CLEAN-UP OF OIL FROM SHORELINES

TECHNICAL INFORMATION PAPER

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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.

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.

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 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.

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

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

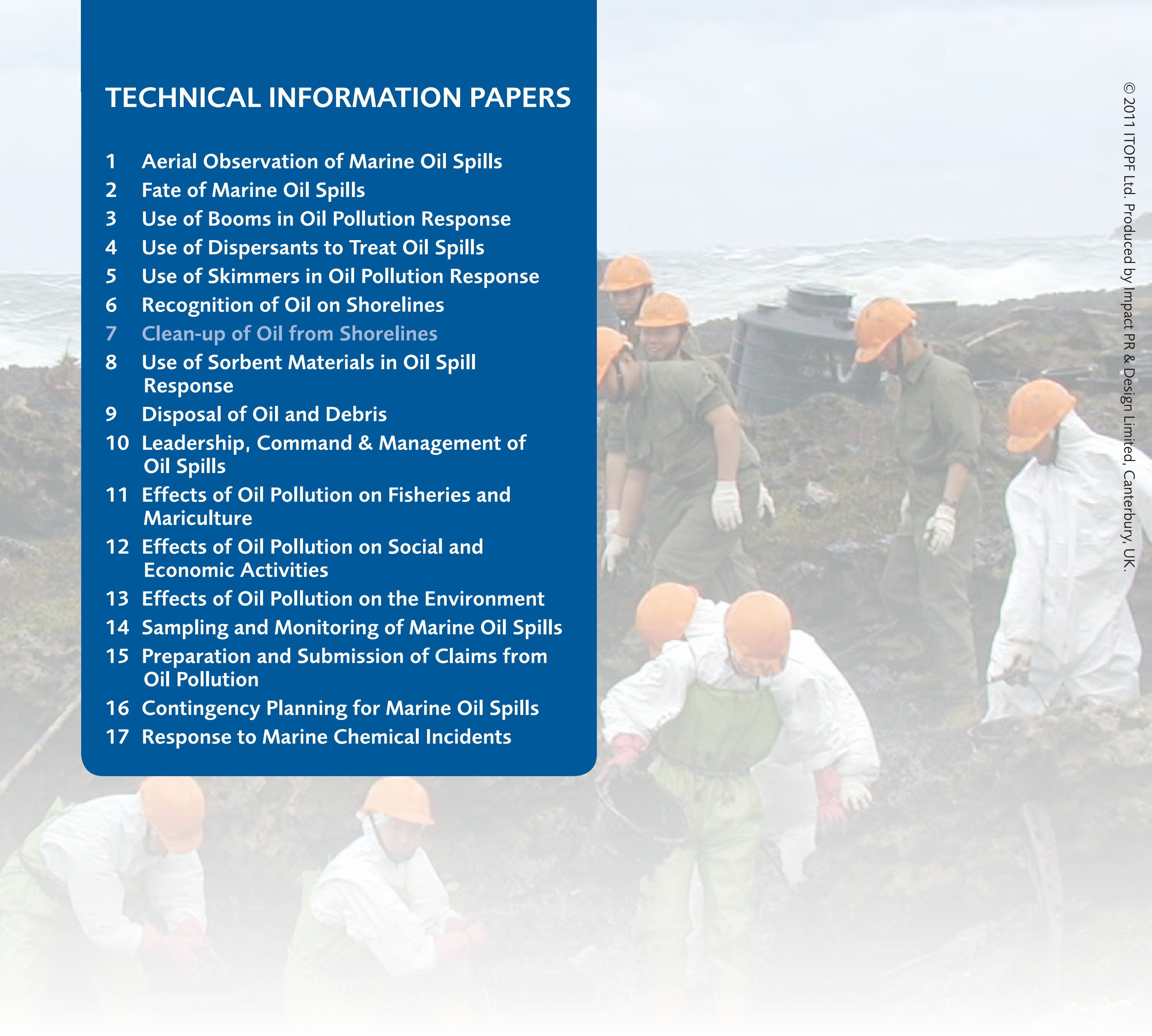
The temporary storage, transport and eventual disposal of recovered oiled waste should also be considered during the preparation of the contingency plan, as these issues can strongly influence the efficiency of the clean-up. Sources of manpower, equipment and materials, together with their contact details, 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.



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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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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.

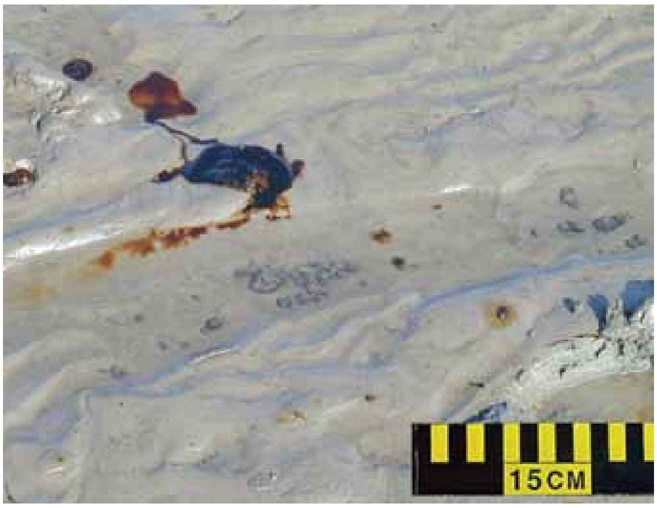


Figure 10: A fresh tarball.

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 = 9m^3 total
or
9,000 litres/(300m x 3m) = 10 litres / m^2
or
Approximately 30 litres of oil per metre strip down the beach

Moderate oiling

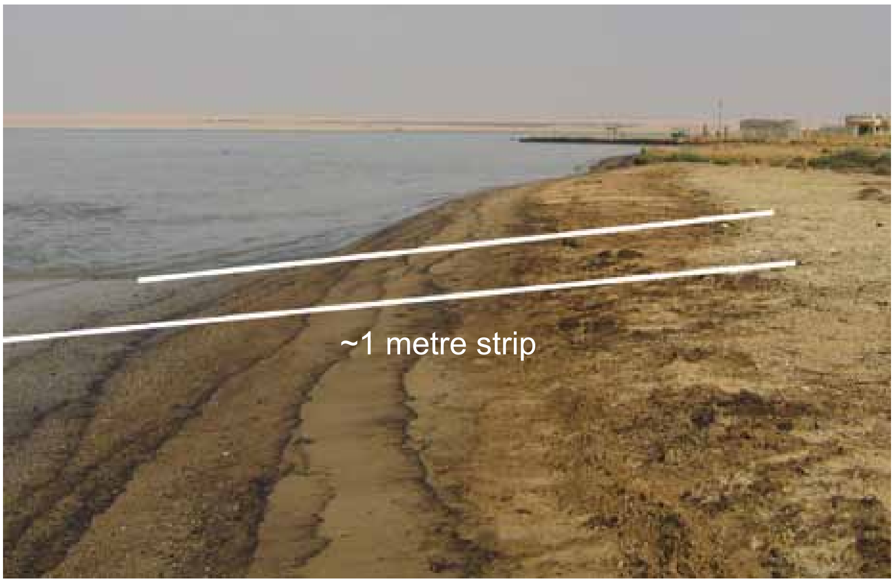
Figure 32: Moderate, broken oiling of a 500 metre long sand beach.

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 = 2.5m^3 total
or
2,500 litres/(500m x 5m) = 1 litre per m^2
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% = 0.1m^3 (100 litres) total
or
100 litres/(200m x 5m) = 0.1 litre / m^2
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.

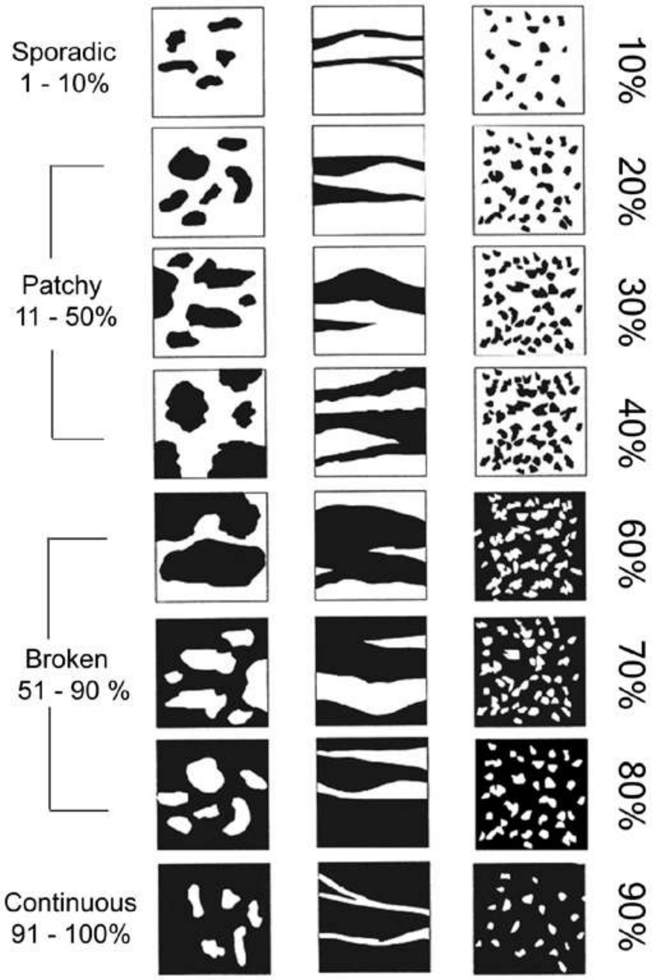
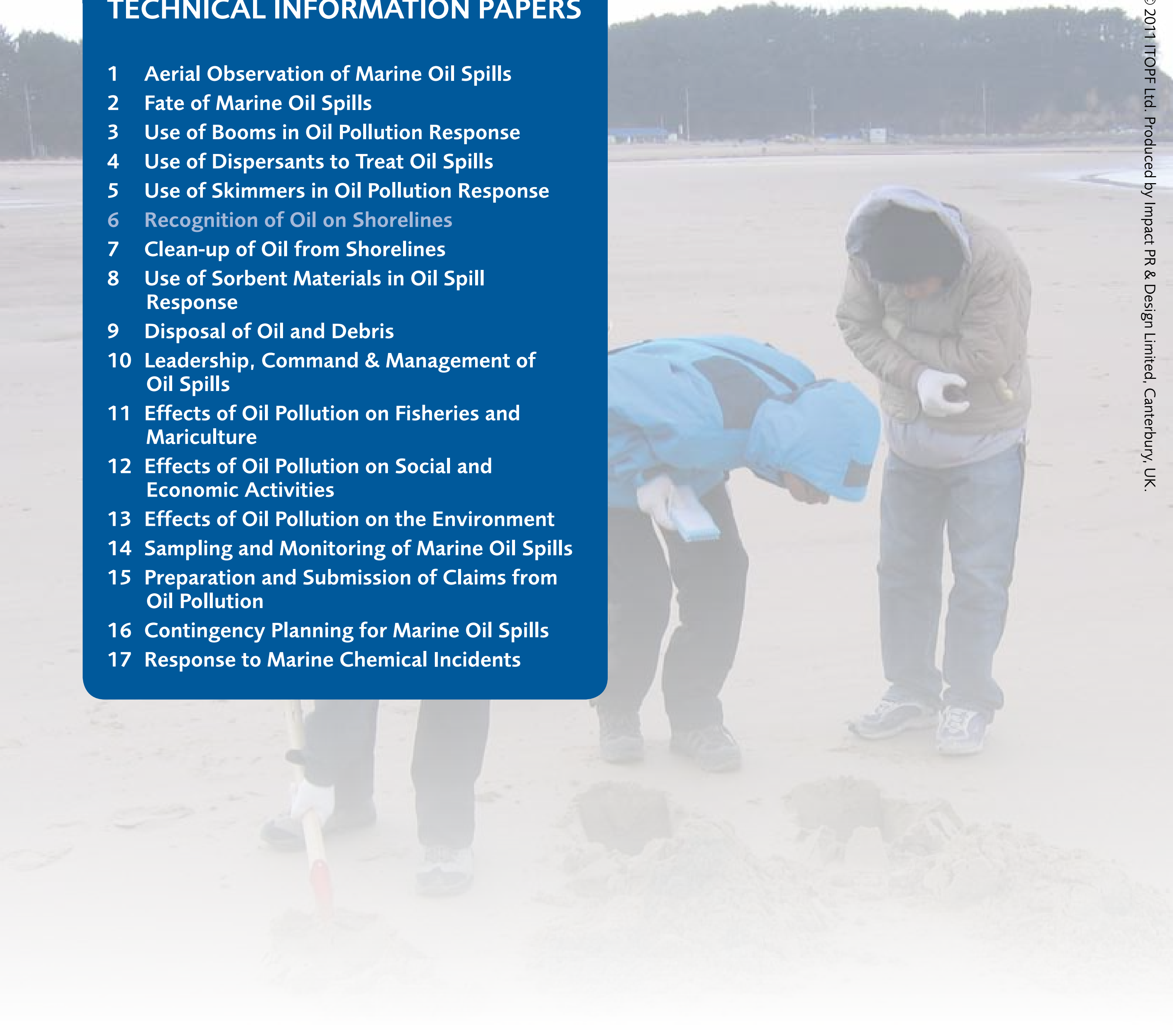


Figure 35: Indicative percentage coverings of oil to allow comparative, qualitative estimates of contamination. (Adapted from Owens, E.H. & Sergy, G.A.. 2000. The SCAT manual. A field guide to the documentation and description of oiled shorelines. 2nd edition. Environment Canada, Edmonton, Alberta, Canada).

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

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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