THE NET ENVIRONMENTAL BENEFIT APPROACH FOR OIL SPILL RESPONSE

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ABSTRACT: This paper discusses Net Environmental Benefit Analysis for oil spill response, from an ecological point of view. This involves the weighing up of advantages and disadvantages of various spill responses to the flora and fauna and their habitats, compared with no response. Particular attention is paid to nearshore dispersant spraying and shore cleanup; and the scientific case history and experimental evidence which can be brought to bear on these responses is reviewed. For shoreline cleanup, consideration is given both to the shore itself, and to potentially interacting systems which could be affected in various ways depending upon the spill response (e.g. a bird colony or nearshore aquaculture facilities). It is concluded that for some scenarios, nearshore dispersant spraying can offer a net environmental benefit. For most cases of shore oiling, there is little ecological justification for any form of cleanup if only the shore itself is considered, but moderate cleanup carried out for the sake of interacting systems is acceptable. Aggressive cleanup often delays recovery.

INTRODUCTION

Some oil spill responses arouse little or no controversy from an environmental point of view. An offshore example is physical containment and recovery. For an onshore example, consider oil stranded on the surface of a sandy beach of low biological productivity but high amenity value. If the oil is removed by physical methods with minimal removal of underlying sand, the cleanup provides an obvious benefit to the users of the beach and no obvious disadvantage from the biological point of view. However, in many cases a possible response to a spill is potentially damaging to the flora and fauna and/or their habitats, and the advantages and disadvantages of different responses need to be weighed up and compared with the advantages and disadvantages of natural cleanup (otherwise known as the ‘do-nothing’ option). This is what is meant by Net Environmental Benefit Analysis (NEBA), for the purposes of this paper. The NEBA process was prominent in the aftermath of the *Exxon Valdez* incident. For example, a study was conducted concerning the advisability of excavation and washing of rocks, for shores with sub-surface oil (NOAA 1990). The conclusion was drawn that whilst the proposed treatment could remove subsurface oil, it did not offer a Net Environmental Benefit because it would alter the shore structure and delay biological recovery (which had already started). NEBA has subsequently been advocated (e.g. IPIECA 1993) as part of the overall contingency planning process, on the grounds that post-spill decisions are best and most rapidly made in the light of pre-spill analyses, consultations and agreements by all the appropriate organizations.

Any NEBA carried out for contingency planning purposes can benefit from case history and field experimental experience published in the scientific literature. It is the purpose of this paper to distil relevant information. Particular attention is paid to nearshore dispersant spraying and shoreline cleanup.

NEARSHORE DISPERSANT SPRAYING

Given the scenario of an oil slick approaching a shoreline, the response requires some sort of decision-making process such as that shown in Figure 1. It is sometimes the case (especially in more remote areas) that the only logistically feasible response is aerial dispersant spraying. Because the 'window of opportunity' for dispersant use is typically only one to two days post-spill, it is particularly important to consider advantages and disadvantages of dispersants before a spill occurs.
Questions need to be answered about subjects such as the following.

* The concentrations of dispersed oil which may be expected under a dispersant-treated slick in nearshore conditions.
* The toxicity of the likely concentrations of dispersed oil to local flora and fauna.
* The distribution and fate of the dispersed oil in water, sediments and organisms.
* The distribution, fate and biological effects of the oil if it is not treated with dispersant, e.g. will it harm shore habitats or wildlife? Not using dispersants is sometimes viewed wrongly as an option with no negative impact.

A range of existing evidence relevant to nearshore conditions is summarized below. Reviews covering both nearshore and open water conditions are available (NRC 1989, IPIECA 1993). The information indicates that for some scenarios there is a net environmental benefit in using dispersants.

Braer spill

120 tonnes of dispersant were sprayed on the *Braer* spill but this incident is of particular interest because natural physical dispersal resulted in ‘worst case’ concentrations of dispersed oil in nearshore waters. The *Braer* grounded on the southern tip of Shetland on the 5th January 1993, and the cargo of 84,700 tonnes of Norwegian Gullfaks crude oil was nearly all dispersed into the water because of the turbulent sea conditions. Published data (ESGOSS 1994) show that initial concentrations of oil in the water near the tanker were measured at some hundreds of parts per million (ppm), and the sea was described as having a brown “coffee-like” coloring typical of dispersed oil. The droplet size of this oil was similar to that of chemically dispersed oil (Rycroft pers. comm.). In the following days values as high as 50 ppm were reported near the wreck, but oil concentrations decreased with time and returned to background concentrations 60-70 days after the grounding. These data show that oil exposure (concentration x time, NRC 1989) for water columnn organisms greatly exceeded anything previously reported (NRC 1989, IPIECA 1993) for field trials or case histories involving application of chemical dispersants. Moreover, according to Rycroft *et al* (1994), it would never be possible to disperse the sort of quantity of oil spilt from the *Braer* with chemicals (for logistical reasons). Thus the *Braer* represents an extreme scenario for considering the ecological advantages and disadvantages of dispersing oil in near-shore waters.

The fate and effects of the oil have been described by ESGOSS (1994). Some summarized findings which are of relevance for dispersant use NEBA are given below. The overall conclusion was that the impact of the spill on the ecology and environment of South Shetland has been minimal.

* Salmon in farms 20-25 km from the wreck site were tainted but did not suffer unusual mortalities. However, many had to be destroyed because they could not be sold. By the end of July 1993 samples from all the affected sites had no taint, and virtually normal values for polycyclic aromatic hydrocarbons (PAH's).

* Many dead wild fish, mainly wrasse and sandeels, were washed up on the beaches near the wreck during the first few days after the spill (SNH 1993 as quoted by Moore (1994). For sandeels (a species of critical importance to several food chains) there was no change in distribution around south Shetland, and no evidence of effect on populations. For all species of wild fish, contamination in samples fell rapidly, and by April 1993 the ban on fishing was lifted.

* For shellfish, there was still evidence in May 1994 of low levels of contamination in some species, and the fishing ban had not been lifted by summer 1994.

* For nearshore and intertidal areas, there is little evidence of lasting hydrocarbon contamination, and residual sediment toxicity is negligible. Questions remain about the degradation rate of oil in fine sediments in relatively deep water, and in some of the south-western voes.

* The oil does not appear to have affected coastal macrobenthos significantly. For benthic communities in areas of fine sediment affected by oil, there were some increases in opportunistic and oil tolerant species; abundance of some indicator meiofauna species declined.

* For seals, otters and cetaceans, the short-term effects of the spill have been negligible.

* For all species of birds, mortality was low by comparison with other spills, and there were no signs of sub-lethal toxic effects apart from some minor effects on kittiwakes.

Searsport experiment

Two controlled discharges of Murban crude, one untreated and one chemically dispersed, were made in shallow water (less than 4 m deep) within test plots at Searsport, Maine. Water, sediments and marine organisms were sampled during a one-year baseline study before the discharges were made, and during the post-spill study period. Concentrations 10 cm above the sea bed in shallow water (not more than 3 m deep) peaked between 20 and 40 ppm, and decreased to background levels within two tidal cycles. There was no evidence of adverse biological effects.

Important findings from this experiment (Page et al 1983), Gilfillan *et al* 1983, 1984) included the following.

* Chemically dispersed oil lost volatile hydrocarbons as the droplets diffused downward.
* There was little incorporation of oil into sediments exposed to the cloud of dispersed oil.
* There was significant incorporation of oil into sediments exposed to untreated oil, with more being found in the upper shore than the lower.
* There was no evidence of adverse effects on the sediment fauna community from exposure to dispersed oil.
* There was clear evidence that exposure to untreated oil adversely affected the sediment fauna. Effects included some mortality of a commercially important bivalve.

BIOS experiment

The following experiment formed part of a larger programme concerning Arctic intertidal and nearshore areas, Baffin Island. Untreated oil was released in a boomed test area and allowed to beach. A dispersed oil cloud was created by discharging an oil/dispersant/seawater mixture through a subtidal diffuser nearshore. The highest recorded concentration of oil in the water column was 160 ppm at 10 m depth. There were marked acute behavioural effects on some of the sub-tidal fauna, but no large-scale mortality. ‘Despite unusually severe conditions of exposure to chemically dispersed oil, the impact on a typical shallow-water benthic habitat was not of major ecological consequence’ (Sergy and Blackall 1987). Sub-tidal organisms accumulated dispersed oil rapidly but most of this was degraded or depurated within one year. Untreated oil residues remained on the beach after two years, with some transport to adjacent subtidal sediments.

TROPICS experiment and Panama refinery spill

The TROPICS experiment in Panama compared the effects of untreated and chemically dispersed oil in an area with mangroves, seagrass beds and corals. The average water depth was less than 1 m, and concentrations of dispersed oil reached as high as 222 ppm. With the dispersed oil treatment, there were declines in the abundance of corals and other reef organisms, reduced coral growth rate in one species, and minor or no effects on seagrasses. Fresh untreated oil had severe long-term effects on survival of mangroves and associated fauna (Ballou *et al* 1989).

The Panama oil spill (IPIECA 1992, Cubit and Connor 1993, Garrity et al 1993) Provides an interesting comparison. Untreated oil caused damage to both mangroves and corals, including corals at a greater depth (3-6m) than those affected in the TROPICS experiment. Branching corals appeared more susceptible than massive corals, and recovery has been slow. The impacts on corals have been attributed (IPIECA 1992) to the slow release of oil from nearby mangrove sediments, and subsequent depression of coral viability because of the chronic low-level contamination of nearshore waters.

Other tropical experiments

Other information relevant to a consideration of mangroves and corals comes from work in Malaysia and Saudi Arabia. With Malaysian mangroves, Lai and Feng (1985) found that untreated crude oil was more toxic than dispersed crude to saplings. Untreated oil in the upper sediments required a longer time to weather and depurate than chemically dispersed oil. In Saudi Arabia, LeGore et al (1989) conducted experiments over coral reefs. During a one-year observation period, there were no visible effects on corals exposed to floating crude oil (0.25 mm thick) or to dispersant alone (at 5 % of oil volume). With dispersed oil there was no effect following a 24-hr exposure, and minor effects following a 5-day exposure. These effects comprised bleaching and failure to survive the cold winter season for not more than 5 % of the total coral.

Information on birds and mammals

Understandably, field experiments comparing the effects of untreated oil and dispersed oil have not included birds and mammals. However, it is clear that direct fouling of birds and fur-insulated mammals (such as sea otters) is disastrous for them, and it is generally assumed that dispersion of surface slicks must be beneficial because it reduces the risk of such fouling. Moreover, dispersion reduces the risk of birds ingesting oil. Work summarised by NRC (1989) shows that use of dispersants as ‘shampoos’ in cleaning experiments increases the wettability of fur and feathers, which can lead to death by hypothermia. This suggests that direct accidental spraying of wildlife with undiluted dispersants will be harmful.

SHORELINE CLEANUP

Notwithstanding the best efforts to protect shorelines, it is often necessary to deal with oil on the shore. This requires evaluation of the requirement for clean-up (Figure 2). The NEBA process can draw upon a huge amount of published information concerning oil on shores. The effects of a variety of cleanup techniques have been studied following spills and also by using field experimental approaches (Baker, Little and Owens 1993). More recently, a detailed analysis of all adequately documented rocky shore and saltmarsh case histories has been carried out (AURIS 1994).

In an attempt to distil all this information, it is possible to distinguish two groups of reasons for possible shore cleanup, one group relating to the actual shore and the other to interacting systems. For the purposes of this paper, **the shore** comprises the physical features which form habitats for organisms, and the shore organisms themselves, meaning those species which only live on the shore and are sessile or of limited mobility (e.g. algae, barnacles, mussels, limpets, and periwinkles). **The interacting systems** impinge on or use or are related to the shore in some way, but are not generally regarded as a permanent shore feature. Examples of features which belong to interacting systems are:

* Bird colonies, with birds nesting above the intertidal zone but sometimes visiting the intertidal zone; or feeding in nearshore water which may receive oily run-off from a polluted shore.
* Marine mammals, with, for example, seals using the shore as a haulout and breeding area.
* Nearshore habitats such as coral reefs, seagrass beds, and kelp beds, which may receive oily run-off from a polluted shore.
* Salmon streams which debouche over the shore, so that salmon entering a stream might have to swim over an oily shore at high tide.
* Socio-economic consideration such as tourists, intertidal shellfish beds, and nearshore aquaculture facilities which may receive run-off from a polluted shore.

The following is a classification of some possible shore scenarios bearing in mind the above distinctions, together with a commentary on each scenario from the NEBA point of view.

Oiled shore, no interacting systems

AURIS (1994) analysed all adequately documented case histories and showed that 85% of rocky shores and 75% of salt marshes recovered within three ans five years respectively, regardless of whether they had been cleaned or not (these figures exclude a few extreme cases which are discussed in the following section). It is unreasonable to expect cleaning to reduce recovery timescales significantly below three and five years, simply because most natural recovery processes of immigration, settlement and growth cannot be accelerated (evidence concerning the timescales of these natural processes in the absence of any oil and cleanup impacts is presented in the AURIS report). Therefore, if there are no interacting systems which take precedence, there is little justification on the basis of current evidence in carrying out any sort of shore clean-up operation on rocky shores or saltmarshes. Evidence for other types of shore has not yet been analysed.

Extremely oiled shore, no interacting systems

In a minority of cases, the shore oiling may be so severe that, on the basis of current evidence, the predicted recovery times may be unacceptably long. It may therefore be decided to clean the shore even if there are no important interacting systems. If this decision is taken, it needs to be borne in mind that aggressive clean-up as a response to extreme oiling can also prolong recovery times. A good comparison is provided by marshes heavily oiled by the *Metula* and *Amoco Cadiz* spills, with the latter being aggressively cleaned and the former not cleaned at all.

In the case of the 1974 *Metula* spill in the Strait of Magellan, Chile (Baker *et al* 1993), one very sheltered marsh received thick deposits of mousse. In 1994 these were still visible on the marsh surface, with the mousse quite fresh beneath the weathered surface skin. There has been little plant recolonization in the areas with the thicker deposits (mean oil depth 4.1 cm). Thus natural recovery times for such an extreme scenario can be predicted as substantially more than 20 years.

In the cases of the 1978 *Amoco Cadiz* spill in Brittany, there was similar heavy oiling, and the decision was taken to clean the Ile Grande marshes using heavy equipment. As much as 50 cm of sediment was removed, at the same time channels were widened and straightened. Subsequently it was realized that the treatment was harmful because some of the marsh surface was lowered to the extent that it was at the wrong intertidal height for plant growth. In 1990 three marshes still had 26%, 35% and 39% of their pre-spill surface areas missing (IPIECA 1994).

There are other examples of aggressive cleanup of heavy oiling having apparently prolonged the recovery time, notably the 1978 *Esso Bernicia* spill in Sullom Voe, Shetland. In areas where there was substantial mechanical removal of rocks and gravel, biological communities had not fully recovered after nine years (AURIS 1994).

What would happen if it was necessary to deal with a new case of very thick oil deposits on a shore ? On the basis of the above evidence, it seems that in some cases neither natural clean-up nor intense treatment will give the best environmental benefit. It seems likely that the greatest benefit would result from a moderate level of cleanup - sufficient to remove most of the bulk oil, but gentle enough to leave the surface of the shore intact and to avoid churning oil into underlying sediments. This could be achieved by using small crews and avoiding the use of heavy machinery as far as possible. The appearance of the shore after such treatment is likely to be somewhat oily and therefore not optimal from an aesthetic viewpoint, but there are numerous examples of biological recovery taking place in the presence of weathered oil remnants (Baker *et al* 1990). If marsh plants were smothered to death before removal of the bulk oil, a replanting scheme could be helpful.

Oiled shores, interacting systems present, moderate cleanup

As already mentioned above, AURIS (1994) analysed all adequately documented case histories and showed that 85% of rocky shores and 75% of saltmarshes recovered within three and five years respectively, regardless of whether they had been cleaned or not. Moreover, it is unreasonable to expect cleaning to reduce recovery timescales significantly below three and five years, because of the inherent timescales of natural recovery processes. This shows on the one hand that there is no justification for cleanup if there are no interacting systems. On the other hand, it also shows that if moderate cleanup is carried out for the sake of interacting systems, this can be done in most cases without prolonging the biological recovery time of the shore in an unacceptable way.

Extremely oiled shores, interacting systems present, aggressive cleanup

Examples of potentially aggressive cleanup methods include sediment removal, combined vegetation and sediment removal, and high pressure hot water flushing. Such methods are most likely to be used following extreme oiling, but the comments in this section also apply if they are used following moderate oiling. There is evidence that aggressive cleanup (notably removal of substratum) can drastically alter shore habitats and prolong recovery times of shore biota by two or three times, or more. Therefore the only justification for its use is if there is an overriding requirement to quickly achieve a shore as free of oil as possible, for the sake of some interacting system. Following aggressive cleanup, some sort of restoration programme may well be necessary, for example sediment replacement and/or marsh grass transplants.

RELATIONSHIPS BETWEEN SOCIO-ECONOMIC AND ECOLOGICAL CONSIDERATIONS

Socio-economic factors will inevitably play an important part in decisions about spill response. For example, a tourist beach or marina may generate considerable income for the local economy (at least seasonally), and so be a priority area for protection (using offshore dispersant spraying if appropriate), or cleanup. What are the relationships between socio-economic and ecological factors in a NEBA? The following are some possibilities.

* The area of concern contains resources which are mainly of ecological interest (e.g. bird colonies), so there is no potential conflict with socio-economic interests. However, there may be conflict between different ecological resources (for example, aggressive shore cleanup may benefit seals about to breed there, but prolong the recovery of shore organisms).

* The area contains mainly socio-economic interests (e.g. harbour facilities), so there is no potential conflict with ecological interests. However, there may be conflict between different socio-economic resources (for example, dispersant spraying may be of benefit to protect amenity beaches, but lead to tainting in nearshore fisheries).

* The area contains both ecological and socio-economic resources, but the optimum response for one is the same as the optimum response for the other. For example, a mangrove swamp may be of importance both ecologically and for shellfish collection - in both cases the highest priority would be given to preventing or reducing the amount of oil entering the mangroves.

* The area contains both ecological and socio-economic resources, but the optimum response for one is not the optimum response for the other. For example, the area contains both birds and fish culture facilities. Dispersant spraying might be the best way of reducing the threat to birds, but would increase the risk of fish tainting.

The contingency planning process should identify such areas of potential conflict, and attempt to resolve them before any spill, with consultation between all the interested organizations. It is worth bearing in mind the rationale of Lindstedt-Siva (1991), who used ecological criteria to define environmental sensitivity. This was on the grounds that "ecological impacts are both longer lasting and, once they have occurred, harder to repair than most other kinds of impacts (e.g. aesthetic, economic)". The following two scenarios provide examples.

Scenario 1. Consider a slick moving over shallow nearshore water in which there are coral reefs of particular conservation interest. The slick is moving towards sandy beaches important for tourism. Dispersant spraying will minimize pollution of the beaches, but it is predicted that some coral species are likely to be damaged by dispersed oil. From an ecological point of view, it is best not to use dispersants but to allow the oil to strand on the beaches, from where it may be quickly and easily cleaned. If dispersants are used, damaged corals could take many years to recover.

Scenario 2. Consider a stony shore with sub-surface oil which is gradually leaching into the nearshore waters. Near the shore are shallow subtidal beds of shellfish which were used for food by local people before the spill. Biological recovery on the shore has started but the shellfish are tainted. It is predicted that some tainting will continue for up to five years, making them inedible for this period of time. Does this justify aggressive removal of the oil? From an ecological point of view, there is no justification, because the recovery of the shore would be set back. Moreover, it is unlikely that there would be any ecological benefit to the shellfish populations, which can survive even though they are tainted. There would habe to be a compelling economic benefit of cleanup to override the ecological point of view.

CONCLUSIONS

* For some spill scenarios, nearshore dispersant spraying can offer a net environmental benefit.

* For the purposes of NEBA for shores, it is necessary to consider both the shore in itself, and systems which interact with the shore in some way (e.g. bird and mammal colonies).

* In most cases of oiling, the evidence for rocky shores and saltmarshes is that there is no ecological justification for cleanup, provided that the only concern is for the shore itself (i.e. habitats with associated plants and invertebrates).

* For extremely oiled shores, moderate cleanup could facilitate recovery, but aggressive cleanup is likely to delay it.

* In most cases of shore oiling where moderate cleanup is considered likely to reduce the threat to interacting systems, the evidence (from rocky shores and saltmarshes) is that this will not make a significant difference to the shore biological recovery times, within normal expectations of three and five years respectively.

* When considering priorities for protection and cleanup, it should be borne in mind that ecological impacts can be both longer lasting and more difficult to repair than socio-economic impacts.

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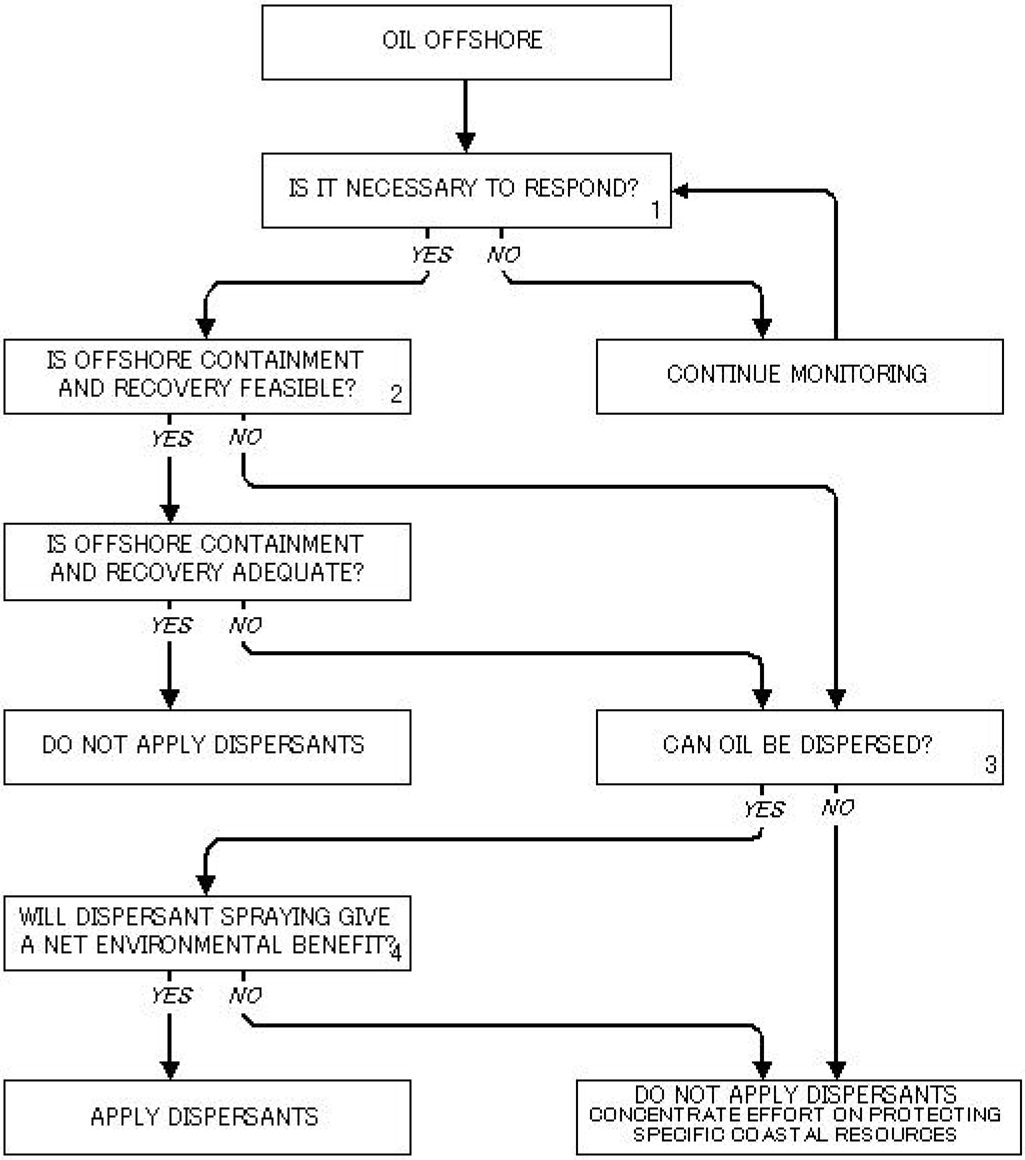
Figure 1. Decision tree for evaluating the requirement for offshore dispersant spraying



1. This question needs to be asked repeatedly as the slick is monitored; the answer is likely to be 'no' if the oil moves towards the open sea and 'yes' if it starts moving towards the shore at any time.

2. In specific cases, non-dispersant options other tyan containmnet and recovery may be considered (e.g. burning).

3. This question requires consideration of oil type, mixing energy of the sea, and logistical feasibility of aircraft/boat operations.

4. To answer this question quickly, there has to be pre-spill net environmental benefit analysis. Consideration of economic factors is also important.

Figure 2. Decision tree for evaluating the requirement for shore clean-up