focuses primarily on claims for clean-up and preventive measures (collectively termed clean-up), much of the information, particularly on record keeping and the applicability of rates for personnel and equipment, is relevant to other categories.

The process of preparing a claim for clean-up costs is undertaken generally in two stages:

- keeping detailed records at the time the costs are incurred; and
- linking the records and costs with the rationale for the activity at the time the claim is compiled, usually when the response has been completed.

In some circumstances, for example when clean-up operations are protracted, the parties may agree to the submission of interim claims prior to the completion of activities. The process of preparing a claim is considered in detail below.

Record keeping for clean-up

In the initial emergency phase, the need to record the information necessary for the subsequent reimbursement of costs is commonly overlooked as operational personnel will be occupied on other tasks focusing on the response. Nevertheless, the importance of accurate records cannot be over-emphasised. Reliance on memory for subsequent claims compilation is not realistic, particularly during a lengthy and fast-moving response. To be most effective, the recording of information should be the responsibility of all personnel, with the gathering of the information necessary to support a claim allocated to a dedicated person or group with a good understanding of the structure and accounting practices of the claimant organisation.

Maintaining comprehensive and accurate records at the time costs are incurred creates plausible evidence of expenses and will ease the process of compiling the claim as well as facilitate answering any queries that may be generated during the subsequent assessment process. In organisations that have a fully prepared and frequently exercised contingency plan, record keeping may be instinctive, logical and ordered, while for others, the task may be overwhelming and less structured. As a consequence, organisations that have anticipated the task will be better prepared.

The period necessary for completion of the response and the quantity and extent of the documentation generated as a consequence of this work is difficult to predict. As a result of the potentially protracted nature of oil spill response, records should be kept in a logical order from the outset of an incident, for example by date, activity, clean-up site or sub-contractor, in order to assist compilation of the claim. These records may serve several important objectives, including some that may not be foreseen at the start of a response, such as investigations or evaluations of the incident response for updating and improving contingency plans. Consequently, it is often preferable to aim to record more information rather than too little.

A claim for clean-up that is considered to be well supported will usually include five generic types of information:

- records of information received;
- records of meetings and decisions;
- records of activity;
- records of expenditure; and
- records of effectiveness and results of actions.

Each is considered in further detail below.

Records of information received

Information is key to effective management, command

Figure 5: Minutes of any meetings held to discuss and decide upon response options should be included within documentation to support a claim.

and leadership of a response. From the initial notification of an incident onwards, information will be received by the designated contact point from numerous sources, including members of the public, the response team working on-site, and external agencies. Procedures should be established to record this information in a logical and methodical way for future reference. At a minimum, the date and time of receipt and the source of the information should be noted. Information received by e-mail or other electronic means should be stored and catalogued appropriately and, if necessary, printed.

Records of meetings and decisions

An effective response may be managed by groups of interested parties, including government agencies, shipowner representatives, clean-up companies and environmental organisations. These groups may meet at frequent intervals to discuss the progress of the response with a view to deciding future work. The minutes of these meetings serve to explain the rationale for the various response options chosen and provide a record of the effectiveness and the results of those actions (*Figure 5*). Minutes can also provide an important chronicle of events as well as a snapshot of developing clean-up activity for the period of the response, for example the movement of the oil, the changes in the levels of manpower and other resources deployed, and the amounts of waste collected.

Other meetings will be held and decisions taken at many levels of authority, from government committees and central incident command to individual work sites, for example beaches or wildlife cleaning stations. Each will contribute to the overall response and it is important to keep accurate records of the discussion and conclusions at all these levels. Useful information will include:

- the date, time and location of the meetings;
- the names and affiliations of attendees and their roles in the response;
- details of any external reports and information under discussion, for example aerial or shoreline surveys and weather reports; and

Figure 6: Vessels recovering oil close to shore. Recording the activity of each vessel will assist with the subsequent reimbursement of costs.

- summaries of the discussion and decisions reached.

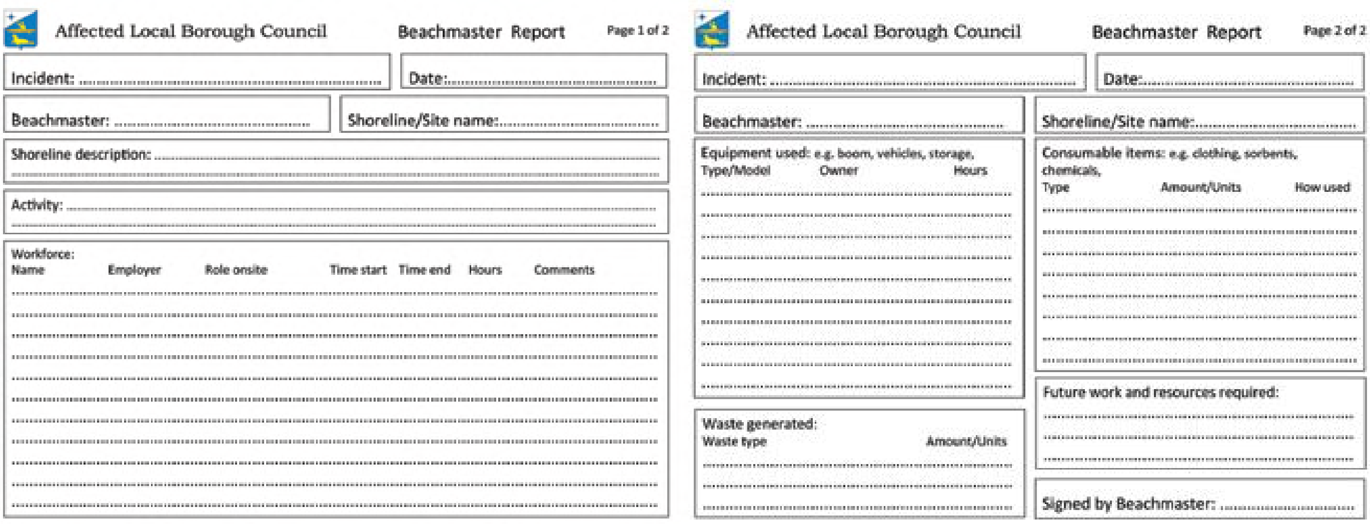
Shorthand or hand-written minutes and other records may require transcription into a format that can be understood by those to whom the claim will be submitted.

Records of activity

A record of the use or involvement of the resources and services for which reimbursement is being sought will be an important component of the documentation to support a claim.

For some resources, such as aircraft or larger vessels, logging hours of use may be a legal requirement of aviation or maritime authorities and, as such, may be done routinely. The relevant extracts of these logs will be invaluable to corroborate the hours of use for a particular activity, for example aerial observation or recovery of oil at sea. Where no requirement exists it is useful to record information such as:

- the date and hours of use;
- weather conditions;
- location and destination;
- crew and passenger details;



Affected Local Borough Council — Beachmaster Report — Page 1 of 2

Incident: .... Date: ....

Beachmaster: .... Shoreline/Site name: ....

Shoreline description: ....

Activity: ....

Workforce:

Name	Employer	Role onsite	Time start	Time end	Hours	Comments

Affected Local Borough Council — Beachmaster Report — Page 2 of 2

Incident: .... Date: ....

Beachmaster: .... Shoreline/Site name: ....

Equipment used: e.g. boom, vehicles, storage,

Type/Model	Owner	Hours

Consumable items: e.g. clothing, sorbents, chemicals,

Type	Amount/Units	How used

Waste generated:

Waste type	Amount/Units

Future work and resources required: ....

Signed by Beachmaster: ....

Figure 7: Sample of a two-page beachmaster or site supervisor report with provision to record information on resources employed and consumed on-site and waste generated. This information can be used to provide information to an incident command or management centre and to support a subsequent claim for reimbursement of costs.

- fuel usage;
- the type and amount of response equipment or oiled waste on-board;
- the activity being undertaken and its duration;
- maps, images and narrative of the work done; and
- the type and characteristics of the aircraft or vessels, with aircraft call signs or vessel names.

These records will allow a greater understanding of the involvement of the resource in the response and can be particularly useful when large numbers of vessels are mobilised to assist from a number of different ports (*Figure 6*).

Timesheets, work records or other logs of activity of personnel and equipment are an important component of supporting documentation required to substantiate claimed expenditure. For shoreline clean-up, the affected area is often divided into individual worksites, delineated typically by natural features, such as individual bays or estuaries. Supervisor reports for each worksite (*Figure 7*) should be used to record details of the site and everything that is on site for future reference, including the:

- name of the worksite and/or its location relative to local landmarks;
- type of shoreline, for example sand beach, harbour wall or mangrove;
- dates and hours of activity;
- state of the tides;
- names, affiliations, roles and responsibilities of the members of each clean-up team;
- level of oiling of the work site (see the separate ITOPF paper on Recognition of Oil on Shorelines);
- methods of clean-up undertaken;
- progress made during the period of the report (for example, the length of beach cleaned);
- type and amount of consumable items used (for example, sorbent, personal protective equipment (PPE) and hand tools);
- type and amount of waste collected; and
- equipment and other resources employed on the work site, such as skimmers, pumps, cranes, trucks, excavators, vessels and waste storage containers, together with the providers of each resource. Specialised equipment should be described to allow a clear understanding of its use.

Figure 8: Cleaning and rehabilitation of wildlife can generate significant claims. Costs may include heating and lighting of the facilities, protective clothing for the workers and food for the birds.

Personnel, and much of the equipment used in a response, are highly mobile and may move between several sites in a day, for example workers may be deployed on various tasks to accommodate tides, and waste skips may be transferred regularly between the shoreline and waste storage or disposal areas. In an incident covering a large area or long distance, assigning a code or tag to a particular resource and logging electronically the movements of that resource may simplify the task of determining how, when and where a particular resource was used. Constructing a record of activity that includes all resources and eliminates double-counting may be assisted by the use of a Geographic Information System (GIS) with output from the GIS submitted in support of a claim. With suitable computer programs, the resultant data may also allow the generation of associated spreadsheets that can facilitate compilation of a claim. However, electronic systems should be used only where a clear benefit in the management of the response or the costs of claim preparation can be shown.

Waste should be tracked as it is generated from clean-up operations, for example from each pollution response vessel and each work site, through temporary storage to final disposal or treatment. This information can assist with the management of the response by providing a clear idea of the clean-up work undertaken and of the overall amount of waste generated. Weighbridge tickets and waybills or consignment notes will allow the amount of waste transported to be verified. Records of pump throughput on road tankers, on-board recovery vessels or at waste receiving stations will allow the volume of liquid waste to be recorded.

Wildlife cleaning and rehabilitation stations may require considerable resources and logistics to operate. Comprehensive records should be kept of the scale of the operation, including the personnel involved, any work undertaken to fit out the premises and of the equipment, protective clothing, medicines, food etc. provided for the care of the wildlife and for the workers (*Figure 8*). An inventory of the animals or birds handled by the station should also be maintained.

Photographs provide an invaluable record of the level of oiling, the work undertaken and the resources involved at a particular site. Labelling images with the date, time and location will assist with subsequent cataloguing and identification of activities.

Records of expenditure

Even for a minor incident, a pollution response may involve a number of different organisations. In addition to utilising owned resources, each organisation may spend relatively large amounts of money to purchase or contract-in goods and services. The resulting trail of expenditure, including tender documents, purchase and sales orders, charter or hire agreements, contracts, invoices, delivery notes, vouchers, receipts etc, can be complex and can number many hundreds or thousands of individual documents. Consequently, it is important that an orderly system for logging and filing associated records is established as quickly as possible after the response commences.

Electronic spreadsheets and databases allow for rapid entry of data and calculation of costs but care should be taken to ensure that the supporting paperwork associated with the expenditure is referenced in a logical way. Paperwork scanned electronically can be linked directly to the relevant costs within a database although claimants should retain original documents to allow for future reference.

In many organisations, for example local government or private response companies, an established accounts department will serve to record expenditure. However, a large incident can quickly overwhelm the existing capability and temporary assistance may be required to ensure that the information is recorded and logged with minimal delay.

Dependent upon the size of the incident, an accurate indication of the overall cost of the response may not be known fully for some time. However, the ability to obtain an estimate of the costs incurred on a regular basis throughout the period of the response is often needed for planning and notification of claims. Establishing a cost-tracking system from the outset of a response can enhance operational efficiency and can allow identification and rationalisation of areas of high expenditure.

Records of effectiveness and results of actions

The sources of information described above will contribute to an understanding of the effectiveness and the results of activities. For example, use of manpower and equipment, as noted in the minutes of meetings, on timesheets, etc. will allow the effort and the results of that activity to be determined. Other sources, such as reports from site surveys, post-spill monitoring and reviews of the incident and response will also assist.

Compiling a clean-up claim

A variety of different organisations and individuals may be entitled to make a claim for compensation following an oil spill that can lead, in the case of a large incident, to many hundreds or thousands of claims.

The arrangement and co-ordination of claims preparation will be important to ensure costs are not omitted or duplicated. In some cases, lead organisations may elect to submit a single claim incorporating the claims of individuals and other organisations (*Figure 9*), and this can be helpful to those charged with assessing the claims. Nevertheless, in many instances, the incorporation of separate claims may be inappropriate or claimants may prefer to submit individually. In such instances, the claims submitted can vary enormously in complexity and quality.

Once all the components of the claim have been identified, the relevant supporting paperwork can be collated and the claim compiled. The total amount claimed can be presented in a covering letter, explaining the basis of the claim and the involvement of the claimant in the response. This total will be the sum of the individual components of the claim and can be summarised in a single table at the front of the supporting documentation (*Figure 10*).

By way of example, a claim submitted by a national authority covering the entire period of the response, may list the components of the claim according to activity in the air, at sea,

Figure 9: Military personnel mobilised to assist in shoreline clean-up. A claim for the associated costs of their involvement may be made directly by the army or as part of a wider government claim.

National Coast Guard

Claim for costs of the response to release of oil from GROUNDED BULKER

Incident date: 1/9/2011
Date claim submitted: 12/1/2012

	Coast Guard Resources	
	Aerial Activity	
1	*Helicopters and other aircraft.*	*139,975*
	Maritime Activity	
2	*Coast Guard cutters and launches*	*308,576*
	Response resources	
3	*Coast Guard vehicles and equipment*	*699,293*
	Personnel	
4	*Salaries for Coast Guard personnel*	*301,393*
	Expenses	
5	*Expenses of Coast Guard personnel*	*55,621*
	Other Resources	
	Sub-contractors	
6	*Costs of sub-contracted equipment*	*100,145*
7	*Costs of sub-contracted personnel*	*379,623*
	Miscellaneous	
8	*Other third party services and purchases, including consumable items*	*111,102*
	Total	**2,095,728**

Figure 10: Example summary of a claim for the cost of clean-up from a national coast guard agency, illustrating the typical components of a claim.

on the shoreline and in the command centre. Alternatively, a claim by a local authority or shoreline clean-up contractor may divide the claim according to individual worksites or into periods of work. In many instances, the components of the claim are ordered according to the costs of owned and contracted equipment, employed and contracted personnel, associated personnel expenses, purchases of consumable items and third party services. In any event, costs should be cross-referenced to the worksites where the resources were deployed.

A detailed breakdown of each component of the claim, listing individual items of equipment or workers, should be listed in a separate table (*Figure 11*), with reference to relevant supporting documentation. Additional tables may be necessary, dependent upon the complexity of the claim. The supporting documentation should be collated according to the component of the claim to which it relates and numbered sequentially or otherwise identified and referenced.

The following sections cover potential components of a clean-up claim and describe the basis upon which claims for reasonable costs might be constructed.

Owned resources

Generally, the costs for use of equipment owned by a claimant will be determined by multiplying the period of use by the unit rate for that period. Examples may include skimmers provided by a government agency, vessels owned by a spill response contractor or salvage company, or cranes and excavators owned by a construction company. The period of use can be determined from appropriate logs or timesheets.

Claims for use of aircraft are usually based on the number of flying hours with additional landing charges, crew expenses etc. as appropriate. If aircraft are not able to fly because of poor weather or other reasons, a daily stand-by charge may be applicable. For military aircraft, a comparison of local market rates for comparable commercial aircraft may provide a suitable hourly charge.

The costs of vessels are commonly based on a daily or hourly rate, dependent upon the duration of use (*Figure 12*), which is usually linked to the annual costs of running the vessel. The amortised capital value of the vessel, with maintenance, survey and running costs, crew wages and insurance, would be divided by the number of days in the year that the vessel would be available for service to achieve an appropriate daily cost. In most cases, fuel would be charged according to the amount consumed during operations. This ensures the claim reflects the costs incurred by the operator of a vessel as a direct result of the incident.

Alternatively, formulaic and comparative methods for determining a rate that are based on vessel characteristics

GROUNDED BULKER oil spill - Costs incurred by National Coast Guard in Week 1											
Equipment and consumables											
	Use	Rate	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Total use	Cost
Workboat - 8m, 60hp	In-use	500 /day	1	1	1		1	1	1	6	3,000.00
	Stand-by	200 /day				1				1	200.00
Boom inflatable 2000mm	In-use	8 /m/day		200	200	200	200	100	100	1000	8,000.00
	Stand-by	3 /m/day	200					100	100	400	1,200.00
Boom anchors	In-use	1 each/day		20	25	25	25	15		110	110.00
	Stand-by	0.5 each/day	25	5				10	25	65	32.50
Skimmer 30m3/hr	In-use	250 /day	1	1	1	1	1	1		6	1,500.00
	Stand-by	125 /day							1	1	125.00
Storage tank 7.5m3	In-use	60 /day	2	2	5	8	8	8	5	38	2,280.00
	Stand-by	20 /day	6	6	3				3	18	360.00
Screw pump 6"	In-use	200 /day		1	1	1	2	2	1	8	1,600.00
	Stand-by	50 /day	2	1	1	1			1	6	300.00
Pressure washer	In-use	100 /day				2	2	2	1	7	700.00
	Stand-by	50 /day			2				1	3	150.00
Car - 4 door saloon		80 /day	1	1	1	1	1	1	1	7	560.00
Car - four-wheel drive		100 /day			1	1	1	1	1	5	500.00
Truck - flat-bed with crane		160 /day			1	1	1	1	1	5	800.00
								Subtotal cost of equipment:			**16,357.50**
Sorbent boom		15 metre		24		36		15		75	1,125.00
Sorbent pads		1 pad		100		100	100			300	300.00
Shovels		7 each	20		5	15				40	280.00
Work suits		4 each	20	30	30	40	20	20	10	170	680.00
Gloves		2 pair	20	40	30	50	20	20	5	185	370.00
Boots		10 pair	20	20	30	20	20	20		130	1,300.00
25 kg bags		0.5 each	20	50	100	80	30	30	5	315	157.50
1 tonne bags		8 each		5	5	4	2	2	5	23	184.00
								Subtotal cost of consumables:			**4,396.50**

▲ *Figure 11: Example spreadsheet detailing the use of equipment and consumables during a one week period of a response. Each item of equipment is shown when in use and on standby with an appropriate rate differential. Consumable items are shown when used. Consumable items brought to site but not used are not included. The cost of each item is calculated by multiplying the total use by the rate. Further spreadsheets would show the use of equipment and consumable items in subsequent periods and other, similar spreadsheets would show the use and costs for other components of a claim, for example aircraft or personnel.*

Figure 12: The costs for use of specialised response vessels should be based on the costs of running the vessel with an allowance for profit where applicable.

may be applicable in the absence of actual operating costs of a vessel, particularly in the case of tugs and similar vessels. Nevertheless, these methods should produce realistic and reasonable rates and it should be borne in mind that formulae designed to calculate rates for use in salvage work reflect the inherent risk of that work compared to the lower risk associated with pollution response generally.

For specialised response equipment, such as skimmers and boom, a reasonable rate can be determined by amortising the value of the equipment over its expected lifetime, with an addition for overheads, such as storage, maintenance, and insurance. The amortisation periods vary according to the type of equipment and are based on the expected durability. For extended periods of use, the rate charged should decrease once the value of the item has been reached, to allow maintenance and operational costs only, with profit as appropriate. Stepped rates, that decrease in intervals after specific periods of use, may also be appropriate to reflect lower fixed costs proportionately with extended use. A description or specification sheet for the equipment should be attached to the claim.

The rates for non-specialised resources, such as construction, agricultural, waste storage, catering and sanitary equipment, portable shelters, lighting and vehicles should be comparable to the rate obtainable from local commercial lease or hire companies. Where relevant, an explanation should be given as to whether the rate includes the costs of drivers and/or operators, fuel and ancillary equipment.

Costs of resources owned by public authorities that would have arisen for the authorities even if the incident had not occurred may be admissible under some compensation regimes in some countries, for example the hire of coast guard vessels usually on patrol but diverted to respond to an incident. For all resources owned publicly, particularly from the military, the rate applied should not include a disproportionate level of indirect charges, for example, back-office or headquarters costs. Indirect charges should not be too remote, in terms of time and distance, from the incident. By way of example, the rates for military vessels should reflect their role in the response and not include charges for any armaments on-board that will not normally be used in the response.

The rate applied may vary according to the operational status of the resource. For periods of hire where equipment is not in use but is held on stand-by or is in transit, or when a vessel remains in port as a result of poor weather or is undergoing cleaning, a reduced stand-by rate may be appropriate. This reduction reflects the continued involvement of the resource in the response but also accounts for the lack of wear and tear and savings in fuel if appropriate, when not deployed. As a consequence, accurate recording of the use and status of resources is required to compile the claim correctly.

For resources operated commercially, a reasonable element of profit would be considered, whereas for government assets no such allowance would be made. Similarly, a reasonable level of administrative expenses may be considered as a mark-up on incurred costs. For large claims, a decreasing percentage mark-up, applied at specified monetary intervals, may be appropriate in order to reflect a lower administrative burden proportionately. Nevertheless, itemised costs for administrative personnel and expenses should be listed in preference to a mark-up in order to reflect the actual costs incurred in administering the response.

Some contractors operate a member scheme, whereby organisations can use resources at a lower rate than non-members in return for a fee, usually paid annually. In such instances, the membership fee may cover annual overheads, such as storage, maintenance etc. and the rate claimed for use of the resource during the response would be correspondingly lower.

Contracted or hired-in resources

A response will often require resources in addition to those owned by the lead organisation and these may be contracted-in. Where resources are contracted or hired, similar information as described above will be required in order to calculate and support the expenditure claimed. Copies of contracts or hire agreements will allow an understanding of how the appropriate contractual terms and conditions affect the claim.

Certain response resources, such as dispersant spraying aircraft or fleet vehicles, are commonly on long-term lease or charter for use by governments or private organisations. Claims for use of the leased or chartered resource should bear a close relationship to the cost of the lease or charter. For example, an appropriate cost for use of a vehicle may be determined as a proportion of the cost of the lease for the period that the vehicle was used in the response.

In a large incident, where sub-contracting can occur at several levels, care should be taken to ensure that the sum of all the administrative mark-ups applied at each level is not excessive.

Personnel

A response may include a wide range of personnel, including specialised consultants, oil spill contractors, aircraft and vessel crew, industry or government employees, agency staff, fire and rescue services, police, military, local residents and volunteers. The costs for their involvement will vary widely, primarily according to local living standards, levels of training and their roles and responsibilities in the response.

Accurate and annotated timesheets should be kept for all personnel. Information contained in minutes of meeting and shoreline activity reports, as well as aircraft and vessel logs, can be used to corroborate personnel involvement. The rate paid for the work should be appropriate for the tasks undertaken and be related closely to the cost of the employee to the employer at the time of their involvement. This cost would include remuneration, national and local taxes, insurance, overheads and profit where applicable. Clothing and PPE provided to workers are usually listed separately as consumable items.

For salaried workers, a rate is usually applied daily, irrespective of the length of the working day. Waged (non-salaried) workers are usually paid hourly with an increase in the rate for anti-social hours of work i.e. evenings, weekends and public holidays. Where the costs for equipment operators are claimed as a part of the rate for the equipment, for example, truck drivers or vessel crew, the uplift for overtime should apply to the personnel component of the hourly rate only and not to the truck or vessel.

Costs for the normal salaries of personnel permanently employed by public authorities, that would have arisen for the authorities even if the incident had not occurred, may be admissible under some compensation regimes in some countries. Claims should be limited to personnel involved in an incident, such as those recovering oil on-board vessels, working on the shoreline or making decisions within a command centre. Under many compensation regimes, the costs for personnel located remotely from the area of the incident or involved solely for political or public relations reasons are not admissible. Conversely, costs for personnel to record, collate and compile information and to prepare and submit a claim may be eligible for compensation, provided that these costs are in proportion to the claimed amount. Despite the best efforts of a claimant to submit a fully comprehensive claim, the bodies assessing a claim will often require clarification of certain items. As a consequence, the continued involvement of the claimant to address these queries and follow the claim through to a conclusion may be necessary. Time for these tasks should be logged carefully to differentiate between any ongoing spill response work.

It is important to recognise that volunteer participation in clean-up operations is not cost-free. Although volunteer labour is offered free of charge *per se*, each volunteer will require some level of PPE, food, transport to the clean-up site as well as competent supervision. In large-scale incidents, significant numbers of volunteers may arrive from outside the local area, requiring accommodation and other assistance (*Figure 13*). Volunteers may be given a *per diem* payment to cover expenses, unless food and accommodation are provided separately. Liability insurance may also be required. A record of the names of each volunteer, their allocated work sites and activities undertaken, should be kept. Mandatory signing in and out of work sites may facilitate accurate recording of this information.

Personnel expenses

Claims for costs to feed and house personnel should be based on receipts and invoices from shops, restaurants, cafés, hotels etc. If workers are based locally, the cost of transport to clean-up sites or command centres may be based on appropriate mileage rates using workers' own vehicles. Otherwise, hired vehicles may be used, or local transport companies contracted for the purpose. Receipts, vouchers and tickets for any air and train travel undertaken should be provided. Workers may be paid an allowance for their own food or alternatively, local catering companies may be engaged to feed workers on-site. The name, role and responsibility of the persons incurring the expense should be recorded and linked to the relevant supporting documents, work site and activity.

Consumables/purchases

A response operation will involve the use and purchase of a wide variety of items. Consumable items, such as dispersant, sorbent material, PPE and tools used in the response, printer ink, toner and paper used to record information and to compile the claim etc. may either be held in store and require restocking after termination of the response or may be purchased specifically for use at the time.

Purchasing non-consumable resources may be an alternative to hiring-in, particularly in situations where the expected use may be protracted and the hire costs may exceed the purchase cost. Purchased items, such as pumps and other response resources, and furniture, computers, and mobile telephones for use in the command centre, may have a residual value following their use in an incident. This value will depend on the period of use in the incident and whether, subsequent to completion of the clean-up, they are suitable for use in future incidents or for some other purpose. The usual method is to 'write-down' or depreciate the items over a number of years, dependent upon local accounting standards, with an appropriate fraction of this period allocated in the claim. Spill response can make severe demands on

▲ *Figure 13: The large scale involvement of volunteers in a response can incur significant costs for protective clothing, food and accommodation.*

▲ *Figure 14: The handling, storage, transport, treatment and disposal of waste can be costly. Special attention should be paid to recording the quantities of waste collected, moved and treated.*

resources and items that are considered to have worn-out prematurely should be identified and explained.

The reason for the use of the consumable or purchased items in the response, the date and location of their use and the purchase cost should all be recorded. Tracking the use of bulk purchases, particularly sorbent and PPE, from central warehouses to local distribution areas and on to specific work sites or vessels can be difficult, particularly during the emergency phase of a large response. For this reason, suitably experienced logistics personnel should be allocated to the task in order to ensure accuracy. Purchase orders, warehouse stock release forms, inventory reports, invoices and receipts should be retained and indexed appropriately. Receipts for fuel should be annotated to identify the response vessel, vehicle or equipment for which the purchase was made.

Third party services

Additional third party services may be required during a response, for example for cleaning equipment, sample analysis, oil trajectory modelling and mapping, providing scientific advice or satellite imagery, security for clean-up sites and equipment storage, and for waste storage and disposal. Adequate documentation should be provided to allow a full understanding of the service provided and how the costs were calculated.

Utility costs, such as water, electricity, mobile and fixed telephone line and call charges should be supported by the relevant paperwork, with the component of the bill appropriate to the response period identified.

Waste storage and disposal can be a significant part of the total costs of a response (*Figure 14*). Claims for waste are often based on a cost per unit of waste handled, by weight or volume. Where appropriate, a breakdown of the unit cost is helpful to allow a full understanding of the individual components, such as transport, storage, handling and ultimate treatment or disposal of the waste, with appropriate invoices attached to the claim.

Property damage

Oil can cause damage to various types of property resulting in claims for cleaning, repair or replacement. Items affected commonly include: hulls of fishing and other commercial vessels; pleasure craft; marina pontoons; fishing gear, such as nets and traps; and mariculture structures, such as fish farms, mussel rafts and oyster trestles. For further information on oil spills and fisheries, the separate ITOPF paper on the Effects of Oil on Fisheries and Mariculture and the IOPC Funds' document on Guidelines for Presenting Claims in the Fisheries, Mariculture and Fish Processing Sector[4] may be consulted.

Property damage claims may also arise as a result of clean-up activity, for example, damage to roads or paths used for access by workers and vehicles. Rectification of damage to vehicles, vessels and other equipment as a direct result of their involvement in a response may also form part of a claim, although, where applicable, compensation should be sought first under vehicle or other insurance policies.

In the event that a separate clean-up claim is not submitted, a claim for costs associated with mitigation measures undertaken to prevent property damage can be included in a property damage claim. This might include protective booming of a mariculture facility, industrial water intake or marina.

Information to support property damage claims

As a minimum, photographs of the property before and after restoration should be provided in support of a claim. Where relevant and practical, the contaminated or damaged property should be disposed of only with the prior consent of the organisation paying compensation. A detailed description of the cause of the damage should also be provided. When possible, several quotations should be sought prior to contracting for the cleaning or repair work and all invoices and receipts should be retained. A claim for replacement rather than repair of a damaged item should be supported by cost estimates, for example from cleaning or repair companies and manufacturers, and include an explanation as to why the item is to be written off.

For many property damage claims, a survey will be necessary prior to the commencement of work to restore the property. This is usually undertaken jointly with representatives of the organisation paying compensation. Surveys are necessary to confirm the link of causation to the incident, to corroborate the level of contamination or other damage claimed and to advise on the appropriate work to be undertaken (*Figure 15*).

The assessment of property damage claims often takes into account the condition and age of the property prior to contamination and payment is typically not made on a 'new for old' basis. For example, a deduction to payments may be made for replacement of fishing gear oiled towards the end of its working life. As a consequence, purchase receipts should be submitted as part of a claim. Deductions may

[4] *www.iopcfund.org/publications.htm*

Figure 15: A field severely damaged by movement of heavy machinery to and from an oiled shoreline. A claim for restoration of the field would necessitate a survey to establish the exact level of damage and any betterment that may arise from the work.

Figure 16: An oiled fish cage undergoing cleaning. Any resulting loss of income may lead to a claim for consequential economic loss.

Figure 17: Clean-up on a tourist beach may affect the overall number of visitors to the region and result in claims for pure economic loss for a number of businesses.

also be made to account for betterment, for example to resurface a former gravel road with a tarmac covering, and any such betterment should be taken into account when preparing the claim.

Economic losses

The income of companies, organisations and individuals may be affected adversely resulting in economic loss as a direct result of an oil spill. Economic loss can be divided into consequential economic loss and pure economic loss.

Claims for economic losses as a result of an oil spill are submitted most commonly from the fisheries and tourism sectors. A wide variety of financial and operational arrangements have been adopted in these business sectors worldwide, and, consequently, the precise information that a particular claimant might provide in support of a claim for economic loss is wide ranging and dependent upon the specific circumstances of the loss. The following information therefore focuses on some of the more common issues with regard to economic loss claims, with particular emphasis on fisheries and mariculture claims.

Consequential economic loss

Claims for consequential economic loss arise typically as a result of contamination of fishing vessels, fishing gear, mariculture facilities (*Figure 16*) or tourism assets, which prevents their subsequent use. Income lost while the oiled items are cleaned or replaced may form the basis of a claim for consequential economic loss. In addition to the documentation required to support the property damage, evidence of the ensuing loss of income will also be required. In this regard, the information required to support claims for consequential economic loss is similar to that required to support claims for pure economic loss and both are discussed together below.

Pure economic loss

Claims for pure economic loss arise even though no damage to property has occurred, for example, if oil at sea prevents a fishing fleet from departing port, or access to a tourism facility is blocked by response activities (*Figure 17*). Media reports of an oil spill may also result in a loss of market confidence, which might deter tourists from visiting a coastal area or the public from purchasing or eating seafood that they perceive to be contaminated by oil. Although accepted under the international compensation regimes, in some national jurisdictions claims for pure economic loss are not admissible. Where claims for pure economic loss are accepted, losses can be seen on a balance sheet only, rather than as a consequence of damage to property. Therefore, for many such claims, the most important supporting documentation will be copies of company accounts or other financial statements.

As a precautionary measure to safeguard public health, authorities may impose restrictions on fisheries activities and the sale of seafood products by merchants, hotels and restaurants from the coastal area affected by the oil spill. Any fisheries restrictions should be managed on technical grounds to ensure that the criteria for imposing, maintaining and lifting the restrictions are understood clearly. Claims

Figure 18: *Financial records for subsistence fishing are often not available to support a claim. Other means and sources of information can sometimes be used to determine the losses.*

Figure 19: *Catch awaiting sale at a fish market. Detailed sales figures will assist in the assessment of any claims for losses as a result of an oil spill.*

for business interruption as a result of fishery restrictions should include copies of the relevant notices issued by the authorities. It should be noted that, while fisheries restrictions may make it illegal for fishing activities to continue, claims may not be considered admissible if the restrictions were imposed or maintained with insufficient technical justification.

Compiling a claim for economic loss

The first step in compiling a claim for economic loss is usually to provide evidence of a legal involvement in a particular business activity. For example, fishing activities are commonly licensed and evidence of membership of a fishing co-operative or vessel registration documents may be available. Similarly, a tourism operator will often be subject to licensing and registration and copies of these documents should be provided. In some parts of the world, illegal or unregulated activities are tolerated but this may lead to difficulties in some claims being accepted.

Official licensing and tax regulations in some parts of the world do not require small-scale fishing to be recorded. In addition, subsistence or artisanal fisheries (*Figure 18*) may focus on the provision of daily food or seafood for barter that may not include financial transactions. These factors combine to make the assessment of claims for many fisheries problematic as the fishermen are often unable to provide any supporting documentation for their claims other than verbal reports of their activities. In these circumstances, it is important that the claimants, appointed experts (including ITOPF), local authorities, fisheries officers and other relevant parties work together to create a realistic financial picture of the fisheries impacted during a spill. This can be a lengthy process requiring extensive field work and information gathering. A similar approach may be necessary for small-scale tourism and other businesses.

Where records exist, copies of financial accounts for at least three years before the incident should be provided to allow an understanding of the business and normal trading patterns and any effects on income due to the oil spill (*Figures 19 and 20*). If circumstances allow, accounts for a period after the

Year	Month	Catch (kg)	Average market price (cost per kg)	Catch sale price	Vessel mortgage/ maintenance	Crew	Fuel	Ice	Electr-icity	Total Costs	Profit
2005	January	300	1.40	420	155	125	54	10	14		
	February	1201	1.44	1,729	175	432	167	45	32		
	March	378	1.45	548	155	200	32	15	16		
	Total	**1879**		**2,698**	**485**	**757**	**253**	**70**	**62**	**1,627**	**1,071**
2006	January	405	1.49	603	165	145	59	10	17		
	February	1105	1.51	1,669	174	500	179	50	38		
	March	312	1.50	468	145	210	38	15	13		
	Total	**1822**		**2,740**	**484**	**855**	**276**	**75**	**68**	**1,758**	**982**
2007	January	314	1.50	471	134	145	60	10	17		
	February	216	1.57	339	120	110	50	10	11		
	March	222	1.56	346	145	254	34	15	15		
	Total	**752**		**1,156**	**399**	**509**	**144**	**35**	**43**	**1,130**	**26**

Figure 20: *Example figures provided in support of a claim for loss of income for a fishing vessel owner. The spill in February 2007 resulted in a fisheries closure during that month, giving rise to a significantly lower catch of fish than for the same period in the two years previously. While savings were made in associated operational costs (vessel maintenance, crew, fuel, ice etc.), the overall profit was reduced. Further analysis would be required to determine whether the loss could have been mitigated, for example by fishing in an area away from the oil spill.*

incident may also be provided. If formal financial accounts are unavailable, copies of business records, tax receipts, fishing catch and sales notes, receipts of purchases such as fish food, ice and fuel, a calendar of fishing activity, feeding and harvesting patterns may all be required to support a claim from fishing businesses. For tourism businesses, similar records may be necessary with details of, for example, the number of hotel rooms or camping pitches let, the number of restaurant customers served, or tickets sold for an attraction.

As with property damage claims, a survey of the claimant's business may be required to corroborate the economic loss claimed and also to determine whether the loss can be mitigated or reduced by considering alternative sources of income.

If circumstances prevent a survey from taking place, a full description of the claimant's business should be provided to assist with the assessment. For example, for fisheries and mariculture claims, a claimant could provide details of the cultured or catch species, production cycles, seasonal and weather factors, gear types and customers. A hotelier could provide a description of the hotel facilities, bookings, visitor demographic and places of interest close by. As with clean-up claims, it is often preferable to provide more rather than less information.

Savings made as a result of restrictions in activity should be noted and accounted for in the claim, for example savings in fuel for fishing vessels remaining in port or reduced food costs for hotel guests that have cancelled their bookings.

Businesses rarely operate in isolation and consequently, companies or individuals reliant on those affected directly by the oil spill may also be affected. This might include fish feed suppliers, fish processors, seafood wholesalers, ship chandlers or hotel suppliers. A claim for economic loss from these parties should contain similar information as for those impacted directly by a spill and should also include details of the contractual arrangements between the claimant and the supplier or buyer if available. A similar situation may arise with a fishing vessel crew where payment may be in the form of a salary, a share of the catch profit or a combination of both. In this circumstance, the crew payment arrangements should be detailed and, if appropriate, a crew waiver provided to indicate that all claims for a fishing vessel will be dealt with collectively.

It is important to note that there should be a clear and close link between any economic loss claimed and the oil spill. Furthermore, claimants should provide evidence to show that they have taken reasonable measures to mitigate their losses, for example a restaurant may be able to purchase seafood from alternative suppliers or a business may be able to minimise variable costs for the period they were unable to operate. The documentation necessary to establish the link of causation and other criteria are varied and specific to individual claimants.

The level of income or profit a business may earn will vary, sometimes considerably, on a daily, seasonal or annual basis and be influenced by many factors that are independent of an oil spill. For example, a downturn in a national economy or a season of bad weather may reduce tourist numbers, and natural variations in spawning and recruitment may increase or decrease the adult fish stock and catch quantities. It is important to distinguish losses incurred as a direct result of the oil spill from those that might have occurred in the absence of the spill. Identifying and quantifying only those economic losses attributable to an oil spill is often complex and may require the assistance of experts and surveys undertaken jointly with other parties.

Fisheries and tourism organisations may undertake a marketing campaign to alleviate adverse publicity from a spill. Such campaigns might include television, radio and newspaper advertisements, the costs of which should be itemised in a claim. Additional information, such as the timing and intended targets of the campaign, together with measurable results, may be required. It is prudent to discuss the objectives of any marketing campaign with those paying compensation at an early stage.

In complex cases, a claimant might consider it appropriate to engage advisers to assist with the preparation of a claim. Advisers should be suitably qualified and have knowledge of the claims process and the standards of claims documentation required. Reasonable costs incurred for the work of advisers may be compensated under some compensation regimes. Costs for advisers should be proportionate to the losses claimed and the work undertaken. ITOPF and other experts appointed by the organisation paying compensation may be able to advise on preparing claims.

Environmental monitoring, damage and restoration

Monitoring of an area affected by a spill of oil can be required for a variety of reasons, including determining the extent and duration of clean-up operations and the level of contamination of the shoreline or biological species. Monitoring can range from straightforward intermittent visual observations to an extensive campaign of sampling and analysis over a period of time. Sampling may also be required to allow identification of the oil. Preferably, monitoring programmes should be agreed with the body paying compensation prior to the commencement of the work.

The documentation necessary to support claims for monitoring, sampling and analysis will vary. Claims for sampling should include the rationale for the work, key information on the type of sample (i.e. oil, water, sediment or biota), the date and location the sample was collected, and the date and method of the analysis. Reports or advisory notices based on the results of monitoring programmes should also be provided. Further information is provided in the separate ITOPF paper on Sampling and Monitoring of Marine Oil Spills.

Under the international compensation regimes, claims for economic loss incurred as result of damage to the environment and the costs of reinstatement of damage may be considered. The documentation required to support economic loss under this heading will be similar to that discussed above, requiring financial records and details of the claimant's business.

Claims for work done to restore damaged resources and encourage natural recovery are acceptable under the International Conventions only if certain criteria are met. Costs should be itemised to explain clearly the work done. Claims based on calculations made according to theoretical models and claims for compensation for loss of function of the environment *per se* are recognised under some national and regional compensation regimes but are inadmissible under the international compensation regimes. Further information is provided in the separate ITOPF paper on Effects of Oil Pollution on the Marine Environment.

Submission of claims

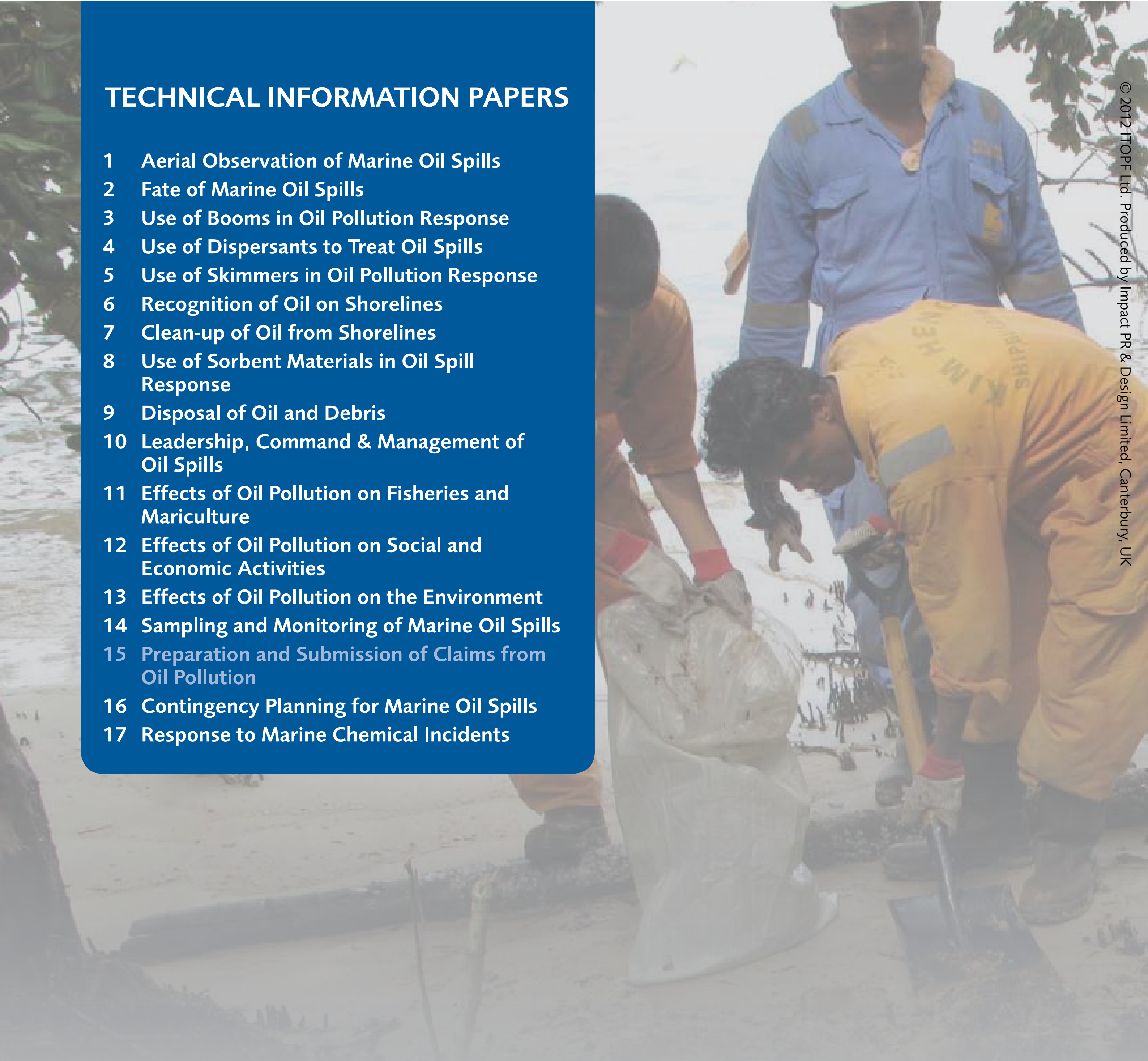
In its most basic form, a claim should include the identity and contact details of the claimant, the name of the incident (usually the vessel name), the amount claimed and the reason for the claim. While a claim submitted in this basic form may serve as a useful notification of intent, in most instances, this will be insufficient to allow an assessment to be made and usually much more information will be required.

Supporting documentation provided as boxes of unreferenced invoices, statements and other documents, will require considerable additional effort to reach a point from which an assessment can be undertaken. In a large-scale incident, the claims documentation can be voluminous and, ideally, should be submitted in a form that can be understood readily by the organisations and their experts who will be tasked with the assessment. In particular, a description of supporting invoices, records and other documents should be provided to explain their relevance to the incident and how they support the claim and be referenced to individual items in the claim. Claim summaries and detailed tables of figures submitted in a readily useable electronic format, preferably in spreadsheets, will negate the need to transcribe the detail of a claim by those undertaking its analysis. Furthermore, the assessment of claims is often a team effort between national and international experts and the electronic submission of documents may assist the process, particularly if translation is required. However, it is important to note that submission of a well documented claim may not mean that, as a consequence, the claim will be admissible and will therefore qualify for compensation.

Unforeseen costs may be incurred after a claim has been submitted. If relatively small, the original claim may be modified to include these costs, although this may delay the subsequent assessment process. Otherwise a supplementary claim can be submitted at a later date but claimants should be aware that under many jurisdictions, including the International Conventions, time bars prevent claims being accepted once a certain period after the incident has elapsed.

Key points

- Losses incurred as a result of a spill of oil from a vessel should be notified to the vessel owner as quickly as possible.
- A basic claim should include information, such as the identity of the claimant, the name of the incident, the amount claimed and the reason for the claim.
- The type of additional documentation required will depend on the type of claim.
- For clean-up claims, the quality of supporting documentation is enhanced by measures taken to record and preserve information from the outset.
- The task of recording information should be incumbent on all personnel. Gathering the information necessary to support a claim should be allocated to a specific person or group and be included in contingency plans.
- Records of all meetings, activity and expenditure should be preserved as it is better to record more information than not enough.
- Clean-up claims should be structured to show the separate components and should be based on reasonable rates for work that has been undertaken in support of the response.
- Claims for damage to property will in many instances require an independent survey to determine the extent of the damage and appropriate repair work.
- Consequential economic loss and pure economic loss claims, particularly in the tourism and fisheries sectors, should be supported by full financial accounts and sales information.
- For small scale and subsistence operations, this data may not be available and other means of corroborating losses may be required.
- Ultimately, it is the responsibility of the claimant to prove their loss.



TECHNICAL INFORMATION PAPERS

1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
6 Recognition of Oil on Shorelines
7 Clean-up of Oil from Shorelines
8 Use of Sorbent Materials in Oil Spill Response
9 Disposal of Oil and Debris
10 Leadership, Command & Management of Oil Spills
11 Effects of Oil Pollution on Fisheries and Mariculture
12 Effects of Oil Pollution on Social and Economic Activities
13 Effects of Oil Pollution on the Environment
14 Sampling and Monitoring of Marine Oil Spills
15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
17 Response to Marine Chemical Incidents

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this paper may be reproduced with the prior express permission of ITOPF. For further information please contact:

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com

CONTINGENCY PLANNING FOR MARINE OIL SPILLS

TECHNICAL INFORMATION PAPER

16

Introduction

An effective response to a spill of oil is dependent to a great extent on the preparedness of the organisations and individuals involved. This can be greatly enhanced by developing and maintaining a plan to address all likely contingencies. The process of producing a contingency plan provides the opportunity to identify roles and responsibilities and to define response strategies and operational procedures without the intense pressures that inevitably arise at the time of a spill.

This Technical Information Paper outlines the typical format and content of contingency plans for response to ship-source spills and highlights the key steps required for an effective plan.

Overview

Responding to a serious oil spill affecting a wide range of people and organisations demands that a variety of decisions are made very quickly. This can be achieved only if all participants are sufficiently prepared to appreciate the unfolding situation, can make crucial decisions and can mobilise appropriate resources without hesitation and with minimal delay. A fully developed contingency plan will assist in achieving this goal. A plan is not merely a written document but comprises all the practical requirements necessary for an immediate and effective response should a spill occur.

Functions necessary for a response should be identified together with the organisations or departments from which suitable personnel will be provided. Response techniques also have to be considered and the availability of equipment to implement the strategies confirmed. Operational aspects have to be balanced against concerns for the effects on the environment, fisheries, industry and recreational activities as well as considerations of public health and safety (*Figure 1*). Inevitably there will be conflicting interests and in many countries the media will be quick to expose any indecision, weakness or disagreement.

Figure 1: A major port with residential and recreational areas nearby: a case for oil spill contingency planning.

The International Convention on Oil Pollution Preparedness, Response and Co-operation 1990 (OPRC Convention) recognises the importance of contingency planning and prompts contracting states to develop an integrated national framework of oil spill response plans extending from individual facilities handling hydrocarbons to a major incident on a national or international scale. These arrangements are intended to provide an ability to escalate a response to an incident through a series of interlocking and compatible plans.

Developing and managing a plan

Contingency plans provide the structure for the management of response operations. While the overall aims are generic, plans should nevertheless reflect the working culture of the country within which they will be implemented and should be working documents; concise, accessible and easily updated. Regardless of geographic or organisational scope, plans should be reasonably self-contained with minimal reference to other publications, which could delay decision making. These requirements may be met most effectively by electronic web-based systems.

The simple existence of a plan is not sufficient preparation for responding to an oil spill. The planning process itself is important, serving to raise awareness of the issues likely to arise in a response. For this reason, a plan is best drawn up by those who will rely on the finished plan when a spill occurs. Plans need to be actively managed, regularly updated and revised, for example, in the light of lessons learnt from actual incidents or exercises or as required by changes in regulations. Once developed, plans also provide a focus for training. In order to work together as a coherent team all responders need to understand the plan and be familiar with their own role and the roles of others within the response structure (*Figure 2*). This can be achieved through regular practical exercises which are critical to maintaining an effective response capability.

Scope of contingency plans

The scope of a plan is determined by the risk of spills within the geographic area that the plan is intended to cover. The responsibility for drawing up plans at a local level, for example for an individual facility, port or stretch of coastline and at a larger district or national level, will be dependent on the relevant domestic administrative arrangements. The plan holders, i.e. the organisations or agencies tasked with implementing the plan and responding to incidents at each level, should be involved from the outset if plans are to be realistic and practical. Responsibility for ensuring that all plans are compatible usually falls to a national agency.

The framework of interlocking and compatible plans is often known as 'tiered response' and is intended to ensure that the response undertaken reflects the scale of the particular spill. Usually, three tiers are recognised with Tier One plans at the facility level, Tier Two at a district or area level and Tier Three for national or international response arrangements. At each level, plans should be capable of addressing the range of potential scenarios identified in risk assessments.

Different agencies may adopt different criteria for escalating a response from one tier to the next. These may be based on the estimated amount of oil spilled or on the need for additional equipment or manpower beyond that available under a lower tier plan. In another approach, escalation might be decided by the migration of a spill from the area covered by one plan into the next, calling for a coordinated response between the two areas.

Components of a plan

Compiling a contingency plan is generally a four-stage process, reflected in the components of the plan:

- Risk assessment – determining the risk of spills and expected consequences;
- Strategic policy – defining the roles and responsibilities and providing a summary of the rationale for operations;
- Operational procedures – establishing procedures when a spill occurs;
- Information directory – collating supporting data.

The order in which the plan is developed follows this logical progression through the stages. The result of the risk assessment will assist in determining the response strategy which in turn will assist in developing operational procedures to be followed when a spill occurs. The type of information required in the directory will become clear as these procedures are developed. The steps required to produce a comprehensive contingency plan are set out in Figure 3.

Risk assessment

Conducting a risk assessment is the first step in the contingency planning process to ensure that plans are developed in the context of the risks they are intended to address. The aim is to identify measures to reduce and manage the risk of spills and the consequences if a spill does occur. The scale of risk assessments can range from the national level to the specific investigation of risks posed by an individual facility or terminal. National risk assessments provide a good indication of where spill response efforts need to be concentrated around a coastline while the latter consider the detailed response arrangements needed locally.

The assessment of the risks presented by oil spills requires the answers to two questions to be analysed:

1. What is the likelihood of a spill occurring?
2. What are the probable consequences?

To address the first question, one approach is to examine the types of incidents that have led to oil spills in the past; their frequency and the types and quantities of oil released. Oil spills occur relatively infrequently and so there are often insufficient historical spill records in the relevant area to make a fully quantitative assessment. Nevertheless, on a global scale, historic data does provide information on the most frequent causes of spills. Applying these statistics to local circumstances helps identify the risks to which the area is exposed. For example, it has been found that most spills occur in or close to ports; they tend to be small in size and are generally the result of routine operations such as loading, discharging and bunkering. The number of calls made by tankers and other vessels to oil terminals and commercial ports and the types of oil or bunkers carried is therefore highly relevant to evaluating risk. Where the types of oil handled are known it may be possible to predict the behaviour and persistence of an oil after it has spilled.

Once areas with a higher risk of spills are identified, an estimate of the probable consequences of a spill can be

Figure 2: A major response will involve personnel from many different agencies and companies. Thorough testing of the contingency plan through regular exercises will assist in ensuring all participants are familiar with their tasks.

Risk assessment

Determine the likelihood of a spill occurring

- Number and type of vessel calls or vessels passing
- Type and volume of oil carried
- Expected frequency and size of spills
- Identify areas with a high risk of spills

Determine the probable consequences

- Location of sensitive resources
- Probable spill movement
- Effects of oil on resources

Determine likely spill scenarios

Gauge the benefits of developing a contingency plan

- Determine existing spill response arrangements
- Determine whether the proposed contingency arrangements serve to reduce the consequences of a spill
- Decide to what extent a contingency plan is required

Strategic policy

Plan overview

- Identify the lead organisations
- Outline the regulatory framework and jurisdiction
- Define the geographical area of the plan
- Define the interaction with other plans – scaling of tiered response
- Outline the role of the shipowner

Response techniques

- State the preferred response techniques to address floating oil and any restrictions on their use
- Determine the importance of and ability to protect sensitive resources identified in the risk assessment, accounting for seasonal variation
- Determine the appropriate clean-up techniques for the shoreline types within the plan area
- Outline response to oiled wildlife

Response resources

- Ensure suitable resources are available to address the risk, either purchased or contracted-in
- Allocate stockpile locations
- Identify suppliers of materials and services likely to be required
- Determine preferred waste storage, treatment and disposal options

Leadership, command and management

- Define the key response functions
- Outline the divisions of responsibility
- Ensure coordination of all the organisations involved
- Define the responsibility for decisions
- Decide command centre and forward operational base locations
- Outline the involvement of third parties in the response
- Allow for media and public relations
- Ensure accurate record keeping

Training and review procedures

- Outline timetable for training and exercises
- Define the procedure for regular review and update of the plan

Operational procedures

Notification

- Establish notification routes
- Outline the details needed to determine the incident circumstances

Evaluation

- Source details of the oil, wind and currents – slick trajectory modelling
- Establish the threat to resources
- Obtain additional information from aerial, boat and foot surveys

Initiation

- Initiate the response
- Identify response team members, their responsibilities and contact details
- Notify or liaise with other organisations, including other plan holders
- Make the response decisions required in the light of threats

Mobilisation

- Determine availability of resources and outline mobilisation procedures
- Ensure resources are deployed in accordance with strategic policy
- Maintain activity & cost records

Clean-up support

- Ensure sufficient logistic support
- Ensure integrated communications for all parts of the response
- Determine optimum waste treatment routes

Progress review

- Ensure all aspects of the response are continuously re-evaluated
- Highlight response aspects requiring modification – scale up or down

Termination

- Determine the criteria for termination and signing-off work sites
- Demobilise, clean, repair and repatriate resources
- Restore temporary waste sites

Plan review

- Establish a review of the response

Information Directory

Operational references

- Contact details and remit of relevant government agencies and other response organisations
- Inventory of available resources and contact details of operators
- Contact details of third party suppliers of materials and services
- Sensitive area maps
- Restrictions on dispersant use

Sample documents

- Example equipment charter and hire agreements
- Sample *pro-forma* daily aerial, at-sea and shoreline progress reports
- Example forms for recording expenditure

Supplementary information

- List of approved response products
- Guidelines for observation and recording oil at-sea and on shore
- Guidelines for use of preferred response techniques, including booming plans
- Guidelines for sampling and for monitoring contamination levels
- Sources of funding and compensation
- Information necessary to expedite cost recovery
- Legislation stating statutory powers of the plan holder

▲ *Figure 3: Examples of the four stage components required for a comprehensive and well designed contingency plan.*

made. For example, whether oil spilled in these locations could reach sensitive natural and economic resources, such as amenity areas, seawater intakes, fisheries and mariculture facilities or seabird roosts. The locations of these resources are recorded on maps (*Figures 4 – 8*), most commonly using Geographical Information Systems (GIS). The movement of spilled oil can be forecast from knowledge of prevailing wind speed and direction, tides and currents, taking into account seasonal variations. An analysis of activities and types of oil handled or carried through the area provides the basis for a range of possible spill scenarios to be developed and the most likely outcomes to be predicted.

The final part of the risk assessment process is to gauge to what extent a contingency plan is necessary or whether existing contingency arrangements should be strengthened or revised. An important question to be asked is whether the proposed contingency measures will serve to reduce the consequences of a spill. For example, the location of equipment stockpiles can be compared against the risk scenarios to ensure that equipment could be deployed in sufficient time for response operations to be conducted before the oil reaches sensitive resources.

Strategic policy

Once the risks and need for contingency arrangements have been identified, the response strategy should be determined. Policy decisions should take into account local, national and international requirements, for example existing civil emergency arrangements as well as cooperation arrangements that may exist between countries in the event that floating oil crosses national borders.

A key policy decision to be addressed with respect to ship-source spills is whether the response is to be shipowner or government led. Since governments are responsible for the protection of a country's interests, governments usually take the lead in responding to spills. Others achieve a similar result by directing the shipowner's response. In some countries, the shipowner may be required by law to enter into contracts with response organisations before vessels are permitted to enter port. To ensure there is clarity, the role of government and the contribution that the shipowner may be expected to make to the response should be explained in the plan with reference to legislation where appropriate.

Plan overview

The strategy section of the document provides an overview of the plan, including its geographical scope, explains its rationale and defines the adopted spill response policies. The plan holders should be identified, making reference to any regulations ascribing their responsibilities and legal jurisdiction. The interaction with plans for adjacent areas and at other levels in a tiered response should be made clear as well as setting out areas of cooperation with others not directly involved in clean-up operations.

Priorities for protection

Setting priorities is probably the most important part of the planning process since, in a major spill, it is unlikely that all the resources at risk can be defended successfully. Therefore, priorities for protection need to be determined in advance. In order to set these priorities, the vulnerable economic and environmental resources identified in the risk assessment should be ranked according to their importance to the community. Whilst the various bodies likely to be affected by a spill would normally be consulted, generally, only governmental authorities will be in a position to take the necessary decisions. It is essential to take into account not only the desire to protect a resource but also the extent to which the defence and protection of the resource is practicable. Provision should be made for response priorities to be altered, for example, if oil has reached these resources before the plan can be implemented.

Seasonal variation can greatly alter protection priorities. For example, priority given to an amenity beach during the approach to and during the summer season may not apply in winter. Similarly, certain biologically sensitive areas may be given high priority during breeding or spawning seasons or when migratory species are known to be present. Maps denoting sensitive areas and priorities for protection should be clearly annotated with any known seasonal variances (*Figure 4*).

Response techniques

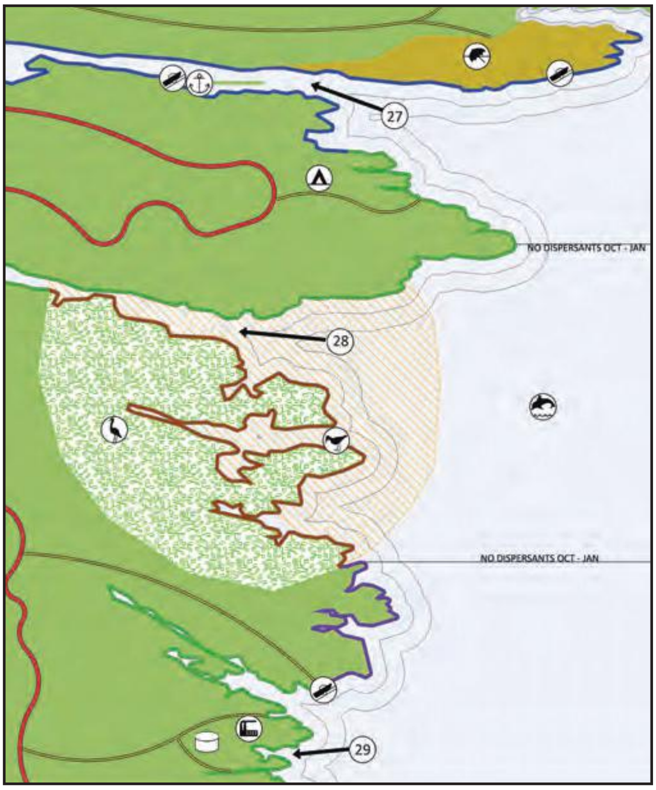
Policies on clean-up strategy at-sea, in harbours or on-shore etc. should be determined, identifying favoured response techniques and any restrictions which might be applied, for example, whether the use of dispersants and other chemicals would be permitted and if so, the conditions under which they may be applied (e.g. the permits required and depth restrictions). The strategies adopted should complement the assessment of the risk of spills and should address the agreed priorities for protection.

For local plans, the shoreline types within the plan area should be described and the most appropriate clean-up techniques for each considered. Factors to be taken into account might include a location's amenity value, its accessibility and suitability for heavy equipment and the presence of flora and fauna. Maps and photographs of shoreline types can be included within the Information Directory to show where each technique could be used and where restrictions might apply. Detailed guidance on individual clean-up techniques can be appended as necessary.

A provision for dealing with oiled wildlife, particularly birds, needs to be carefully considered and a response policy decided. Plans should include contact details for vets or specialist care organisations and, at a local level, should also identify existing treatment centres or potential locations for establishing temporary centres. Contact details for suppliers of equipment and feed that may be required should be incorporated into the Information Directory.

Response resources

Implementation of the strategy requires identification of the



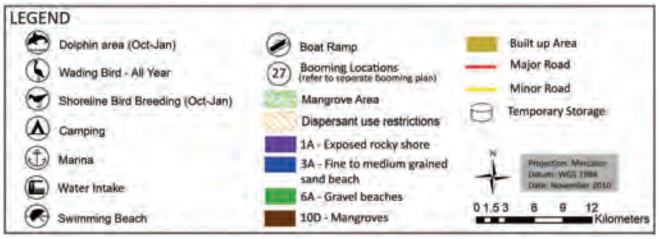


Figure 4: Sensitivity map. The number of maps required in the plan and their scale will depend upon the size of the area covered by the contingency plan and the complexity of the features to be illustrated. Maps in national plans will usually only give a broad indication of the main features of the coastal region, the resources at risk and potential sources of spills. Maps in local plans will provide more detailed information, such as the probable movement of surface slicks, agreed response strategies, shore access points and temporary storage and disposal sites. For clarity it may be appropriate to divide information between two or more maps. Reference may also be given to additional sketches or photographs illustrating elements of the response arrangements in more detail. GIS offers a more convenient means of combining all this information. An example sensitivity map is shown with photographs below corresponding to priority areas for spill response on the map.

Figure 5: Boom deployment site near the river mouth. The boom is being set to deflect oil to a collection point with good access on the shore.

Figure 6: Power station with a water intake in the foreground. Several deflection booms are deployed to prevent the ingress of oil.

Figure 7: Tidal flat backed by mangroves and wetlands forming a nature reserve for bird life. Whilst the use of dispersants may be considered on oil approaching this area, consideration should be given to spawning in nearshore waters that may limit its use at certain times of the year. The soft mud may not support vehicles and clean-up equipment.

Figure 8: Bathing beach adjacent to hotels and apartment blocks. In the event of pollution, the beach will require priority attention, particularly during the summer months. Good access for vehicles.

Figure 9: As part of the planning process, suitable and sufficient response equipment and materials to respond to various scenarios should be identified in the plan.

resources required to mount an effective response, taking into account the anticipated range of weather conditions, oil types and areas of expected use. These resources may be provided by the plan holder or purchased/contracted-in as necessary.

An inventory of available equipment should be appended to the plan and procedures for mobilisation outlined within the Operational section. Descriptions are most easily presented as a table within the Information Directory, detailing for each location the equipment type, dimensions, capacity, transport requirements and a contact point for its release. A description of the suitability of the equipment with different types of oils, current velocities, shoreline types etc. may allow rapid selection of correct equipment. Entry of this information into computer databases and linked GIS permits equipment closest to the spill site to be identified and all equipment of a particular type to be located quickly. Potential suppliers of non-specialised equipment, such as construction and agricultural machinery, which could be used in beach cleaning and waste handling operations, should also be identified. For equipment and services owned or provided by contractors, industry or other parties, agreed contractual terms could be appended to the plan.

The choice of optimum location for stockpiles of specialised equipment (*Figure 9*) should balance the benefits of placing equipment in identified high risk areas or at a central location. Centrally located stockpiles may offer benefits of scale for equipment maintenance and operators may gain more practical experience from frequent call-outs. Against this, response times are likely to be longer and associated transport costs higher than if equipment were to be stockpiled locally. Distributing stockpiles close to identified higher risk areas would inevitably necessitate multiple purchases of some types of equipment.

Organisations that could satisfy the immediate demand for labour to deploy equipment and undertake the clean-up need to be identified in advance. The extent to which personnel requirements can be met from the organisation implementing the plan will depend upon the ability to release personnel from other activities, the supervisory needs of the workforce, and the amount of specialised equipment to be deployed. Sources of additional support personnel from contractors, government departments, local industry, etc. should be listed in the Information Directory and should be considered as part of the tiered response approach.

Logistic support to clean-up crews such as personal protective equipment (PPE), food, accommodation and medical resources are issues to be considered during the development of the plan. Suppliers of equipment and materials likely to be required, as well as services such as the transport of resources and waste, will need to be procured. The names and addresses of potential suppliers, both within the area of the plan and beyond should be included in the Information Directory. In the event resources may be required from abroad, immigration and customs procedures, allowing the urgent clearance of personnel and equipment in an emergency, should be identified in the plan. Sources of adequate funding for operations, for example purchases of food and fuel and the payment of wages, invoices etc., should be identified to ensure the response can continue for as long as may be necessary.

In developing the plan, decisions on waste storage and the options for treatment, disposal or reuse of waste should be made, taking into account environmental considerations and legal requirements, including licensing. If available, details of the capacity and probable unit costs for each option could be appended to the plan. Usually, separate disposal routes are indentified for liquid and different types of solid wastes and plans should allow for their segregation into distinct waste streams from the start of the response. To minimise transport costs, temporary storage sites for oil and oily waste should be identified as near as possible to the potential clean-up sites identified in the risk assessment and shown on relevant maps. Contact details for licensed waste transporters and disposal facilities should be included as well as for national licensing authorities.

Leadership, command and management

In any incident there are a number of functions that have to be fulfilled. In a major spill each of these may require a team to complete the necessary tasks, whereas in a smaller incident these functions can be combined and undertaken by a smaller group or individual. The key functions are planning operations, controlling or managing ongoing operations, providing logistics support and administration. A single government organisation, with an established chain of command or existing management structure, which has complete responsibility for the entire operation, will help to avoid confusion that may be generated by divisions of responsibility. However, the wide ranging interests in the utilisation of the marine environment and the customary division of responsibilities between response operations at-sea and on-shore usually result in several organisations being involved. Therefore, procedures for co-ordination of these various organisations need to be put in place and their roles clearly defined. It is essential that all participants fully understand where in the organisational structure the responsibility lies for the different decisions that have to be made during the response. For example, some issues will

Figure 10: Public and media demand for information from the response team can be intense and may affect the ability to respond effectively. A plan should incorporate procedures for addressing these issues. (Image courtesy USCG).

have to be passed up the chain of command while others can be decided at an operational level.*

One or more offices or buildings to accommodate the response team have to be identified. The command centre serves as the focal point for the management of the response and for liaison with outside interests including the public and media. The facilities will require space for the large numbers of people involved in the management of a major incident, with meeting rooms and communication systems; telephone lines, internet connections and radio links, sufficient to ensure the free flow of information into and out of the command centre. Separate communications and briefing areas for the media within the command centre should be considered.

Where clean-up operations are conducted over extended distances, a number of temporary command centres located close to the scene of each operation may be required. All information on the clean-up operations and logistic requirements should be channelled through the command centre. In a major spill, operations at sea, on shore and in the air may occur simultaneously and radio communications between the command centre and each of these sectors will be essential to maintain the rapid transfer of information and instructions. Operations in more remote areas may call for temporary communications stations to be established or the use of satellite communication systems. The ability for vessels at sea to communicate directly with surveillance aircraft requires particular attention and specialised equipment. Communications equipment and procedures, including designated radio frequency channels, should all be considered within the plan.

The work of other parties involved in the response to an incident may affect or be affected by clean-up operations and liaison arrangements should be included in the plan. In ship-source incidents, regular contact with salvors is a vital element of the overall response enabling developments in salvage work to be monitored and the likelihood of further releases of oil to be assessed. Coastal fisheries and mariculture are often affected and government authorities responsible for ensuring the safety and marketability of marine produce may need to to consider imposing fishery restrictions. The planning process also provides an opportunity for such organisations to work through their own contingency arrangements, such as the criteria under which fishing restrictions would be imposed and later lifted. Other groups, including tourism and wildlife organisations, will have a keen interest in the response and arrangements to keep them informed should be made.

In many countries the pressure applied through the media cannot be under-estimated but if provision is made for keeping journalists and the public well-informed, interference with the conduct of the response may be reduced. Dedicated press and public relations officers can deal with enquiries while briefings by the head of operations or another senior

*Please refer to the separate Technical Information Paper on Leadership, Command & Management of Marine Oil Spills.

Information requirements	Information source
The location and type of incident.	Vessel master, vessel operator, salvors, port authority or coast guard.
Type of oil.	Bunker certificate or cargo manifest (available from the vessel master, operator or owner, the cargo owner or the vessel insurer). Once the oil name is known its characteristics may be obtained from the oil's assay.
Currents, tides and weather forecasts.	Tidal stream atlases, tide tables, local marine charts and pilot books, port and airport authorities and national meteorological services.
Location and seasonal sensitivity of environmental and socio-economic resources and priorities for protection.	Information Directory/GIS, appended to the plan.
Contact details for those with interests in resources under threat.	Information Directory/GIS, appended to the plan.

Table 1: Potential sources of information that may be required to evaluate and respond to an incident.

member of the organisation give a public face to the response and can add to its credibility (*Figure 10*). In a major spill, consideration should be given to establishing a dedicated website where regular bulletins can be posted, allowing accurate information to be made available within minutes of developments occurring. The various social media, networking and web logging services available should also be considered to publicise information and may be useful to monitor public comment.

Not only is it essential to document actions taken but minutes of meetings should be kept and communications logged to record how decisions were reached during the response. These can be examined in the light of the outcome and the decisions justified should they be queried at a later date. Accurate records regarding the use of labour, equipment, materials, and expenditure are also very important. For the sake of consistency, it is worth preparing examples of record forms and including these in the Information Directory. Comprehensive documentation will assist in formulating claims for cost recovery.*

Training, exercises and review

A timetable for training and exercises needs to be set out in the plan. Training programmes should be developed for all levels and include marine and shoreline response teams and interested parties. Regular and realistic exercises will help to ensure that contingency arrangements function properly and that the roles and responsibilities of all parties are thoroughly tested and understood. Equipment should be mobilised and deployed regularly to assess its availability and performance (*Figure 11*). Such exercises also ensure that contact details and equipment listings are current. Plans should be reviewed and, if appropriate, amended in the light of lessons learnt from exercises or actual incidents. All those involved need to be made aware of any changes to the plan.

Operational procedure

Upon notification of an incident, activities to be followed for the subsequent evaluation and initiation of the response should be clearly described in chronological order in the operations section of the plan. This section will be the first point of reference once notification of an incident is received and should be clearly identified and easily accessed within the plan.

Notification

In many instances, reports from the vessel crew to a local coast guard station or port authority may be the first indication of a spill. Alternatively, reports of spills may originate from a variety of sources including the general public. The plan should indicate the route by which reports should be passed to the plan holder.

Once alerted to a spill, assigned individuals should seek to establish the exact circumstances of the incident. This section of the plan should include a checklist of the information necessary to make the preliminary evaluation, including:

▲ *Figure 11: Regular deployment of equipment as part of exercises will help to ensure it is maintained and ready when a spill occurs.*

- Date and time of observation: Local time or GMT/ UTC;
- Position of the incident (e.g. latitude & longitude, location relative to a landmark or stretch of coast);
- Source and cause of pollution (e.g. name and type of vessel; collision or grounding);
- Estimate of the amount of oil spilled, its type and characteristics;
- Description of the spilled oil including direction, length, breadth and appearance of slicks;
- Current and forecast weather and sea conditions;
- Status of the vessel and details of salvage operations;
- Distribution of oil cargo and/or bunkers relative to the area of damage and risk of further spillage; and
- Action taken to combat pollution.

Evaluation

It is unlikely that the initial reports will include all of the information necessary to fully evaluate the threat posed by the oil to environmental and economic resources. The plan should therefore include guidelines to evaluate the threat based on a partial understanding of the incident, for example whether resources could be mobilised without an accurate estimate of the amount of oil spilled.

Technical expertise may be required to assist in the evaluation of the magnitude, severity and response to the incident. The potential sources of data required for this evaluation are outlined in Table 1. To supplement these sources, the plan should outline procedures for obtaining additional information by:

- Determining the predicted trajectory of the oil slick;
- Arranging aerial surveillance to verify these predictions and gain a better perspective of the scale of the incident;
- Establishing surveys of the affected area to verify the reports e.g. by vessel for floating oil or by foot if oil has already stranded on-shore.

** Please refer to the separate Technical Information Paper on the Preparation and Submission of Claims.*

Response initiation

If the scale of the initial incident and the threat posed by any spilled oil are considered to be serious, the members of the response team identified in the plan should be notified and a command centre established. An organisational chart of response personnel and a list of their responsibilities, as well as a list of actions to be taken in the first few hours after the incident, will help to expedite this process. To assist with operations, additional responders may be required from outside of the immediate area and contact details of accommodation and catering facilities should be included in the Information Directory.

The callout procedure set out in the plan should allow the evaluation of the incident to continue as notification proceeds. A list of other persons and agencies to be notified according to the severity of the spill should be included together with a short description of their remit and contact details in the Information Directory.

The plan should outline the response decisions to be made:

- If no key resources are threatened and it is predicted that the oil will dissipate naturally;
- If no response is feasible, perhaps due to weather conditions; and
- If key resources are threatened or affected, for example whether the circumstances merit the use of dispersant on oil at sea or whether containment and recovery is appropriate. Similarly, when oil comes ashore, the most effective shoreline clean-up technique, for example whether low-pressure high-volume flushing or surf washing can be used to minimise the generation of waste to be sent for disposal and/or additional damage to the shoreline.

The resources at risk from the spill and the contact details of parties with interests in these resources can be identified using maps and information contained within local plans, for example fisheries, power stations, neighbouring plan holders etc. Procedures to activate a higher tier of response should be included in anticipation of an incident beyond the scope of the plan.

Mobilisation

Procedures should be defined within the plan for, *inter alia*:

- Mobilising the equipment, labour and materials necessary for the chosen response techniques, including arrangements to place response resources on stand-by while awaiting the order to mobilise;
- Deploying equipment in accordance with the response decisions, for example identifying vessels from which equipment could be deployed, and placing booms at pre-designated sites to protect key resources, with reference to booming plans annexed to the plan; and
- Ensuring records of activity, decisions and expenditure are maintained.

Clean-up support

The plan should include procedures for mobilising the logistic support necessary for the overall success of the response, for example, the distribution of PPE and food for response teams and fuel for machinery and for the transport of labour, equipment and recovered waste, so as to minimise delays.

Figure 12: Equipment should be cleaned and repaired, where possible, so that it can be readily mobilised for the next incident.

This section of the plan should also describe procedures for establishing integrated communications across the response operation, for example, by exchanging mobile phone numbers or the procedures for allocating VHF radio frequencies and transceivers amongst response personnel.

Guidelines should also be included for selecting the most suitable route for the storage, treatment and disposal of waste from those identified during the strategy process.

Progress review

Inputs from aerial surveillance and personnel on-site will allow the clean-up to be closely monitored and the plan should identify the required type and format of the status reports and how these can be made available to the team managing the response. The plan should incorporate procedures for the continual reassessment of the response as operations progress, in particular whether the scale of the response remains appropriate for the clean-up activity remaining to be completed.

Termination of the clean-up

As the clean-up progresses a point will arrive when some techniques become ineffective or when the desired level of clean-up has been achieved. The operational section of the plan should provide for:

- Liaison and agreement between all interested parties on the level of clean-up appropriate to each location (i.e. clean-up end points and technical criteria for termination);
- Joint surveys to be undertaken by representatives of the various interested parties to monitor progress and decide when agreed end points have been reached;
- Standing down equipment and returning it to stores for cleaning and maintenance (*Figure 12*). Re-ordering consumed materials and repairing or replacing damaged equipment; and
- Restoring temporary waste storage and other work sites.

Plan review

Once the response is finalised, a report on the operation should be drafted to allow a review of the contingency plan and to support claims for reimbursement of expenses.

Information Directory & Annexes

The Information Directory provides support to the operations and the decision-making process through the provision of information and maps relevant to the geographic area covered by the plan. It should contain information to enable the users to evaluate the scale of an incident and to initiate a rapid, yet appropriate, level of response according to the strategy agreed during the development of the plan. The Directory should be designed so that it can be updated readily, as much of the information it contains will be subject to frequent change. As noted previously GIS and databases can facilitate this process. The Information Directory would include, for example:

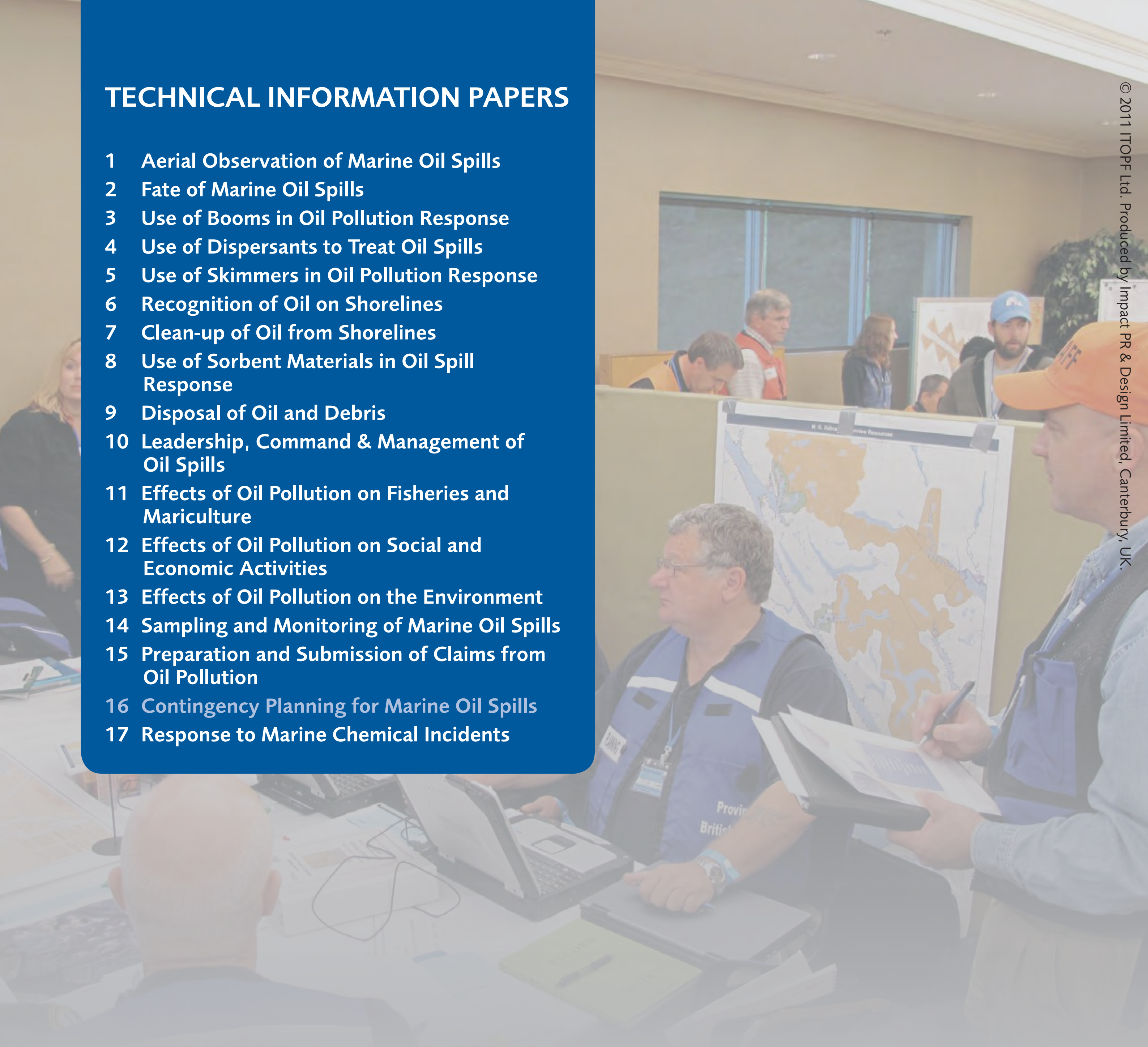
- Contact details and the remit of all relevant central government, local authority and marine agencies;
- Contact details for organisations with interests in sensitive environmental and socio-economic resources;
- Dispersant use and non-use areas;
- A list of spill response equipment (e.g. skimmers, booms, dispersant, sorbents) and contact details for its release;
- Sources of auxiliary equipment (e.g. aircraft, excavators, vacuum trucks) and contact details of operators;
- Details of shoreline types and sensitive areas and priorities for their protection;
- Access routes to potential clean-up sites;
- Storage and disposal sites for oil and other wastes;
- Contact details for services such as computer modelling, IT and communications support and technical advice on spill response and scientific issues; and
- A list of media contacts.

Annexes might include, for example:

- A list of products approved by an Administration (e.g. dispersants or cleaning agents);
- Sample *pro forma* documents for recording observations of oiling and the progress of the clean-up;
- Guidelines for use of preferred response techniques, including boom deployment plans;
- Contractual terms for hiring third party equipment;
- Communications plans;
- Details of disposal options;
- A list of providers of support services (e.g. catering, accommodation, security, medical etc.);
- Sources of funding and compensation for cost recovery;
- A glossary of acronyms used in the plan (alternatively, this may be placed at the front of the plan).

Ten questions for assessing the adequacy of a contingency plan

- Bearing in mind the probable movement of any oil spilled, has there been a realistic assessment of the scale and severity of the possible threat, and of the resources most at risk?
- Have priorities for protection been agreed, taking into account the feasibility of the various protection and clean-up options?
- Has a strategy for protecting and cleaning the various areas been agreed and clearly explained?
- Have all the functions necessary for the response been allocated and the responsibilities of all those involved been clearly stated – are all organisations and agencies aware of their responsibilities?
- Are the levels of equipment, materials and labour sufficient to address the anticipated size of spill? If not, have back-up resources been identified and, where necessary, have mechanisms for obtaining their release and entry to the country been established?
- Have temporary waste storage sites and final disposal routes for collected debris been identified?
- Have the notification and initial evaluation procedures been fully explained and have arrangements been made for continual review of the progress and effectiveness of the clean-up operations?
- Have the arrangements for ensuring effective communication between shore, sea and air been described?
- Is the plan compatible with plans for adjacent areas and other activities?
- Have all aspects of the plan been tested?



TECHNICAL INFORMATION PAPERS

1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
6 Recognition of Oil on Shorelines
7 Clean-up of Oil from Shorelines
8 Use of Sorbent Materials in Oil Spill Response
9 Disposal of Oil and Debris
10 Leadership, Command & Management of Oil Spills
11 Effects of Oil Pollution on Fisheries and Mariculture
12 Effects of Oil Pollution on Social and Economic Activities
13 Effects of Oil Pollution on the Environment
14 Sampling and Monitoring of Marine Oil Spills
15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
17 Response to Marine Chemical Incidents

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this leaflet may be reproduced with the prior express permission of ITOPF. For further information please contact:

THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606
E-mail: central@itopf.com
Web: www.itopf.com

RESPONSE TO MARINE CHEMICAL INCIDENTS

TECHNICAL INFORMATION PAPER

17

Introduction

The volume of chemicals transported by sea continues to increase year by year and, as a result, there is growing international awareness of the need for the development of safe and effective contingency arrangements for responding to chemical spills. However, the wide variety of chemicals, their varying physical properties and different behaviour once spilt and the potential for effects on human health and the marine environment mean that preparedness and response arrangements for chemical spills are far more complex than for oil spills.

This paper provides an introduction to the issues involved in responding to chemical spills and addresses the range of hazards present, the behaviour of chemicals when spilt at sea and briefly reviews available response options.

What are chemicals?

The term 'chemical' encompasses every substance known to man. However, not all chemicals transported by sea are considered hazardous but those that are have been termed 'hazardous and noxious substances' (HNS). The OPRC–HNS Protocol[1] defines HNS as "any substance other than oil that, if introduced into the marine environment, is likely to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea". The hazard associated with a particular chemical is dictated by its inherent properties and, as such, HNS may exhibit one or more of the following five properties: flammable, explosive, toxic, corrosive or reactive.

Another definition of HNS, but one that differs widely from that of the OPRC-HNS Protocol, is provided by the HNS Convention[2]. Under that Convention, a substance is classed as HNS if it is included in one or more lists in the International Maritime Organization (IMO) Conventions and Codes listed in Table 1. The Conventions and Codes listed are designed to ensure the safe transport of all types of chemicals. In addition to listing the different types of HNS, they also prescribe design and construction standards for the different ships involved in the transport of HNS, and regulations on the labelling, packing and stowage of chemicals. Radioactive and infectious substances are outside the scope of the HNS Convention and of this paper.

Figure 1: Chemical tanker.

The OPRC-HNS Protocol is designed for preparedness and response and the HNS Convention for compensation. The difference between the two definitions of HNS is significant because each covers cargoes that are not included in the other. For example, the OPRC-HNS Protocol includes cargoes such as coal, cement, various metal ores and grain. The loss of such cargoes can cause environmental

[1] Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances, 2000 (see www.imo.org).
[2] International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea, 1996. As of March 2012, the HNS Convention is not yet in force (see www.hnsconvention.org).

HNS material	Conventions & Codes
Oils carried in bulk	Appendix I of Annex I to the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL73/78)
Bulk liquids	Chapter 17 of International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code) and also Appendix II of Annex II to MARPOL 73/78
Gases	Chapter 19 of International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
Solids in bulk	Section 9 of International Maritime Solid Bulk Cargoes Code (IMSBC Code) if also covered by IMDG Code in packaged form
Packaged goods	International Maritime Dangerous Goods Code (IMDG Code)

Table 1: Examples of IMO Conventions and Codes providing HNS lists (see www.imo.org).

▲ *Figure 2: Spilt oil and containers floating from a grounded container vessel (image courtesy SMIT).*

▲ *Figure 3: Stranded tanktainers and a container lashed together on a shoreline.*

damage through smothering and, in the case of grain, its decomposition can also bring about localised high biological oxygen demand and the release of hydrogen sulphide, a toxic gas. Conversely, the HNS Convention covers many of the common non-persistent distilled products of mineral oil, such as kerosene and petrol (gasoline) and also, in some instances, persistent oil, all of which are not covered by the OPRC-HNS Protocol as they fall under the OPRC 90 Convention[3]. Both the OPRC-HNS Protocol 2000 and the HNS Convention cover vegetable oils. The response to spilt oils is covered in the other papers in this ITOPF TIP series, as listed on the back cover.

Shipping of HNS

Increasing global demand for chemicals used in a wide variety of industries has resulted in rapid growth of the seaborne chemical trade. In 2010, the IMO listed the top 20 chemicals, (excluding crude oil, its liquid products and vegetable oils), carried by sea and most likely to be involved in an HNS incident. This list was developed by gathering data on the volumes of chemicals produced, the most commonly transported chemicals and those most frequently spilt (*Table 2*).

Cargoes of HNS may be transported by sea in two ways: either in bulk (liquids and solids) or in packaged form. Several different types of ship transport HNS, as follows:

- **Bulk Carriers** – carry solids in bulk as un-packaged dry cargoes, for example iron ore, rock phosphate, coal, cement and grain.
- **Chemical, parcel or product tankers** – carry bulk liquid cargoes, the difference being how the tanks are segregated and the type of chemicals carried, for example benzene or styrene (*Figure 1*).
- **Gas carriers** – transport cargoes of liquefied gas under pressure and/or reduced temperatures, namely Liquefied Natural Gas (mainly methane) (LNG) and Liquefied Petroleum Gas (propane and butane) (LPG).
- **Container ships** (*Figure 2*) – carry cargoes of packaged goods in intermodal containers that allow efficient loading and offloading. The size of a container ship is often quoted in TEU (twenty-foot equivalent units), which is the number of standard-sized containers the vessel can carry. A small proportion of the containers shipped are isotanks or 'tanktainers', for carriage of bulk liquids (*Figure 3*).
- **General cargo vessels** – carry smaller consignments of loosely packaged goods, for example on or in pallets, crates, boxes or drums. In terms of ship type these represent the largest category of the world fleet.
- **Roll on-Roll off (Ro-Ro) vessels** – transport road trailers or rail freight rolling stock carrying loosely packaged goods, containers or bulk liquids and solids.

An incident involving a ship carrying more than one HNS, for example, container ships, parcel tankers or Ro-Ro vessels, presents additional complications due to the potential for the various cargoes to mix with each other, as well as with water should individual containers, tanks or trailers become damaged. In particular, identification of the specific contents of a container or trailer and the assessment of the hazards posed may be difficult to accomplish and in some cases, the dangerous goods manifest (*Figure 4*) and stowage plans may not provide sufficient detail to adequately assess the severity of a potential incident.

Even relatively small quantities of HNS may pose a significant risk. As an example, aluminium phosphide (AlP), a widely carried fumigant, reacts with water to produce phosphine (PH_3), a toxic gas (*Figure 5*). An incident may also involve a spill of bunker fuel or other oil (*Figures 2 and 5*), which may add further complications to the response. If the HNS represents a danger to human health, a response to the spilt oil at sea or on the shoreline may not be possible or may be compromised.

Behaviour of chemicals in the marine environment

Physical behaviour

Classifying substances, whether gases, liquids or solids, according to the behaviour exhibited when released into the marine environment, is a useful tool when developing a response strategy. The fate of a substance is determined by

[3] *International Convention on Oil Pollution Preparedness, Response and Co-operation.*

Rank	Chemical	Behaviour	Main hazard
1	Sulphuric acid	Sinker/dissolver	Corrosive / exothermic reaction with water / fumes
2	Hydrochloric acid	Sinker/dissolver	Corrosive / exothermic reaction with water / fumes
3	Sodium hydroxide / caustic soda	Sinker/dissolver	Corrosive / exothermic reaction with water
4	Phosphoric acid	Sinker/dissolver	Corrosive / exothermic reaction with water / fumes
5	Nitric acid	Sinker/dissolver	Corrosive / exothermic reaction with water / fumes
6	LPG/LNG	Gas (transported as a liquid)	Flammable / explosive
7	Ammonia	Gas (transported as a liquid)	Toxic
8	Benzene	Floater/evaporator	Flammable / explosive
9	Xylene	Floater/evaporator	Flammable / explosive
10	Phenol	Dissolver/evaporator	Toxic / flammable
11	Styrene	Floater/evaporator	Flammable / toxic / polymerisation
12	Methanol	Floater/dissolver	Flammable / explosive
13	Ethylene glycol	Sinker/dissolver	Toxic
14	Chlorine	Gas (transported as a liquid)	Toxic
15	Acetone	Floater/evaporator/dissolver	Flammable / explosive
16	Ammonium nitrate	Sinker/dissolver	Oxidizer / explosive
17	Urea	Sinker/dissolver	Irritating
18	Toluene	Floater/evaporator	Flammable / explosive
19	Acrylonitrile	Floater/evaporator/dissolver	Flammable / toxic / polymerisation
20	Vinyl acetate	Floater/evaporator/dissolver	Flammable /toxic / polymerisation

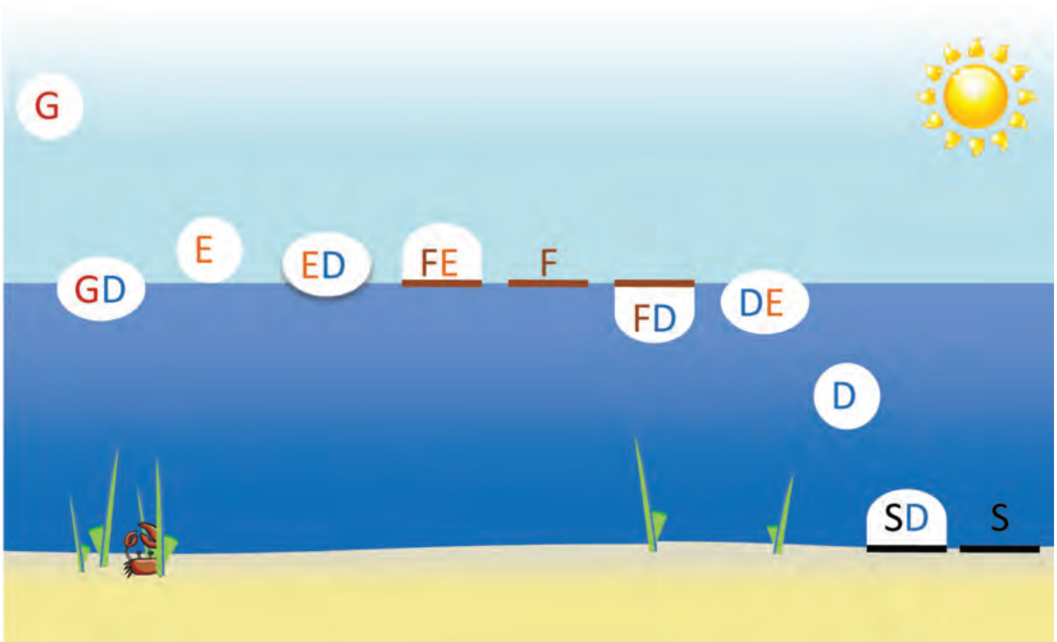
Table 2: IMO list of the top 20 chemicals likely to pose the highest risk of being involved in an HNS incident, not including crude oil, liquid distilled crude oil products or vegetable oils (source: MEPC/OPRC-HNS/TG 10/5/4, see www.imo.org).

DANGEROUS GOODS MANIFEST
M/V BOXSHIP L1234567 (Inbound to Panama)

Shipper/Consignee	Pkg. No.	Shipping Description	Stowage Position	Gross Weight	Container	Port of Discharge	Shipment No.
Local Chemical Co.	25 Drums	ACROLEIN, class 6.1 UN1092, P.G. I (3), Marine Pollutant	030862	2500 Kgs	243917	NYNY	7654321
Manufacturing Co.	30 Tins	ADHESIVES (liquid), Class 3, UN1133, P.G. III Flammable Liquid	420190	19.22 Kgs	678345	NYNY	6453210
Manufacturing Co.	500 Bottles	DICHLOROMETHANE (liquid), Class 6.1, UN1593, P.G. III Toxic substance	420190	1000 Kgs	678345	NYNY	6465210

Figure 4: Example of a dangerous cargo manifest, providing details of two containers containing HNS.

Figure 5: The presence of an HNS can hinder the response to a spill of oil. Here unidentified bottles, covered in bunker oil, were located on the shoreline, some of which may be Aluminium Phosphide (inset) which produces highly toxic phosphine gas on contact with water. In this instance, a detailed risk assessment plan was drafted to ensure the safety of shoreline clean-up personnel (inset image courtesy United Phosphorous).



▲ *Figure 6: Diagramatic representation of the Standard European Behaviour Classification.*

the properties of volatility, solubility and density and these in turn determine the hazard(s) presented by the substance (toxicity, flammability, reactivity, explosivity, corrosivity, etc).

The Standard European Behaviour Classification (SEBC) system categorises HNS into 12 groups on the basis of their dominant behaviour in water (*Figure 6 and Table 3*). The main properties giving indications of the behaviour of a chemical spilt at sea are listed in Table 4. However, it is important to be aware that this system only classifies chemicals according to their dominant behaviour relevant to spill response and a chemical may also exhibit other characteristics. For example, benzene is classed according to its dominant characteristic (evaporator) but it is also soluble to a certain extent. All aspects of a substance's behaviour should be considered when planning a response.

	Property Group	Properties
G	gas	evaporate immediately
GD	gas/dissolver	evaporate immediately, dissolve
E	evaporator	evaporate rapidly
ED	evaporator/dissolver	evaporate rapidly, dissolve
FE	floater/evaporator	float, evaporate
FED	floater/evaporator/dissolver	float, evaporate, dissolve
F	floater	float
FD	floater/dissolver	float, dissolve
DE	dissolver/evaporator	dissolve rapidly, evaporate
D	dissolver	dissolve rapidly
SD	sinker/dissolver	sink, dissolve
S	sinker	sink

▲ *Table 3: The Standard European Behaviour Classification (SEBC) System for chemicals.*

Hazards

Under the UN Globally Harmonized System of Classification and Labelling of Chemicals (GHS)[4] chemicals are classified according to the types of hazard they represent and portrayed by harmonised hazard communication with consistent labelling and Safety Data Sheets. The GHS aims to ensure that information on physical hazards and toxicity from chemicals is available to enhance the protection of human health and the environment during the handling, transport and use of these chemicals. Two sets of pictograms are included within the GHS: one for the labelling of containers and for workplace hazard warnings (*Figure 7*), and a second for use during the transport of dangerous goods (*Figure 8*).

[4] *www.unece.org/trans/danger/danger.html*

▲ *Figure7: GHS pictograms for HNS labelling. Left to right: flammable, explosive, oxidising, acute toxicity, corrosive, harmful/irritant, toxic to the environment, carcinogen/ sensitiser and compressed gas. These are intended to replace national and regional labels.*

Property	Description
Density	Density, ρ, (substance)=mass/volume. Gives an indication of the likelihood that a substance will float or sink (average density of sea water: ρ =1.025 g/cm³). ρ(benzene) = 0.88 g/cm³, floats. ρ(solid phosphoric acid) =1.864 g/cm³, sinks.
Specific Gravity	Specific Gravity = ρ (substance)/ρ (water) is a non-dimensional parameter i.e. does not have units. In fresh water also known as relative density.
Solubility	The ability of a solid, liquid or gas to dissolve in a liquid (usually given for fresh water). In sea water: s(benzene) = 0.07%, slightly soluble; s(phosphoric acid) =100%, miscible.
Vapour Pressure	Describes the likelihood that a substance will evaporate to form a vapour. The higher the vapour pressure, the more a substance tends to evaporate (Slow evaporator VP > 300 Pa, fast evaporator VP > 3 kPa). VP(ethylene glycol) = 500 Pa; VP(ethanol) = 5 kPa; VP(propane) = 2.2 MPa.
Vapour Density	Relative weight of a gas or vapour compared to air, which has an arbitrary value of one. If a gas has a vapour density of less than one it will generally rise in air. If the vapour density is greater than one, the gas will generally sink in air. The property is based on molecular weights. Molecular weight of air = 29 atomic mass units (AMU). Hydrogen = 2 AMU and thus has a vapour density of 2/29 = 0.068, rises. Hexane = 84 AMU: vapour density = 84/29 = 2.9, sinks.
Flash Point	The flash point of a volatile material is the lowest temperature at which it can vaporise to form a mixture in air that will ignite when exposed to an ignition source. Flash Point T(phenol) = 79°C, Flash Point T(benzene) = - 11.1°C.
Lower Explosive Limit (LEL)	The lowest concentration (percentage) of a gas or a vapour in air capable of igniting in the presence of an ignition source. At a concentration in air below the LEL, insufficient fuel is available to burn and the air/fuel mixture is 'too lean'. Also expressed as lower flammable limit (LFL). LEL(benzene) =1.2% by volume of air (12,000 ppm). LEL(methane (CH_4)) at 20°C = 5.1 %.
Upper Explosive Limit (UEL)	Highest concentration (percentage) of a gas or a vapour in air capable of igniting in the presence of an ignition source. Concentrations higher than the UEL are 'too rich' to burn, also expressed as upper flammable limit (UFL). UEL(benzene) =7.8% by volume of air (78,000 ppm).
Flammable Range	The concentration range between the upper and lower flammable limits.
Auto-ignition Temperature	Minimum temperature at which a chemical ignites when no ignition source is present. Auto-ignition T(benzene) = 538°C.
Boiling Point	Boiling Point T(propane)= -42°C, T(ammonia) = -33°C, T(sulphuric acid) = 337°C.

▲ *Table 4: Key physical properties to assess the fate and behaviour of a chemical.*

Either one or the other is chosen, depending on the target audience, but the two are not used together. The following hazards, as portrayed by the seven initial pictograms, may be generated by a spill of an HNS itself or by reactions between the HNS and other chemicals, water or air.

Flammability

Flammability is the ease with which a material ignites either naturally or through the presence of an ignition source. The flammability of a liquid is governed by its vapour pressure or flash point. Flammable liquids are characterised by low boiling and flash points. Other flammable materials may catch fire spontaneously in contact with air. An HNS fire can lead to the release of heat, solid particles and toxic gases (*Figure 9*).

Explosivity

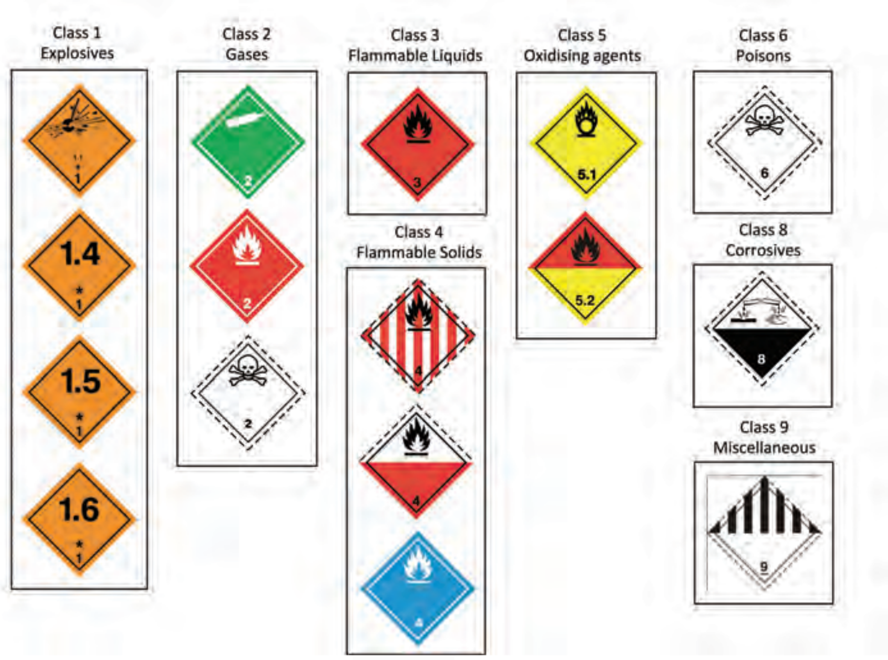
An explosive substance is a chemical or mixture of chemicals that becomes unstable under certain environmental conditions, for example, by heat, friction, impact or static electricity, and releases its stored energy. Substances are classified by their sensitivity to environmental conditions, their velocity upon detonation and by their chemical composition. The classification also includes such materials as pyrotechnic devices and ammunition.

Explosions can be accompanied by shockwaves, fire and heat. In particular, damage occurs when the energy released cannot be dissipated quickly. An important example of an explosive combination of a volatile material and environmental conditions is a BLEVE (Boiling Liquid Expanding Vapour Explosion); e.g. the heating of a contained, compressed, liquefied gas can lead to the rupture of the container due to overpressure following the boiling of the liquid inside. The result is an instantaneous release, that can develop into a sufficiently large flammable cloud to generate a flash fire, fireball or a vapour cloud explosion.

The lower and upper explosive limits (LEL and UEL) define the range in which a gas or a vapour in air is capable of igniting in the presence of an ignition source.

Oxidising hazard

An oxidising hazard may be presented by substances that in



▲ *Figure 8: United Nations pictograms for HNS transportation. Classes 1 to 6 and 8 are a part of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Class 7 materials (radioactive – not shown) and Class 9 (miscellaneous), while within the IMDG code symbols, are not included within the GHS.*

themselves are not necessarily combustible, but by providing oxygen may cause or contribute to the combustion of other material. Strong oxidising agents, for example nitric acid (HNO_3), can react particularly violently with organic material.

Toxicity

Toxic chemicals include those that cause death or injury to living organisms if inhaled, ingested or absorbed through the skin at low levels. Toxicity is often measured and classified by the degree of risk a particular concentration represents to human health or the environment. Acute and chronic concentration exposure limits are often cited. Acute exposure is defined as a single exposure to a toxic substance which may result in severe biological harm or death and is usually characterised as exposure lasting no longer than a day. Chronic exposure is defined as continuous exposure to a toxin over an extended period of time, often measured in months or years, which can cause irreversible side effects. Chlorine is an example of a highly toxic gas.

▲ *Figure 9: Containers collapsed and distorted by the heat of a fire on the bow section of a stranded Ro-Ro vessel.*

Corrosive hazard

Corrosive chemicals can destroy or irreversibly damage another surface or substance with which they come into contact, including both living tissues (skin, eyes, lungs) and materials such as response equipment, other cargoes or packaging. Examples include sulphuric acid (H_2SO_4) and sodium hydroxide (NaOH).

Irritant/Harmful

A chemical in this category may be harmful to health while those with irritant properties can cause inflammation to the skin (dermatitis) and mucous membranes in a live organism (for example, the eyes, throat and/or lungs).

Environmental hazard

Chemicals that may present an immediate or delayed danger to one or more components of the environment and for which particular care should be exercised over their disposal.

Reactivity

Chemicals may react with adjacent materials, fuel oil, water or air in a variety of ways, including corrosion, decomposition, oxidation/reduction or polymerisation reaction. It is important to know the reactivity of the substance in order to formulate an appropriate response as these reactions can generate heat and flammable or toxic gases. For example, iron may react with some strong acids or alkalis to release hydrogen that in air produces an explosive hydrogen-air mixture. Some chemicals can polymerise with the addition of heat or water. Polymerisation is often accompanied by volume expansion and the release of heat (exothermic), potentially causing damage to the container in which the material is stored. The product may also decompose into secondary products due to interactions with its surrounding environment. Particular hazards with decomposition are the formation of gases, such as carbon dioxide (CO_2) and hydrogen sulphide (H_2S), that are in themselves toxic, and can result in low oxygen levels that demand safe practices for entry into ships' holds and other confined spaces. The US National Oceanic and Atmospheric Administration's (NOAA) Office of Response and Restoration[5] provides a downloadable Chemical Reactivity Worksheet (CRW) that allows the user to determine the reactivity of a substance with air, water and other chemicals.

Hazard assessment

When ranking the hazards presented by the loss of a particular cargo, two easily accessible and simple guides provide an important first step in evaluating the potential severity of an incident: Annexes II and III of MARPOL 73/78 and the GESAMP hazard profiles.

The MARPOL Convention

The MARPOL Convention is the primary international convention covering prevention of pollution from ships. Two annexes of MARPOL are relevant to HNS:

Annex II

MARPOL Annex II contains regulations for bulk liquid cargoes that may cause environmental pollution if discharged at sea. Within the Annex, four categories are defined according to the hazard that the bulk liquid presents to human health, marine resources and amenities. Appendix II of Annex II contains a list of substances grouped according to the four categories shown below:

- Category X – liquid substances that are deemed to present a major hazard to either marine resources or human health and therefore justify the prohibition of the discharge into the marine environment;
- Category Y – liquid substances that are deemed to present a hazard to either marine resources or human health or cause harm to amenities or other uses of the sea and therefore justify a limitation on the quality and quantity of the discharge into the marine environment;
- Category Z – liquid substances that are deemed to present a minor hazard to either marine resources or human health and therefore justify less stringent restrictions on the quality and quantity of the discharge into the marine environment; and
- Category OS – these 'other substances' are deemed to fall outside of categories X, Y, and Z and are deemed to present no harm to marine resources, human health, amenities or other uses of the marine environment.

Annex III

Annex III deals with the provisions for the prevention of pollution by harmful substances carried by sea in packaged form. As part of these regulations, any substances that are environmentally harmful (known as marine pollutants) must be clearly marked and labelled as a 'marine pollutant" to distinguish them from less harmful cargoes (*Figure 10*).

GESAMP hazard profiles

The hazards presented by HNS to both humans and the marine environment have been summarised by the Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP), an advisory body to the United Nations established in 1969. The Group comprises individual experts in their field drawn from a wide range of relevant disciplines.

GESAMP has published a Hazard Evaluation of Substances Transported by Ships[6] that addresses the hazards presented by the most commonly transported chemicals that enter the marine environment through operational discharge, accidental spillage or loss overboard from ships. The properties of each chemical have been evaluated in relation to a number of predefined effects should any of the listed chemicals be spilt at sea. This information is collated into a hazard profile that identifies the hazardous characteristics for each substance according to the following categories:

a. Bioaccumulation and biodegradation;
b. Aquatic toxicity;
c. Acute mammalian toxicity;
d. Irritation, corrosion and long term health effects; or
e. Interference with other uses of the sea.

Hazard profiling by GESAMP is an ongoing process and an updated listing is maintained by the IMO[7].

Human health concerns

Besides the effects associated with hazards such as the shock wave of an explosion, fire injuries or oxygen depletion, exposure to chemical substances may also occur as a result of absorption via contact with the skin, inhalation or ingestion. Inhalation is a major route of entry for gases and particles. Absorption can occur through a healthy skin, or through the chemically damaged surface of the skin (for example burns or dermatitis). Ingestion occurs when a hazardous agent is swallowed.

HNS manufacturers and others publish Material Safety Data Sheets (MSDS) that summarise the specific hazards associated with each substance. Over time these will be replaced by Safety Data Sheets (SDS) under the UN GHS. MSDS and SDS both broadly follow the same format (*Figure 11*) and provide the information contained in Table 5. Nevertheless, it should be noted that, in terms of reliability and comprehensiveness, the quality of the information currently provided by MSDS can vary considerably between

Figure 10: Marine pollutant placard. This placard does not relate to a specific class of hazard and is used when shipping any marine pollutant.

[5] *http://response.restoration.noaa.gov*
[6] *www.gesamp.org/publications/publicationdisplaypages/rs64*
[7] *www.imo.org/OurWork/Environment/PollutionPrevention*

1. Identification
2. Hazard(s) identification
3. Composition/ingredients
4. First-aid measures
5. Fire-fighting measures
6. Accidental release measures
7. Handling & storage
8. Exposure controls/personal protection
9. Physical & chemical properties
10. Stability & reactivity
11. Toxicological information
12. Ecological information
13. Disposal considerations
14. Transport information
15. Regulatory information
16. Other information

Table 5: Information provided by MSDS and SDS.


SIGMA-ALDRICH

SAFETY DATA SHEET
according to Regulation (EC) No. 1907/2006
Version 4.2 Revision Date 03.12.2011
Print Date 01.02.2012

1. IDENTIFICATION OF THE SUBSTANCE/MIXTURE AND OF THE COMPANY/UNDERTAKING

1.1 Product identifiers

Product name : Dichloromethane

Product Number : 270997
Brand : Sigma-Aldrich
Index-No. : 602-004-00-3
CAS-No : 75-09-2

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich Company Ltd.
The Old Brickyard
NEW ROAD, GILLINGHAM
Dorset
SP8 4XT
UNITED KINGDOM

Telephone : +44 (0)1747 833000
Fax : +44 (0)1747 833313
E-mail address : eurtechserv@sial.com

1.4 Emergency telephone number

Emergency Phone # : +44 (0)1747 833100

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Classification according to Regulation (EC) No 1272/2008 [EU-GHS/CLP]
Carcinogenicity (Category 2)

Classification according to EU Directives 67/548/EEC or 1999/45/EC
Limited evidence of a carcinogenic effect.

2.2 Label elements

Labelling according Regulation (EC) No 1272/2008 [CLP]
Pictogram

Signal word : Warning
Hazard statement(s)
H351 : Suspected of causing cancer.
Precautionary statement(s)
P281 : Use personal protective equipment as required.
Supplemental Hazard Statements : none

According to European Directive 67/548/EEC as amended.
Hazard symbol(s)

Sigma-Aldrich - 270997 Page 1 of 7

Figure 11: Example of the first page of a manufacturer's SDS for dichloromethane.

different providers and it is important to make every attempt to obtain information from the manufacturer of the specific cargo involved in an incident. It is anticipated that with the full implementation of GHS, Safety Data Sheets will provide more consistent and reliable information.

Exposure limits

The chemical industry and specialised government agencies have established exposure limits to protect workers dealing with hazardous substances. Permissible exposure limits (PEL) are regulatory limits on the maximum amount or concentration of a substance in the air. A PEL is established using a time-weighted average (TWA) exposure, usually eight hours (a typical work day). These limits are based on Threshold Limit Values (TLV) that reflect the exposure to airborne gases and vapours that a typical worker can experience without serious risk of disease or injury. These limits are intended to allow for chronic exposure to hazardous substances but are not intended to deal with acute exposures following a spillage.

In order to deal with immediate effects, short-term exposure limits and ceiling limits have sometimes been established. The short-term exposure limit is one that addresses exposure to a maximum concentration over a 15 minute period and cannot be repeated more than four times a day. A ceiling limit is one that may not be exceeded for any period of time and is applied to irritants and other materials that have immediate effects. In this respect, the criterion, Immediately Dangerous to Life or Health (IDLH), is the ceiling exposure limit most frequently used and describes an atmosphere that is immediately dangerous to life or health for a typical adult male. IDLH limits were originally created to assist in making decisions regarding respirator use. Two factors are considered when defining IDLH limits: workers must be able to escape the hazardous environment and should not suffer permanent health damage or severe eye or respiratory tract irritation or other conditions that might impair their escape.

More specific guidelines for responding to potential releases of airborne substances continue to be developed by the industry and by government agencies, for example the US Environmental Protection Agency[8].

ERPG (Emergency Response Planning Guidelines) are air concentration guidelines for single exposures to hazardous substances and are intended for use as tools to assess the adequacy of accident prevention and emergency response plans. ERPG are developed by the ERPG Committee of the American Industrial Hygiene Association (AIHA)[9].

AEGL (Acute Exposure Guideline Levels) are intended to describe the risk to humans resulting from once-in-a-lifetime, or rare, exposure to airborne chemicals. The development of AEGL is a collaborative effort of the public and private sectors worldwide. The US National Advisory Committee for

[8] *www.epa.gov/osweroe1/docs/chem/tech.pdf*
[9] *www.aiha.org*

the Development of Acute Exposure Guideline Levels for Hazardous Substances (AEGL Committee)[10] is involved in developing these guidelines to help deal with emergencies involving spills or other catastrophic exposures.

TEEL (Temporary Emergency Exposure Limits) are levels of concern representing the adverse health effects of a hazardous substance on the general public. TEEL are defined by the U.S. Department of Energy[11] for use when ERPG or AEGL are not available.

Effects on marine resources

The effects of one or more chemicals on the marine environment depend on a number of factors. Most significant is the toxicity of the chemicals or mixture of substances lost or their reaction products. The extent of the impact will also depend on the quantities involved and resulting concentrations in the water column, as well as the length of time that biota are exposed to that concentration and the sensitivity of the organisms to the particular chemical or chemicals. Not only do different aquatic species exhibit different tolerances to substances, but the tolerance of a given species can vary according to different stages in its life cycle and the season. The prevailing meteorological conditions and local topography can also strongly influence the effects of a spill. In calm conditions, the area exposed to adverse effects may be relatively small and expand only slowly, with the intensity of impact diminishing with distance from the spill source. On the other hand, in a river or confined waterway, a moving plume can travel downstream quickly, exposing a rapidly expanding area to high or damaging concentrations.

In the open sea, tidal ebb and flow, ocean currents and turbulent diffusion usually result in the rapid dilution of pollutants. However, even if concentrations are below levels that would result in mortality, sub-lethal concentrations can nevertheless lead to other effects. Chemically-induced stress can reduce the overall ability of the organism to reproduce, grow, feed or otherwise function normally. Also of importance is the potential of chemicals, even at these sub-lethal levels, to disrupt other legitimate uses of the sea, for example, through tainting of fish or closure of beaches.

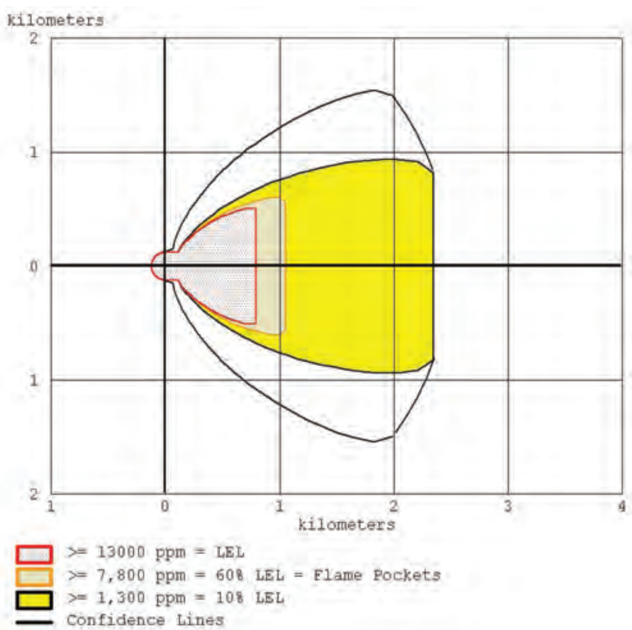
Some substances can persist for long periods in the marine environment once lost into the sea, including elements such as mercury and other heavy metals and some organic compounds, such as pesticides, that do not break down easily. The uptake of such substances by living organisms can lead to their 'bio-accumulation'. Bio-accumulation refers to the build up of the persistent material within an organism, and in particular within certain tissues, at a rate exceeding the rate of elimination by metabolic breakdown or excretion. Sessile marine organisms that filter seawater for food, such as bivalve molluscs (oysters and mussels), are particularly vulnerable to exposure. 'Bio-magnification', the sequential increase in concentration of a bio-accumulative substance from prey to predator, may also occur up the food chain. Consequently, the highest concentrations of the substance are typically found within the tissues of the top predators, for example, increasing from minute quantities in plankton to higher concentrations in fish and eventually resulting in significant body burdens in humans.

Planning a response to an HNS incident

The potential consequences of a spill involving HNS on human health are such that effective organisation and planning of a response is crucial. The role of each member of the response team should be defined clearly and their responsibilities and capabilities identified. Training and exercise requirements should be detailed in a contingency plan and put into effect in order to provide response personnel with the skills necessary to do their jobs safely.

Risk assessment

When responding to accidents involving HNS, the first steps to be taken are much the same regardless of the substances involved, the circumstances of the incident and its location. It is essential not to respond on-site to a chemical incident until a thorough assessment of the situation has been carried out, focusing in particular on the health and safety aspects. It is important to identify all the chemicals involved, noting their mode of transport (bulk, container, palleted goods, drums, etc.) as well as the nature of the spill or discharge (e.g. escaped chemicals, lost packaged dangerous goods). The risk of fire and explosion, as well as health risks and risks to adjacent areas must be assessed quickly and information from sources, such as the Emergency Response Guidelines (ERG) of the IMDG Code, individual MSDS, International Chemical Safety Cards (ICSC)[12] and chemical information databases, for example NOAA's CAMEO[13], can be helpful.



▲ *Figure 12: Example of the output of the ALOHA model (NOAA) showing various levels of concern (explosivity) for cyclohexane in relation to the distance from the source. ALOHA = Area Locations of Hazardous Atmospheres.*

[10] *www.epa.gov/opptintr/aegl*
[11] *www.hss.doe.gov*
[12] *www.ilo.org/icsc*
[13] *Computer Aided Management of Emergency Operations*

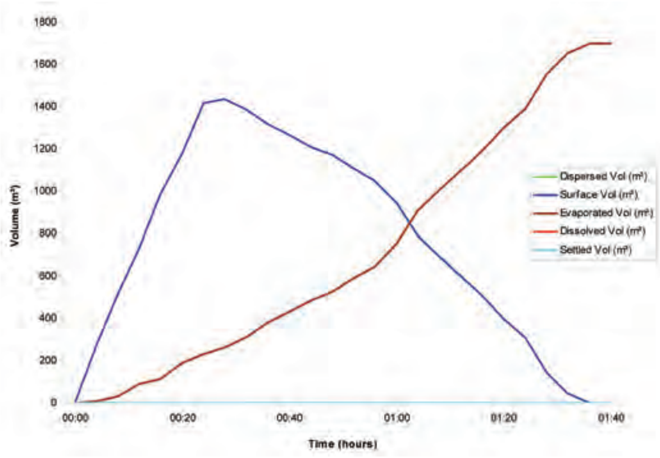


Figure 13: Example of the modelled behaviour of a finite volume of cyclohexane (C_6H_{12}) over time, as released from a sunken wreck. The graph indicates cyclohexane would rise to the water surface and steadily evaporate to the atmosphere. The maximum surface slick area would be reached 20 hours after the initial release. As cyclohexane is immiscible and has a density of 0.78 g/cm³, the dissolved and settled (i.e. sunk to the sea floor) volumes, as well the dispersed volume, are negligible or zero (Source: Chemsys – National Chemical Emergency Centre (NCEC), http://the-ncec.com).

Based on the physical properties of the chemicals as well as environmental conditions (such as air and water temperature, water movement and the prevailing wind strength and direction) a relatively simple, first estimate of the probable fate and behaviour of the chemical can be made. Only after these hazards have been identified and any risk of further leakage established, can an initial risk assessment be completed and an appropriate response strategy considered.

Modelling

A number of different computer models exist, some of which provide predictions on the likely spread of chemicals (*Figures 12 and 13*) in two dimensions, for example, across the water surface, while others consider dispersion in three dimensions in air and in the water column. However, computer models have a number of limitations, including the general assumptions made to develop the model's algorithms and source code, and very few have been validated against actual spills. In addition, factors such as the reliability of input data and the operator's level of training and skills of interpretation also need to be taken into account when reviewing the model output. Nevertheless, they provide a useful tool for contingency planning and, to a limited extent, in response operations, especially when combined with real-time monitoring and particularly when the HNS is colourless.

Monitoring

Monitoring forms a crucial part of the response to a chemical spill and for gases and substances that rapidly evaporate, it may be the only form of response. Two forms of monitoring may be conducted during the response phase: air dispersion monitoring and monitoring the spread of chemicals in water

Detector	Detection method	Advantages	Disadvantages
Chemical detection paper	Changes colour upon exposure to an HNS, according to the type of HNS.	One of the least sophisticated and least expensive methods.	Lacks specificity and is prone to false-positive readings.
Colorimetric tubes e.g. Draeger and RAE tubes	A gas sample is drawn into a specific tube, allowing the concentration to be read. 160 substance-specific reagent tubes are available to identify different HNS.	Simple and inexpensive way of detecting and identifying an HNS.	A different tube must be used for each HNS. Knowledge of the likely HNS present is required to prevent false negatives. One-off use.
Photo-Ionisation Detector (PID)	Suspect gas is ionised by ultraviolet light with specific ranges of UV ionising molecules in certain HNS. An ion detector registers the ionised molecules.	Highly sensitive. Relatively inexpensive. Can produce instantaneous readings and operate continuously.	The user must know with high certainty the identity of the gas or vapour to be detected.
Ion mobility spectroscopy (IMS)	A gaseous sample is ionised by radioactive emitters and compared to a sample of clean air. An HNS, identified according to pre-determined parameters, causes an alarm to sound.	It is less sensitive to contaminants because it relies on a clean air sample for calibration. Instantaneous readings. Many commercial variants available.	Relatively expensive. Generally limited to military or industrial use.
Infrared spectroscopy	Mid-IR light (frequency 4000 cm^{-1} to 200 cm^{-1}) is used to excite gaseous molecules. Each gas has a unique infrared fingerprint. Detection causes an alarm to sound.	Highly selective technique. Various detector types available – hand-held or remote stand-alone devices.	Relatively expensive.

Table 6: Advantages and disadvantages of a number of HNS detector types available for real-time monitoring.

(on the surface, in the water column or on the seabed). Monitoring is carried out for a number of purposes:

- to identify the specific chemicals spilt;
- to detect the presence or absence of substances;
- to measure the concentration of substances;
- to establish a safety perimeter; and
- to validate models.

Air monitoring

Real-time monitoring can be used to assess toxic, fire and explosion hazards, to help determine safe working areas or potential evacuation zones and to assist with decisions on the appropriate level of personal protective equipment (PPE). For example, monitoring using chemical cell oxygen meters can be carried out to check for oxygen deficient environments and, if the atmosphere is found to contain less than 19.5% oxygen, Self-Contained Breathing Apparatus (SCBA) should be worn.

Equipment of varying degrees of sophistication is available for monitoring HNS (*Table 6*). One of the key factors to be taken into account when selecting equipment is how quickly results will be obtained as, to be of most use, information needs to be in 'real time'. A further important consideration is whether the monitoring equipment is autonomous and can be deployed remotely. If it requires human intervention, for example a hand-held device (*Figure 14*), then clearly operators must be properly protected with the appropriate PPE. It is also necessary to recognise that all equipment will require training in its use and some designs will require calibration.

Water monitoring

Some analysis techniques may be useful for determining the concentrations of HNS in the water column. Some organic substances can be monitored using, for example, portable gas chromatography (GC), Mass Spectroscopy linked to Gas Chromatography (portable GCMS), titration methods or ultra violet (UV) / infra red (IR) spectroscopy. Sensor based probes are available for the measurement of inorganic parameters such as biological oxygen demand (BOD), turbidity, conductivity, pH, ammonium ions, bromide, chlorine and copper, while simple methods such as indicator papers can be used to indicate acidity and alkalinity. In other cases, biological impacts such as bleaching or mortality of marine organisms may make it possible to track the dispersion of a pollutant. Sinking chemicals are more difficult to monitor but the use of sonar, underwater video cameras mounted on a Remotely Operated Vehicle (ROV) or a matrix of weighted sorbents may allow the spread of the pollutant to be mapped on the sea bed.

▲ *Figure 14: Demonstration of a hand-held phosphine gas monitor outside a hazardous area.*

Personal Protective Equipment (PPE)

Following an initial risk assessment, an evaluation team is usually mobilised to the vicinity of the casualty to assess the situation and to determine whether any mitigating actions are possible on the vessel. Clearly, it is essential that the evaluation team and responders wear the correct PPE.

PPE refers to the clothing and respiratory equipment necessary to protect a person from the hazardous properties of chemicals. Its selection should be appropriate to the particular hazards associated with the chemicals spilt. Unfortunately, no single material can be used to protect against all chemicals as the ability of the material to perform as a barrier depends on how long the material is exposed to the chemical, the concentration of the chemical and the external temperature. If the chemical that was spilt has not been identified, responders should assume a worst case scenario and wear the highest level of protection. As more information becomes available, an informed decision can be made as to whether it is appropriate to downgrade the level of PPE. As well as the resistance of the PPE material to the chemicals spilt, other factors to take into consideration when choosing appropriate PPE include the level of respiratory protection required, the durability of the PPE material and the effect that the PPE may have on heat stress and the responder's ability to undertake specific work tasks.

A number of government agencies, including the US Occupational Safety and Health Administration (OSHA)[14] has devised four categories of PPE based on the level of protection afforded (Levels A, B, C and D). These four levels are recognised by most response organisations. Level A offers the highest level of protection (*Figure 15*), whereas Level D protection could be considered as a work uniform, and should only be worn when it is certain that personnel will not be exposed to harmful levels of HNS. Table 7 shows the constituent items of PPE for each of the levels A to D, although additional items such as hard hats and safety glasses may also be included within each level. It is important that responders are thoroughly trained in the use of PPE to minimise the risk of harm through the use of the PPE itself or through their use in the wrong circumstances.

Response options for HNS spills

The response to a spill should be proportional to the threat posed by the volume and hazards presented by the particular chemicals lost to the sea. The volume and containment of

[14] *www.osha.gov*

Personal Protective Equipment (PPE)	Level A	Level B	Level C	Level D
Self Contained Breathing Apparatus (SCBA)	x	x		
Full face or half mask respirator			x	
Totally Encapsulating Chemical Protection Suit (TECPS)	x			
Hooded, chemical resistant clothing		x	x	
Chemical resistant outer gloves	x	x	x	
Chemical resistant inner gloves	x	x	x	
Chemical resistant boots	x	x		
Disposable protective suit	x			
Coveralls				x

▲ *Table 7: Items of equipment required for each level of protection according to the US OSHA.*

a product will affect the response; for example, the release of an entire tank of acid from a chemical tanker may have a much more rapid and damaging effect than a damaged container, in which a small number of bottles of acid are ruptured. Also, some chemicals such as aluminium and cyanides become far more toxic in acidic conditions (low pH) and consideration must be given to secondary reactions with other substances that they may come into contact with and hazards that may result. In every instance, responders must wear the appropriate PPE and response and monitoring equipment must be adequately designed to enter hazardous atmospheres, for example with suitable air filtering equipment or spark-proof engines.

The following provides a brief summary of potential response techniques for the different groups of chemicals.

Gases & evaporators

The release of a gas or evaporating liquid HNS has the potential to generate vapour clouds that might be toxic or form an explosive mixture with air. As a result, there may be potential health and safety implications for the crew of the casualty, responders and centres of population nearby. When such incidents occur near centres of population, the local fire service often have the commanding role in the response.

In order to plan a response, it is important to know how the gas or vapour will behave and the likely trajectory of the hazardous cloud. Computer modelling of the airborne contaminants is likely to assist in forecasting the movement, spread and fate of the plume as it disperses. Safety zones can then be put into place as necessary and the public advised as appropriate.

It may be an option to manoeuvre the casualty so that toxic, corrosive or flammable vapours are carried away from populated areas. If this is not possible, the authorities may need to advise the public to remain indoors and to close doors and windows or, in severe cases, the order may be given to evacuate locations under threat. Evacuation brings with it associated risks, for example of panic, particularly in large population centres and these have to be balanced against the potential consequences if the population remains in place.

Response techniques such as 'knocking down' a vapour cloud, or attempting to stop or deflect it using water sprays or foam, are measures that may be available to responders who should, however, be aware of the possible reactions with water and balance any consequences against the risks. Consideration should also be given to the consequences of generating large volumes of contaminated water and the

▲ *Figure 15: Responders equipped with Level A Personal Protective Equipment.*

▲ *Figure 16: An exercise simulating a response to a spill of HNS using fire vessels (image source unknown).*

Figure 17: Plume of rock phosphate escaping from a casualty.

stability of the casualty in case of flooding. These methods can be used with any water soluble gases, such as ammonia and sulphur dioxide. The risk of fire and explosion of non-water soluble gases can be reduced by cooling hot surfaces and suppressing sparks and flames (*Figure 16*) using water spray and foam.

In an open environment, toxic vapour will usually disperse as a result of natural air movement and turbulence. Often the only feasible response measure will be to monitor the cloud and its dispersion.

Dissolvers

A significant proportion of the chemicals transported by sea are soluble substances. A dissolving chemical lost to the sea will form a growing 'plume' of decreasing concentration as the plume moves away from the source (*Figure 17*). Many dissolvers are not visible and rapidly disperse, meaning that monitoring concentrations in the water column may not be straightforward. However, computer models can give useful indications of the likely distribution and fate of the substance and predict potential hazards to the marine environment and other resources such as fisheries, water intakes and recreational areas. Where elevated concentrations are anticipated, monitoring will be essential to verify the computer generated predictions.

The ability to contain and recover dissolved chemicals is extremely limited. Providing means to accelerate the natural processes of dispersion and dilution may be the only way to respond to such chemicals. Some dissolved chemical plumes may, in theory, be neutralised, flocculated, oxidised or reduced by the application of other chemicals. On land and in confined water bodies, and with the approval of the relevant authorities, neutralising agents may be effective tools if applied correctly. Products that could be used for treatment of chemicals in water, such as flocculation agents, gelling agents, activated carbon, complexing agents (chemicals that trap contaminants within their molecular structure) and ion exchangers, should have the following attributes:

- be non toxic;
- the neutralising process and by-products must be non toxic;
- have low biological oxygen demand (BOD);
- be safe to use by trained personnel;
- be easy to handle and store; and
- be commonly available at a reasonable cost.

Nevertheless, in the open sea, the time delay between a spill and the response, together with the large volume of water involved, invariably mean that chemical treatment is unlikely to be practical or provide any benefit and would not normally be recommended.

Floaters

Floating chemicals can be low or high viscosity liquids, or may even be solid. If the spilt chemical has a high vapour pressure it may evaporate quickly and form a vapour cloud above the slick. Many floaters will spread across the water surface to form a slick in a similar manner to oil. However, unlike oil they may not be visible on the water. For spills involving relatively persistent chemicals that float, it may be possible, in some cases, to detect and monitor floating materials using technologies such as aerial surveillance (SLAR, IR and UV) and possibly satellite imagery, although there is limited practical experience of using these techniques for HNS spills.

If safe, it may be possible to consider deploying booms to contain and control the movement of substances on the water's surface. Skimmers and other oil spill response equipment may also be used to recover the material from the surface of the water. However, prior to use, it is important to ensure that the spilt chemical will not react adversely with the equipment or explode if a spark is generated. Containment and recovery may not be advisable when dealing with highly toxic or flammable HNS as containment could lead to increased concentrations creating very dangerous environments for responders and the local population. In such cases it is often preferable to allow natural dissipation to reduce the concentrations to below harmful levels. Where fire and explosion is a risk and legislation allows, emergency responders may apply fire-fighting or suppressant foams.

In certain circumstances, sorbent materials may be deployed to collect and concentrate an HNS spill. An important distinction should be made between absorbents that incorporate the spilt chemical into the structure of the material and adsorbents whereby the chemical coats the surface of the sorbent material. Absorbents encapsulate a spilt chemical, preventing its release and reducing its volatility. Conversely, the use of adsorbents can increase the surface area of the spilt chemical with an attendant increase in the rate of vapour release. Furthermore, an adsorbent may exhibit poor retention of the recovered chemical as the material is recovered from the water. Although used extensively on land based spills, the deployment and recovery of sorbents in a marine environment is less effective. The use of sorbent booms or mats is preferred over loose powders or fibres as collection of the latter is often unachievable. The main disadvantages of sorbent products are that they can be expensive and they produce a higher volume of contaminated material that is bulky to transport and must be disposed of in compliance with local regulations.

In some cases, it may be possible to burn-off a floating chemical, but due consideration must be given to the possibility of the formation of toxic fumes leading to health and safety concerns for responders and the uncontrolled spread of the fire and smoke.

Sinkers

Chemicals that sink have the potential to contaminate the seabed and may sometimes persist in the sediment. The response to sunken chemicals may therefore need to consider the recovery of the chemical and any heavily contaminated sediment. In shallow waters, mechanical dredgers and pump/vacuum devices may be used to recover sunken substances. Careful attention will also need to be given to the treatment and disposal of recovered chemicals and contaminated sediments.

Sunken wrecks

HNS cargo remaining within a sunken wreck (*Figure 18*) is likely to raise concerns with respect to the potential risk associated with its future release, either sudden and catastrophic or continuous over a long time period. In such cases, a risk assessment should be undertaken to determine which of the following three main approaches usually considered by responders, should be followed:

- **Passive release** through vents and/or following the long term corrosion of the vessel's hull. This approach is adopted when the risk assessment shows that a release is unlikely to result in significant damage to the environment or when no other option is feasible.
- **Controlled release** of the cargo is usually considered for substances, e.g. dissolvers, which may result in some localised impacts, but which are unlikely to cause widespread damage if released relatively slowly into the water column, although a sudden release could cause concern.
- **Cargo removal** is considered for substances raising the highest levels of concern in terms of potential damage to human health, the environment and economic activities in the vicinity.

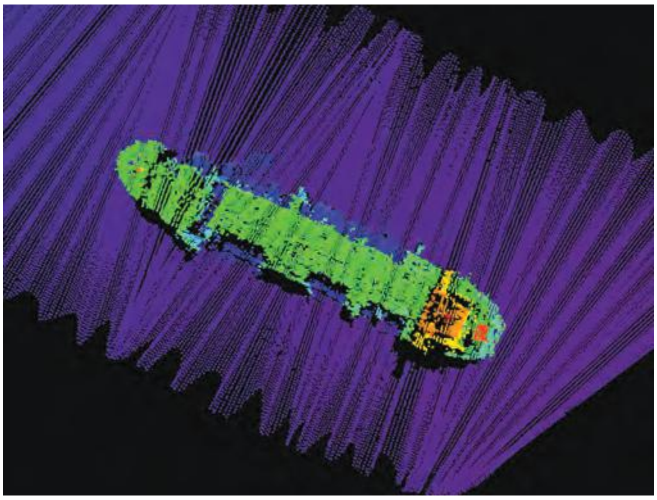


Figure 18: Sonar imagery of the wreck of a sunken chemical tanker (image courtesy NOAA).

Key points

- If a chemical is flammable, explosive, an oxidising agent, corrosive, an irritant or an environmental hazard, it is likely to be considered a Hazardous and Noxious Substance (HNS).
- The physical properties of HNS govern their behaviour when lost into the sea and determine whether the substance behaves as a gas, evaporates, dissolves or sinks.
- The effects of an HNS on the marine environment depends on the toxicity, exposure and sensitivity of marine organisms to the chemical concerned.
- It is important to anticipate the potential reaction of certain HNS with water, on exposure to air, or if several chemicals are spilt, with each other to produce heat or toxic products.
- Hazards to human health and the marine environment have been evaluated by GESAMP while exposure limits for humans are expressed as IDLH, ERPG, AEGL and TEEL to assist with the safe response to HNS incidents. Relevant data is provided in Safety Data Sheets.
- Before responding to an HNS incident, it is essential that a risk assessment is conducted based on modelling and monitoring of HNS pollutant levels.
- Response options depend largely upon whether the substance is a gas, evaporator, dissolver or sinker. For gases and substances that evaporate or dissolve quickly, monitoring may be the only form of response while recovery may be possible for some floaters and sinkers.
- Four levels of PPE are widely recognised, A, B, C and D, with A offering the highest level of protection. PPE appropriate to the hazard should be selected but when high levels of protection are required it is vital to take environmental conditions into account when setting the length of work periods.

TECHNICAL INFORMATION PAPERS

1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
6 Recognition of Oil on Shorelines
7 Clean-up of Oil from Shorelines
8 Use of Sorbent Materials in Oil Spill Response
9 Disposal of Oil and Debris
10 Leadership, Command & Management of Oil Spills
11 Effects of Oil Pollution on Fisheries and Mariculture
12 Effects of Oil Pollution on Social and Economic Activities
13 Effects of Oil Pollution on the Environment
14 Sampling and Monitoring of Marine Oil Spills
15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
17 Response to Marine Chemical Incidents

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THE INTERNATIONAL TANKER OWNERS POLLUTION FEDERATION LIMITED

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)7623 984 606

E-mail: central@itopf.com
Web: www.itopf.com