Most Optimum Response Option Based On A NEEBA Approach

W. Koops, R de Vos and D.P.C. van der Veen

TNO Environment, Energy and Process Innovation
Department for Ecological Risk Studies
P.O. Box 57
1780 AB Den Helder
The Netherlands

Abstract

This paper discusses the most optimum response option(s) in relation to spill characteristics like type of oil, weather, distance from the coast, mobilization time density organisms in spill area etc. Based on several runs with the Net Environmental – Economic Benefit (NEEBA) model developed by TNO, the most important parameters determining the "best" response options have been identified and the window of opportunity for each response option was determined.
The minimization of environmental damage is best served by preventing spillage of oil or the rapid mechanical recovery of spilled oil. When these options are not feasible or cannot be completed before the oil has reached sensitive areas, the use of dispersants can be considered to minimize the effect of surface slicks of oil on birds or to reduce the amount of oil washing ashore.
The effects of the oil on aquatic organisms should be considered prior to the application of this technique, as oil is dispersed into the water column following the successful use of dispersants. This paper provides information to support decision making on the most adequate response method in a particular spill situation.
(Ook kort samenvatten van andere technieken, nu lijkt het alleen over dispersants te gaan).

Introduction

Use of any oil spill response technique is a policy decision, which is the responsibility of the appropriate authority. In general, the minimization of environmental damage is best served by preventing spillage of oil or the mechanical recovery of spilled oil. When these options are not feasible, the use of dispersants can be considered to minimize the effect of surface slicks of oil on birds or to reduce the amount of oil washing ashore. The effects of the oil on aquatic organisms should be considered prior to the application of this technique, as oil is dispersed into the water column following the use of dispersants. This paper provides information to support decision making on the use of a particular response option by providing information on the feasibility, the limitations and the economic and environmental benefit.
Aerial surveillance of oil spills is a common detection technique for larger water systems and is needed to require the necessary information for an appropriate decision making. During aerial surveillance the dimension of total area polluted, the coverage percentage of oil in this area, the physical form of the oil and the percentages of each individual colour/appearance can be assessed. This information is needed to decide which response option will be very or moderately effective or feasible or ineffective or even counter productive.

The most important parameters determining the "best" feasible response options have been determined with the help of the NEEBA model. The feasibility is also based on the outcome of two workshops with experienced oil spill responders.
There are several response options available from mechanical recovery from the water surface, enhancing the natural dispersion of the oil into the water column to doing nothing or even wait till the oil washes ashore and recover it there. This paper describes the criteria determining which response option suits best in the different spill situations or to determine the window of opportunity for each method.

Feasibility oil spill response method

Factors determining the feasibility of a response option can be grouped in:

1. Spill dependent factors such as quantity spilled, physical form of the oil spill;
2. Site dependent factors like water depth, wind, wave height and currents;
3. Equipment depended factors like mobilization times, aerial or water bound, etc.

Spill Dependent Factors

Spill depended factors are related to the dimensions, properties and appearance/physical form of the pollution. The physical form of the polluted is often a function of the behaviour (evaporation and water-in-oil emulsification) and the properties of the initial oil spilled.

It is very important to estimate the quantity of an observed spill, before deciding upon the most adequate response. On the basis of the estimated quantity one can determine if a slick is technically combatable and which method is the "best / proper" response option.
To decide if the slick is also operationally combatable, besides quantity/layer thickness, other factors have to be taken into account such as meteorological conditions, mobilisation times, potential threat and weather forecast.

In

Figure 1 the feasibility of a number of response options is presented in a box whisker diagram as a function of the spill size.

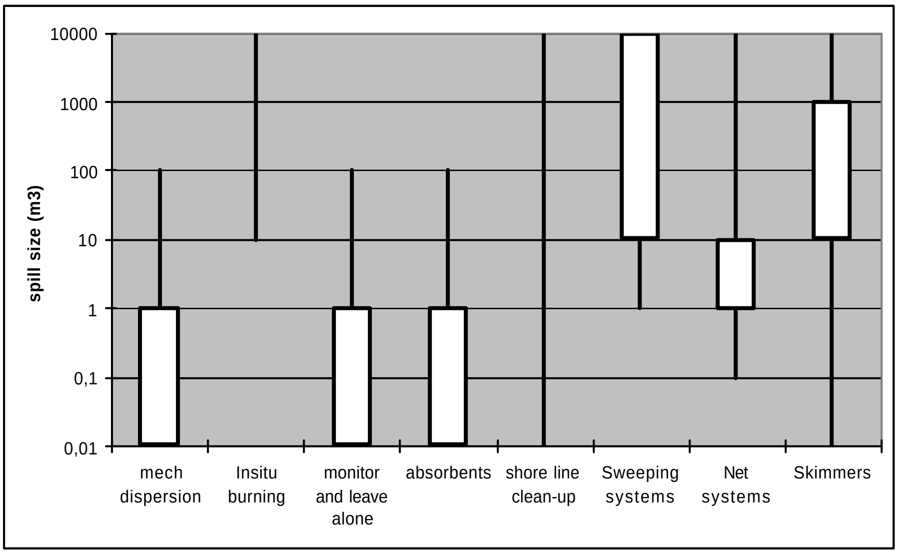

Figure 1 Feasibility of a few response options as a function of the spill size

In this figure the box area represent the spill size for which the response option is very effective and the whiskers represent the moderately effective and "may be feasible", depending on circumstances area.

The layer thickness plays also a very important role, as the evaporation is proportional to the oil-air area of a certain volume of oil. The same amount of oil but spread over twice as large an area will evaporate roughly twice as fast. In Figure 2 the feasibility of a number of response options is presented in a box whisker diagram as a function of the spill layer thickness. In this figure the box area represent the layer thickness for which the response option is very effective and the whiskers represent the moderately effective and "may be feasible", depending on circumstances area.

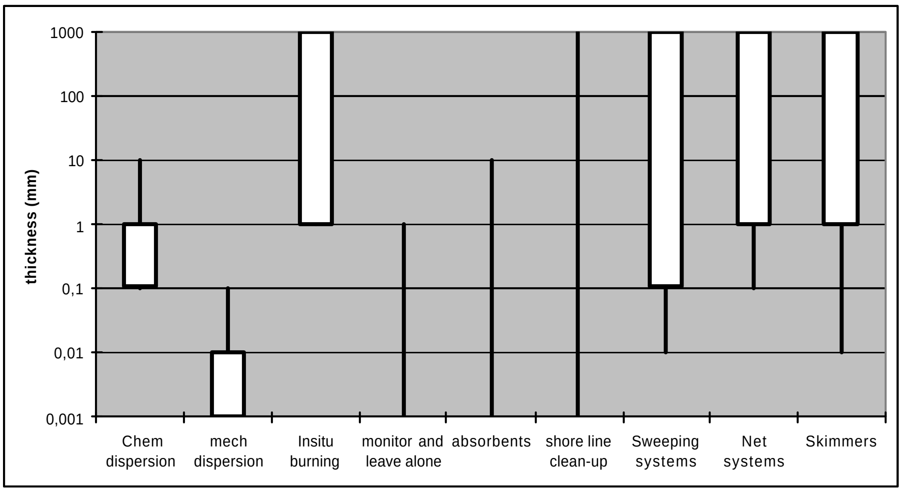

Figure 2 Feasibility of a few response options as a function of the spill layer thickness

Coverage with oil provides a numerical estimate of the percentage of the designated area that consists of an average oil thickness.

The extent of water in oil emulsion …….(typical water contents are between 5 and 85 %). Through emulsification (water content >60 %) the colour of the oil slick will change into red-brown (therefore, an emulsion is often called a chocolate mousse). Ja, dus…wat wil je hiermee zeggen?? Staat nu op zichzelf.

Four oil types are distinguished that determine the behaviour of an oil spill in the marine environment and the best-suited response. These oil types are: (1) Light volatile products; (2) Moderate to heavy oil; (3) Heavy oils to emulsions; (4) Residual oils and solid emulsions. Viscosity of the oil is an important property that determines which type of response can be applied. Spraying dispersants is limited by high viscosity of the oil. The efficiency of mechanical oil recovery equipment is often also reduced as the oil viscosity increases. The threshold of oil with a high viscosity is a viscosity higher than 5.000 cSt. Voor zowel dispersants als mechanical recovery? Dan ook aangeven, anders aparte grenswaarden aangeven.

As a result of the behaviour and the original type of oil spilled, the following physical forms of a spill can be distinguished: (1) Sheen; (2) Fragmented oil semi solid oil (coverage <1%); (3) Patches (lumps>1 m^2); (4) Ribbons; (5) Slicks; (6) Submerged oil. The spill nature and conditions are very important in deciding which response option is most adequate.(see Figure 3). In Figure 3 the feasibility of a response options is represented by the length of the horizontal bar in each column. No horizontal bar means that the response option for that particular physical form is ineffective or even counter productive. A full bar means “very effective” a 2/3 bar “moderately effective” and 1/3 bar “may be feasible, depending on circumstances”

.

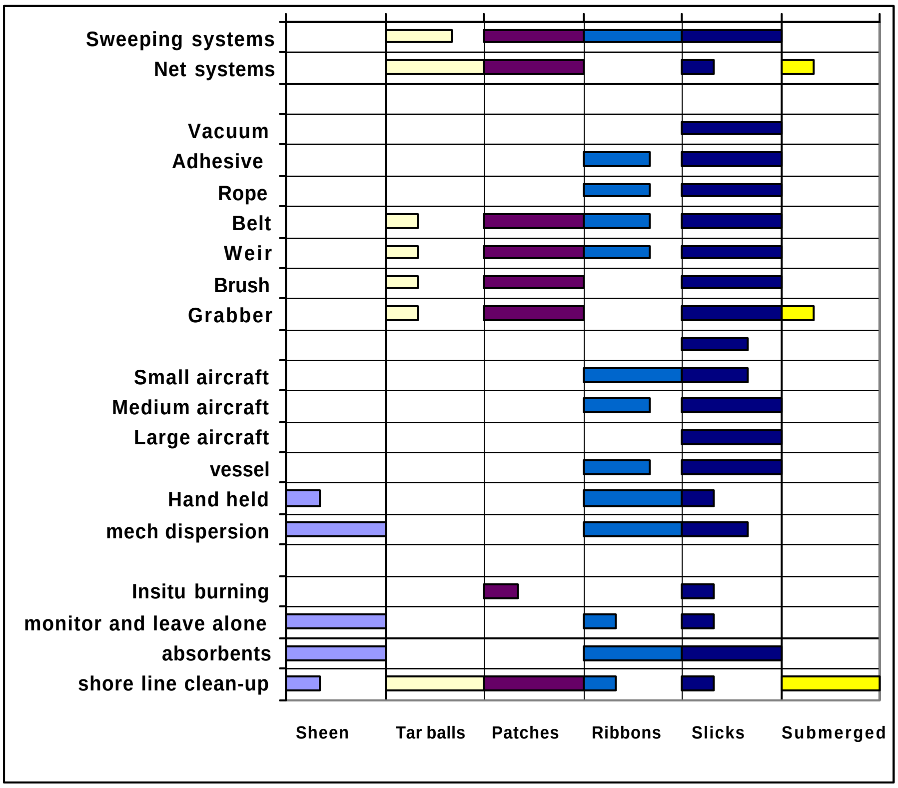

Figure 3 **Feasibility a response options as a function of the physical forms**

From Figure 3 it is clear that most options work well for slicks and ribbons of oil. The problem is the submerged oil, the tar balls and the patches of oil. All these three physical forms have in common that the oil is very viscous to almost solid and difficult to detect from the air.
The type of pollutant, which can be handled by the response option is very important. Viscosity is an important property of the oil in this respect and problems with debris also could play a role.

Site Depended Factors

The location determines the type of response means that can be used. Water depth, wave height and sensitivity of the area are important factors to decide on the most appropriate response.

The critical current velocity for many crude oils and refined products ranges from 0.7 (0.34 m/s) to 1.2 knots (0.58 m/s). Generally 0.7 knots (0.34 m/s) is accepted as a conservative estimate. Entrainment loss determines how fast a boom or a sweeping system can be towed or the maximum current in which it will be effective.
In strong currents, a head wave often builds upstream of the boom. At high current velocities, turbulence occurs at the downstream side of the head wave. Due to turbulence oil droplets can break away from the head wave, become trapped in the flowing water and pass under the boom. Unless the head wave is a considerable distance up stream, oil droplets will not have time to resurface to be contained by the boom. The amount of oil lost in head wave failure depends on the thickness of the oil in the head wave, which is a combination of the water velocity and the specific gravity /density of the oil.
The velocity at which the head wave becomes unstable and droplets of oil begin to strip off, is called critical velocity. At this velocity, droplets are entrained in the water streamline and flow under the boom.
Figure 4 shows the feasibility of a number of response options as a function of the current at the spill site. Option which depends on the natural dispersion or on enhancing the natural dispersion are more effective at high currents and response options which remove the oil from the water surface are more effective at low currents.

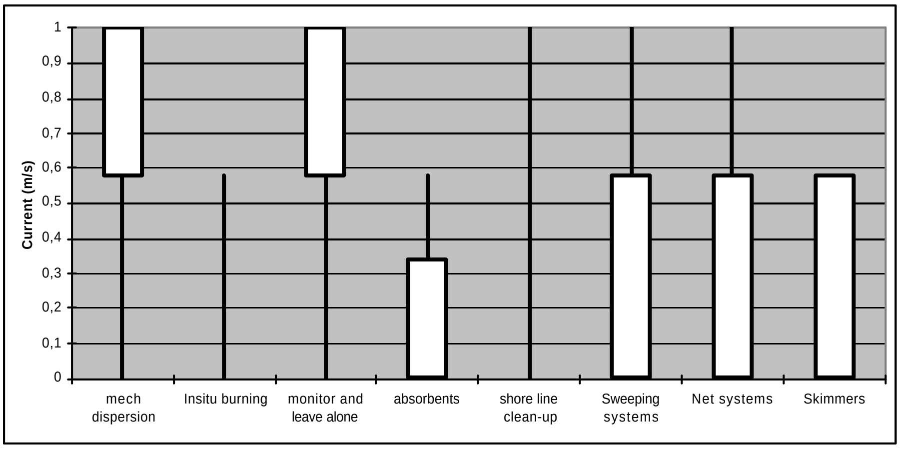

Figure 4 **Feasibility of a few response options as a function of the current**

In case the natural dispersion of oil is enhanced by adding extra energy, or by applying dispersants, it is important that the oil is rapidly diluted in the water, in order to keep the negative toxic effects to a minimum.

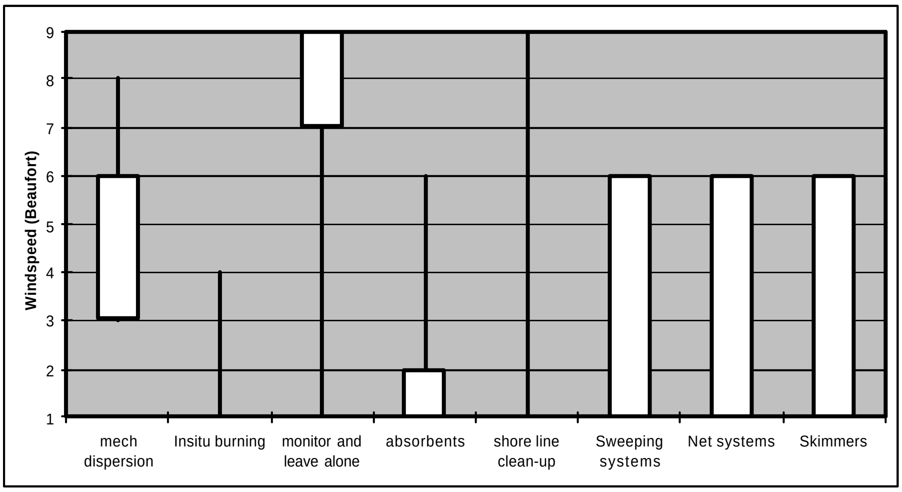

Figure 5 Feasibility of a few response options as a function of the wind speed (Beaufort) (waar wordt naar deze figuur verwezen??)

For booms as well as for sweeping systems, containment failure occurs in choppy seas when oil splashes over the barrier's freeboard. Splash over failure may occur if wave height is greater than the boom freeboard and the wavelength to height ratio is less then 10:1. Gentle swell on the other hand even when the wave height is much larger than the freeboard, will not be a problem for most booms and sweeping systems.

Deployability is the condition in which the response options can safely and usefully be deployed. The factor that determines the deploy ability for sea going response operations is the state of the sea, i.e. the wave height. Response option with an aircraft or helicopter therefore score a high deploy ability with respect to sea state/wave height.
Mechanical recovery methods are limited by maximum wave heights, while enhancing the dispersion is limited by a minimum wave height (mixing energy). Wave height is mainly determined by the wind.

Most important site dependent factor is the turbulence on the water surface. Turbulence increases on one hand the dilution required for all the response options that enhance the natural dispersion and on the other hand limit the recovery of oil from the water surface.
The conditions in which the response option can safely and usefully be deployed. The factor that mainly determines the deployment ability for sea going response operations is the sea state or wave height.

Equipment Dependent Factors

The time for a ship/aircraft to get on scene depends on the mobilization time and the time to reach the location of the spill. Assuming that the speed of a vessel is about 10 miles/hour, it may take hours to get on the scene of operation. Ships equipped with mechanical recovery facilities or equipped with dispersants normally need the same time to get on scene; only the dispersant spraying speed (the encounter rate) is faster. The mechanical addition of extra energy is an option that could be deployed faster as there is less time required, because also ships already in the neighbourhood of the spill, could be used. Aircrafts of course are much faster.

The spill location also plays a role in the mobilization time. From a logistic point of view, response options using an aircraft or helicopter can be much faster on scene and their encounter rate is also higher.
Single engine aircraft are limited in the distances they are allowed to go from the shoreline.

An oil slick on the water surface will not stay in its original position but will move under the influence of external factors. The main causes of these transport processes are wind and currents. The transport of a slick on the water surface is an important factor. One must be able to forecast where the slick can be found at what time.
The major currents move normally parallel to the coastline. As a result, also the slick will normally moveparallel to the coastline. Onshore wind direction determines when an oil slick will reach the coast. The movement of a slick is about 3% of the wind speed, measured at 10 metres height.
In general, also the sea state (combination of wind induced waves, current induced waves, tide, current) determines the response option, but also the oil slick shape and position play an important role.

An important criterion, with regard to safety requirements on board oil recovery vessels, is the flashpoint of the oil. When the flashpoint of the oil is below 61°C, the safety regulations for the recovery vessels are very stringent (similar to tanker regulations).
The flashpoint depends on the composition of the oil. After a spill, the light components quickly evaporate and the flashpoint increases. Model calculations and experiments have shown that the thickness of an oil layer is the prime factor determining the speed of flashpoint increase. As an operational rule of the 'thumb' it was concluded that the time (hours) that will elapse until oil in a slick will pass the value of 60 °C is approximately 2 to 6 times the layer thickness (in mm). (verwijzing rapport vlampunt lijkt me goed). Thus, for an average free-floating slick of 0.2 mm, it will take 0.4 to 1.2 hour of evaporation time before the flashpoint passes 60°C.
Specially equipped recovery vessels, the so-called "first line oil recovery vessels", complying with the most stringent safety regulations remain necessary. Also, when oil is concentrated – by floating booms or natural barriers- the layer thickness may rapidly increase, with a corresponding decrease in evaporation as a result. This is particular important when fresh oil is concentrated close to the point of release.

In relation to the mobilization time one should know how long an oil spill will stay at the water surface. It is known that small oil spillages due to natural dispersion will stay for a short time on the water surface. But even larger oil spills will in bad weather conditions disappear from the water surface due to natural dispersion. In this kind of situations it is important that either response is very fast or one can decide that that the oil can be left alone to the natural processes. Fast response is only possible using aircraft(s) or with ships already on scene.

Another limitation could be the time elapse between spillage and the time the oil washed ashore. Spillages very close to the coast could wash ashore in case of on land wind in a very short time. For instance at wind force 5 Beaufort an oil spill will move about 1 km/hour. Very fast response at sea is required in these situations to prevent that the oil will wash ashore. Or one can decide to wait till the oil washes ashore. Alsoany combination is possible

Oil recovery vessels are limited by their draft. Near the coast and in shallow waters only vessels with little draft can be applied.

Capacity is on one hand determined by an encounter rate (mostly speed (m/s) x width (m)) and on the other hand limited by a storage capacity for the recovered oil, or, in case of treatment with chemicals, the load of chemicals that can be taken out to the site.

Environmental Benefit

Factors influencing the degree of ecological damage of the residual oil on the water surface are: (1) area polluted (surface area and sensitivity) and (2) retention time of the oil slick on the water surface. The larger the area covered by the oil and the longer oil will stay on the water surface, the more chance that vulnerable environmental resources (ik weet ff niet het geode word, maar resources verwijst naar een menselijk gebruik van die waarde) (birds and other marine wildlife) get into contact with the oil. Response to the remaining oil must therefore, aim at either reducing the surface covered by the oil or reducing the retention time of an oil slick on the water surface. The gravity of the effects is also related to the bird density in the area polluted.

The spill size mainly determines the amount of equipment (capacity) that needs to be mobilized. In case of dynamical recovery systems, the encounter rate will be determined by the dimension of the spill (area polluted and the layer thickness). In case of chemically dispersing the oil the spill size (total area) becomes very important for the dilution factor and thus the effects. Increasing spill size results in a decreasing dilution factor. Nee, verdunningsfactor bljift hetzelfde maar de concentratie oliedeeltjes in het water wordt hoger Spill magnitude determines the encounter rate of most response options.

After release, the oil will immediately be exposed to natural weathering processes. In the initial stage of a spill, the most important weathering processes are evaporation and natural dispersion. Due to evaporation, the light components will disappear into the air. Only a very small fraction of the oil will dissolve into the water column. Especially with small operational spillages, the lighter fraction (up to C_{10}) will rapidly evaporate. This fast evaporating fraction also includes the toxic BTEX components. Experiments on plants and organisms have shown that severe toxic effects are associated with these compounds with low boiling points, particular the mono aromatics such as the BTEX. (als je dit zegt moet je ook verwijzen naar de referentie waar dit uitkomt, of zijn het eigen studies?) These components are, however, not combatable as they disappear very fast. No response option can prevent that these toxic components (up to C_{10}) get into the environment (mostly into the air compartment).once spilled.

Water depth is important with respect to dilution in the case of enhancing the natural dispersion of oil into the water column. For that reason some countries restrict the use of dispersants to a certain water depth.

The temperature determines the vapour pressure of each hydrocarbon component in the oil. The vapour pressure increases approximately a factor 1.5 for each 10 degrees temperature increase. Evaporation is proportional to the vapour pressure.

This explains why the light components (short hydrocarbon chain length and high vapour pressure) disappear faster from an oil slick than the longer chain length hydrocarbons with much lower vapour pressures. As an example C_5 (pentane) will evaporate about 12 times faster than C_7 (heptane).

In most spill situations and in particular for smaller spillages the remaining oil on the water surface exists out of components $>C_{15}$ and depending the elapse time after release a smaller or larger part of the $C_{10} – C_{15}$ components. In the water column a very small fraction of the oil will dissolve. Oil toxicity is reduced as oil weathers. The main problem of weathered oil (emulsion), however, is the smothering effect. The oil will stick to organisms and in particular birds
The main aim of responding to an oil spill is to minimize the potential impact of oil on human health and the environment. Little can be done to minimize the effects of volatile components, due to the rapid evaporation and natural dispersion. Particularly in case of smaller operational spillages, the BTEX components will disappear fast from the water surface (minutes to hours). The residual floating oil mainly poses a physical threat to birds, as these live at the water interface. Especially swimming ducks and diving birds are at risk. Oiled birds usually die. The threshold value for floating oil on the water surface, independent of the composition, is 25 ml per m^2. (Scholten et al,….)

Hydrocarbons normally biodegrade to water and CO_2. Some oil components, however, biodegrade very slowly. Oils that stay long in the aqueous environment due to their slow biodegradation, are called persistent. Such oils should be recovered from the environment instead of enhancing the natural dispersion.

Emulsification (water-in-oil) increases the viscosity of the oil and, thereby, reduces the pumping capacity. Also the affectivity of dispersants is limited as more water is emulsified into the oil. Another effect of emulsification is the excess of water when emulsified oil is recovered. There are three kinds of emulsions: unstable, stable and meso-stable emulsions.. The most commonly formed emulsions are the meso-stable emulsion. Emulsification is often a result of large droplets that resurface and entrain water.

The “window of opportunity” of response options overlap each other, therefore a priority ranking needs to be made. What method will have preference in a particular spill scenario, where more than one option is applicable. There are different ways to rank the options in order of priority. Ranking could be based upon economics (cheapest method first), environmental point of view (most oil out of the environment first), or could be based on operational considerations (availability, mobilization time etc.). Also a combination is possible, depending on the time of year, or spill size. Organizations responsible for combating spills may have a different approach on how to deal with a particular spill depending the way the rank the priority..

The reasons for attempting to combat an oil spill while it is still at sea are to protect; individual organisms, resources in the vicinity of the slick, the marine environment in general and to minimise the quantity of oil, which comes ashore or enters estuaries. Everything possible should be done to prevent oil to wash ashore on mud flats and salt marshes as they constitute the most ecological sensitive parts and are difficult, if not impossible, to clean up.

In order to decide whether or not a response is necessary, or what sort and extent of response is appropriate, the threat posed by the oil must be evaluated. This requires techniques for predicting the behaviour of the oil, which in turn will rely on timely and adequate information about the type and quantity spilled, the location of the spill and weather conditions. Advice on sensitive resources likely to be impacted by the spill will also be needed.
Because of the considerable uncertainty which usually surrounds a spill, and the difficulty of predicting the damage, the assessment of the threat will be tentative at first, becoming more firm as information becomes available. The response teams, however, will not be able to await a firm assessment and an element of expert judgement will normally be necessary during at least the first stages of the response.

Oil slicks can be technically and/or operationally combatable. Apart from location and weather conditions, the quantity of oil plays an important role in the decision whether the oil could be combated or not.
A technically combatable slick is an oil slick, which should be recovered, or treated if at that moment a response mean is on scene. A technically combatable slick can be determined on the basis of volume/layer thickness of oil present and depends on the treat of the spill and the availability of appropriate means.

In case of an operationally combatable slick, besides quantity/layer thickness also other factors have to be taken into account, such as meteorological conditions, mobilisation times, potential threat and weather forecast.
At present, it is generally accepted for the recovery of oil at sea, that the quantity of oil must be in excess of 1 m^3 (depending on the type of oil) or the polluted area must be more than 1 km^2 in order to determine the slick as “operationally combatable at sea”.

To determine the quantity of an oil slick, the colour or appearance code (can be used as a guide to estimate oil film thickness. In pollution observation reports the percentage of covered area and a percentage per discriminated colour need to be filled out under “description of the pollution”.

Operational spillages are in the range of litres to several m^3. In the next paragraph the different response options available and the factors that determine the most appropriate response will be discussed. In order to evaluate oil response options the following criteria are often used:
Most countries give preference to the response option that recovers as much oil as possible out of the marine/aquatic environment. That is why the dynamic and the stationary recovery response options have the highest priority (first line defense) in most countries. However mechanical recovery is not always the “best” option, if we take into account the high costs and the limited amount of oil that can be recovered pardon…In de PRESTIGE is wel degelijk heel veel opgehaald door mechanical recovery, zelfs bij slecht weer. Especially in case of bad weather conditions and/or due to the long arrival time to the spill site before recovery can start, a low volume of oil can be recovered.

Net Environmental - Economic Benefit Analysis (NEEBA) recognizes that in some instances an oil spill response action might protect one resource at the potential expense of another. The decision process should take into account the ecological characteristics of communities liable to be affected; the physical characteristics of the potential spill site and human use of environmental resources and details of proposed clean up method.

In reaching an optimum clean up response, the advantages and disadvantages of the proposed clean up strategy Vs those of natural clean up should be considered with reference to ecological value and human use of environmental resources. It must be stated that the optimum response often cannot avoid some disadvantages.

Window of opportunity of a response option

Mechanical Recovery
The mechanical recovery options at sea are mainly designed to be used for larger spills (>100m^3). For smaller spillages (<10 m^3) this method is relatively expensive and can be ineffective, depending on the oil type. En voor volumes tussen 10 en 100 m3?

Mechanical recovery with dynamic systems will generally not remove all the oil from the water surface, due to continuous spreading of the oil slick and turbulence at the water surface. Reduction of the negative environmental and/or economic effects will mainly be achieved if the water surface can be cleaned quickly. Reducing the amount of oil on the water surface will speed up the natural dispersion of the remaining oil. Mechanical recovery methods work best in calm conditions and effectiveness is decreased as sea state increases. In heavy sea conditions, sea state/wind forces in excess of 6 Beaufort, recovery at sea is not effective.

Static Oil Recovery Systems
The success or failure of static oil recovery systems depends in the first instance on the speed at which skimmers and booms are launched and to what degree the spreading of the oil can be controlled. Because there is great variety in skimmers, the type of skimmer that can be used effectively depends on a number of factors, such as:

- Spill quantities
- The type properties of the oil
- The local conditions: water depth, current (the critical velocity is 0.58m/s)
- The weather/sea state condition: up to sea state 3

In view of the fact that so many factors play a role in the oil removal process, different type of and sizes of skimmers need to be stand-by for different situations, each with its own specific application.
Most skimmers are best suited for calm water, since their effectiveness is sharply reduced by wave action.

There are some differences between the different skimmer principles. Disk/drum skimmers and all adhesive skimmers have the advantage that they are very useful on light and moderate oils and can also be used for very small spills as they recover pure oil without water.
The endless rope, which is also an adhesive skimmer, and in particular the vertical version of the endless rope, has the advantage that it can be used in higher wave conditions as well.
The main advantage of the conveyor belt/drum, or any other bucket system, is that it can handle solid materials and debris which makes it very useful in harbour areas.
Weir systems have high recovery capacities and as they often recover an excess of water, they can handle heavy and residual oils using the water as a carrying phase.
Brush skimmers can be used on heavy, high viscous and solid oils.

It is emphasized that the ability to recover oil efficiently by using stationary skimmers, declines dramatically from wind force 4 Beaufort onwards. Large skimmers may still be useful, although their stability in waves is affected. (fotootjes van skimmers om op te leuken, het is erg veel tekst zo).
.

Use Of Dispersant

The use of dispersants can be a fast response method when aircrafts are used for spraying. Small, medium and large aircrafts are best used in the range 1-100 m3, >1 m3 and >100 m3 respectively (and distances …).
Handheld spraying equipment is best suited for small spillages. Vessels are generally moderate effective, due to their mobilization time. The mobilization time of vessels is often much longer than the mobilization time of aircrafts in the case of spills at sea.

The chemical dispersion option should primarily be used for spills up to 100 m^3 as this method can be applied very fast (aircraft) and will reduce the effects on birds if applied fast. Without the use of dispersants these oil spills will stay on the water surface for a longer time (hours to days). Chemical dispersion of spill up to 100 m^3 will enhance the dispersion process without resulting in a too high concentration of oil/dispersant in the water column (uitgaande van verdunningsfactor, waterdiepte, stroomsnelheid). Larger amounts of oil will result in too high concentrations of oil in the water column. In medium to rough weather conditions the dilution will be enhanced and high oil concentrations will be reduced very rapidly. The limitation of enhancing the dispersion is limited to a certain viscosity range (up to 3000-5000 cSt) High viscous oil spills in this quantity range therefore should be recovered mechanically or if not applicable due to weather circumstances let be washed ashore to recover the remaining oil there.

Oil slicks are often not homogeneously spread over the polluted area. The capacity (encounter rates of spraying dispersants) depends heavily on the layer thickness and coverage. Clean places (no oil coverage) should be avoided in spraying operations.
Dispersant removes the oil from the water surface into the water column and, thereby reducing the impact on birds and coastline. Dispersants also have the ability to treat a lot of oil with a relatively small amount Chemical dispersion is limited by; minimum turbulence of the water and water mixing, the location, weathering process, and the type of oil

Mechanical Dispersion

Mechanical dispersion is not a main stream clean up technique and can easily cause more problems if misapplied. This technique should be used only with great caution. The mechanical dispersion option should primarily be used for spills between 0,1 and 10 m^3 of thin layer oil slicks and low to medium viscous oils. Mechanical dispersion is a relatively cheap and effective way to enhance the dispersion process. Reducing the retention time of the oil slick on the water surface by enhanced dispersion results in less negative effects to birds. This response option is also applicable to treat the remaining floating oil, when the major part of the oil is removed mechanical,. The limitation of enhancing the dispersion is limited to a certain viscosity range (up to 2000 cSt).

In Situ Burning

In Situ Burning is not a very environmental sustainable solution. It may be useful in special circumstances but has a limited window of opportunity. Because of the weathering and emulsification that occurs rapidly at sea, burning must be conducted as early as possible (preferably within the first 12 to 24 hours of exposure). Very calm seas may extend "window" to 48 hours or more. For spills in cold climates, particularly when trapped on, in or under ice/snow, burning may be conducted months or even years later.
Burning of oil should not be considered as a response option for the smaller operational spills as igniting is limited to a minimum layer thickness of a few mm. Spills up to 100 m3 are in a short notice already too thin to ignite. Minmum layer thickness is approx. 2? Mm. Spills in excess of 100 m^3 should be recovered by mechanical means. Oil which is still in a leaking tanker and poses a potential threat to the environment or human safety could be considered to set on fire on a safe place .

The Monitoring And Leave To Natural Processes Option
The monitoring and leave to natural processes option can be applied as first line of defence in case of small spillages of light, volatile oils up to $1m^3$ with a low layer thickness as these spillages normally will disappear in such a short notice from the water surface that effective response with one of the response methods is not likely to be efficient.
This option preferably should be applied in open sea with a sea state higher than 3 and medium to strong currents in order to have appropriate dilution.
High viscous oils will disappear very slowly by the natural processes. The remaining of such oils mostly will wash ashore sooner or later.

Sorbents
Sorbents are normally used to recover smaller amounts of liquid oil. Sorbents are often used as a barrier to concentrate the oil and at the same time to recover the oil by sorption. Some sorbents are designed for light oil to moderate oil. Each product has its own specification and window of opportunity which types of oil it can absorb. On open sea application of sorbents is generally not useful because of operational factors like wind speed en current. For spills in harbours and/or inland waters this method can be useful.

Coastal Cleanup
The efficiency of the recovery operation on shore depends heavily on the type of coastline, the oil concentration, the accessibility of the area and the properties of the oil. For each type of oil another clean-up techniques should be used. Shoreline cleanup is in particular a response option to be considered in the case of very viscous/solid oils or floating/ submerged heavy fuel oil, which cannot be treated efficiently with chemicals and also when the chance of mechanical recovery is limited.

Two concepts are relevant for shoreline cleanup.
Damaged ships that still have heavy (fuel) oils on board should, in some cases, be brought as close to shore as possible. This will result in a shorter length of coastline polluted in case of a leakage. To optimise this response option, one should try to let the oil wash ashore under relatively controlled conditions and select a landing site (beach) that can most easily be cleaned. The option of bringing (towing) a ship in distress to the coastline with the objective to keep the possible treated area limited appears to be difficult as is shown in the PRESTIGE accident. Rate of success is depending on political decisions and the capability of available vessels to tow the ship in the direction of the selected coastal area.

The second option is to recover oil from the shoreline under certain circumstances. It depends on the coastline type – for example, heavy oil in a mangrove swamp or certain wetlands can be a major problem to cleanup and can result in major environmental damage. Mechanical recovery is less effective for heavy oils in particular when such oil slicks are scattered over a large area or are submerged.

Factors that need to be considered in the decision-making process are economic, environmental and political. The decision-making process for both options is highly complex and may be subject to more detailed risk assessment, investigation and implementation in Net Environmental – Economical Benefit Analysis tools. Sensitivity ranking of the coastline is in this respect a very important preparative aspect.

The recovery of oil from the shoreline is a relevant option for very heavy oils (persistent oils). Mechanical recovery is less effective for heavy oils in particular when such oil are scattered over a large area or are submerged. Ships with a danger of a potential loss of such oils should be brought as close as possible to the shoreline in order to keep the length of the coastline polluted as short as possible. Sensitivity ranking of the coastline is in this respect a very important preparative aspect. Shoreline cleanup should be considered as the primary defence response option for this kind of oils

Discussion & Conclusions

Decision makers which have to make a choice which response option to apply need to know on one hand how long it takes to get on scene with a vessel or aircraft to respond and on the other hand how long it takes before the oil completely has been disappeared by the weathering processes and in particular the natural dispersion.

Once a vessel/aircraft reaches the slick in time, e.g. still enough oil on the water surface to respond to, a choice can be made between booming/sweeping the oil in order to recover it or enhance the dispersion process either with dispersants or with adding mechanical energy. Ship availability can influence the choice as the faster a ship is on scene the more efficient it will be in reducing the effects. It will shorten the retention time as well as reducing the spreading of the oil. Similar if an aircraft can be faster on scene than a ship this could be a reason to choose for using an aircraft to disperse the oil.
The choice which response option to apply is more related to the availability and time required to get on scene than the method itself. For the larger accidental spills the time to arrive on scene is less important for the choice which response method as the response could last several days.

The time for a ship/aircraft to get on scene depends on the time to be ready to go and the sailing/flying time to the location of the spill. Assuming that the speed of a vessel is about 10 miles/hour, it takes hours to get on the scene of operation. Ships equipped with the mechanical recovery method or equipped with the dispersant method normally need the same time to get on scene only the dispersant spraying speed (the encounter rate) is faster. The mechanical adding extra energy is an option that could be deployed faster as there is less time required as also ships already in the neighbourhood of the spill could be used. Aircrafts of course are much faster but single engine aircraft are limited in the distances they are allowed to go from the shoreline. Larger double engine aircraft will due to their much higher costs mostly not being used for small operational spills.

TNO uses a Net Environmental - Economic Benefit analysis model by which it is possible to determine the most appropriate response option for a given spill scenario. With such a model the reduction of the effects due to different response options can be determined more precisely.

It is very important to estimate the quantity of an observed spill to decide upon the most adequate response. On the basis of the estimated quantity one can determine if a slick is **technically combatable** or not and which method is the "best" response option. For accidental or operational spillages there is a role for all the available response options as discussed in this paper.. Based upon 1970 observed slicks over a period of 7 years it roughly can be estimated how often a certain method was the "best" technically response option: e.g. the mechanical recovery method was 7 times (0.4%) the best option, the chemical dispersion method 109 times (5.5%), the mechanical dispersion method 461 times (23.4 %) and the doing nothing option 1393 times (70.7%).

To decide if the slick is also **operationally combatable,** besides quantity/layer thickness also other factors have to be taken into account such as meteorological conditions, mobilization times, potential treat and weather forecast. The window of opportunity of the different options also needs to be taken into account.
The use of dispersants is one of the options to reduce the effects of floating oil. Alternative response methods should always be considered. The use of dispersants enhances natural dispersion and by that also the biodegradation rate. The oil is not removed by dispersants, but it is brought in a changed form (droplets) in a different compartment of the environment, viz. the water column. Since the oil-water surface is increased by the formation of tiny droplets, dissolution and biodegradation rate is enhanced. Response methods that remove the oil out of the marine environment should have priority, since no increased effects in the water column will occur. The use of the dispersion method should be selected only if environmental profits are likely to occur.

The use of dispersants from an aircraft is a fast response method compared to the other response methods that need a vessel to apply. If time is important this could be enhance the possibility of the use of the dispersant method.

Dispersants should not be used for very thin layers ("sheen" and "rainbow") of oil, since dispersants droplets will fall through and will not be effective. The net environmental benefit of using dispersants in such cases may even be negative.

It should be stressed that the assumptions outlined so far do also depend on the efficiency of the dispersants to be applied. Less effective dispersants will reduce the amount of oil entering the water column, but will also not be able to effectively reduce the risk of oil at the water surface. The effectiveness and efficiency of the use of dispersants needs always to be evaluated on scene, in order to allow for changes in the response strategy. In the decision making support system that is presented here, it is assumed that the oil will disperse completely after treatment.

The lack of accurate and reliable data with respect to hydrological parameters and the great variety of circumstances makes it difficult to derive simple estimates of dilution factors in the surface waters. On the other hand, the dilution factor is not the most important factor for predicting the environmental concentration. The spill dimension (surface area polluted before application of the dispersants) plays even a more important role.

References

Koops W. and Huisman, J., (2001): Problems in estimating the quantity of operational oil discharges from ships,Congress pp 234- 242 Proceedings The marine environment how to preserve, The institute of Marine Engineers Rotterdam 26 – 28 September 2001.

Tamis. J.E., Koops. W.and Jongbloed. R.H.,(2003): Chemicals in combating oil spills: the use of dispersants, TNO report TNO-MEP – R2003/221, Den Helder, The Netherlands