The use of dispersants to combat oil spills in Germany at sea

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Editors:
Matthias Grote, Almut Nagel, Hartmut Nies, Jens Rauterberg,
Dierk-Steffen Wahrendorf

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Content

1 Einleitung / Introductory Remarks

Matthias Grote

Federal Institute for Risk Assessment (BfR), Berlin, Germany

Einleitung

Ölunfälle auf See können verheerende Auswirkungen auf die Meeresumwelt, Küstengebiete und die menschliche Gesundheit hervorrufen. Im Falle eines solchen Unfalls müssen Unfallbekämpfer die effektivste Bekämpfung auswählen um den Schaden für Mensch und Umwelt zu minimieren. Neben mechanischen Methoden, wie Ölsperren und die Aufnahme des Öls, können auch chemische Verfahren eingesetzt werden. Dabei versucht man durch Einsatz von Dispergatoren, Ölfilme an der Wasseroberfläche aufzubrechen und die Bildung von Dispersionen (feinen Tröpfchen) zu fördern. Dadurch sollen Verölungen von Seevögeln und Küstenabschnitten reduziert werden. Außerdem können durch die Vergrößerung der Oberfläche natürliche Abbauprozesse beschleunigt werden. Allerdings wird durch die Dispersion auch die Bioverfügbarkeit der Ölbestandteile erhöht und somit werden toxische Effekte auf wasser- und sedimentbewohnende Organismen verstärkt. Der Einsatz von Dispergatoren zur Bekämpfung von Mineralöl nach Schiffshavarien wird deshalb im Hinblick auf eine Abwägung von Gesundheits- und Umweltgefahren kontrovers diskutiert. Eine wissenschaftliche Risikobewertung für deutsche Meeresgewässer wurde bisher jedoch nicht unter deutschen Experten ausgearbeitet. Damit steht denjenigen, die den Einsatz im deutschen Zuständigkeitsbereich auf See planen müssen, keine klare wissenschaftliche Position zu den Risiken und Chancen eines Einsatzes von Dispergatoren zur Verfügung.

Vom 12.-13. November 2015 wurde deshalb in Berlin ein internationaler Workshop mit dem Titel „The use of dispersants to combat oil spills in Germany at sea” veranstaltet. Experten von Behörden, wissenschaftlichen Einrichtungen und internationalen Organisationen erörterten aus diesem Anlass den Stand des Wissens und Fragen zur Abwägung zwischen Nutzen und Risiken eines Dispergatoreneinsatzes. Der Workshop wurde vom Bundesinstitut für Risikobewertung (BfR) in Zusammenarbeit mit der Bundesanstalt für Seeschifffahrt und Hydrographie (BSH), der Bundesanstalt für Gewässerforschung (BfG), dem Havariekommando (HK) und der Unabhängigen Umweltexpertengruppe „Folgen von Schadstoffunfällen“ (UEG) organisiert.

Der vorliegende *BfR-Wissenschaft* Bericht hat zum Ziel, den Stand des Wissens über potentielle Effekte und die Abwägung von Chancen und Risiken eines potentiellen Dispergatoreneinsatzes insbesondere in Deutschland zu darzustellen. Er enthält schriftliche Ausarbeitungen der auf dem Workshop vorgestellten Beiträge, die die wichtigsten Ergebnisse und Schlussfolgerungen dokumentieren.

Introductory Remarks

Mineral oil spills at sea have significant effects on coastal areas, marine life and human health. In case of an oil spill at sea, spill managers have to decide on the most effective spill response to minimize the damage to the environment and human health. Besides the mechanical containment and recovery, dispersants could be used for supporting the breakup of oil slicks into small droplets, which offer the chance for biodegradation of oil in the sea. In this way, oiling of coastal areas and coating of species like birds could be reduced. However, as the bioavailability of oil components is enhanced, acute toxic effects on water and sediment living organisms are increased. Currently, there are conflicting scientific views concerning the potential risks for human health and the environment generated by the use of dispersants during maritime oil spills. Until today, no comprehensive assessment of risks and chances of the use of chemical dispersants has been developed for marine German waters, which could provide guidance for the national spill manager, the German Central Command for Maritime Emergencies.

On November 12th and 13th 2015 the workshop „The use of dispersants to combat oil spills in Germany at sea" was held in Berlin. Experts from authorities, research institutions and international organizations summarized and discussed the current scientific knowledge on risks and benefits. It was organized by the Federal Institute for Risk Assessment (BfR) in cooperation with the Central Command for Maritime Emergencies (HK), the Federal Institute of Hydrology (BfG), the Federal Maritime and Hydrographic Agency (BSH), and the Independent Group of Environmental Experts "Consequences of Pollution Accidents" at the Central Command for Maritime Emergencies (UEG).

This report is intended to document the status of knowledge on the potential effects and the trade-off of risks and benefits of dispersant use as oil spill response with a special focus on the situation in Germany. It provides outlines of presentations held at the two day event highlighting the main results and conclusions.

2 Status of discussion by environmental experts in Germany

Almut Nagel

Chair of the Independent Group of Environmental Experts "Consequences of Pollution Accidents" at the Central Command for Maritime Emergencies (UEG), Germany

The use of dispersants is a response option to combat oils spills at sea that has gained increasing attention in the last years. Among other reasons, this is due to their extensive use during the Deep Water Horizon accident in the Gulf of Mexico and respectively new insights (see articles of Dierk-Steffen Wahrendorf and Carolin Gräbsch further on).

As for Germany, the Federal Government and the Coastal States and their joint institution, the Central Command for Maritime Emergencies rely on mechanical containment and recovery in case of oil spills. Meanwhile neighboring states have included dispersants in their national spill response strategies (as first or secondary response options) or are considering their future use. Furthermore, the European Maritime Safety Agency (EMSA) has contracted oil spill response vessels with dispersant application systems and dispersant stockpiles, which could be used to top-up national response options in case of emergency (see article of Walter Nordhausen).

In this framework of ongoing scientific discussions and activities of other EU member states and the EMSA, Germany is in a situation to consider the use of modern dispersants as a potential complementary option to mechanical response in its spill response strategy. For this purpose the Central Command for Maritime Emergencies is currently reassessing advantages and disadvantages of the use of dispersants in national waters aiming to identify opportunities and limitations. The working group instated by the Central Command is focusing on operational aspects including the preparation of a decision support system (analytical tool/decision tree) to carry out an in-situ Net Environmental Benefit Analysis (NEBA) in case of an oil spill (see article of Jens Rauterberg).

The Independent Group of Environmental Experts "Consequences of Pollution Accidents" (UEG) is tasked to advise the Central Command for Maritime Emergencies in terms of environmental and health issues related to marine pollution emergencies. In the context of the revision of the national spill response strategy, the expert group was asked by the responsible committee of the German coastal states to provide scientific opinion and recommendations on the use of dispersants in German coastal and marine waters. This expertise will complement the outcomes of the Central Command working group on operational issues and give advice in regard to the NEBA analytic tool.

In the aftermath of the oil spill induced by the PALLAS casualty on the North Frisian coast in 1998, a group of experts of governmental and scientific institutions engaged in assessing advantages and limits of dispersant use in Germany with first documents published in 2000 and 2001 (Bernem et al., 2000). As in 2004 the UEG was founded, these experts became members and have followed ongoing political and scientific discussions on dispersants use. This knowledge builds the basis for the current reappraisal. A first collection of the state of knowledge was compiled in summer 2015 by the UEG. It aimed at providing an overview on dispersant use and to identify actual open scientific questions and research gaps concerning their use in marine and coastal waters in Germany. In order to gather further available knowledge and prepare common ground for continued discussions, the workshop "The use of dispersants to combat oil spills in Germany at sea" was held in Berlin in November 2015. It was initiated by the UEG, organized and hosted by BfR, supported by BSH, BfG, the UEG's experts and the Central Command.
The aim of the workshop was to:

- Join scientific expertise from German experts on local conditions (ecosystems, hydrodynamics, etc.) with international spill response experts and their practical knowledge.
- Discuss and structure the current scientific knowledge on risks and benefits of dispersant use in Germany at sea (e.g. on dispersants products, their availability, application, effectivity, toxicity, biodegradation effects, environmental effects, approval procedures etc.)
- Clarify common grounds, point out conflicting or diverse views and identify open questions and relevant research needs.

References

Bernem, K.-H.v., Lübbe, T.-P., Brenk, V., Bustorff, U., Reichenbach, D., Schroh, K., Wunderlich, M., 2000. Dispergatoren als Option bei der Ölunfallbekämpfung. Hydrologie und Wasserbewirtschaftung 44, 290-301.

3 Current position of German spill managers regarding dispersant use

Jens Rauterberg

Central Command for Maritime Emergencies (HK), Cuxhaven, Germany

The Central Command for Maritime Emergencies (CCME) is a joint institution of the German Federal Government and the Federal Coastal States. It was established to set up and carry out a mutual maritime emergency management in the North Sea and in the Baltic Sea. It is based in Cuxhaven (Northwest Germany). In cases of severe oil spills the CCME takes over the command for all spill response operations at sea and at the shoreline. In such cases, the CCME would have to take the decision to use dispersants or not, supported by the local competent authority.

Historical Development

The discussion about the use of dispersants reaches back to the oil spill of the Torey Canyon in 1967 near Lands End, UK. The use of very toxic industrial detergents aiming to promote the dispersion of the spilled oil led to huge damage to the marine environment. Therefore the use of first generation dispersants was not considered in the spill response strategy in Germany.

In the late eighties some research around the dispersants of the second generation was done. The results were not very promising because of the limited effectivity and the high toxicity of the dispersant itself. The use of dispersants was therefore not recommended here in Germany by the Federal Ministry of Transport. The main priority was given to the mechanical recovery of the oil from the water surface with specialized ships and technical equipment.

At the end of the nineties the earlier findings were confirmed by the Federal Ministry of Transport. The use of dispersants was not part of the contingency measures for oil spill response, even though the dispersants of the 3rd generation were less toxic and more efficient. Only one exception was foreseen for very large oil spills, but no dispersants and dispersants spray equipment was purchased. In this case, Germany would have asked for support from the neighbouring countries. For the Baltic Sea, Germany followed the HELCOM recommendation not to use dispersants in this area.

Current spill fighting concept

Germany reconsidered the use of dispersants in 2007, with newer dispersants of the 3rd generation available and the experiences from neighbouring countries. These dispersants have a higher effectivity and less toxicity. In the new concept Germanys territorial waters were divided in three zones depending on the water depth (Figure 3.1).

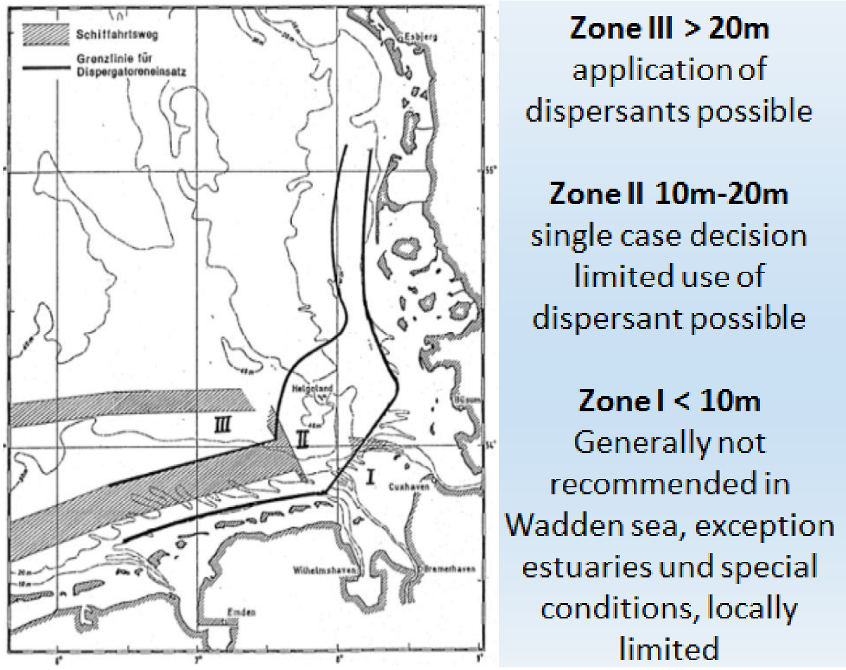

Figure 3.1: Zoning of the North Sea depending on water depth for dispersant use (Umweltbundesamt, Report 10204 216/05).

In zone III with a water depth of more than 20 m the use of dispersants is generally possible. Due to research results the water body in these areas is big enough to enable a proper dilution of the oil/dispersant mixture which keeps harmful effects to the marine environment on a low level.

In zone II, the water depth ranges between 10 m and 20 m and the use of dispersants is considered as an option on the basis of a single case decision with limited amounts.

In zone I with water depth below 10 m the use of dispersants is not recommended with exception of the estuaries of the big German rivers Elbe and Weser, locally limited.

The concept of 2007 does not contain any hard criteria how to decide if the use of dispersant is better for the marine environment than letting the oil drift ashore. The benefit of the use of dispersants for the ecosystem has to be indicated by a net environmental benefit analysis (NEBA). However, a NEBA for the coastal waters of Germany as preparation for the decision making process prior to an oil spill has not yet been conducted and would have to be performed during the spill. The use of dispersants in the Baltic Sea was still no option.

Even with the current concept the mechanical recovery of oil remains the priority response strategy in Germany. The main aim is still to remove as much oil as possible from the water surface in order to minimize damage to the ecosystem. Therefore, equipment acquisition and training has mainly been focussed on mechanical recovery. Until now, no dispersant stockpiles have been built and no dispersant specific equipment has been purchased by Germany.

Intended revisions of the spill response concept

In 2016, Germany plans to revise the dispersants concept from 2007. Some key points of the new concept are to find situations and areas along the coastline which would benefit from the use of dispersants in case of an oil spill.

In a first step the Sea Track Web drift model from the Federal Agency for Hydrology was extended. It is now possible to calculate the oil/dispersant drift in the water column and compare it with the oil drift on the water surface. With the results of this comparison it is possible to evaluate the effectivity of the use of dispersants in regard to the impact on different parts of the marine ecosystem (e.g. oil ashore or in the water column).

With assistance of the Federal Institute for Hydrology we executed several drift calculations. Our test calculations are still under evaluation but some findings can already be summarized. As this model calculates with an effectiveness of 100 % dispersed oil the findings do not show the reality. Even when using a dispersant there will be some oil left on the water surface but hopefully the main part dispersed in the water column.

Offshore wind

In case of offshore wind the use of dispersants is not necessary because the oil will not reach the shoreline. Having enough time mechanical recovery should be performed. With the drift model the development of the situation can be monitored and in case of a change of the wind direction the situation can be re-evaluated.

Onshore wind

Depending on the distance to the shoreline of the Wadden Sea and the time available to apply the dispersant it may be possible to prevent the oil to reach the shoreline. This could also be an option for the estuaries of the big rivers Elbe and Weser.

In those cases the first thing to do is to compare the results of the drift modelling of oil with and without dispersant. Given enough time to mobilize and apply the dispersant it is possible to prevent a significant amount of the oil coming ashore. To support that decision a NEBA is needed which supports the decision to disperse the oil at sea.

In a second step the CCME is going to tender a net environmental benefit analysis in the beginning of 2016 to find areas and situations which would benefit from the use of dispersants. As the use of dispersants is a time critical process, it is important to define the frame of action prior to the spill. The operational decision makers need solid information to weigh the pros and cons of the use of dispersants. This information should be available already before the spill happens. In general, there is no time for a profound NEBA during a spill.

To support the decision making process all the data collected in advance should be integrated in a decision tree. The spill managers can work through this tree to get to the right decision very quick while having a proper documentation. This is one of the most demanding projects for the next year. The process to decide whether the use of dispersants is or is not beneficial for the ecosystem is a difficult task. The spill managers will be under constant pressure during a spill and have to justify the actions they are taking. Even among biologists there are often different opinions whether it is better to use dispersants to save the birds or to protect the benthic and pelagic organisms.

The decision making tree should enable the spill manager to take right decision very quick and well supported. Part of this tree are the following questions:

- Mechanical recovery not possible or sufficient?
- Use of dispersants is predicted to be effective?
- Weather conditions are in favour for dispersant use?

- Drift model shows that sensitive areas based on the NEBA would benefit from the use of dispersants?
- Spraying equipment, personnel and dispersant is available?
- Use of dispersants can be carried out?

Based on the coarse decision tree CCME develops a detailed questionnaire which leads the spill manager through the decision process. This questionnaire contains all the ecological and tactical facts which were already evaluated prior to a spill and enables quick decisions and gives a good documentation of the decision process.

4 What are dispersants?

Stéphane Le Floch

Centre of Documentation, Research and Experimentation on Accidental Water Pollution (Cedre), Brest, France

Introduction

When a spill occurs, whether it be an oil tanker releasing its cargo at sea or a subsea wellhead blowout, the oil released into the environment will constitute a major source of pollution. Although the intensity of this contamination will be directly proportional to the quantity spilt, this contamination can be considered as a major event which will systematically have disastrous consequences for the environment. As soon as oil has been released into the environment, the response authority is in charge of mitigating the environmental impact, i.e. minimising both the effects of the oil on marine flora and fauna and choosing the response techniques which will be least harmful for the marine ecosystem.

The authorities must deal with the following situation: oil is accidentally released in the environment, a significant environmental impact is likely, and the response strategy to be deployed must be considered quickly. In addition, this strategy must be defined taking into account the intrinsic impact of the selected response techniques, for instance the impact of heavy equipment on the shoreline during operations to recover stranded slicks.

The spill response can be divided into two strategies which, according to the situation, may be complementary. These strategies consist in:

1. **Removing the oil from the environment**, whether at sea through containment and pumping operations or on land through manual or mechanical collection, bearing in mind that in both cases the oil collected will need to be treated as waste.
2. **Treating oil slicks directly in the environment**, whether at sea through chemical dispersion or in situ burning operations or on land through bioremediation operations on stranded oil or oil trapped in the sediment matrix.

While response authorities tend to choose option 1 as the main priority, i.e. recovering the spilt oil, it may be advisable, in certain clearly identified cases, to choose option 2, i.e. treat the oil slick directly in the environment. This article aims to present the chemical dispersion technique for oil slicks at sea (option 2) by defining dispersants, describing how they work, outlining the environmental constraints affecting their efficiency and providing an introduction to the tests applicable in France for their approval.

General concerns relating to dispersant use

The use of dispersant is a highly controversial matter. At issue is whether the risk of ecological effects on marine species from toxic oil components increases or decreases when oil slicks are dispersed before they reach the shoreline (Fucik, 1994). The main objective of dispersant use is indeed the transfer of oil from the water surface into the water column. As a result, exposure for surface dwelling and intertidal species is potentially decreased, while it is increased for pelagic and benthic organisms. Thus, inherent to the use of dispersants is the implicit trade-off among different habitats and species with different ecological, social, and economical values. This controversy was further amplified following the Deepwater Horizon accident (Claireaux G, 2013).

Consequently, it is important to remember that the primary aim of this response technique is to minimise the overall environmental impact of an oil slick drifting at sea by transforming it into a multitude of oil droplets in suspension in the water column. From an operational point of view, chemical dispersion:

1. transforms the hazards inherent to the oil slick by eliminating the risk of responders being exposed to a toxic or even explosive cloud, and by reducing the exposure of birds and marine mammals;
2. reduces the amount of oil which will wash up on the shoreline and therefore downscales shoreline clean-up operations, reduces the production of waste which requires specialised treatment and decreases the amount of oil buried in the sediment matrix;
3. promotes the assimilation of the oil by the environment, in particular by increasing its dilution and final degradation by micro-organisms naturally present in the environment.

Characteristics of dispersant

Dispersants are liquids that are sprayed onto an oil slick at the sea surface in order to facilitate the natural dispersion of the oil in the water column. In fact, the natural dispersion of oil droplets in the sea water column can be observed if enough energy is present at the sea surface (e.g. waves) and dispersants will increase this phenomenon. In addition, suspended oil droplets have a smaller diameter which will cause an increase in the contact surface between oil and water.

Chemical composition

By definition, dispersants are blends of surfactants in solvents. By reducing the interfacial tension between oil and water, surfactants enable these two phases to mix with each other more easily. Surfactants are usually organic compounds that are amphiphilic, meaning they contain both hydrophobic groups (attract oil) and hydrophilic groups (attract water). Therefore, a surfactant contains both a water-insoluble (or oil-soluble) component and a water-soluble component (Figure 4.1). Even though there are thousands of individual surfactants, only a few (usually non-ionic surfactants) are used in dispersant products.

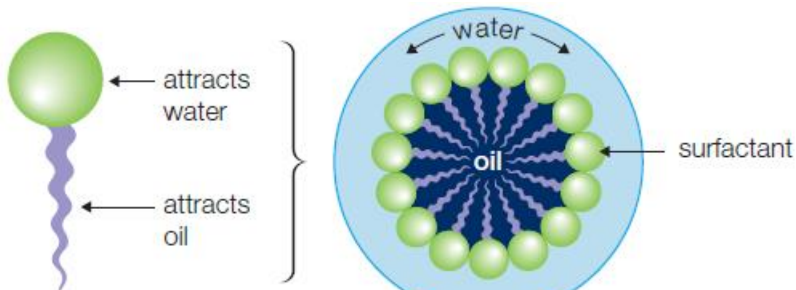

Figure 4.1: Structure of a surfactant and Interaction of surfactant with oil in water (IPIECA-IOGP, 2015).

Solvents are used to dissolve the surfactants, which allows the dispersant to be sprayed onto the spilled oil and also facilitates the surfactant's penetration into the oil slick.

Dispersant interaction with oil

The purpose of dispersants is to increase the natural dispersion of the oil by promoting the transfer of spilled oil from the surface of the sea into the water column. In addition, oil droplets will have a smaller diameter by adding dispersant than without dispersant, which means a larger contact surface available for micro-organisms.

Natural dispersion of the oil

Natural dispersion is the phenomenon by which spilled oil forms oil droplets, with a wide range of sizes, suspended in the water column through the action of waves. The intensity of this phenomenon is directly linked to the level of mixing energy provided by waves and wind.

It is widely agreed that larger oil droplets will resurface and coalesce to regenerate an oil slick, and will do so more quickly than smaller droplets. Only very small oil droplets can become permanently entrained in the water column and can drift according to the subsurface currents. Nevertheless, natural dispersion of oil in the sea water column is not a predominant process and it will not be the main behaviour of the oil slick in the environment (Le Floch et al., 2002).

In addition, the rate of natural dispersion is greatly reduced by changes in the characteristics of the oil caused by weathering processes (evaporation, dissolution, emulsification and photo-oxidation). These processes will reduce the natural dispersion rate by increasing the viscosity of the oil.

Chemical dispersion of the oil

By adding dispersants, the natural dispersion of the oil in the water column is increased. In fact, the surfactant contained in the dispersant formulae will allow the breaking waves to convert a huge amount of oil from the slick into very small oil droplets (IPIECA, 2001). In addition, the distribution size of oil droplets is very homogeneous and, usually, droplet diameters range between 10 and 50 µm.

The low buoyancy of these small droplets (oil + surfactant) will not allow them to resurface mainly due to the intrinsic mixing energy of the sea. In addition, dilution of these droplets in the whole water column will be induced by the subsurface currents and, depending on their intensity, the oil concentration can drop rapidly.

Observations made in the field during the *Sea Empress* accident illustrate perfectly this trend. During this accident close to the coast of Wales in 1996, major dispersant spraying operations were carried out (over 440 tonnes were sprayed) and oil concentrations were monitored in the upper water column (Table 4.1).

Table 4.1: Oil concentration in the upper water column after dispersant spraying operations during the *Sea Empress* incident (Lewis et al., 2006)

Time after dispersant application	Oil concentration in the upper water column (ppm)
Just after treatment	10
2 days after treatment	1
1 week after treatment	0.5
1 month after treatment	0.2
3 months after treatment	Background level

Evolution of commercial dispersant formulations

Surfactants are substances that are widely used in the detergent industry and are well known for their efficacy on oil and grease. They were used in large quantities during the *Torrey Canyon* accident (1967). Approximately 10,000 tonnes of detergents were directly used for beach clean-up and 14,000 tonnes of solvents were released into coastal waters in Cornwall, UK. However, these detergents contained surfactants dissolved in oil fractions composed of aromatic hydrocarbons with low boiling points. Those aromatics are well known for their carcinogenic potential and their high toxicity and, which could explain the high mortality observed in marine organisms. Scientific investigations conducted after the accident showed that the observed toxicity was essentially induced by the solvents and not the surfactants. The conclusions of these investigations led the British government to establish an authorisation process for the use of dispersants. As a consequence, research was initiated in order to optimise dispersant formulation to ensure high efficacy and low harmful effects on the environment.

Solvents

The initiated research on dispersants has led to the generation of new formulations suitable for use on drifting oil slicks in the open sea. The research mainly focused on two topics: identification of solvents with low toxicity and optimisation of solvent/surfactant ratios.

Hence, 2nd generation dispersants were developed, characterised by solvents with few (or no) aromatic compounds (BTX – benzene, toluene, xylene). The necessary doses remained unchanged, i.e. 1 volume of dispersant for 2-3 equivalent volumes of oil.

Finally, 3rd generation dispersants are now available with the following characteristics: toxicity lower than that of the dispersed oil, and more importantly with LC_{50} values well above the recommended use concentrations. Moreover, they are more concentrated, i.e. 1 volume of dispersant can be applied to 50 equivalent volumes of oil.

Surfactants

The suitability of surfactants to interact with oil in the water phase is often described using the Hydrophilic-Lipophilic Balance (HLB), the balance between the hydrophilic head and hydrophobic tail. Commonly, marine dispersants have an HLB value between 6 and 14 (Figure 4.2).

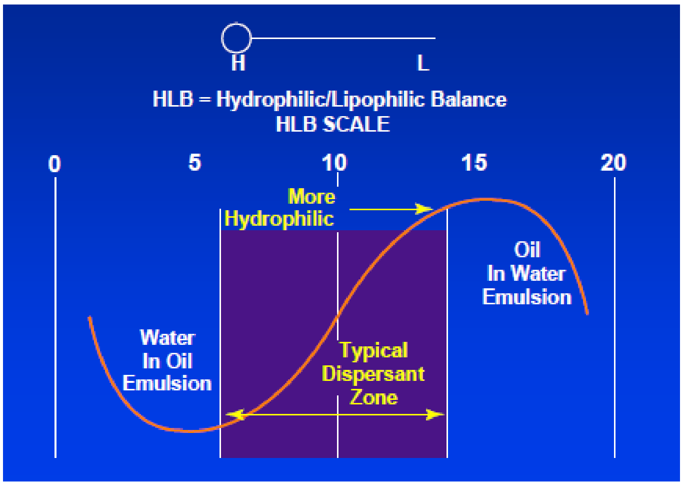

Figure 4.2: Typical HLB value for marine dispersant (Clark, 2004).

However, it has to be noted that commercial formulations typically contain surfactant mixtures containing 2 to 4 compounds with different HLB values in variable ratios in order to obtain optimal efficacy.

Moreover, due to the chemical structure of surfactants, their efficacy depends on the salinity of the water. Hence, the majority of surfactants developed for the dispersion of oil slicks at sea are optimized for salinities of 30 psu. Their efficacy decreases continuously until 10 psu, and most products become ineffective below this value. Therefore, in France distinct dispersant formulations have been developed for either marine waters or inland waters (rivers, lakes).

Furthermore, it could be worthwhile studying the impact of salinity on the efficacy of marine dispersants for a potential use in low salinity regions such as the Arctic or the Baltic Sea as the risks of oil spills may increase with increasing maritime traffic or more oil platforms in these regions.

Stability of dispersants

Dispersants are complex mixtures of dissolved surfactants and solvents, originating from specific oil fractions. Hence, the stability of these mixtures over time and more importantly the stability of their efficacy have to be assessed. For this purpose, the French Navy assesses the quality of its dispersants stockpiles regularly.

On a European scale, the question arises as to how different countries can share their stockpiles in order to optimise their use in a similar way to what is done on the global scale by Oil Spill Response Limited (OSRL).

Table 4.2: List of stocked quantities of dispersants in the world by the Subsea Well Intervention Service (O'Driscoll, 2013).

Type	Quantity (m3)	Location
Dasic Slickgone NS	500	OSRL Base UK Southampton
Finasol 52	500	OSRL Base UK Southampton
Finasol 52	1000	OSRL Base Singapore
Finasol 52	1500	Supplier Warehouse - Europe
Finasol 52	500	OSRL Base South Africa
Corexit EC9500A	500	Florida / Texas USA
Corexit EC9500A	500	Brazil

With respect to research, it would be interesting to monitor the stability of dispersant formulations under different storage conditions, notably in polar conditions if stockpiles are built up in this region.

Dispersant efficacy with respect to oil types

Oil weathering processes

When released into the marine environment, the chemical nature of the oil will evolve due to different physico-chemical processes, which take place simultaneously. The main processes involved are dissolution and evaporation of light molecules, emulsification due to surface movement and photo-oxidation. The combination of all these phenomena is commonly named oil weathering.

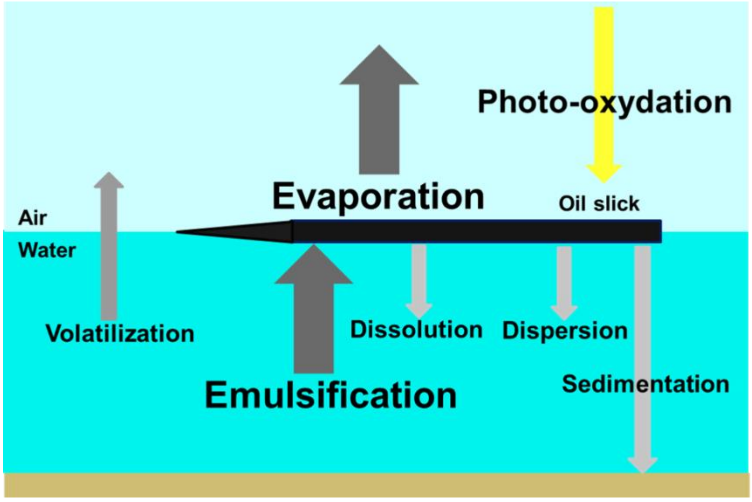

Figure 4.3: Oil weathering processes.

The weathering of oil at sea results in an increasing viscosity, and as a consequence it will reduce the efficacy of chemical dispersion. However, the speed of these phenomena depends directly on the environmental conditions in the zone, i.e. the same oil may remain dispersible depending on the sea state and on the temperature, as temperature greatly affects the oil viscosity. Therefore, oil, which is fluid in tropical climates and thus potentially dispersible, may become highly viscous in arctic regions and thus be non-dispersible.

Therefore, after a certain time, floating oil will become non-dispersible due to weathering processes. In operational terms, this is reflected by a “window of opportunity” for dispersant use, i.e. strategically speaking the decision whether or not to disperse an oil slick has to be taken quickly.

Chemical composition of oil

Even though information on the viscosity of the oil is an important parameter for the assessment of its dispersibility, this information alone is not sufficient. On two oil types with similar viscosity, dispersants may show very different efficacy depending on the chemical composition of the oil (Mukherjee et al., 2011). It is commonly accepted that the higher the ratio of polar compounds in the oil, the more the oil is dispersible, as long as the viscosity does not exceed 500 cSt. By contrast, paraffin type oils are regarded as having a low dispersion potential.

Experimental research

There is no simple rule on how to evaluate the efficacy of dispersants with regard to a given oil type and given environmental conditions. Therefore, Cedre has developed an experimental test chamber in order to conduct efficacy tests in controlled conditions. This tool (Flume Tank, Figure 4.4) can be used to implement controlled weathering of an oil under specific conditions (Table 4.3) and to subsequently assess its dispersibility over time in order to derive the “window of opportunity” (Figure 4.5).

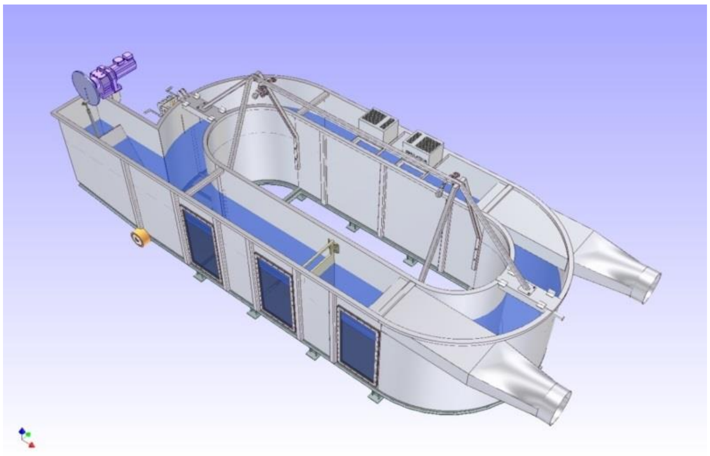

Figure 4.4: Cedre's flume tank used for the evaluation of oil dispersibility according to weathering under controlled conditions.

Table 4.3: Examples of oils and their dispersion potential

Type of hydrocarbon	Response option
Light refined products Example: • Gasoline/diesel/kerosene	**Treatment possible, but ineffective**
Hydrocarbons > 2000 cSt (at sea temperature) • Weathered light and moderate crudes • Heavy crudes (e.g. Boscan, Venezuela) • Heavy fuel oils (e.g. Bunker C)	**Dispersion possible**
Paraffinic crudes With a pour point greater than the temperature of seawater • Bu Attifil (Libya)	**Dispersion impossible**

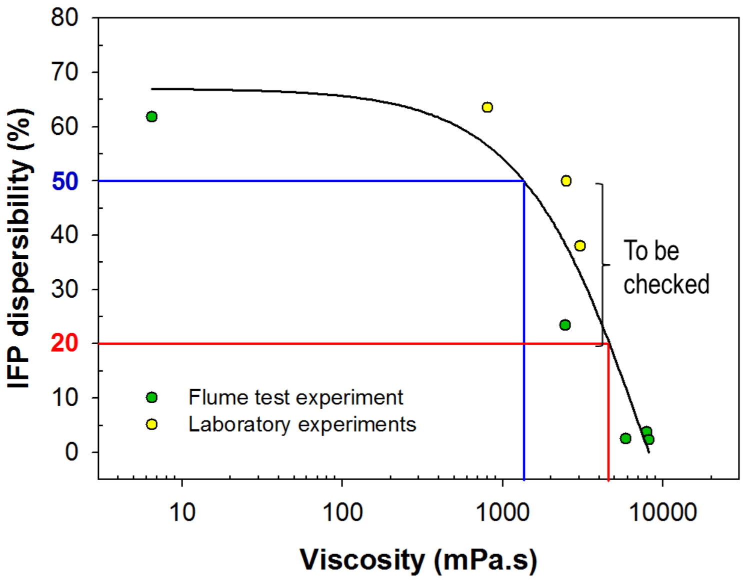

Figure 4.5: For a given oil, the "window of opportunity" for a potential dispersant treatment can be assessed. IFP dispersibility is determined by following a standardised procedure which is used in the French dispersant approval process.

Conditions for dispersant use

Environmental conditions

Chemical dispersion of an oil spill at sea requires a minimum level of surface agitation, i.e. a sea state of 3 on the Douglas Sea scale. Otherwise, droplets of dispersed oil cannot stay in suspension in the water column and will systematically coalesce and resurface (phenomenon of resurfacing).

Several techniques have been developed to compensate for a possible lack of agitation, such as the use of chains towed by a ship (Figure 4.6), however success is not guaranteed as the resurfacing of oil droplets cannot be avoided.

Figure 4.6: Use of chains towed by a ship aiming to introduce mechanical energy required for chemical oil dispersion (source: Cedre)

Spraying

Spraying equipment for dispersant application has considerably evolved over the years from simple fire hoses used in the *Amoco Cadiz* incident (France, 1978; Figure 4.7) to more sophisticated systems with spraying arms equipped with spraying nozzles used in the Deepwater Horizon incident (US, 2010). The latter systems can control the application rate and nebulization (droplet size) and thus comply more closely with the application recommendations.

Figure 4.7: Use of fire hoses for dispersant spraying in the *Amoco Cadiz* casualty. In retrospect, the lack of efficient flow control did not enable application according to the use recommendations. (source: Cedre).

Nowadays, 3rd generation dispersants can be directly applied to oil films without predilution. Different spraying arms are now available on the market and can be installed on ships, planes or helicopters.

Dispersant application dosage

Each dispersant formulation has its own specific dosage requirement which is defined by the supplier or manufacturer, i.e. the application conditions and the Dispersant Oil Ratio (DOR).

Nevertheless, in the event of a spill, it is important to adapt the dosage according to the characteristics of the spilled oil and its state of weathering. In practical terms, the DOR has to be adapted to the oil quality. In France, the following rules apply:

- Non-emulsified product
  A ratio of 5%, a Dispersant: Oil Ratio (DOR) = 1:20
- Emulsified product
  A ratio from 2 to 5%, a Dispersant: Emulsified Oil Ratio = 1:50
- Highly viscous oil
  Non-emulsified: DOR = 1:10
  Emulsified: double spraying, the first to break the emulsion (1:50), the second to disperse the oil (1:20)

French dispersant approval procedure

In France, dispersants have to be evaluated prior to any use in the environment according to a procedure based on three standardised tests. The aim of this procedure is to choose the most efficient and the least toxic dispersants.

This procedure aims at characterising the dispersant's efficacy (Efficiency test or IFP test, NF T90 345), its ecotoxicity (Toxicity test, NF T 90 349) and its persistence in the environment (Biodegradability test, NF T 90 346). The two latter tests are conducted on the pure formulation, i.e. without adding any oil.

For ecotoxicity testing, France decided to test the pure product, as 3rd generation dispersants are typically less toxic than the spilled oil. Moreover, the toxicity of the spilled oil largely depends on its chemical nature, notably on its content of aromatic components, and their respective bioavailability. The more efficient a dispersant is, the more oil components will be present in the water column and the greater its bioavailability. Therefore, the more efficient the dispersant, the higher the toxicity of the oil/dispersant mixture. As a consequence, basing the toxicity assessment on the dispersant/oil mixture will systematically eliminate the most effective products in terms of dispersion. For this reason, France has decided to base its assessment on the intrinsic toxicity of the dispersant, i.e. on the pure formulation.

Conclusion

The use of dispersant to respond to an oil spill has always been controversial, and discussions on this issue have intensified in recent years in the aftermath of the Deepwater Horizon accident.

However, since the first use of dispersants in an accidental context, enormous advances have been achieved not only with regard to their efficacy, but also to their biodegradability. Furthermore, the intrinsic toxicity of 3rd generation dispersants is very low and systematically lower than that of dispersed oil.

Despite these encouraging points, it has to be recalled that further studies are required in order to better assess the consequences of subsea injection of dispersants and to under-stand the role of salinity on the dispersant's efficacy and the stability of dispersed oil in the water column.

Finally, chemical dispersion is one spill response technique among others. Prior to any dispersant application, the potential consequences have to be evaluated via a Net Environmental Benefit Analysis.

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5 Oil and dispersants – marine sensitivity aspects

K.H. Carlo van Bernem

Helmholtz-Zentrum Geesthacht (HZG), Institute for Coastal Research,Geesthacht, Germany

Whenever a decision-maker has to decide which kind of action could be applied to respond to an oil spill, a risk evaluation is necessary. Belluck et al. (1993) defined three classes for ecological risk assessment (scientific, regulatory and planning) that lie along a continuum from most to least quantitative. Because costs (and usually time) increase with the level of scientific detail that can be obtained, the desire to improve the analysis must always be weighted against the effort of the additional information.

The behaviour of oil in water should be assessed before the questions “Will dispersants work effectively with a particular oil in the environment of interest?“ and “What are the ecological consequences of dispersant use?“ can be answered.
The main processes involved when oil (especially crude oil) is spilled on sea water, summarized as “weathering“ (Daling et al., 1990) are spreading, evaporation, dissolution, formation of emulsions, dispersion in the water column, sedimentation and, biodegradation.

Direction and speed of a driven oil slick depend on current conditions and on wind velocity. Consequently a drift model for coastal waters is a good tool for use as part of a conceptual model to predict the areas at risk. A spreading slick itself forms a large region of „sheen“ about 1 µm thick containing less than 5 % of the total oil volume. The majority of oil is bound to a much smaller area with a thickness of several millimetres in case of a stable emulsion. Within the first few hours or days most crude oils will loose up to 40 % of their volume by evaporation. This process, driven by temperature and wind speed, reduces the portion of lighter components of the oil leaving a smaller pollution volume with a higher viscosity and minor toxicity. This loss of oil components to the atmosphere is supplemented by a much smaller rate of dissolution. The amount of water soluble hydrocarbons around an oil slick is generally in the ppb range but remains toxic and bioavailable for marine organisms. On the other hand the incorporation of water into the oil residue left by evaporation and dissolution leads to a large increase of pollutant volume raising the viscosity once again. Very stable emulsions formed by some oils are resistant to chemical treatments or heating. Under rough sea conditions low viscous oils disperse naturally into the water column to a large extent, forming droplets of a wide range of sizes. While larger oil droplets resurface, only the smaller (< 70 µm) are found in permanent dispersion. Clay and particles of similar size (1-100 µm diameter), and microscopic organisms, interact with dispersed oil droplets by adsorption and ingestion. In waters of high turbidity, as for example in estuaries, the resulting flocculation (oil-mineral-microbial complexes) can reach high levels and obey the characteristic environmental processes of sedimentation and accumulation in areas of low hydraulic energy like nearshore tidal flats and watersheds.

The final weathering-process of spilled oil is biodegradation. All but the most refractory components of a crude oil can be degraded by biological actions in the water column as well as in sediments. The rates depend on temperature and the availability of oxygen. They range from 1-50 mg/m^3/day to years in very cold or anaerobic environments.

The advantages of using chemical dispersants are twofold: in the first place they reduce the pollutant volume on the water surface. Secondly they increase the rate of biodegradation processes by increasing the reactive surface of the oil. Their effectiveness depends mainly on the kind of the oil, its state of weathering (viscosity and degree of water-in-oil emulsions) and on the hydraulic energy in the area of concern. Other factors of gradual influence are: salinity, turbidity and temperature.

The increase of degradation, however, remains doubtful because of possible changes of microbial assemblages caused by the presence of dispersants (Kleindienst et al., 2015). Uptake and metabolism of hydrocarbons by organisms is reported for many species. Unlike bacteria, fungi and algae higher organisms tend not to utilise petroleum hydrocarbons as a carbon source, but generally metabolize them if they possess mfo (mixed function oxidase) – enzymes. The intermediate- and end-products of these metabolism processes very often hold for a higher toxicity compared to the basic substances.

Last but not least, the effects of oil contamination may be strongly extended by the sedimentary deposition of oil droplets and flocculae in anaerobiotic layers of sediments in areas of low energy (sheltered bays, coves and creeks).
Investigations about these topics are numerous. But the results, aside from fundamental processes, differ in terms of regions, times, methods and species of concern. Consequently there is not enough systematically gained knowledge allowing a quantitative prognosis of consequences in this regard for the German North Sea Coast.

Oil causes most damage in systems of low physical energy in which it can be trapped or ponded for long periods of time. The most susceptible types of shore on this scale are mainly associated with "shelter", a physical concept involving protection from wind, wave and current. Sheltered habitats are usually characterized by fine sediments and productive marine communities, and many cases have been reported of considerable oil damage by direct physico-chemical toxicity at the time of the spill or subsequently by long-term retention of the oil in these areas. Conversely, least damage is likely to occur in systems of high physical energy which turn over rapidly, and which may support impoverished communities of highly adapted organisms resistant to physical stress, e.g. exposed rocky headlands. Lesser damage to these systems may result partly from rapid removal of oil by physical means, partly from the fact that communities may be of low productivity, and partly because the modes of life of some species provide protection against physical (but not necessarily chemical) impacts of oil (van Bernem & Lübbe, 1997; van Bernem, 2010).

Although such generalization inevitably has numerous exceptions, several authors have constructed a simple, effective and widely applicable vulnerability scale for a range of shore types based on geomorphological and biological characteristics which are globally applied. They usually aim at a mitigation of intensity, duration and spatial extension of expected effects. Ecology-related criteria are often achieved by including criteria concerning natural resource protection.

The "Wadden Sea" - a sensitive environment

A contiguous region of tidal flats, barrier islands, alluvial terrestrial zones and salt marshes, about 500 km long and up to 25 km wide, extends along the North Sea coast of Germany, the Netherlands and Denmark. This „Wadden Sea" is of enormous value as a cleansing site for the coastal water, as a nursery for young fish, and as a feeding and nesting ground for nearly all palaearctic species of wading birds and waterfowl. Predation is one of the most important processes. It keeps densities of the large burrowing infauna (organisms living beyond the sediment surface) below carrying capacity, thus positively influencing the amelioration of the sediment.

The proximity of important shipping routes and ports is a permanent threat, especially to the German part of the region, which became a national park in 1985/86. Large quantities of petroleum, for example, which can be spread over wide areas by tides and winds, present not only the danger of temporary damage but rather of permanent harm, since oil, bound to the sediment, is released very slowly and can therefore repeatedly contaminate those parts of the tidal flats that have become free of the oil.

Thus, for oil spill response and precaution measures, a sensitivity study of the entire intertidal area was badly needed in order to assess the potential to minimize ecological and economical damage. Based on comprehensive field surveys (i.a. Dörjes et al. 1984, Farke et al. 1985, van Bernem et al. 1989) and in close cooperation with the Central Command for Maritime Emergencies (Havariekommando - HK), an automated expert-model for the German part of "Wadden Sea" areas was developed at the Institute for Coastal Research (Helmholtz-Zentrum Geesthacht, HZG) (Schiller et.al 2005, van Bernem et. al 2007). As an operational model it serves as important instrument for decision making processes, precautionary measures and the further design of oil spill response strategies.

Sheltered tidal flats, salt marshes and adjacent estuaries belong to the types of coast which are most sensitive to oil pollution. Since it is not possible to protect the entire German North Sea coast equally at all levels, oil spill contingency planning requires a more detailed classification. For this reason, individual soft bottom habitats, communities and stocks of salt marshes, macrofauna, waterfowl and estuarine biotope types were evaluated and classified according to their vulnerability to oil pollution.

The sensitivity of a particular area to oil contamination depends largely upon the physical characteristics of the habitat, the susceptibilities of individual species and their ecological properties within the communities. Hence, the field work for habitat mapping during 2003-2006 was a central part of the study. For this part, the experiences and results obtained from the previous HZG-project "Thematic Mapping and Sensitivity Study of Intertidal Flats" during the years 1987-1992 served as a valuable basis. For example, the documentation of changes during these periods of observation provides information on stability features of the ecosystems involved. During the first project nearly 5000 locations were processed and characterized using about 70 parameters for each site. The in-situ mapping was a combination of estimated and measured values, collected along a grid net of locations with 1 km interval. The estimated values, including biotic and abiotic parameters, were documented using a standardized protocol („record sheet"). They comprised, for example, information on the presence of micro- and macroalgae, surface structure (i.e. ripple, colour) and sediment characteristics. The measured values included grain size, shear strength, water content of sediments as well as the macrofauna species present.

The assessment of value of each location was calculated using an automated expert system developed at HZG and based on neural network techniques and advanced classification methods (tree fit). Four classes have been defined to scale the oil sensitivity of tidal flat areas from low (1: green) to high (4: magenta). The design of this model enables the „Central Command for Maritime Emergencies", as the main-user to calculate the spatio-temporal sensitivity of intertidal areas without extensive further expert assistance.

The spatial distribution of the sensitivity of tidal flat areas (benthic index) was combined with data on saltmarsh distribution and the presence of sea grass and mussel beds. These additional data were integrated using the monitoring results of the national park authorities of Lower Saxony, Schleswig-Holstein and Hamburg. The temporal aspect of this sensitivity was calculated using the monitoring data of breeding and migratory birds which are compiled yearly by these authorities. The complete data sets were used together with a geographic information system (GIS) to generate sensitivity maps of the German North Sea Coast (Figure 5.1).

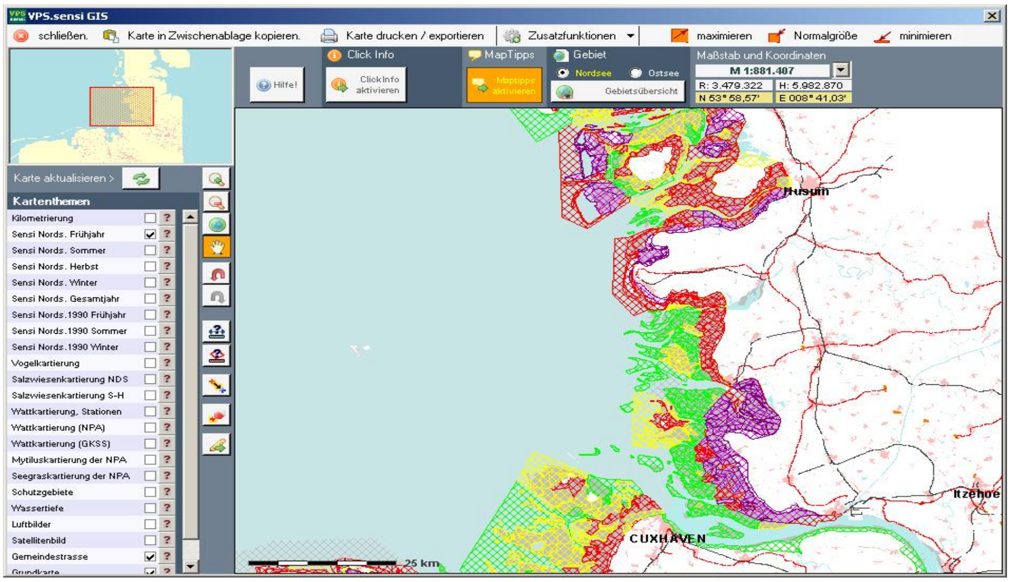

Figure 5.1: Example of the sensitivity model used by the HK. Increasing sensitivity is marked by the colors ”green” to “magenta”. The scale on the left allows selecting different topics of the underlying data base (for example: different seasons, saltmarshes, seagras, aerial images). The bar on top offers i.a. the selection and focus of areas.

Dealing with uncertainty

With regard to the reasons mentioned above, there is no conclusive way to soundly define the usefulness of chemical dispersants in a particular environment with different temporal and spatial conditions. Appropriate scenarios for individual cases have to be evaluated during a comparative analysis of the risks and benefits.
A fundamental goal for oil spill response holds: minimize the ecological impacts of a spill (Lindstedt-Siva, 1991). The decision as to whether it is better to protect sensitive habitats – rather than to optimize cleanup, needs a specific methodology to optimize all possibilities of response into an integrated program. In this concern a “Net Environmental Benefit Analysis” NEBA, (Baker, 1995) based on an ecological risk assessment approach can serve as part of integrated precaution measures.

By the way, aside of ecological and natural protection viewpoints, oceanographic and socio-economic features as well as logistic considerations play an important role in defining a comprehensive NEBA study. Hence it needs an integrated approach of natural scientists, „coastal users“ like fishery and tourism managers as well as natural protection agencies, oil spill response operators and other stakeholders to establish extensive strategies for decision finding.

The basic activities to establish an ecological risk assessment in the first instance can be summarized in three phases: problem formulation, analysis, and risk characterization (US EPA, 1992a). Within these phases quantitative as well as qualitative data may be used depending on the state of knowledge about the systems involved. The uncertainty of data and methods has to be defined as far as possible before the resulting information can be incorporated into conceptual or mathematical models. Another key element as prerequisite to develop decision strategies is the identification of clear and consistent **endpoints** related to the protection of resources.

Applying these briefly depicted features to the environment at risk, the Wadden Sea, we can establish the following characteristic aspects to define the limits for a selection of possible scenarios which meet the basic question:

- Is it possible to mitigate the damage of oil pollution by using chemical dispersants as (part of) the response measures?

(Hypothesis: If there is an increased degradation of oil and a decreased occurrence of oil slicks on the water surface, the ecological damage will be lower.)

The coastal water of this area shows a wide range of salinity, turbidity and energy characteristics: With increasing distance from the coast, depending on the tide especially in estuarine areas, the salinity changes from less than 5 ‰ to more than 30 ‰. The gradient of turbidity is reverse but it is interrupted by high differences of about 80 to far more than 1000 ppm. The heterogeneity of wave energy on a small scale (some 100 m), caused by changing wind conditions, water depth and current speed in estuaries, tidal channels and creeks also decreases with distance from the coastline while the heterogeneity and number of sensitive tidal and subtidal habitats increases. Briefly: the effectiveness as well as the controlled application of dispersants may be greater the further offshore they are applied (wave energy and salinity) but is very different on a small scale in nearshore areas (up to 25km wide), depending on currents and water depth – the danger to fundamental systems functions is greater if they are used nearshore (high adsorption rate of oil droplets to particles leads to increased microbial degradation and potentially detrimental to the oxygen balance).

Additionally there are several nearshore phenomena of a high sensitivity to oil slicks: e.g. mussel beds, shell mounds, sea grass meadows, salt marshes and stocks of resting and moulting birds. For most of these phenomena an evaluation about the “good or bad” effects of chemical dispersant use also depends on the individual conditions of an accident. However, a special case exists with regard to moulting and resting birds. In particular, moulting bird stocks are clearly much more vulnerable to untreated oil slicks in comparison to chemical dispersions. During one to two months in summer these birds are not able to fly because of changing their feathers. In distinct areas these stocks can reach far more than 100.000 individuals; just swimming or drifting on the water they are helpless in the face of being contaminated by oil slick residues. Their stock sizes and population dynamics are very well known and steadily monitored so that the degree of uncertainty in estimating damages to the population level is comparably low. Although there may be no danger to the survival of their population and role in systems functions, nevertheless a rough decrease of their local stock size has to be avoided for reasons of natural resource protection.

Extracting the formulation of “**endpoints**” out of these roughly summarized conditions to develop special strategies of oil pollution response, the resulting simplified scenarios would correspond as examples.

Example 1:
Moulting birds

A drift model shows the probability of a high damage to moulting birds. As **endpoint** the decision is: natural protection of local stocks is given higher priority than possible ecological consequences. Resulting from this statement, dispersants must be used in such a way that success is guaranteed as far as possible. Any half-hearted and ineffectual use will lead to damages in both directions and means a defeat of the strategy involved.

Example 2 (Figure 5.2):

A drift model shows: the oil remains in the „Jade“, a big tidal channel leading to the Jade-basin. The subtidal and adjacent intertidal of this channel is of minor sensitivity (Figure 5.2). Additionally the subtidal and the flats are accessible by foot and suitable vehicles. Effective cleaning is possible. As an **endpoint** may hold: because removal of oil is possible without greater harm to sub- and intertidal habitats and with focus on the sedimentation problems mentioned above, the contamination of the Jade-basin with oil-dispersion should be avoided. Thus: no necessity to use dispersants.

Example 3 (Figure 5.2):

Drift model forecast: a big part (up to 50 % in Figure 5.2) will enter the Jade-basin. The intertidal of this Bay is predominantly of high sensitivity. Most of the flats are extremely muddy. Effective mechanical protection and cleaning is not possible. Endpoint: no effective removal possible. The threat of long lasting ecological damage, especially with regard to the adjacent saltmarshes is obvious. The threat of ecological damage by oil dispersion is estimated to be essentially minor and at least more uncertain. Thus the immediate use of dispersants is highly recommended.

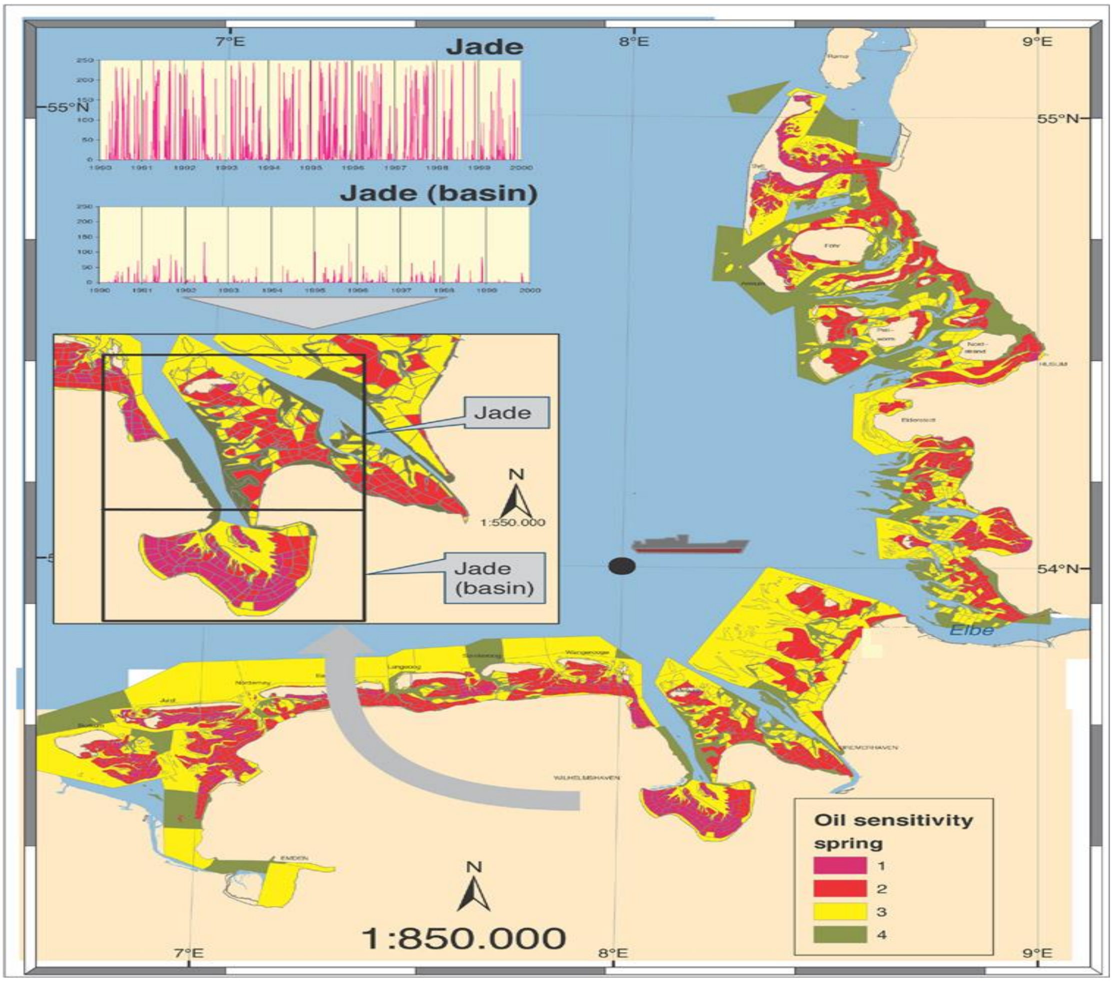

Figure 5.2: The place of accident is depicted as black dot at 54°N/8°E. The drift of oil alone is calculated using 250 particles during a period of 10 years according to realistic weather conditions. The amount (number of particles) and frequency of oil contaminating the tidal channel "Jade" is indicated on the upper scale. The scale beneath indicates the proportion polluting the highly sensitive "Jade-Bay".

Conclusions

The high variability of complex biological interactions causes large statistical and systematical errors which make it impossible to realistically reflect nature using complex simulation models. An adequate correspondence with reality, however, is a prerequisite when considering the tolerance of ecosystems to man made disturbances and countermeasures.

Even though the “Wadden Sea” is one of the best investigated marine environments, the uncertainty to define such consequences remains high. As a matter of course an environmental risk analysis as basic part of a NEBA has to consider all reasonable information available such as: drift analyses, sensitivity of habitats, toxicity, effectivity of measures, ecological as well as natural protection damages. The design and development of response actions, however, is only possible by the decision to determine scenario-depending endpoints which enforcedly are based on the educated guess of experts as well as on their careful consideration of probability and plausibility.

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6 Regions where the application of dispersants can be expected to be beneficial - an assessment based on drift modelling

Ulrich Callies, Fabian Schwichtenberg

Helmholtz-Zentrum Geesthacht (HZG), Geesthacht, Germany

Introduction

The use of hydrodynamic models for predicting oil slick movements and effects of weathering processes is nowadays an essential component of any contingency planning. When the use of dispersants is an option, hydrodynamic modelling can also support corresponding decision making.

A key effect of dispersants is that they remove oil from the surface and allow it to be mixed into the water column. An essential consequence of this is that oil becomes sheltered from the direct influences of wind forcing, which is the most important driver of oil slick movements (cf. Figure 6.1).

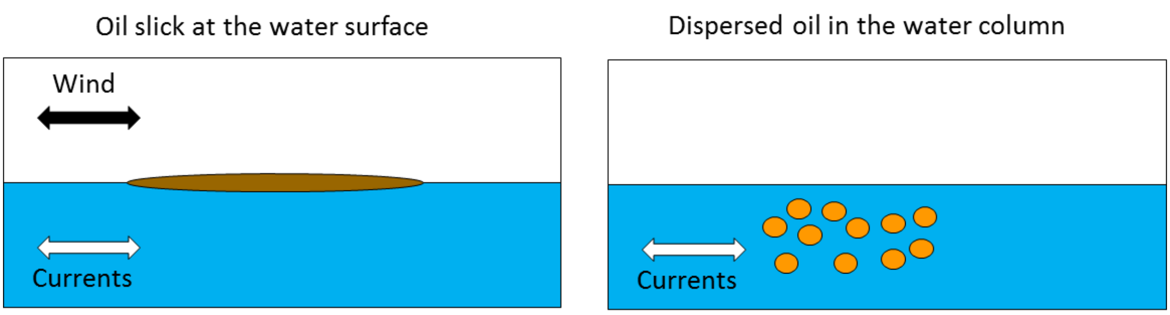

Figure 6.1: Sketch of dispersed oil becoming sheltered from wind forcing after dispersion.

Changes in the drift paths of released oil brought about by the application of chemical dispersants can be very substantial. Wind forcing lets an oil slick drifting on the water surface move faster and possibly also into other directions than the water body underneath. Therefore, among others a major effect of chemical dispersant application can be a shift to less sensitive areas being endangered by an oil spill.

Hydrodynamic simulations can be used for studying such effects. Figure 6.2 summarizes results of simulations that refer to a hypothetical location close to where the PALLAS accident took place in autumn 1998 (Reineking, 1999). Simulations focus on the drift problem, disregarding any oil weathering processes. Linking the particle tracking module PELETS (Callies et al., 2011) to hydrodynamic fields from the operational model of Federal Maritime and Hydrographic Agency (BSH) (Dick et al., 2001), particles were tracked over a five day time span. Such model simulations were set up for each low tide situation within the year 2008.

Details of two of these simulations are shown in the left panel of Figure 6.2. For oil assumed to be released on Jan 7 (blue dots), all untreated oil drifting at the water surface is simulated to end up in the tidal basin. By contrast, the oil-dispersant mixture in the water column stays outside the Wadden Sea. For a second simulation, assuming an oil release on Nov 5 (red dots), the situation is more complex. In this case chemical dispersion cannot fully prevent the pollutant from entering the sensitive Wadden Sea. At the same time, however, the impacts of untreated oil on the coast are delayed by a longer drift path which may offer the possibility for efficient mechanical cleaning before the oil slick would hit the Danish coast more to the north. Already this simplified example, not yet addressing any toxicity issue, illustrates that practical decision making with regard to the application of chemical dispersants is supposed to be very complex.

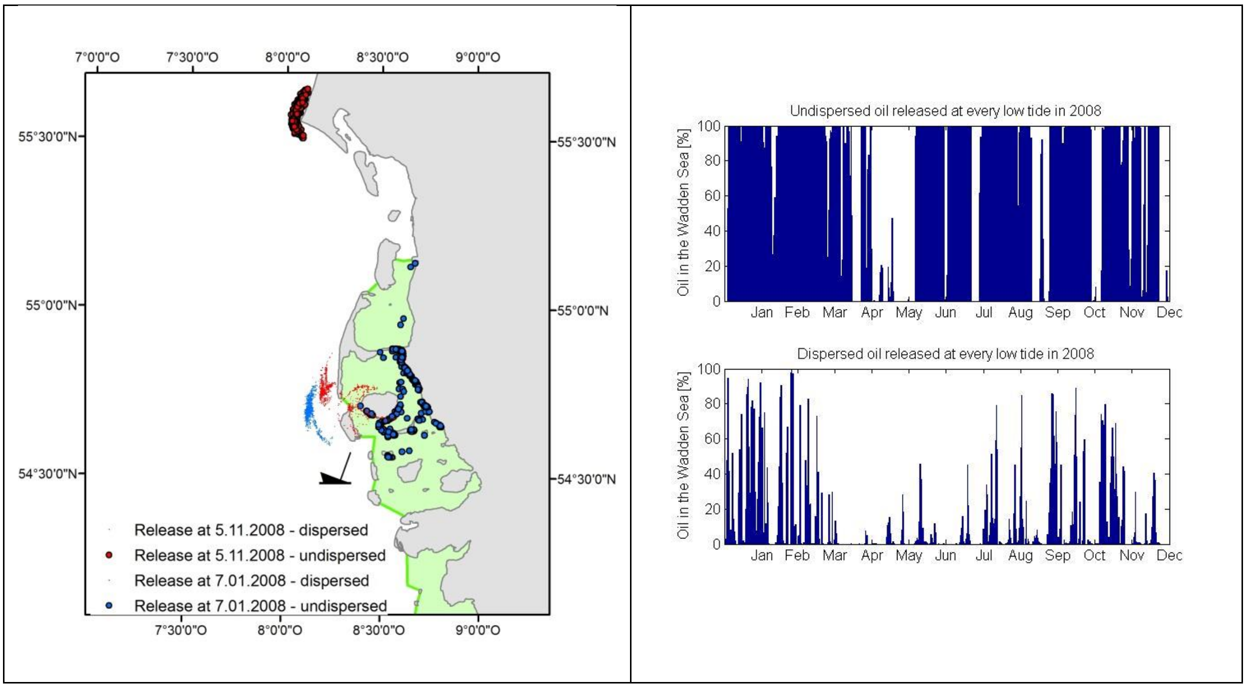

Figure 6.2: The left panel shows simulated distributions of pollutants five days after a hypothetical oil release took place at the location indicated by the ship symbol. Two examples assuming oil being released on Jan 7 or Nov 5 in the year 2008 are colour coded in blue and red, respectively. Both of the two hypothetical accidents were simulated assuming a) that the oil remained untreated (large dots) and b) that the oil was fully dispersed right after its release (small dots). Time series on the right hand side summarize results with (bottom panel) and without (top panel) chemical dispersion for a whole ensemble of simulations started at each low tide within the year 2008. Both of the two graphs show percentages of pollutant that enter sensitive Wadden Sea areas (green areas in the left panel) at any time within the first five days after the hypothetical accident took place.

The time series on the right hand side of Figure 6.2 summarize for all simulations the percentages of pollutant that would have entered sensitive German Wadden Sea areas with and without the application of a 100 % effective chemical dispersant. A substantial reduction of the probability that the pollutant would enter the Wadden Sea by means of an effective dispersion can clearly be recognized. Of course, the results shown hold just for the specific location selected. Schwichtenberg et al. (2016) extended this kind of analysis to produce a probability map covering the whole German Bight area (see below).

With regard to the behaviour of untreated oil it should be noted that our simulations did not take into account the process of beaching so that simulated tracer particles can move along the coastline until they enter a tidal inlet.

Variability in space

To study the spatial variability of benefits from using dispersants, Schwichtenberg et al. (2016) introduced a regular grid made up by 636 cells of about 5×5 km^2, covering the whole area of the inner German Bight. Considering each of these grid cells as a hypothetical source of oil pollution, they initialized corresponding simulations every 28 hours in the years 2008-2014. Based on the outcomes of the resulting 2190 simulations per grid cell (integration time: seven days) they compared the times after which the first oil reached any sensitive coastal area with and without application of a chemical dispersant. A substantial increase of the 10^{th} percentiles of travel time caused by dispersion becomes evident comparing the two panels in

Figure 6.3 (reproduced from Schwichtenberg et al. (2016)). White areas in the right panel indicate that in no experiment any oil released in these grid cells reached the coast in a one week's time.

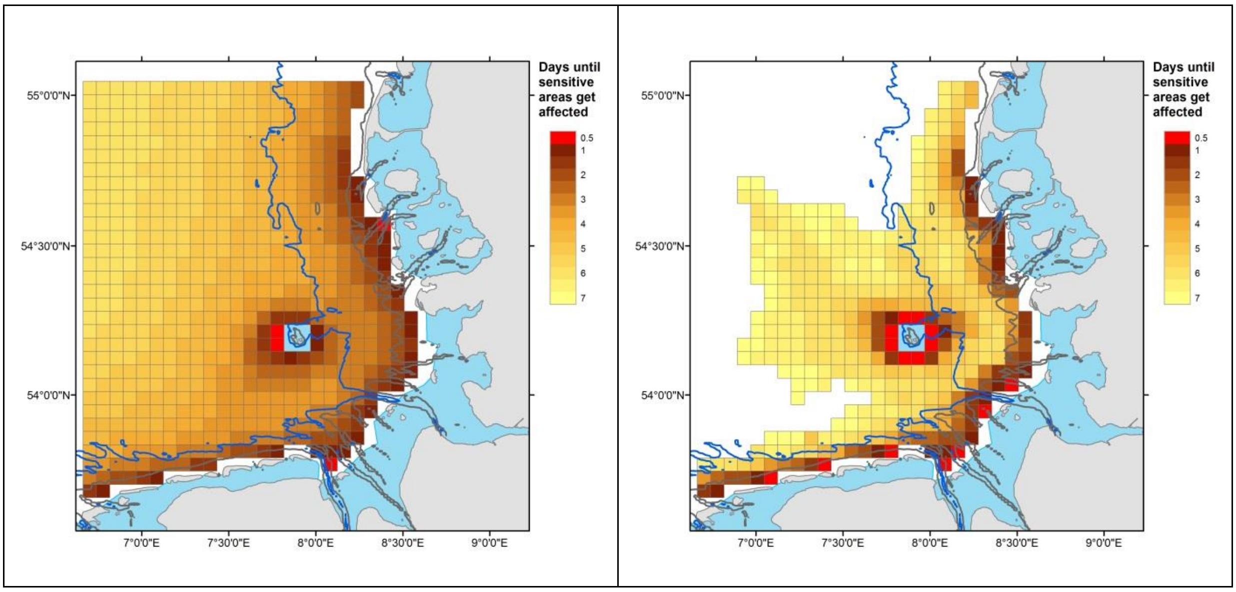

Figure 6.3: 10th percentiles of simulated travel times from a respective grid cell to any sensitive Wadden Sea area. Panels refer to untreated (left) and chemically dispersed (right) oil. White areas indicate that no oil reached the Wadden Sea within a seven days' time. The grey (blue) line indicates the 10m (20m) depth line. The figure is reproduced from Schwichtenberg et al. (2016).

Travel time between the location of an accident and sensitive areas is an issue of practical importance. In case of untreated oil it defines the time window available for mechanical counter measures. In case of dispersed oil, large travel times imply the chance for sufficient dilution (mostly in the vertical) of the oil/dispersant mixture.

To assess benefits of a perfect chemical dispersant's use, it must first be defined what successful application should mean. In their simplified study focussing on modified drift paths Schwichtenberg et al. (2016) labelled application of a dispersant as successful if it reduced the amount of oil in the Wadden Sea by at least 95 %. Note that this definition is based on the amount of oil that would hit the coast without intervention rather than on the total amount of oil released. Consequently, the 100 % reference value could be a very small amount in absolute units. However, that only a small percentage of untreated oil hits the coast will occur rarely as in most cases the initial oil slick will not be spread too much (see the example in Figure 6.2).

Figure 6.4 shows for each grid cell the probability that chemical dispersion would be beneficial. Schwichtenberg et al. (2016) calculated these probabilities in terms of the fractions of the 2190 simulations during 2008-2014 for which the above criterion for success was met. Note that red areas, in which dispersants turned out to have little effects on the amount of oil that entered the Wadden Sea, occur for two different reasons. First, any reduction of Wadden Sea pollution (i.e. benefit from using a chemical dispersant) will be impossible if the Wadden Sea hadn't been polluted anyway. This situation occurs in regions far from the coast. Second, the amount of oil entering coastal regions may be either not reduced or even increased. This latter situation underlies the red colouring of inshore regions. Examples, where suppressing wind forcing does not help or is even counterproductive, are when either dispersed oil can enter tidal basins with tidal currents or wind forcing acts in favour of coastal protection (i.e. winds blow offshore).

Between the two red areas in Figure 6.4, a band of green colouring indicates those regions where application of dispersants has the potential to make much of a difference for Wadden Sea pollution. With regard to absolute numbers of probabilities it must be mentioned that generally all simulations with wave heights either below 0.5 m or above 3 m were labelled as unsuccessful. Such situations occurred in about 25 % of all cases, so that the maximum probability against which probabilities in Figure 6.4 should be compared is roughly 75 %. Taking this into account, in some regions the use of dispersants seems to be a promising option.

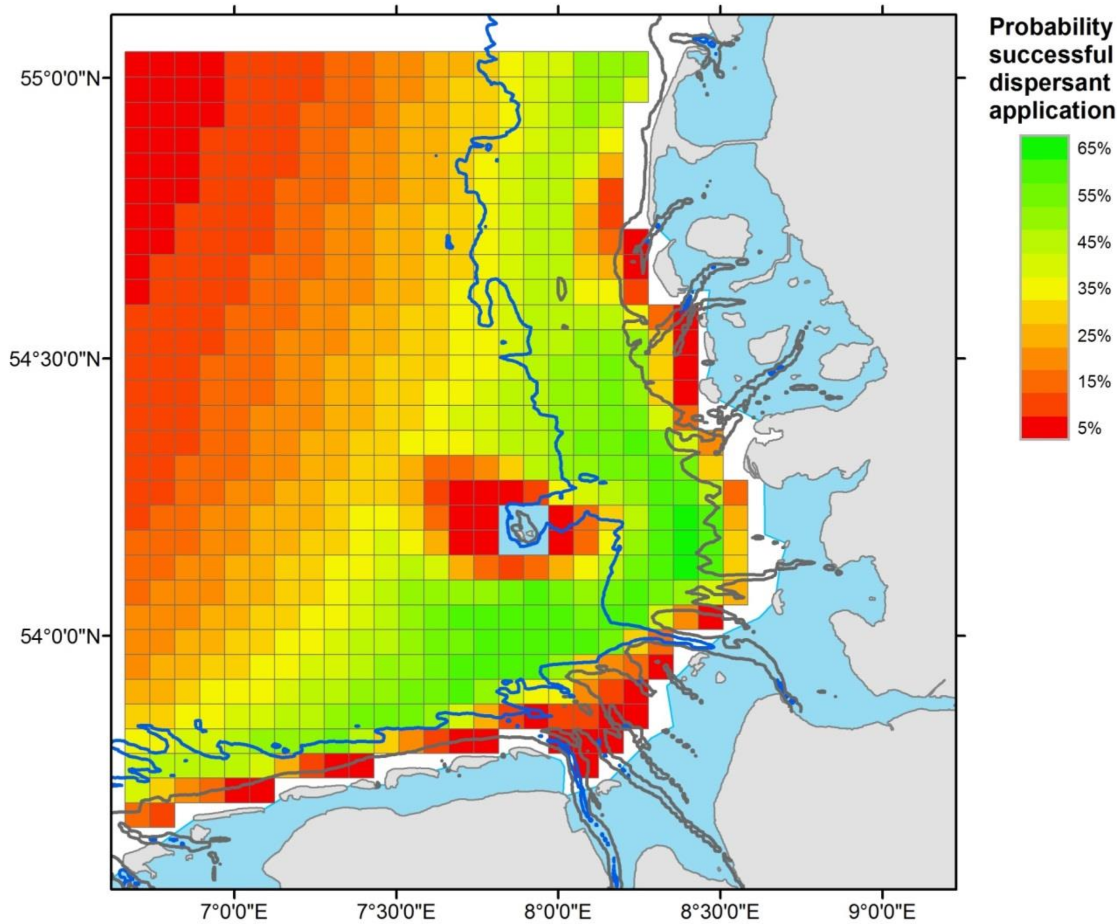

Figure 6.4: Probabilities that application of a 100% effective dispersant right after oil was released would reduce the amount of oil entering sensitive coastal areas by at least 95%.The grey (blue) line indicates the 10m (20m) depth line. The figure is reproduced from Schwichtenberg et al. (2016).

Conclusions

A large ensemble of simplified drift simulations, treating oil as a passive tracer, helped identify regions where using dispersants has the potential to be beneficial in the sense that it prevents the pollutant from entering most sensitive areas. The above study is not yet a full net environmental benefit analysis (NEBA) as no possible toxic effects have been taken into account. Nevertheless, a map like the one shown in Figure 6.4 suggests regions for which conducting a NEBA would be worthwhile.

Acknowledgements

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7 Health effects of mineral oil, dispersants and oil-dispersant-mixtures

Carolin Gräbsch

Federal Institute for Risk Assessment (BfR), Berlin, Germany

Introduction

When assessing human health effects connected to the use of oil dispersants, three important aspects should be considered. First, during an oil spill, mineral oil is already there and an exposure to mineral oil is probable. Therefore, oil-mediated health effects for clean-up worker are likely. Second; by using dispersants as chemical response to an oil spill, people may additionally be exposed to those substances. Third; clean-up worker are exposed to oil-dispersant mixtures. Within the mixture, different constituents can interact and induce the toxic effect.

Therefore, the assessment of health effects of oil-dispersant mixtures is performed stepwise in this article by looking on health effects of mineral oil only, toxicity data of dispersants as such and focusing on Deepwater Horizon as a case study for oil-dispersant-mixture toxicity.

Health Effects of Mineral Oil

Mineral oils consist of hundreds of compounds. The composition depends on the type of the mineral oil and is essential for understanding of resulting health effects. Relevant toxic components are the large group of hydrocarbons, like the volatile organic compounds (VOCs) and the benzene, toluene, ethylbenzene and xylene fraction (BTEX), the more persistent PAHs and the huge group of aliphatic hydrocarbons. Furthermore, certain heavy metals and sulfur-containing substances are non-hydrocarbon components. The resulting health effects can be grouped in acute and chronic effects. Irritation of eye, skin and respiratory tract or the neurological impact are typical acute effects from volatile compounds after inhalation exposure. Mutagenicity and carcinogenicity are examples for typical chronic effects after a PAH exposure. However, it is beyond the scope of this overview to discuss toxicity of oil components. Here, we focus on oil-mediated health effects resulting from exposure related to oil spills.

Table 7.1: Assortment of oil spills (from CEDRE and ITOPF data basis, see references)

Name	Date	Spill Size [kt]	Oil Type	Dispersants [t]	Health related articles in international per-reviewed journals
Torrey Canyon	18th Mar. 1967	119	Crude oil	10,000	0
Exxon Valdez	24th Mar. 1989	37	Crude oil	yes	6
Braer	4th Jan. 1993	85	Crude oil	130	4
Sea Empress	15th Feb. 1996	72	Light crude oil	444	2
Erika	11th Dec. 1999	20	Heavy fuel oil	no	6
Prestige	13th Nov. 2002	63	Heavy fuel oil	no	18
Hebei Spirit	7th Dec. 2007	10	different Middle Eastern crude oils	yes	12
Deepwater Horizon	20th Apr. 2010	500-1,000	South Louisiana sweet crude oil	~ 6700	> 30

Public attention towards the history of oil spills began with the Torrey Canyon oil spill in 1967. From that time, a number of oil spills occurred (Table 7.1). Oil spills differ in spill size, oil type and the corresponding response or clean-up strategies.

Interestingly, the attention towards human health effects after oil spills has increased over the last ten years, more precisely after the Prestige oil spill in 2002. In comparison to the multitude of information about environmental consequences after oil spills, the impact of oil spills on human health is a relative new topic. The majority of investigations are cross-sectional epidemiological studies that analyze acute physical effects or psychological consequences in the affected people (Aguilera et al. 2010). Here, an overview over two spills with relatively good coverage of health effects are presented, the Hebei Spirit and the Prestige oil spills.

For the investigation of oil-mediated health effects, the Prestige oil spill serves as an example, because there is a good data basis and dispersants were not used during the clean-up activities. Furthermore, the Hebei Spirit was also considered as a case study as the use of dispersants was very limited.

Within the first days after an oil spill, inhalation exposure is expected to be high as volatile compounds evaporate into the atmosphere. During both spills, the Prestige as well as the Hebei Spirit, acute symptoms were monitored very promptly and documented within two weeks after the spill (see Figure 7.1, initial phase data: yellow bars adopted from Spanish Department of Health (Plan Sanitario Combinado del Servicio Galego de Saúde, cited from Rodriguez-Trigo et al., 2007, dark blue bars adopted from Na et a. 2012)).

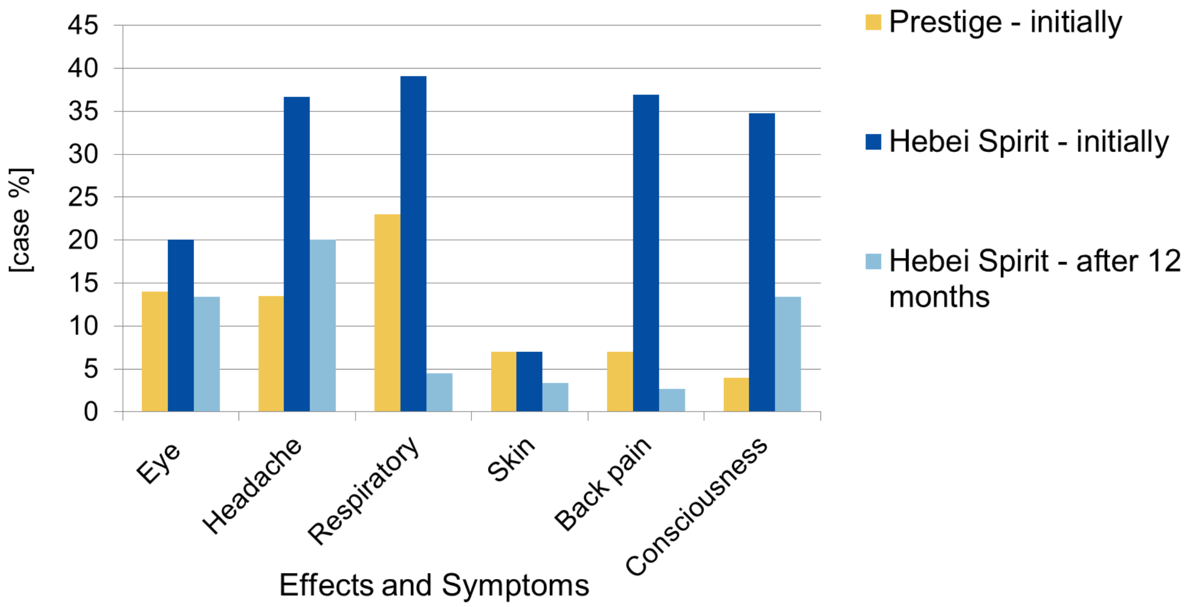

Figure 7.1: Monitoring of acute health symptoms of oil spill clean-up workers during the Prestige and Hebei Spirit oil spills

Three dominant symptoms were reported. Irritation to eyes, respiratory tract irritation and headache are prevalent in both spills, but more frequently during the Hebei Spirit clean-up. In general, dermal irritation had a lower prevalence in both cases. Back pain complaints and impact on consciousness were more frequent in oil clean-up workers at the Hebei spirit clean-up.

The question arises: Why do these differences exist? The different frequencies of irritation to eyes, respiratory tract and headache could be explained by the different types of mineral oil but also by the limited use of dispersants use during Hebei Spirit clean-up. Indeed, no detailed data exist regarding the time point, the quantity and formulas of dispersants. Furthermore, huge differences in the clean-up population exist: During Hebei Spirit, the majority of the clean-up workers was female and over 60 years old (Na et al. 2012). During the Prestige, the main population was male with ages between 16-45 years (Rodríguez-Trigo et al. 2007). Maybe this background could explain the higher frequencies of back pain complaints of the clean-up workers during the Hebei Spirit clean-up. Interestingly, Na et al. (2012) observed also the average duration of the health complaints. The back pain complaints had the lowest time of duration, maybe due to the adaption of the physical strain.

The light blue bars in Figure 7.1 illustrate health symptoms during the Hebei clean-up after 12 months, which lasted over a year (adopted from Na, et al. 2012). The symptoms and health complaints still exist, but the frequencies are decreased. After twelve months continuous clean-up work, headache and eye irritation dominate the health effects among the clean-up workers.

For both oil spills, initial phase data on health complaints of the oil spill clean-up workers exist, when exposure to volatile compounds is expected to be very high. However, uncertainties and data gaps limit the informative value: There is no detailed characterization of the clean-up workers, no data on the work duration, no data on the use and the quality of personal protective equipment - and no control groups were included in the studies.

The Prestige oil spill was the only case for which long-term endpoints like genotoxicity were investigated (Hildur et al. 2015; Laffon et al. 2014; Monyarch et al. 2013; Perez-Cadahia et al. 2008; Rodriguez-Trigo et al. 2010, and data from Gestal-Otero et al., 2004 cited in Rodriguez-Trigo et al., 2007). Furthermore, respiratory effects and oxidative stress markers in the lung (Rodriguez-Trigo et al. 2010; Zock et al. 2007; Zock et al. 2014; Zock et al. 2012), as well as the impact on psychic health (Carrasco et al. 2007; Sabucedo et al. 2010) were studied. Respiratory symptoms of the lower respiratory tract were observed up to 5 years after the spill. After two years, oxidative stress marker and growth factors were detected in exhaled breath condensate. This could be an evidence for lung damage, but also an evidence for related repair mechanism. Although the long-term studies are of value, a number of uncertainties and data gaps limit their explanatory power.

Genotoxicity was assessed by different methods: the detection of DNA damage described by the Comet-Assay and chromosomal alterations described by Micronucleus-Assay, Sister-Chromatid-Exchange or karyotyping. In the first year DNA damage was observed in oil spill workers with differences regarding their activity, whereby DNA-damage of volunteers correlates with exposure toward VOCs (data from Gestal-Otero et al., 2004 cited in Rodriguez-Trigo et al., 2007). Chromosome alterations were observed two and six years after the oil spill (Monyarch et al. 2013). However, after six years Hildur et al. (2015) also reported a higher prevalence of chromosomal lesions not only in former clean-up workers but also in a non-exposed group of fishermen with no participation in clean-up activities in the past compared to a control group located 600 km away from the Prestige accident. The authors discussed the possibility of indirect exposure of fishermen to some compounds of oil or other toxic agents due to the improper storage of the oil or frequently ingestion of low-level contaminated sea food.

Without exposure data from the time of the clean-up activites or current biomonitoring data it is difficult to clearly link the described genotoxic effects with the exposure during the clean-up activities.

For exposure-response relationships, the measurements of the personal exposure or biomonitoring are important factors. Gestal-Otero (2004) measured the personal VOC exposure of different clean-up worker groups. The VOC levels were comparable to highly polluted cities like Athens or Mexico City with a predominance of light hydrocarbons. Only for benzene very high levels were detected. The levels from volunteers (388 $\mu g/m^3$) were threefold higher than the levels from paid workers (155 $\mu g/m^3$) (Rodriguez-Trigo et al., 2007). The high benzene levels of the volunteers correlated with a higher degree of DNA damage.

The different risk of different clean-up worker groups (volunteers, paid workers, fishermen) was investigated by Carrasco et al. (2006). Fishermen, who were the poorest informed, suffered the most toxicity problems (perhaps as a consequence of the scant use of masks) and constituted the subset among whom the information received was least effective (Carrasco et al. 2006). The case of the Prestige showed the importance of a clear risk communication and the briefing of the clean-up workers resulting in the use of personal protective equipment and a lower risk for oil-mediated health effects.

Health Effects of Dispersants

In general, dispersants consist of solvents and surface active agents. The same components are found in many dispersant formulas. However, a complete list of all constituents is missing for the most dispersants e.g. those listed by EMSA (see references).

Since the Deepwater Horizon rig explosion and the use of enormous amounts of COREXIT© 9500 and COREXIT© 9527, the U.S. EPA published the lists of constituents of the COREXIT formulas (U.S. EPA).

The Deepwater Horizon spill is a good case study on dispersant use since the compositions of the formulas are available. Therefore, the COREXIT formulas may be taken as an example for dispersants in general.

Some constituents of the COREXIT© formulas are chemicals generally used in consumer products. The non-ionic surfactants Span 80®, Tween 80 and propylene glycol are also used as food additives (Span 80: E494; Tween: 80 E433; propylene glycol: E1520) and possess a low toxicity. The anionic surface active agent dioctyl sodium sulfosuccinate (DOSS) is even used as a laxative pharmaceutical. It is general assumed in toxicology that surface active agents increase the absorption in the gut. 2-Butoxyethanol is used as solvent with modest surfactant properties in household products and cosmetics. In general, it can be stated that the main toxic effects of the mentioned substances are irritation to the eyes, the skin and mucous membranes. The solvent petroleum distillates possess a higher toxicity compared to the other components. The health effects shown in Table 7.2 are those of the single compounds, not their mixtures.

Material safety data sheets (MSDS) for both products explain skin and eye irritation, but slight differences in toxicity exist. The issue of a MSDS is the safe handling of chemicals and the description of precautionary measures. Therefore, the risk during the handling of dispersants (preparation and turnout of the formulas) is covered but no additional exposure with mineral oil is considered.

Table 7.2: Components of COREXIT© 9500 and COREXIT© 9527

Chemical name	Hazard classification according to GHS (UN 2013)#	Hazard
1,2-Propanediol (propylene glycol)	Acute Tox. 4	low-moderately toxic
2-Butoxy-ethanol*	Acute Tox. 4, Skin Irrit. 2 Eye Irrit. 2	low-moderately toxic causes eye and skin irritation
Dioctyl sodium sulfosuccinate (DOSS	Skin Irrit. 2, Eye Dam. 1	causes eye damage and skin irritation
Span 80, Sorbitan, mono-(9Z)-9-octadecenoate	Eye Irrit. 2	causes eye irritation
Tween 80, Sorbitan, mono-(9Z)-9-octadecenoate, poly(oxy-1,2-ethanediyl) derivs.	Not classified	non-toxic
Tween 85, Sorbitan, tri-(9Z)-9-octadecenoate, poly(oxy-1,2-ethanediyl) derivs	Eye Irrit. 2	causes eye irritation
1-(2-butoxy-1-methylethoxy)- 2-Propanol (dipropylene glycol monobutyl ether)	Eye Irrit. 2	causes eye irritation
Distillates (petroleum)	Asp. Tox. 1	aspiration toxicity (may be fatal if swallowed and enters airways)

*Note: This chemical component (Ethanol, 2-butoxy-) is not included in the composition of COREXIT 9500
#Note: GHS Classification and Labelling according C&L Inventory database of ECHA showing classification by industry as well as legally binding classifications (http://echa.europa.eu/information-on-chemicals/cl-inventory-database)

Several animal studies on toxicity endpoints were conducted after the Deepwater Horizon oil spill. No signs of lung inflammation or lung injury were reported after acute and short-time repeated inhalation exposure to COREXIT© EC9500A to rats (Roberts et al 2011, 2014). However, breathing difficulties were observed in rats. The findings suggest that the inhalation of COREXIT© in sufficient concentrations may lead to the formation of precipitates in the airway surface liquid (Roberts et al., 2011). COREXIT© EC9500A did cause transient chronotropic effects on cardiac function (Roberts et al. 2014). The respiratory and the cardiac effects were transient. Sriram et al. (2011) observed neurotoxic effects in rats. The findings are suggestive of disruptions in olfactory signal transduction, in axonal function, and in synaptic vesicle fusion. All events potentially result in an imbalance in neurotransmitter signalling. Whether such acute molecular aberrations might produce chronic neurological effects remains to be ascertained.

The animal studies may show probable target effects but information about chronic effects after long-term exposure is missing as well as effects after exposure to oil-dispersant mixtures.

Expected Influence of Dispersant Use

Apart from direct effects dispersants may also modify the physical properties of the mineral oil constituents or their toxicokinetic or toxicodynamic mechanisms in the human body. Laboratory investigations showed a change of the composition of the water accommodated fraction (WAF) of oil-dispersant mixtures compared to the WAF of oil itself (Major et al. 2012). Depending on the used COREXIT© formula differences in the composition of the WAF of the oil-dispersant mixtures were detected. In particular, low molecular weight (MW) alkanes and benzene derivatives were identified in the WAF-oil / COREXIT© 9500, whereas the WAF-oil / COREXIT© 9527 sample contained a variety of high MW alkanes and polycyclic aromatic hydrocarbon (PAH) derivatives (Major et al. 2012). Without dispersant use, a quick evaporation of those substances close to the spill site but no persistence of those fractions in the water column would be expected.

It is conceivable, that the WAFs of oil-dispersant mixtures are probably aerosolized in the marine environment, similar to the creation of other sea surface aerosols. There is a possibility of inhalation and dermal exposure not only at the spill site, but also on a wider area and especially within zones of breaking waves near the beaches.

It is assumed that toxic effects, especially the dispersant-mediated absorption of oil constituents in the gut but also in the lung will have an impact. The dispersant component DOSS for example is known as enhancer for alveolar absorption (Wollmer et al. 2000). Additionally, target-specific effects of the surface active substances in the lung are likely.

Health Effects of Oil-Dispersant-Mixtures

In April 2010, the Deepwater Horizon rig exploded. Only after hospitalization of some oil spill clean-up workers and two months after the sinking of the Deepwater Horizon oil rig, NIOSH conducted a health survey among clean-up workers. No data on health effects exist for the initial phase of the spill when exposure started.

The survey considers different working activities related to different exposure scenarios at different locations. NIOSH included also a control group, which was involved in the administrative work only. All groups suffered more or less to the same extend from heat stress or psycho-social strains.

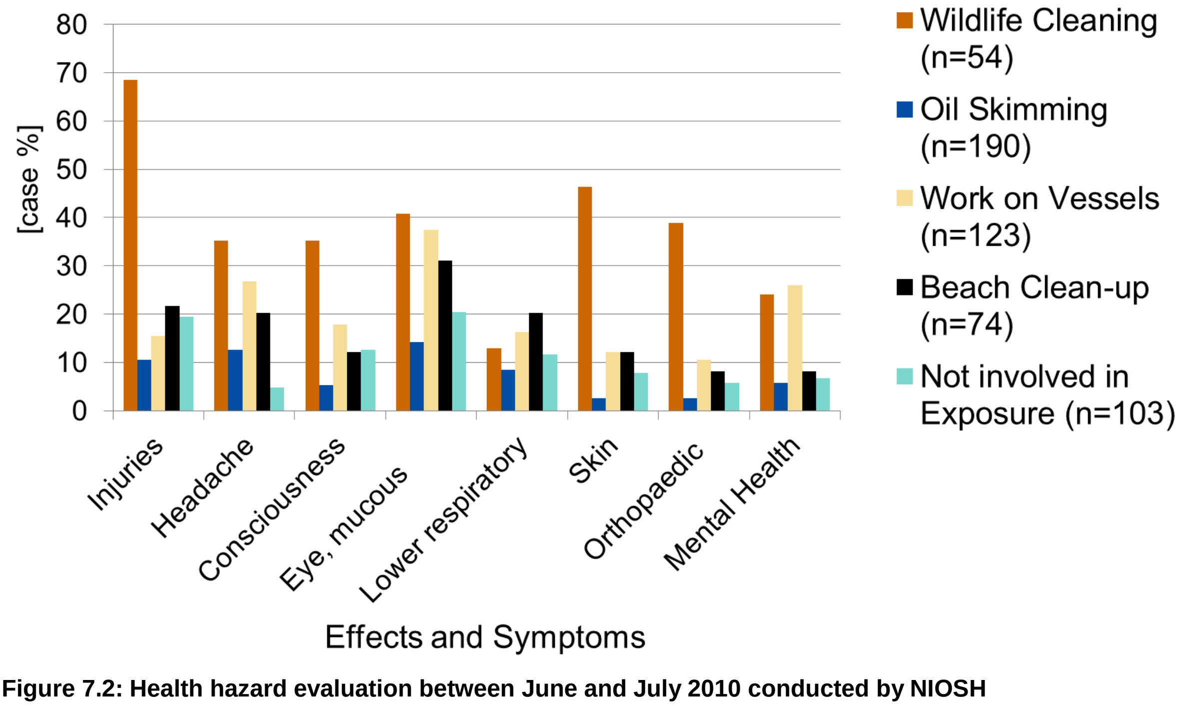

Figure 7.2: Health hazard evaluation between June and July 2010 conducted by NIOSH data adopted from (Goldstein et al. 2011)

As seen in Figure 7.2, wildlife clean-up workers suffered the strongest health effects, with injuries and orthopedic symptoms dominating. Both could be explained by the handling of wildlife animals and the physical strain of this clean-up activity. Irritation of the skin was significant and originated from direct skin contact with oil and dispersants when handling the animals. The other group with perceptible health impacts was the group of workers on vessels at sea, who applied or monitored the dispersants. They suffered from irritation to eyes and upper airways. But also headache and impact on psychic health were reported.

Beach cleaners reported additionally also effects on the lower respiratory tract. Fishermen on shrimp boats which were involved in skimming of oil had a lower frequency of symptoms.

The control group was working at the commander’s camp and was not exposed to oil or dispersants. Cases of injuries and irritation to eyes, impact on consciousness and mucous membranes were the most frequently reported symptoms among the control group and were higher than the complaint rate from workers on shrimp boats.

The specific clean-up activities with their different exposure situations show different symptom pattern. Wildlife clean-up workers had the highest risk for health effects followed by workers involved in the dispersant use.

The long-term human health effects of the Deepwater Horizon oil spill are of high interest and are under evaluation when this report is written. The GULF-study enrolled over 32,000 participants, 75 % were oil spill clean-up workers. The majority (83 %) were residents from the gulf coast. The study will consider the health effects of different exposure scenarios during 50 to 60 different activities of these persons (U.S. Department of Health and Human Services).

Unfortunately, the study started more than one year after the spill. Such long time frame is problematic regarding retrospective quantification of exposure and acute health effects. Today, data are not available, because the clinical examination were scheduled to end January 2016.

During the time of the health hazard evaluations, NIOSH also conducted exposure measurements during different clean-up activities. A widespread number of oil and dispersant components as well as gases and particulate matter were measured. The substances´ concentrations lay below either detection limits or occupational exposure limits.

NIOSH reported on some cases where samplers were saturated, maybe due to high humidity and thus any quantification was not possible. Only few Carbon Monoxide measurements on vessels showed significant levels. But the values could be explained by the exhaust from the boats´ engines. NIOSH already denied that a full assessment of the real exposure would become possible.

Summary and Outlook

Acute health effects of oil and oil-dispersant mixtures are similar and depend on the constituents of the oil spilled. Irritation to eyes, skin, mucous membranes and respiratory tract as well as headache were reported after the Prestige as well as after the Deepwater Horizon oil spill. Orthopedic symptoms and injuries are the consequence of physical work; injuries are often resulting from wild-life cleaning. But the impact on consciousness, headache and irritation to eyes could also lead to a higher risk for injuries when dispersants are not used. The impact on psychic health seems to be specific for residents of the affected area but will be independent from whether or not dispersants are used.

The use of dispersants results in specific clean-up activities which are not common when oil is recovered mechanically; for example, the application and monitoring of dispersants by vessels on sea. On the one hand, the risk for beach clean-up workers will change due to the exposure to the aerosolized mixture instead exposure to the vapour of oil components. On the other hand, there will be a lower demand for onshore workers when using dispersants and thus fewer people will be exposed.

Because of the extensive use of the product during the Deepwater Horizon accident, acute toxic effects of COREXIT© 9500 were investigated in animal studies. The studies may show probable target effects, like pulmonary, cardiac or neurotoxic effects. But unlike the exposure scenarios of the oil spill clean-up workers, the animal studies are limited to acute or subacute exposure. No information exists about the documentation of health-related long-term effects in humans after exposure to dispersants and oil-dispersant mixtures. Therefore, health-related long-term effects cannot be excluded.

The Prestige oil spill was the only case where long-term endpoints were investigated.

From a scientific viewpoint, all existing studies on the human health effects of oil spills with or without the use of dispersants show limitations. In many studies, the control groups or base-line data were not suitable. In general, there is a lack of confirmed exposure scenarios including measurements of the air and water pollutants. Depending on the type of clean-up activity the exposure scenario will change significantly. A precise definition of sub-groups in the population exposed to the spill is essential. However, some general conclusions can be drawn from these studies:

Oil mediated effects during clean-up activities after oil spills are irritation of skin, eyes and mucous membranes of the respiratory tract. Headache and the impact on consciousness could be also oil mediated and could be additionally favored by heat or overexertion during the clean-up activities. Previously mentioned symptoms could be minimized due to a clear risk communication and a briefing for the use of the personal protective equipment of the clean-up workers before starting clean-up activities. Orthopedic symptoms are probably the consequence of the unwonted physical exertion and therefore the symptoms are not directly oil mediated effects. Injuries and accidents are directly influenced by the kind of clean-up activity, but could be also triggered by other symptoms like headache, impact on consciousness or eye irritations.

During oil spills, several other factors contribute to health effects, like mixed low-level exposure of numerous compounds, the personal health risk, psycho-social strains and other factors like local climate. With the use of dispersants, there will be a shift in the chemical fate, a changed exposure situation and there will be different risk groups.

There is a need for more toxicological data on the dispersant formulas, on their components and the specific oil-dispersant mixtures. Study designs should consider acute and repeated exposures with different ways of applications.

For future oil spills there is a strong need for preparing studies on human health effects. An already prepared study plan for epidemiological surveys is essential and should include considerations about different exposure groups, suitable control groups or the enquiry of base-line data, a strategy for exposure measurement and options for long-term follow-ups. In case of an oil spill, there will not be enough time to plan and prepare well-organized studies. Only well prepared studies will eliminate the existing data gaps and uncertainties for a better and a more reliable health risk assessment.

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8 Meta-analysis on experiences from Deepwater Horizon

Dierk-Steffen Wahrendorf

Federal Institute of Hydrology (BfG), Koblenz, Germany

The incident and the response measures

The failure of a blowout preventer and other concomitant factors led to the explosion of the Deepwater Horizon drilling platform in April 2010. This incident in the Gulf of Mexico caused 11 deaths and 380 to 780 million liters of crude oil were spilled into the marine environment. The incident caused the largest single marine oil spill in global history, cf. Figure 8.1.

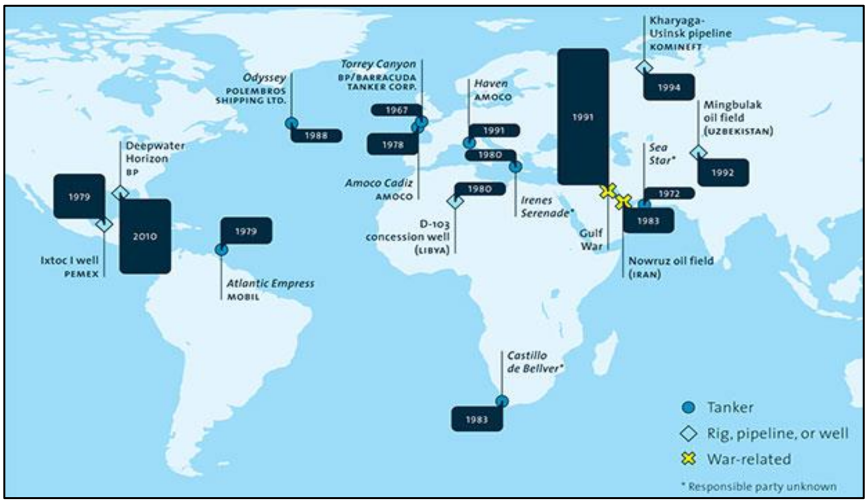


Figure 8.1: Biggest oil spills in history (illustration by Nicholas Feltron, feltron.com).

Beside the attempts to stop the oil flow as fast as possible several oil spill response measures were initiated at the incident site in order to reduce its impact on the marine environment, Figure 8.2. Mechanical oil recovery was carried out at sea and on shore, in situ burning was conducted and oil booms and sand walls were used to keep oil away from the coastlines. To reduce the oil amount on the water surface approximately 7 million liters of dispersants were applied. For surface application 3700 m³ of Corexit EC9500A and Corexit EC9527A were directly sprayed onto the oil slicks by vessels and aircrafts. And additional 2900 m³ of Corexit EC9500A were used for the subsea application. In particular the application of dispersants is scientifically very interesting, as the dispersants were used in unprecedented quantities and also the subsea injection of dispersants directly at the wellhead was a novelty. Following the oil spill incident numerous research and monitoring programs were undertaken by industry and private companies, governmental agencies, public institutions, universities and NGOs. In order to determine the impact of the oil potentially affected organisms and habitats were monitored.

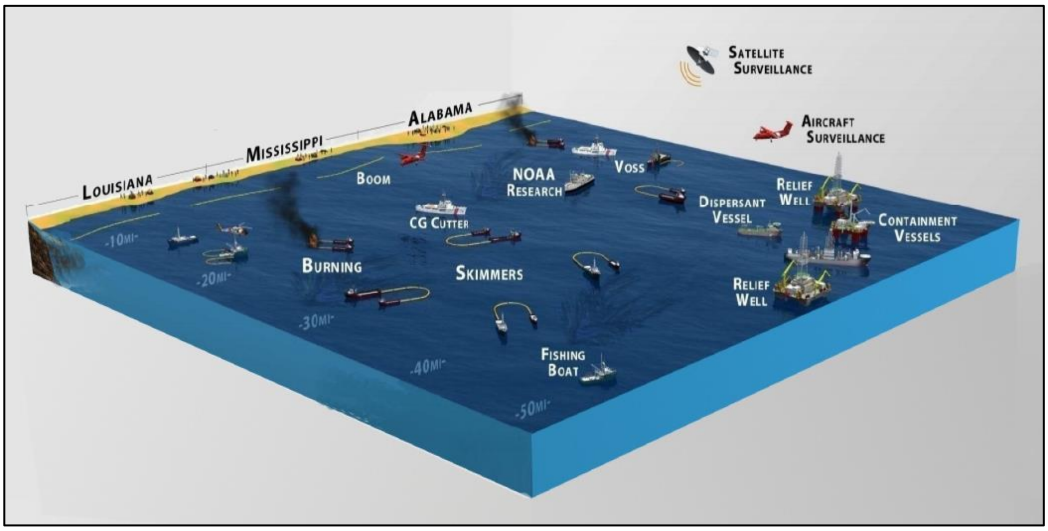


Figure 8.2: Schematic representation of the response measures carried out at and near the area of the Deepwater Horizon disaster (picture: cutout from the U.S. Government Handout Graphic, www.whitehouse.gov).

Scientific activities and publications

Even 5 year after the spill many of these studies and monitoring programs are not published or publicly accessible due to various reasons. One reason is that many of the projects are still running and ongoing to determine long term effects. Currently only an intermediary assessment of the oil spill impact is possible, cf.Figure 8.3.

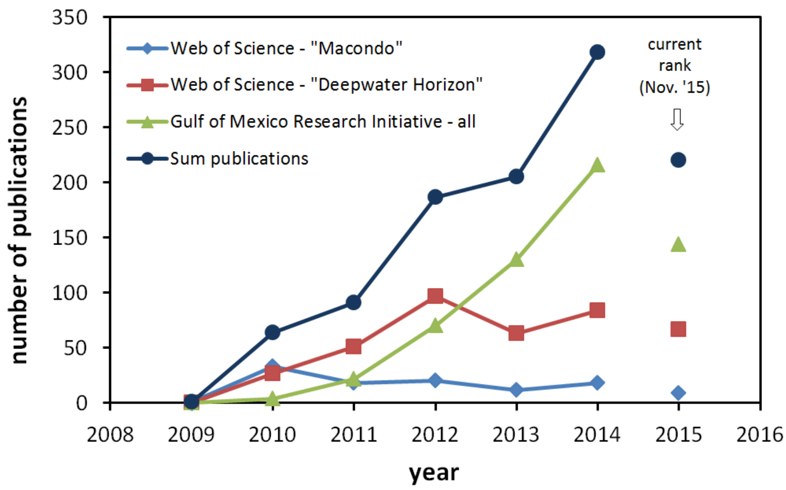


Figure 8.3: Number of publications to specific keywords concerning the Deepwater Horizon incident in Web of Science and Gulf of Mexico Research Initiative.

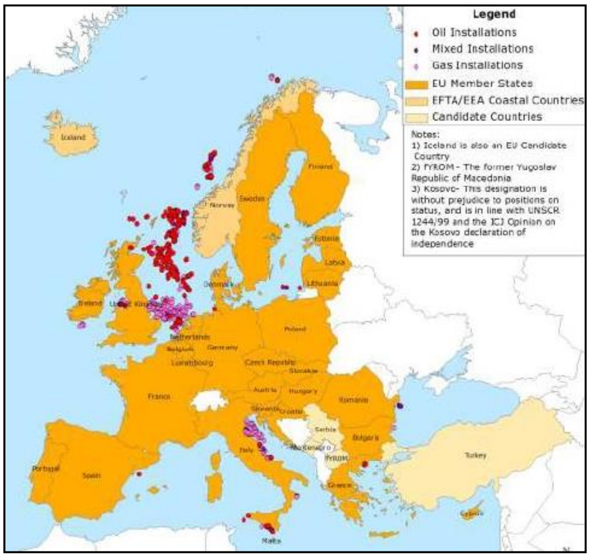
Costs of the incident

With the oil spill response measures and the impact assessment huge financial costs are associated. BP alone set $43 billion on reserves for the oil spill response operations, research programs and compensation fees aside. $28 billion were paid for the cleanup operations and damage limitation, the settlements for various parties were $6 billion. Recently BP was sentenced to $20.8 billion for federal and state claims. The cost in total for BP is currently at approximately $54 billion.

Is the incident important for Europe?

For the countries in Europe the question arises, if the Macondo incident is important for the situation and contingency planning in Europe. The conditions in the North Sea for example are not directly comparable, due to lower maximum water depths, different topography and lower average sea temperatures as well as the different regulatory backgrounds. Despite the constantly rising safety standards accidents on drilling platforms, oil tankers and other ships can never be excluded. In Figure 8.4a the existing oil and gas installations in the European Waters are shown, and in Figure 8.4b the main shipping and transportation routes in Europe are visualized. Due to the potential hazard of oil spills the knowledge and preparation for the contingency planning and response measures have to be kept up to date to implement new and relevant findings.

a)



b)

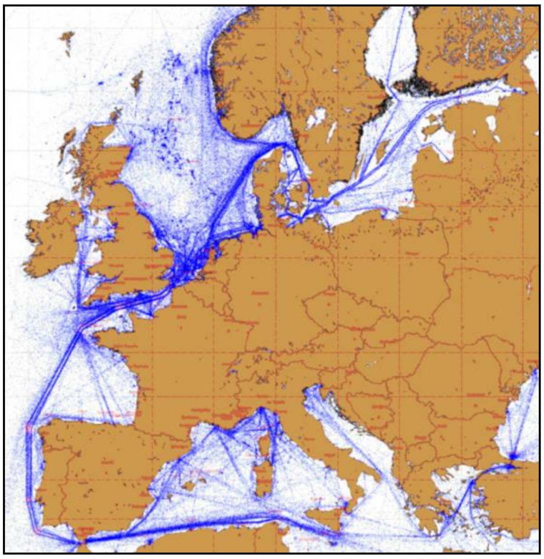


Figure 8.4: a) Oil and gas installations in the EU member states (image: EMSA 2014).
b) Shipping routes in Europe (Kerbaol & Hajduch, CLS France, ENVISAT ESA 2002-2009).

Main topics and subject area for an assessment

New findings from the incident can be deducted for several subject-specific topics. The findings of the Macondo incident can be subdivided in the following major scientific topics:

- contingency planning and decision making
- efficiency of the mechanical oil spill response
- in situ burning and its aftermath
- application and efficiency of the chemical response
- process understanding, distribution, fate and degradation
- adverse impact on the environment and recovery
- procedures for oiled organisms and benefits
- monitoring concepts to survey the incident
- human health issues and operational aspects
- economic aspects
- media communications and information transfer
- political implementation and regulatory consequences

A first evaluation of the main topics was also carried out by the members of the German Independent Environmental Group of Experts "Consequences of Pollution Incidents" (UEG) in a report in 2011 (UEG 2011). Several aspects and interactions of the afore-mentioned topics are currently still discussed in the scientific communities. Because of the complexity and the huge amount of information, in this context only some findings with relevance for an implementation in the oil spill response and contingency planning are presented for selected topics.

Process understanding, distribution, fate and degradation

Due to the high temperatures in the Gulf of Mexico, high amounts of volatile oil components evaporated into the atmosphere. The degradation of the remaining oil components occurs under aerobic as well as anaerobic conditions, whereas the aerobic degradation is generally quicker. NOAA (National Oceanic and Atmospheric Administration) estimates that approximately 64.000 t of oil per year reach the Gulf of Mexico by natural processes like oil seeps. Therefore it is assumed the oil degradation processes in the gulf had a shorter lag phase. Microbiological degradation processes are only known roughly, likewise the impact of the applied dispersants is unknown. It was measured, that the decomposition of methane at first was very fast and then was reduced dramatically at the end of June, the reasons are yet unknown.

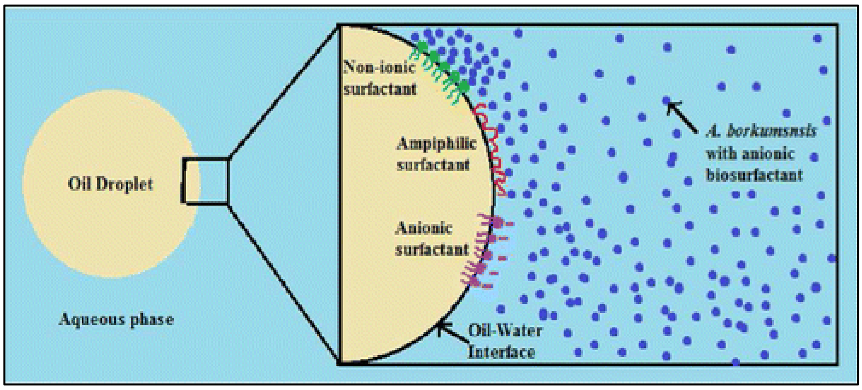


Figure 8.5: Interaction of A. borkumensis with different dispersant surfactants at the oil-water interface (from Bookstaver et al. 2015).

There is no clear conclusion on the efficiency of the application of dispersants and its influence on the microbiological communities and processes. Currently it is highly debated if dispersants promote or suppress the biodegradation of oil compounds. Bookstaver et al. (2015) propose that the degradation possibly depends on the dispersant product and its surfactants that are applied. They analysed the hydrocarbon degrading bacterium *Alcanivorax borkumensis* and its growth at the interface of oil and water. Low levels of negatively charged (anionic) surfactants repelled *A. borkumensis*, whereas low levels of the neutrally charged (nonionic) surfactant nearly doubled its growth rate compared to a control, see Figure 8.5. Of the surfactants tested only Tween 20 assists the bacterial growth, Corexit EC9500A affected the growth negatively. Apparently not every surfactant does enhance the natural degradation abilities of bacteria, since the applied anionic surfactants repel the bacteria with its own biosurfactants (Bookstaver et al 2015). The use of non-ionic surfactants (as Tween 20) should be investigated further.

Corexit EC9500A was applied in the Gulf of Mexico. In contrast to North-Amerika Corexit is not stored in relevant amounts in the European stockpiles (EMSA 2014). The dispersants in the European stockpiles with higher capacities are: Dasic Slickgone NS, Gamlen OD4000, Inipol IP80, Finasol OSR62, Dispolene 36S, BP Enersperes 1583, Finasol OSR65, Dasic Slickgone LTSW.

The processes, distribution, fate and degradation of oil and dispersants are not fully understood. For the dispersant application in the Gulf of Mexico it is presumed that the formation of the oil plumes was intensified by the underwater application of dispersants. To learn more about where the Corexit finally ended up, researchers used the component DOSS (dioctyl sodium sulfosuccinate) to trace the dispersant (Kujawinski et al. 2011).

The oil spill covered up to 75 000 km^2 of the sea surface and approximately 2000 km of coast were affected. Due to the weathering of the oil and other processes the non-volatile not quickly degraded oil compounds from the water surface and the water column are sinking on the sea bottom. David et al. (2014) identified a region of at least 3200 km^2 of sea bottom that was covered with oil from the Macondo Well. From the seabed the oil can be partly incorporated into the sediment. Five years after the incident the oil from Macondo well is still found in or on the seabed. Estimations assume more than 380 000 tons of oil are still in the environment. These depositions can be resuspended. Especially after hurricanes and storm events tar balls were found at the beaches.

Adverse impact on the environment and its recovery

Adverse effects on various species from different trophic levels were measured in the various monitoring projects e.g. for invertebrates, corals, shellfish, fish, birds and marine mammals. The impact of the oil can be divided in immediate (acute) effects and long-term (chronic) effects. Acute effects can comprise general unspecific toxic effects potentially leading to subsequent lethal effects, consequences of physical effects (oiling of organisms), which may lead to loss of buoyancy and thermal insulation, or internal inflammation and bleeding resulting from the ingestion of oil. Chronic effects can comprise direct long-term toxic effects such as reproduction inhibition or indirect effects resulting from modified food supply due to effect on other species in the food chain. Due to the fact, that many organisms of higher trophic level have lower reproduction rates, the consequences on the marine populations are currently not completely assessable. The same is valid for deep sea species, which live in lower temperatures and therefore have much lower metabolic rates and reproduction. The influence of the big amount of oil with its toxicity and also its organic load on the deep sea environment and its food web is today largely unknown. The same applies to the long-termed effects of the dispersants on the whole marine ecosystem.

Human health issues and operational aspects

It has been reported that up to 200.000 people were having health issues due to the Deepwater Horizon incident. The health issues range from skin problems, respiratory symptoms to mental disorders with depressions and distress. Partly these issues could have been prevented by the proper use of personal protective equipment (PPE) and adequate safety training for the potentially endangered staff. Hence these aspects should be taken into account when planning dispersant application involving the public and the locally deployed oil spill combating units. Anyway, it was a novelty, that dispersants were applied in spill operations under mission-tactical reasons to reduce the atmospheric load with volatile organic compounds.

Conclusions

The Deepwater Horizon incident has initiated an intensive debate over the usage of dispersants. Many research programs are still running and a lot of the results are still not published - or they are not publicly accessible today. The adverse effects of the Deepwater Horizon oil spill on the environment and the biocoenosis are still measurable - and further impairment can be assumed, since the spilled oil only partly degraded and to date can be found in the environment. Five years of monitoring and research are too short to determine the long-term effects on the marine ecosystem and to fully assess the impact of this incident. Nevertheless the current and future findings should also be used in Europe to include these in the contingency plans where appropriate.

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9 Decision making process

Ivan Calvez

Centre of Documentation, Research and Experimentation on Accidental Water Pollution (Cedre), Brest, France

Introduction

Aiming at providing the general public and oil spill responders with pertinent information documents and practical guidelines under the framework of the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC), the 61st session of the Marine Environmental Committee (MEPC) of the International Maritime Organization (IMO) decided to review the existing IMO guideline (dating from 1995) on the use of oil spill dispersants at sea.

To this end, a Pollution Prevention and Response (PPR) inter-sessional correspondence group, including representatives from various countries and from both public/private sector, coordinated by CEntre de Documentation Recherche et Expérimentations sur les pollutions accidentelles des eaux (Cedre) (France) and Department Fisheries and Oceans (DFO) (Canada), has been tasked to draft parts I-III of an upcoming revised "Guideline for the use of dispersants for combating oil pollution at sea". Those parts, approved by MEPC, address specific issues as follows[1]:

- Part I (Basic Information on Dispersants and Their Application)
- Part II (Outline for a National Policy)
- Part III (Operational and Technical Sheets)

In particular, Part II aims at assisting competent authorities in defining/reviewing their policy regarding chemical dispersants use at sea. In a nutshell, it sums up tasks to be completed when establishing a national oil spill contingency plan (NOSCP), integrating scientific issues (oil dispersibility studies, principles for NEBA[2], geographical boundaries…), technical issues (selection processes for dispersants, spraying equipment…), as well as operational/logistical related issues (e.g. authorities in charge, flight pre-authorizations, efficiency assessment/monitoring ops, ancillary resources…).

Amongst various topics, it provides a rationale for facilitating the decision-making process when considering dispersant application at the time of the incident. This process may be represented under the form of a decision-tree, laid out through 3 successive steps addressing 3 essential concerns: oil dispersibility, potential impacts, and logistical capability.

Chemical dispersion is one of the available response strategies to combat oil spills at sea, amongst which containment and mechanical recovery is one of the most typical. As for any technique and despite having operational advantages, its applicability may be impeded by different factors (oil properties, metoceanic features, etc.). Thus, the selection of the most appropriate strategy(ies) should rely upon a comparative examination of the options own merits, i.e. their expected feasibility, efficiency, as well as overall benefit (i.e. mitigation of environmental/economic impacts).

Applied onto oil slicks, chemical dispersants tend:

(i) to reduce interfacial tension between water and oil and, as a result, allow for a natural (wave-induced) mixing of the oil into tiny droplets, as well as

(ii) to prevent their coalescence (reverting, eventually, into an water-in-oil emulsion slick).

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[1] Part IV (Sub-sea Dispersant Application) is in progress, under the coordination of the United States Cost Guard (USCG).

[2] Net Environmental Benefit Analysis

By being suspended in the water column, such droplets are expected to be diluted into the marine environment thanks to turbulence and currents. Basically, such dispersion operations aim at transferring oil from the sea surface into the water column, “scattering” the slicks into a more readily biodegradable (*i.e.* tiny droplets bioavailable for microorganisms) form.

Other expected benefits from chemical dispersion are to mitigate early impacts on marine fauna using sea surface (e.g. marine diving birds), to prevent stranding of persistent/emulsified slicks on the shoreline (and related environmental/economic resources), as well as to avoid or limit waste management (e.g. as required after mechanical recovery and/or shoreline cleanup).

Nevertheless, along the decision process those advantages should be put into balance with the various constraints (e.g. oil type, mixing energy) that may limit the efficiency of chemical dispersants, or generate unwanted effects. Regarding this latter point, the locally increased concentration of droplets in the water column should be as transient as possible (i.e. potential for dilution should be ensured) to avoid potentially harmful/toxic effects on organisms that would otherwise have not been exposed/affected. From an operational point of view, caution has also to be taken to avoid counteracting with other response strategies (chemical dispersion should not be performed in areas where containment & recovery operations take place)[3].

In this context, at the time of an incident the overall purpose of a useable decision process is to enable relevant authorities to check swiftly if it is possible (or not) to “perform dispersion in the right way”, *i.e.* to verify that conditions are met to achieve optimum/expected results.
Considering that chemical dispersants are efficient mostly during the early stages/hours after the spill, it is of utmost importance that decision is taken as quickly as possible. The delay is dependent on the degree of preparation and, also, considerations about physico-chemical (e.g. oil characteristics) vs. environmental and logistic issues.
It is proposed that those issues are addressed by answering 3 successive questions as follows:

1. Is dispersion possible? (oil dispersible from a physico-chemical point of view)
2. Is dispersion acceptable? (“beneficial” trade-off from an environmental point of view)
3. Is dispersion feasible? (from a logistical point of view)

Along this process, as soon as any answer is ‘no’ (Figure 9.1), response options other than chemical dispersion need to be considered.

[3] once dispersant is spread on the oil, even if dispersion is not totally effective, mechanical recovery becomes difficult

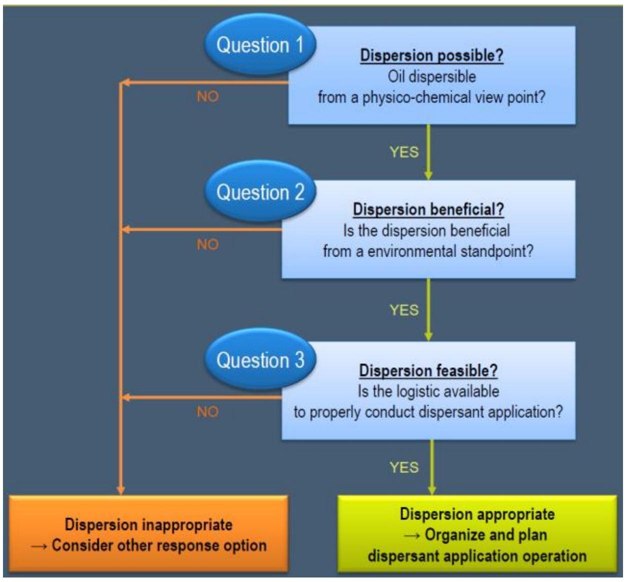

Figure 9.1 (adapt. from Merlin, 2015)

Oil dispersible or not? (Figure 9.2)

The effectiveness of chemical dispersion depends on the nature of the oil; the viscosity at ambient temperature constitutes one of the most important factors.

Chemical dispersion is usually possible for viscosities under 5,000 cSt (with some exceptions, for example, in the case of hydrocarbons high in paraffin). When viscosity increases beyond 5,000 cSt, the chances of success decrease quickly. More than often, dispersion is considered not suitable for viscosities ranging from 10,000 cSt and beyond.

Besides its intrinsic physic-chemical characteristics, oil viscosity increases with time spent at-sea, due to the (met-oceanic driven) weathering process. As a result, its dispersibility decreases with time, and oil is generally dispersible for a limited duration referred to as the "window of opportunity for chemical dispersion":

- To estimate the viscosity of an oil, once spilled at-sea, and the window of opportunity for dispersion, various data-processing models can be used to calculate the weathering of a given oil (according to both its composition and the met-oceanic conditions);
- For an oil of high viscosity, the greater the mixing energy (wave action, sea state), the higher the potential for an efficient action of chemical dispersants;
- Oil Pour Point[4] is also a characteristic to be considered, knowing that when ambient temperature is a few degrees less than the pour point value, oil ceases to be fluid and becomes undispersible.

It should be noted that, whenever particular oils at risk of being spilled have been identified in a given NOSCP (e.g. oil frequently transported in -or in the close vicinity- of national waters, import/storage harbor activities, etc.), it is recommended to carry out dedicated studies to assess the "window of opportunity for dispersion" for those oils. This can be done through modelling tools, as well as through laboratory estimations of oil dispersibility vs. weathering/viscosity. Results may be integrated in tables showing the expected oil viscosity, and the

[4] Pour point: the temperature under which an oil does no longer flow, according to specific laboratory conditions (ASTM –D97 / IP 15)

corresponding window of opportunity, according to metoceanic conditions (temperature, wind).
During a spill emergency, the most straightforward way to assess dispersibility of the spilled oil would be to perform dispersibility tests on *in situ* oil samples.
Nevertheless, such field sampling may not be possible, and spilled oil viscosity should then be assessed according to the following steps:

- does the viscosity of *fresh* oil, given sea temperature, makes it dispersible *a priori* (> or < 10,000 cSt)?
- according to the oil pour point vs. sea temperature, is there a chance for the oil to stay fluid?
- after having assessed the actual oil viscosity at sea, generally through oil weathering models, is the oil dispersible at the time of dispersant application? Data from weathering pre-studies (dispersibility as a function of viscosity), if available, may be useful to answer this question. Otherwise simplified tables (expected dispersibility based on oil viscosity vs. sea state) may be used.

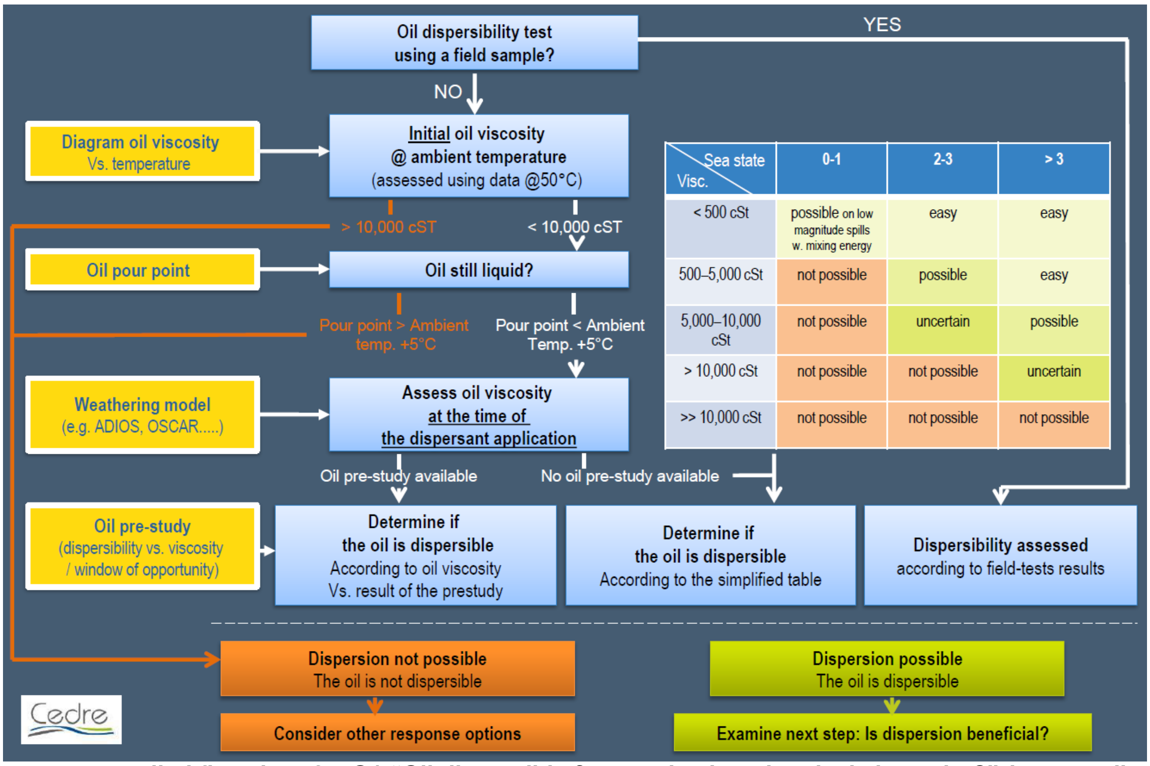

Figure 9.2: Detailed flowchart for Q1 "Oil dispersible from a physico-chemical viewpoint?" (*Note: Yellow boxes indicate the information which should be, as possible, made available in NOSCP*) (adapt. from Merlin, 2015).

Chemical dispersion: an environmentally "beneficial" trade-off? (Figure 9.3)

Toxicity of dispersed oil (*i.e.* bioavailable small-sized droplets -typically tenths of micrometers) may adversely impact marine fauna and flora. For this reason, chemical dispersion is not applicable everywhere, and is generally not recommended :

(i) in, or in the immediate vicinity of, ecologically vulnerable/sensitive areas, or
(ii) in areas where renewal and mixing of water do not guarantee rapid dilution of the droplets.

Also, if implemented in sheltered and/or shallow waters, dispersion process may lead to adsorption of droplets on suspended matter and eventually its incorporation into sediments.

The definition of areas where chemical dispersion can be reasonably undertaken is a relatively long and complex process, since it should account for many local environmental parameters and data (currents, ecological resources and related sensitivities, etc.). Such a task -that is having defined geographical boundaries for the use of dispersants- can hardly be carried out during an incident. More realistically, it should be included in contingency planning activities:

- through scenarios-based studies, allowing for a comparison of expected environmental and socio-economic impacts under “dispersed oil scenario” vs. “undispersed oil scenario” (mechanical recovery at-sea, shoreline cleanup);
- according to a NEBA approach, taking into account local characteristics: sensitive ecological and socio-economic resources (e.g. species of environmental value, marine protected areas, fisheries resources, life cycles and seasonal variations, and migration of the marine species of interest, currents).

These areas may also be predefined within boundaries (i.e. distance from the shore and water depth allowing for sufficient dilution) corresponding to chemical dispersion of spills of increasing magnitude, from small [e.g. up to 200 t. spills] to large [e.g. larger than 200 t.] events.

At the time of a spill, the first step for decision is to assess if the oil is sufficiently far from the shoreline or from other sensitive items, so as not to cause damage. If geographical boundaries for dispersant use (see above) have been pre-established, decision may be made according to the location of the slicks: if those are outside (offshore) the boundaries, chemical dispersion may be implemented. Otherwise, or in case no boundaries have been pre-established, decision may rely upon a NEBA approach carried out using drift models and available data about ecological resources at risk (maps, distribution, sensitivities, etc.).

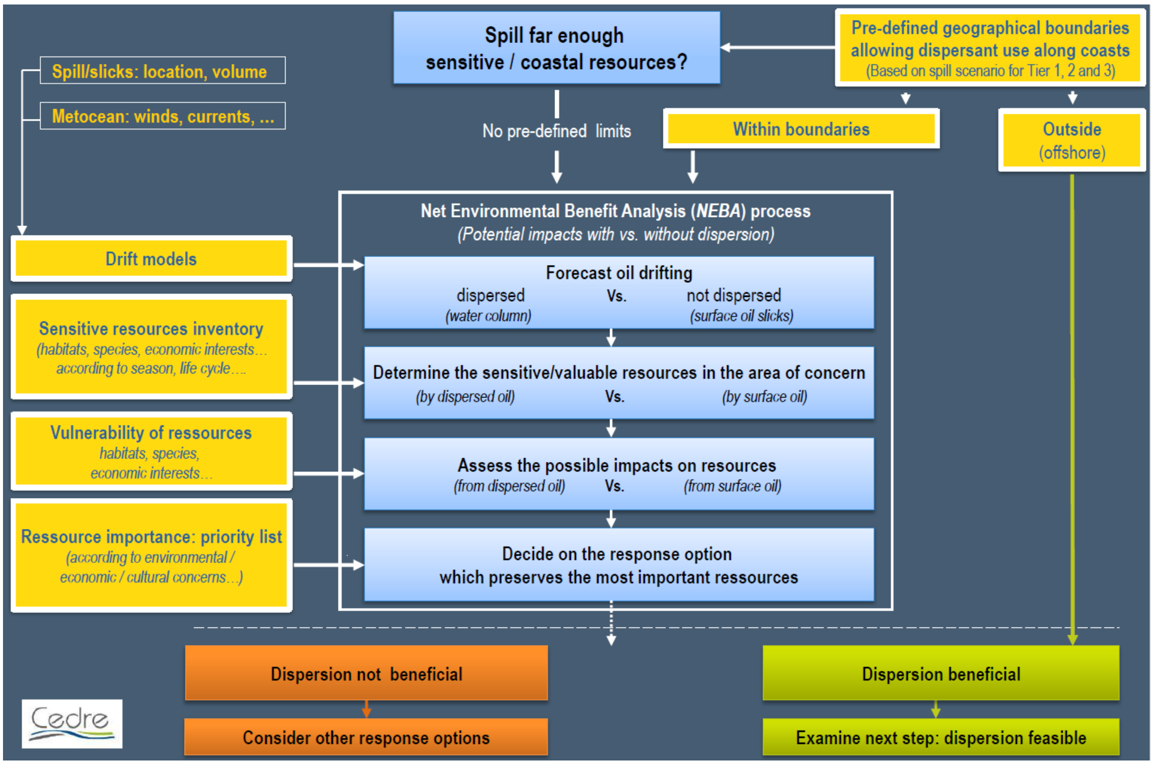

Figure 9.3: Detailed flowchart for Q2 “Is dispersion beneficial from an environmental viewpoint?” (*Note: Yellow boxes indicate information which should be, as possible, made available in NOSCP*) (adapt. from Merlin, 2015).

Are logistics available and sufficient for dispersant application? (Figure 9.4)

During an actual spill event, the first thing to check regarding logistics is the availability of dispersant and, moreover, whether quantities are sufficient for the size of the spill. Such updated inventory of dispersant stockpile should be included in the NOSCP, along with inventories of spraying systems, other ancillary resources, as well as a listing of requirements (stockpiles location, equipment characteristics, compatibility, availability, operational limit conditions, mobilization and deployment timeframe, etc.)[5].

Dispersants may be available, but in insufficient quantity for an application on the entire spill: in such case it can be decided to target an appropriate selection of oil slicks (e.g. slicks that may pose a significant risk towards vulnerable areas).

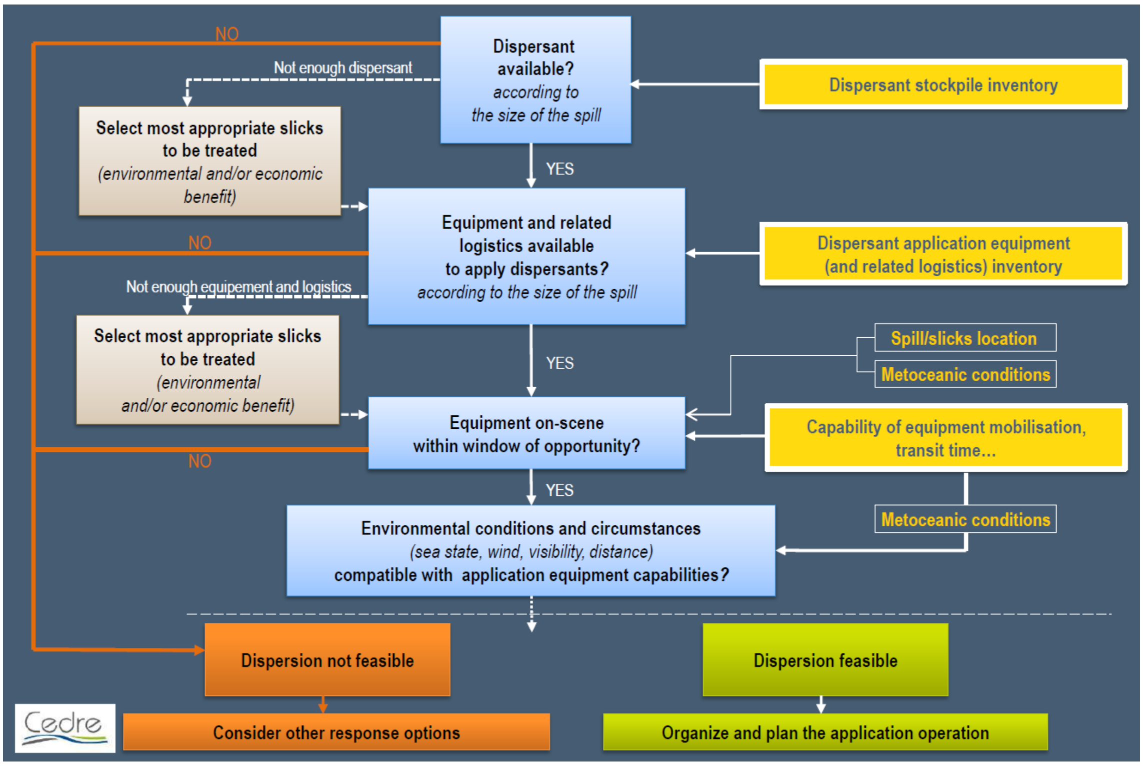

Figure 9.4: Detailed flowchart for Q3 "Is dispersion feasible from a logistical view point?" (*Note: Yellow boxes indicate information which should be, as possible, made available in NOSCP*) (adapt. from Merlin, 2015).

The next steps are:

(i) to verify the availability (or not) of dispersant application equipment and ancillary resources, and that conducting the operations is logistically feasible;

(ii) to ensure that equipment and resources can be mobilized on location in due time (i.e. within the "window of opportunity for dispersion of the oil").

Such verifications rely upon inventory of stockpiles/resources, as well as info regarding mobilization delays, which should have been included in a NOSCP.

[5] Complementary resources include aerial surveillance aircrafts for guiding the operations at sea and checking/monitoring dispersion ops efficiency, communication/reporting as well as transfer equipment.

The final step is to check if dispersant application can be conducted properly according to the capabilities of the equipment and the prevailing weather: if not, consider other response options; otherwise, plan and implement the dispersant application operation.

In conclusion, Part II of the IMO guideline for the use of dispersants for combatting oil spills at sea, may be viewed as a tool to facilitate setting up national regulation & organization, by including recommendations as to the way to act, the requirements to be met for a sound planning, and -as described here- relevant criteria for decision-making at the time of the spill. In this latter case, it may contribute to ease the decision whether of not use dispersants during the spill.

Finally, the development of these guidelines in the international framework (that is the IMO) may help harmonizing policies at a regional level, and ultimately be beneficial for the various potentially involved public and private stakeholders.

References

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10 Dispersants: Operational experience and sea trials in the UK

Kevin Colcomb

Maritime and Coastguard Agency (MCA), Southampton, UK

Dispersant use as a response to maritime oil pollution in the UK

The UK response to oil spills is based on a basket of options, dispersant use is but one of those options and in many cases carried out in parallel with other techniques such as at-sea recovery. Decisions taken are based on a wide range of parameters such as the oil type, is the oil amenable? What is the spill threatening in terms of economy, environment, amenity etc? Is the spill in shallow water and thereby oil dispersion likely to make matters worse? Each incident is assessed on its own merits through a well-established protocol by MCA and the range of UK stakeholders routinely involved in oil spill response. Typically the main players are MCA, the appropriate Environmental Regulator, Statutory Nature Conservation Body, Fisheries Department and Local Authorities.

Dispersants remain a primary United Kingdom response to oil spilled in the marine environment. However, legislation prohibits the use in UK waters of oil treatment substances unless approved by an appropriate regulatory and licensing authority.

The licensing process for dispersant use is exclusively determined by the individual responsible authorities: Marine Management Organisation (MMO) for England, Natural Resources Wales for Wales (NRW), Marine Scotland (MS) for Scotland and Northern Ireland Environment Agency (NIEA) for Northern Ireland. The rationale for an ongoing dispersant campaign during incident response will be influenced by those bodies plus input from the UK Environment Groups (EG's).

Dispersants: A summary of the UK Regulations

- Regulations are not advisory, it is an offence to not comply
- Illegal to use unlicensed products
- Illegal to spray knowing operations are ineffective
- Illegal to spray in shallow water without dispensation
- Best efforts must be made to hit dispersible oil
- Best efforts must be made to confirm dispersion is real

The regulations exist to promote best practise and protect the environment. After formal approval has been given for an operational dispersant campaign to commence the UK regulators will typically closely monitor ongoing dispersant operations as some factors may well change over time.

The approval process for the use of oil spill treatment products in the UK.

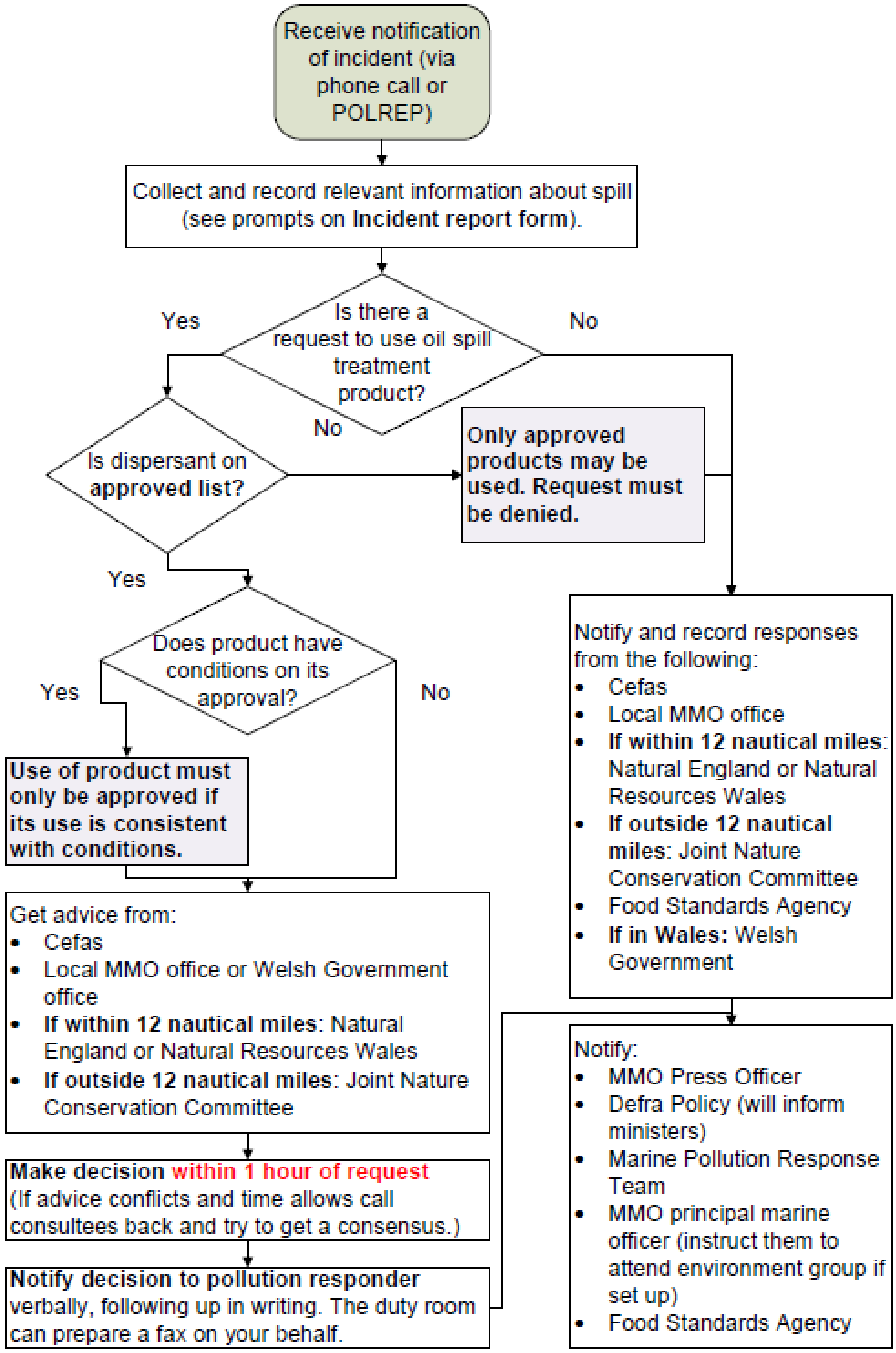

Figure 10.1: Scheme illustrating the approval process for the use of oil spill treatment products

Over the last 50 years or so there have been a number of incidents involving use of dispersants in the UK, probably more than in any other European States:

1967	TORREY CANYON
1969	HAMILTON TRADER
1970	PACIFIC GLORY
1973	CONOCO BRITANNIA
1978	ELENI V
1978	CHRISTOS BITAS
1983	SIVAND
1989	PHILLIPS OKLAHOMA
1990	ROSE BAY
1993	BRAER
1996	SEA EMPRESS
1997	CAPTAIN FIELD
2007	NAPOLI

Here is a brief summary of three of the most well-known incidents where dispersants were used:

Torrey Canyon "detergent" response

The very first significant use of dispersants was, with hindsight, a very damaging response. The products used were developed in the absence of a regulatory regime and were highly toxic. The application of those products was again, with hindsight, delivered in a manner which led to increased environmental damage.

- 1967
- 110,000 tonnes of Kuwait crude oil carried - some burned, some sunk
- Approximately 70,000 tonnes of oil spilled
- Approximately 12,000 to 15,000 tonnes of detergent used in the UK
- Highly toxic surfactants
- Devastating effect on near-shore marine life
- Long held in memory of opponents of dispersants
- Detergent added to oil in surf zone
  - Greatest mixing energy, but nowhere for dispersed oil to go
- Barrels punctured and rolled down cliffs
  - Because of lack of proper spraying equipment
- Detergent hosed onto oil on the beach
  - Turned beaches into a 'quicksand' in places

Dispersant use at the Braer spill

Dispersants were used as a primary response to the BRAER oil spill in Shetland. What wasn't fully understood at the time were the properties of the Gullfacs crude oil. That particular crude was very light and readily dispersible without any help from chemical dispersants, that combined with the extremely high prevailing energy conditions meant that the oil would have dispersed without the application of dispersants.

- January 1993
- 84,700 tonnes Gullfaks crude spilt
- Extremely rough seas
- 120 tonnes dispersant sprayed

- Oil could not emulsify
- With 20/20 hindsight, no reason to spray dispersant

Dispersant use at the Sea Empress spill

Dispersant use during the Sea Empress incident was regarded as highly successful as a response measure. The dispersant campaign was estimated to have reduced by up to 2/3 the quantity of oil coming ashore and impacting sites of amenity value and environmental sensitivity.

- February 1996
- 72,000 tonnes Forties crude spilt
- 30-15 knot winds
- 446 tonnes dispersant sprayed
- 37,000 tonnes oil dispersed:
    - 50 % - 66 % by dispersant
    - 33 % - 50 % naturally

Both the Braer and the Sea Empress incidents were followed up by detailed technical and environmental evaluations: The Ecological Steering Group on the Oil Spill in Shetland (ESGOSS) and The Sea Empress Environmental Evaluation Committee (SEEEC).

Oil spill response – Research and Development in the UK.

Research and Operational experience has helped the UK with the development of smarter response and decision making with respect to dispersant use. The UK has carried out extensive research into oil spill response over the last 30+ years. Much of that work was carried out at Warren Spring Laboratory, Stevenage UK and subsequently AEA Technology. MCA have more recently sponsored much research into a wide range of marine pollution related work including:

- beach cleaning techniques
- clean-up techniques for saltmarshes
- fate of oil at sea and on the shoreline
- waste disposal options
- use of dispersants and demulsifiers
- bioremediation
- chemical spill risk assessment
- limiting viscosity parameters for dispersant use.
- environmental sensitivities of the UK coastal environment including mapping
- potentially polluting shipwrecks
- properties of crude oils
- dispersant droplet size and swath width
- beach material washing – cement mixer and sand scrubber machine
  And many more.

UK Dispersant sea trials: 1977 – 2003

Wide ranging dispersant use sea trials were carried out for many years in the southern North Sea on the research vessel SEASPRING.

- Trials area off Southwold, Suffolk UK – Southern N. Sea
- Licensed by UK Govt.

- Parameters measured across various oil types:
- Trials across range of Crudes and Fuel oils
- 8+ dispersant types
- Range of sea energy conditions
- Range of Dispersant Oil Ratios (DOR's)
- Gives us a good indication of likely effectiveness for incident response.
- Further details of individual trials can be provided by the UK MCA.

And specifically: The 2003 UK Sea Trials

The 2003 UK sea trials were funded by UK MCA and were carried out in the southern North Sea off Southwold in Suffolk. AEA Technology together with MCA devised the trials programme in order to explore the factors which most influence the success or otherwise of dispersants as a countermeasure to oil spills.

Figure 10.2: Picture from UK sea trials

The ability to disperse spilled oils at sea depends on several factors, including oil properties, prevailing sea-state and the treatment rate of oil spill dispersant applied to the oil.

We knew that oil spill dispersants function by allowing a high proportion of the spilled oil volume to be converted by cresting wave action into very small oil droplets that are permanently dispersed. Oil spill dispersants do this because the surfactants that they contain are capable of causing a very large decrease in the oil / water interfacial tension (IFT). IFT (or surface free energy) is caused by the dissimilarity between the polar nature of the molecules of water and the non-polar nature of the hydrocarbon molecules of oil.

The trials sought to look closely at the effect of oil viscosity. In the case of low viscosity oils, it is the IFT that provides the main barrier to dispersion and the application of dispersants can overcome this barrier. The dispersant-enhanced dispersion then proceeds much more rapidly, and to a greater extent, than natural dispersion. In the case of higher viscosity oils, such as HFOs (Heavy Fuel Oils) and highly weathered crude oils, the high viscosity exhibited by the oil, or the emulsified oil, is the major barrier than must be overcome by the dispersant, if the oil is to be dispersed. The high viscosity of a fuel oil or an emulsified crude oil can prevent dispersion in two ways:

(i) The high viscosity of the oil may prevent the dispersant from penetrating into the oil before it is washed off and away into the sea by wave action. Dispersants are only effective if the surfactants that they contain can contact the oil / water interface from within the oil.

(ii) The oil may exhibit a high enough viscosity, or is accompanied by an elastic component, that makes the oil capable of physically resisting the disruptive shearing forces caused by a breaking or cresting wave. Instead of forming oil droplets, the spilled oil layer is temporarily distorted and deformed, but subsequently retains its coherent form. This is, to some extent, sea-state dependent; rougher seas with more frequent and more intense breaking waves are more capable of creating oil droplets than calmer seas.

These two effects are often congruent and it has not been possible to say which is more dominant. The practical effect is to create a limiting oil viscosity for effective dispersion. This is of operational significance to oil spill responders since it imposes a limitation of the use of dispersants as an effective oil spill response method.

Attempts to correlate results with laboratory testing of oil spill dispersants with performance at sea have been difficult because of the inherent limitations of laboratory test methods; none of them can ever be said to be an accurate simulation of the mixing conditions at sea. In addition, the wave conditions at sea vary over an enormous range from flat calm to severe storms and, although a particular lab test method might simulate some aspect of some sea condition, it has not proved possible to correlate any lab test to any particular sea-state.

The work described in the trials final report was a 'return to the basics' of using dispersants; an attempt to use a matrix of oil viscosity, dispersant brand, dispersant treatment rate and prevailing sea conditions to provide information on the limiting oil viscosity of dispersion by using a very simple method of visual observation to determine whether dispersion was or was not occurring.

The main findings – under the conditions of testing which were a sea temperature of 15ºC, producing oil viscosities of 2,000 cP (IFO-180 grade fuel oil) and 7,000 cP (IFO-380 grade fuel oil) and waves associated with wind speeds of between 7 and 14 knots – were that:

(i) The IFO-180 fuel oil appeared to be totally and rapidly dispersed by Dispersant C used at a nominal DOR of 1:25 at 12 knots wind speed. Dispersant B and Dispersant A appeared to be somewhat less effective, but still caused moderate dispersion when use at a nominal DOR of 1:25. At lower wind speeds of 7 to 8 knots, Dispersant C at a nominal DOR of 1:25 was seen to be less effective, but still appeared to cause moderately rapid dispersion of IFO-180.

(ii) The IFO-380 fuel oil did not appear to be rapidly and totally dispersed by any of the three dispersants when used at any of the treatments rates, ranging from nominal DORs of 1:25 to 1:100 at wind speeds of 7 to 9 knots. At wind speeds of 13 - 14 knots, the performance of both Dispersant B and Dispersant C at a DOR of 1:25 improved to produce moderately rapid dispersion of IFO-380. The performance of Dispersant A was less than that of the other two dispersants, but was not tested at the highest wind speeds.

Many more important findings are contained within the main sea trials report (Lewis 2004).

Comparison of the results from the sea-trials with results obtained using the WSL test method (the efficacy test used for the approval of dispersants in the UK) showed that a high level of visible dispersion was only achieved at sea by those combinations of test oil, dispersant brand and dispersant treatment rate that produced over 80 % WSL results and that moderate visible performance was achieved by combinations that produced over 60 % WSL results. These WSL result 'thresholds' are applicable to wind speeds of between 7 and 14 knots.

The report concludes that some oil spill dispersants will be an effective response to oils with viscosity of 2,000 cP, but will not be effective on oils with a viscosity of 7,000 cP or more, in waves associated with wind speeds of 7 to 14 knots. The precise limiting viscosity between 2,000 and 7,000 cP is not known. The limiting viscosity will increase with wind speed; it is possible that oil with a viscosity of 7,000 cP will disperse at 20 or more knots wind speed. However, it was not possible to test this at sea.

Further details on MCA research can be obtained from the MCA Counter Pollution and Salvage Branch.

References

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11 Operational experience worldwide

Alex Hunt

ITOPF, London, UK

Background to ITOPF

ITOPF is a not-for-profit organisation that was established in 1968 in the wake of the TORREY CANYON oil spill in the UK. The main role of its small London-based team is to attend on site at ship-sourced spills of oil, chemicals and other hazardous substances, to provide objective technical advice to all parties, including government authorities, clean-up contractors, claimants, the shipowner and their insurer. This service is normally performed, without charge, at the request of the P&I Club for the vessel or the International Oil Pollution Compensation Funds (IOPC Funds) who rely on the technical expertise provided by ITOPF. Our role on site varies according to the circumstances of the incident, but it is always advisory and based on a consistent scientific approach.

Over the past 48 years ITOPF's technical staff have responded to over 750 incidents in 99 countries in order to give objective advice on clean-up measures, environmental and economic effects, and compensation. While many of these incidents involved crude oil spilled from tankers, ITOPF staff are also increasingly called upon to respond to spills of bunker fuel, chemicals and bulk cargoes from all types of ship. Advice is also occasionally given in relation to oil spills from pipelines and offshore installations, and physical damage to sensitive marine habitats resulting from ship groundings.

Over 90 % of ITOPF's income derives from subscriptions paid by P&I insurers on behalf of their shipowner members. ITOPF Membership comprises over 6,970 tanker owners and bareboat charterers, who between them own or operate about 11,700 tankers, barges and combination carriers with a total gross tonnage of about 357 million GT. This represents virtually all the world's bulk oil, chemical and gas carrier tonnage, and so it is extremely rare for the owner of any such ship engaged in international trade not to be a Member of ITOPF.
ITOPF Associates comprise the owners and bareboat charterers of all other types of ship, currently totalling some 717 million GT. This reflects ITOPF's increasingly important role in responding to bunker spills from non-tankers.

ITOPF's activities are overseen by an international Board of Directors representing the organisation's independent and oil company tanker owner Members, its Associates and P&I insurers. Since its establishment in 1968, ITOPF has evolved into the maritime industry's primary source of objective technical advice, expertise and information on effective response to ship-sourced pollution.

ITOPF has observer status at both the International Maritime Organization (IMO) and the International Oil Pollution Compensation Funds (IOPC Funds), and regularly contributes to discussions on matters relating to ship-sourced pollution.

The first-hand experience gained by our staff through direct involvement in pollution incidents is also utilised during contingency planning and training assignments for governments and industry, as well as in the production of technical publications that are freely available in a wide range of languages.

Further information on the work of ITOPF can be found on our website at www.itopf.com.

Operational Experience of dispersant use

When used judiciously in appropriate conditions, dispersants can be an effective oil spill response strategy. In open water dispersants are capable of rapidly transferring large quantities of floating oil from the sea surface into the top few metres of the water column where it is diluted through the action of sub-surface currents and subsequently degraded by naturally occurring micro-organisms. In many cases significant environmental and economic benefits can be achieved through the use of dispersants, particularly when other at-sea response techniques are limited by weather conditions or availability of resources.

However, as with all spill response techniques, when formulating a strategy the application of dispersants must be carefully considered to take into account the characteristics of the oil, the sea state, weather conditions and environmental or socio-economic sensitivities. When making the decision to use dispersants in a given scenario a key consideration ought to be the potential effect of dispersed oil on nearby sensitive sub-surface resources, such as fish spawning grounds or aquaculture installations. Ideally the risk and consequences of such impacts would be compared and contrasted with the implications of following alternative strategies. For instance, the implications of dispersing oil offshore might be contrasted with the potential impacts of floating oil on seabird populations, or the effect of stranded oil on sensitive coastal habitats, such as saltmarshes or mudflats. This balanced approach to the formulation of a spill response strategy is often referred to as Net Environmental Benefit Analysis (NEBA), and when working through this process it can be particularly helpful to consider the lessons learned from responses to past spills. Taking account of the particular circumstances of case studies can help to inform the decision-making process during the response to a spill, and also during the contingency planning process.

In this section of our report, we provide a summary of the main messages delivered during the ITOPF presentation given at the workshop in Berlin on the subject of 'International Experience of Dispersant Use at Ship-Sourced Spills'. The talk focussed on the experience gained and lessons learned during the responses to four international oil spill incidents that involved the application of dispersant.

Experience of Large-Scale Application

Dispersant application at sea is frequently observed by ITOPF when attending small and medium-scale oil spills in countries where this is a favoured method of response. However, detailed information on the effectiveness of operations is rarely documented or available for subsequent review by the international spill response community. For instance, the specific rationale and decision-making process behind their use is often unclear; and technical details such as the methods of application, application rates, type of dispersant, testing protocols, monitoring of effectiveness or potential impacts are often uncertain, particularly if a variety of different private contractors are involved and they are not directly controlled by the relevant authorities.

The relative paucity of detailed information on dispersant application at smaller scale incidents makes it very difficult to take account of such cases when considering the relative merits and potential risks associated with this key response strategy. However, information is often more readily available in relation to major spills. For these larger cases it is frequently possible to benefit from different perspectives from the organisations and individuals directly involved in operations, such as oil spill response organisations (OSROs), scientific institutes and international technical advisers, in addition to the government authorities taking the lead on the spill response. Having access to a variety of viewpoints in this way can help to build a more complete picture of the actions taken and the lessons learned. In addition, after dealing with major incidents, national governments often carry out a thorough review of the response activities carried out and their relative merits in order to assess their own spill response capability and revise their national contingency plan. The outcomes of such reviews can provide useful information on the benefits and limitations of dispersant application in those particular scenarios.

Fortunately, major oil spills are relatively rare. Certainly in modern times. But this also means that the number of cases where large-scale dispersant operations have been carried out, and where detailed information is available, is also rather limited. In addition, it's worth noting that dispersant application was not considered to be an appropriate strategy in response to many major spills due to factors such as oil type (e.g. Heavy Fuel Oil), weather conditions (e.g. too much or too little wind), location (e.g. too close to shore and/or too shallow) or as a result of a national response policy that does not favour this approach. For example, dispersants were not applied during the response to the AMOCO CADIZ incident (France 1978) as a result of the proximity to shore. Dispersant application did not play a key role during the response to the EXXON VALDEZ spill (USA 1989), although they were used to some degree. In addition, they were not applied during the response to the ERIKA (France 1999) and PRESTIGE (Spain 2002) incidents due to the highly viscous nature of the oil spilled in these cases.

Looking back over the past ten years of ITOPF records (2005-2015), of the 222 incidents for which our technical team has attended on site, there were seven major crude oil spills (>700 MT), and just two of these incidents resulted in the confirmed use of dispersants. Hence, it is clear that large-scale dispersant operations to ship-sourced spills occur relatively rarely. However, it is also notable that two major dispersant spraying operations have been carried out in response to offshore blowout incidents in recent years: namely the MONTARA incident in the Timor Sea in September 2009, and the DEEPWATER HORIZON incident in the Gulf of Mexico in April 2010. The latter incident is widely regarded as the largest accidental oil spill in history with an estimated 4.9 million barrels of crude oil released from the well (source: US EPA). The response involved the largest scale use of dispersants for any spill, with some 1.8 million gallons (6.8 million litres) applied to the released oil (source: US EPA). Approximately 40 % of the dispersants used in the response were applied directly at the source, some 1,500 m below the sea surface, with the remainder applied in the conventional way by spraying onto surface slicks, using both aerial platforms and vessels.

It is understood by ITOPF that for the purposes of this risk assessment process for spills in German waters, the focus is on the potential for dispersant application in response to ship-sourced spills, and hence the case studies discussed in this report relate to such incidents.

Case Study: SEA EMPRESS (United Kingdom 1996)

Despite the fact that we are approaching the 20th anniversary of the SEA EMPRESS oil spill, this case is still a highly pertinent one when it comes to the subject of operational experience of dispersants. Prior to the DEEPWATER HORIZON blowout, the response to the SEA EMPRESS involved the largest scale application of modern concentrate (Type III) dispersants, and as a result there are some key lessons that can be learned from this incident.

The oil tanker SEA EMPRESS, carrying 130,000 tonnes of Forties Blend crude oil from the North Sea, ran aground in the entrance to Milford Haven in Pembrokeshire, South-West Wales on the evening of 15th February 1996. Although the tanker was re-floated within a couple of hours, she sustained serious damage to her starboard and centre tanks, resulting in a large-scale release of oil. Attempts to bring the vessel under control and to undertake a ship-to-ship transfer operation were thwarted by severe weather and the tanker grounded and re-floated several more times over a period of five days. In all, some 72,000 tonnes of crude oil and 370 tonnes of heavy fuel oil were released into the sea between the initial grounding and the final re-floating operation.

The response operation at sea was managed from the Coastguard Centre in Milford Haven by the Marine Pollution Control Unit (MPCU) [now the Counter Pollution and Response Branch of the Maritime and Coastguard Agency (MCA)]. A Joint Response Centre (JRC) was established in Milford Haven by the MPCU and the various local authorities who were involved in the shoreline clean-up. Within the JRC a Technical Team and an Environment Team carried out assessments of shoreline contamination, environmental concerns and priorities, on the basis of which appropriate clean-up techniques were selected. ITOPF was included in the Technical Team along with MPCU (MCA), the local county council, Texaco and the UK Petroleum Industry Association.

Due to severe weather, little could be done to recover oil at sea using booms and skimmers during the initial stages. Throughout the entire response operation some 7,260 tonnes of oily waste was recovered at sea, with an estimated 700 – 1,400 tonnes of 'pure oil' contained within it. However, the conditions and oil type were particularly suitable for the use of dispersants, and as a result the MPCU made the decision to undertake a large-scale offshore aerial spraying operation using their own fleet of six aircraft as well as the C-130 Hercules Aerial Dispersant Delivery System ('ADDS Pack') operated by Oil Spill Response Limited (OSRL). The spraying aircraft were controlled by an Air Coordinator onboard a spotter aircraft who would guide them towards the heaviest concentrations of oil using both visual observations and remote sensing.

The use of a spotter aircraft was a particularly effective approach to the coordination of the operation since it allowed the geographic limits for dispersant use to be confirmed and helped each spraying run to focus on freshly released oil which was in thicker slicks and was more amenable to dispersion. Weathered and emulsified slicks were sprayed as a secondary priority. Once patches of oil had become too weathered to effectively disperse or too fragmented to target by the aircraft spraying would cease.

In addition to the spotter aircraft, there was also an in-situ monitoring team operating from a boat to assess the effectiveness of the spraying operations. This team would survey the sprayed area between runs and would stop the operations once sufficient dispersant had been applied. A submerged flow-through Ultraviolet Fluorescence (UVF) Spectrometer was used to monitor oil concentrations in the sea to indicate effective dispersion. Although the UVF Spectrometer could not determine exactly how much oil was dispersed, by measuring the oil concentration before and after dispersant application, it could indicate qualitatively whether or not dispersed oil in the water column has increased significantly, and therefore whether or not the application was successful.

The application of dispersants during the SEA EMPRESS spill is widely considered to have been highly effective amongst the spill response community, particularly as a result of the measures applied by MPCU for the purposes of coordinating and monitoring the operations. During the eight day aerial spraying operation a total of 446 tonnes of seven different types of dispersant was applied to the released oil, and on the basis of the real-time measurements of oil concentrations in the water column and subsequent mass balance calculations, it was estimated that approximately 37,500 tonnes of crude oil dispersed into the water column, either through natural dispersion or as a result of the application of dispersants. This equates to roughly 52 % of the 72,000 tonnes spilled from SEA EMPRESS, and therefore there is little doubt that the application of dispersants resulted in a dramatic reduction in the amount of oil that eventually stranded along the sensitive shorelines of Pembrokeshire. It is estimated that between around 5,000 tonnes and 15,000 tonnes of oil and emulsion came ashore along around 200 km of coastline, much of it within the Pembrokeshire National Park, but the situation could have been far more severe had dispersants not been applied. Bearing in mind that slicks were fairly rapidly forming water-in-oil emulsions in rough sea conditions, the quantity of oily waste to be recovered from the shoreline could potentially have been greater than 100,000 MT. As it was the main recreational beaches were cleaned in time for the Easter holidays, just two months after the spill.

Aside from the considerable increase in scale and complexity of clean-up operations that would have likely resulted from the greater severity of shoreline contamination, it is also considered likely that the impact on seabirds, coastal waders, intertidal invertebrates and amenity areas were significantly mitigated as a result of the decision to apply dispersants on such a large scale in this case. This is particularly pertinent as the adjoining coastline of Milford Haven is the only coastal National Park in the UK, and nearby islands are bird sanctuaries with internationally-significant populations of puffins, guillemots, gannets and Manx shearwaters. Parts of the region are designed as areas of special scientific interest and are also Special Protected Areas under the European Birds Directive.

In order to assess the environmental damage caused by the spill the UK government appointed an independent committee, the Sea Empress Environmental Evaluation Committee (SEEEC), which brought together teams of experts and commissioned around 80 scientific studies on the effects of the incident. These studies included investigations into the environmental impact of the use of dispersants during the response, and despite their widespread use in this case, it is reasonable to conclude that there were no discernible effects on the biodiversity of the marine environment in Haven estuary that could have been attributed to the use of dispersants. Fortunately, there were no reports of mortalities of commercially exploited crustaceans or fish as a result of the oil spill. Rather, to the contrary, the temporary ban on fishing during the period of elevated hydrocarbon concentrations in the water column resulted in an abundant harvest for commercial stocks over the following year. Studies of the seabed showed little impact resulting from the spill except for marked reductions in the abundance of some species of amphipod in areas to the north of the grounding site. However, as these amphipods were situated within the Haven estuary, where dispersants were not used, it is considered most likely that they were affected by naturally dispersed oil, driven into the water column by the turbulent conditions within the entrance to the Haven. Recovery of the amphipod fauna was evident in all reaches of the Haven estuary some two years after the spill.

Although a very large amount of oil was spilled in a particularly sensitive area as a result of the SEA EMPRESS incident, the impact was far less severe than many people had expected. This was due to a combination of factors: the time of year, the type of oil, weather conditions at the time of the spill, the clean-up response, the strategic use of dispersants, along with the natural resilience and recovery potential of many marine species.
In ITOPF's view, on the basis of its involvement in the response to this incident, both on site and post-spill, the effective mitigation of environmental and economic damages resulting from the SEA EMPRESS spill was due in no small part to the extensive application of dispersants, and in our opinion this highlights the benefits of the UK policy at that time to maintain large-scale aerial dispersant spraying capability.

Case Study: NATUNA SEA (Singapore Strait 2000)

When considering the different factors that can prevent the effective application of dispersants during an oil spill the NATUNA SEA incident in the Singapore Strait in 2000 is a very worthwhile case to reflect on. The response to this particular spill highlights the importance of considering oil type and amenability to dispersion when formulating a strategy. It also serves as a good example of the importance of having information on the oil properties and weather conditions at the time of an incident.

The oil tanker NATUNA SEA (51,095 GT; built 1980) grounded in Indonesian waters in the Singapore Strait on 3rd October 2000. At the time of the incident, the vessel was laden with

70,000 tonnes of Nile Blend crude oil. The grounding damaged a number of cargo tanks and estimates put the spill size at around 7,000 tonnes based on ullage measurements. With almost no wind, the oil moved with the tides back and forth along the length of the Singapore Strait, eventually contaminating shorelines in all three countries bordering the Strait: Singapore, Indonesia and Malaysia.

A response was mounted by the ship's managers, under the direction of the Singapore Maritime and Port Authority (MPA), and the at-sea response initially consisted of the aerial application of dispersant, which is understood to have been judged successful by those on site at the time. Further application was requested by MPA, but due to the oil's high wax content and pour point (33-36°C), the ambient sea temperature (28°C) and the effects of more than 24 hours' weathering, it was considered highly unlikely that this would be effective. Since the sea surface temperature was 3˚C below the pour point of the oil, the viscosity was estimated to be considerably greater than 50,000 centistokes (cSt) and therefore way beyond the envelope of effective dispersion (i.e. typically up to around 5,000 cSt, and not greater than 10,000 cSt). The situation was further exacerbated by calm weather conditions with little wave energy to promote effective dispersion.

No previous testing had been carried out to assess dispersant effectiveness on this little known crude oil but visual observations showed that the oil was semi-solid as early as the first day after the spill. A comprehensive evaluation of subsequent dispersant spraying operations from boats was conducted by two independent scientists from the UK on 5th October 2000, along with ITOPF technical staff on site. This investigation included aerial surveillance and the use of in-situ fluorometry. The results of the fluorometry verified the visual observations and predictions based on the oil properties and it was concluded that the spilled oil was no longer amenable to dispersion.

The strategy for oil pollution counter-measures at sea thus turned to containment and recovery. A number of obstacles still had to be overcome however: the semi-solid nature of the oil along with the associated heavy debris presented severe problems for skimming and pumping, whilst the lack of suitable vessels, particularly barges to receive the recovered oil, delayed these operations by several days. Approximately 1,000 tonnes of oily waste was recovered at sea, which was sent to Indonesia for disposal.

Bearing in mind the issues associated with application of dispersants in this case, the NATUNA SEA spill is considered to be a good example of an incident that demonstrates the critical importance of prior testing of dispersant effectiveness before conducting widespread spraying, and the value of continuous monitoring and re-evaluation of the response strategies.

Case Study: TASMAN SPIRIT (Pakistan 2003)

When devising an appropriate spill response strategy it is important to take account of the potential implications of each technique under consideration, and weigh these against the likely benefits, before coming to a decision. This decision making process is often referred to as a Net Environmental Benefit Analysis, or NEBA. The aim of this process is to mitigate the environmental and socioeconomic damage from the oil spill as much as can be realistically expected. This process is particularly pertinent when considering the application of dispersants, since if the approach is carried out effectively, oil is removed from the sea surface and transferred into the water column, and hence the fate and trajectory of the oil, and the resources it may affect can be rather different than for floating oil slicks or oil stranded on the shoreline.

One particular case that demonstrates the NEBA process with respect to the potential benefits and negative implications of dispersant use is the TASMAN SPIRIT in Pakistan in 2003.

The Maltese tanker TASMAN SPIRIT grounded at the entrance to Karachi Port, Pakistan in the early hours on 27th July 2003. She was carrying 67,800 tonnes of Iranian Light crude oil destined for the national refinery in Karachi. There were also 440 tonnes of heavy fuel oil in aft bunker tanks.

The area in the vicinity of the incident had a number of sensitive sites that had either been contaminated or were under threat of contamination, including the commercial port, the fishing port, salt pans, and also crucially, the Indus River Delta, which is home to the largest arid mangrove forest in the world. This highly sensitive habitat acts as a nursery ground for commercially-exploited species of fish and protected species such as the Indus Dolphin can be found there.

At the time of the incident there was no national contingency plan for oil spill response or resources and expertise for dealing with them, and on the basis of ITOPF advice, personnel and equipment were flown in from Oil Spill Response Ltd (OSRL) in the UK and East Asian Response Ltd (EARL) from Singapore to assist with the response. The involvement of OSRL and EARL was funded directly by the P&I Club.

The condition of the grounded tanker deteriorated as she was subjected to continuous stress from the heavy swell of the prevailing south-west monsoon and by 11th August she began to show signs of breaking up. During discussions with the Pakistani authorities, and in preparation for the likelihood that the tanker would break up in the rough seas and release large quantities of oil cargo, ITOPF advised that the most effective approach to respond to a large-scale release of oil would be to carry out widespread aerial dispersant spraying of oil at sea, despite the fact that the waters surrounding the grounded tanker were relatively shallow. This advice was based on the fact that the oil type was a light crude oil, which would be expected to have a tendency to disperse naturally in the choppy seas driven by monsoon winds, and that the degree of risk posed to the sensitive Indus River Delta mangroves by floating oil slicks was considered to be relatively high in comparison with the risk of dispersed oil affecting resources in the shallow waters near to the grounding site.

Approval for large-scale dispersant use was given by the Karachi Port Trust (KPT) and the Pakistan Environment Protection Agency, and by the time the vessel broke in two overnight on 13th August releasing several thousand tonnes of oil OSRL and EARL had been mobilised to Karachi, along with a C-130 Hercules aircraft from Singapore and a specialised ‘ADDS Pack’ (Aerial Dispersant Delivery System) for large scale aerial dispersant application. An additional 100 tonnes of dispersant were also provided to Pakistan by the UK government to assist with the response. Much of the spilled oil quickly stranded on Clifton Beach, the main recreational beach in Karachi, but significant quantities remained afloat both inside and outside Karachi port. In total, it is estimated that some 30,000 tonnes of oil was spilled from TASMAN SPIRIT.

Between 15th and 17th August dispersants were applied to freshly released oil using the Hercules aircraft, guided towards the heavier slicks by observers within an aerial surveillance aircraft. The approach proved to be effective at dispersing large quantities of floating oil at sea, with observers noting that quantity of oil visible on the sea surface was significantly reduced as a result.

By 18th August some 25,000 tonnes of crude oil cargo had been recovered from the vessel’s tanks by the appointed salvage company, and at that stage approximately 14,000 tonnes remained as the ship continued to break up in the heavy monsoon swells. An additional large release of oil occurred on 29th August when aerial dispersant spraying was carried out again. By this point some 31 tonnes of dispersant had been sprayed onto floating oil from the C-130 and an additional 6 tonnes were sprayed from response vessels near to the grounded casualty. Aerial dispersant spraying operations were eventually stopped shortly afterwards as it was apparent that additional releases of the light crude oil were dispersing naturally with the strong wave action and there was no longer enough of a slick on the sea surface to warrant widespread spraying by that stage. Given the low persistence of Iranian Light crude oil and the high mixing energy in the damaged cargo tanks generated by the incessant heavy swell, it is considered likely that much of the spilled oil dispersed naturally. Hence dispersant application simply accelerated this natural process, while further reducing the risk of floating slicks reaching the Indus River Delta mangroves.

Shoreline contamination resulting from the TASMAN SPIRIT spill was relatively small scale considering the quantity of oil released. Oil came ashore along approximately 8-10 km of shoreline, much of it along Clifton Beach, a sandy recreational beach downwind of the casualty and adjacent to the port. A shoreline clean-up operation was carried out along Clifton Beach and within the harbour, mainly using manual recovery techniques with local workers. Sections of the beach that had been heavily contaminated were tilled at low tide using agricultural ploughs to accelerate the biodegradation of oil within the sediment.

Overall the strategic decision to conduct large scale dispersant application in this case is considered to have been a successful one given the limited extent of spill-related environmental and socio-economic impacts associated with such a large spill in a densely populated and environmentally sensitive area. Field surveys conducted after the incident showed little or no impact on mangroves, salt pans and other sensitive resources in the vicinity, and the geographical extent of shoreline oiling was limited to a ten-mile radius around the grounded tanker. In addition, there were very few reports of impacts of the oil on fisheries.

Case Study: HEBEI SPIRIT (Republic of Korea 2007)

A key consideration when planning the response to any oil spill is the ‘window of opportunity’ for a particular strategy, and this is particularly relevant for dispersant application. Once oil has been released at sea it begins to spread out, fragment and its properties change as a result of a variety of processes, collectively known as weathering. These processes act to reduce the amenability of the floating oil to dispersion since the loss of lighter components to evaporation results in an increased viscosity of the remaining oil, and the incorporation of droplets of seawater in the slicks with wave action can create a water-in-oil emulsion for some oil types, further increasing the viscosity. In addition, as the oil spreads out it becomes increasingly difficult to locate and target suitable slicks. Hence quick decision-making is frequently necessary if an effective dispersant spraying operation is to be mounted. It is therefore advantageous to have considered the use of dispersants for a variety of different spill scenarios during the contingency planning stage, and a clear policy to have been formulated in advance, along with a detailed plan of action with logistical considerations taken into account.

An incident that highlights the issues associated with the window of opportunity for dispersant application is the HEBEI SPIRIT spill in South Korea. On 7th December 2007, the VLCC HEBEI SPIRIT (146,848 GT, built 1993), laden with 209,000 tonnes of four different Middle Eastern crude oils, was struck by a crane barge whilst at anchor off Taean on the west coast of South Korea. The barge broke free from its tow in poor weather, puncturing three port-side cargo tanks on the tanker. Despite mitigating efforts by the crew of HEBEI SPIRIT, approximately 10,900 tonnes of Iranian Heavy, Upper Zakum and Kuwait Export crude oils were released to the sea.

The at-sea response was led by the Korea Coast Guard with support from the Korean Navy and Korea Ocean Environment Management (KOEM) with more than 100 vessels from these organisations involved, along with over 1,500 fishing boats. Dispersants were applied from vessels, from helicopters equipped with spray systems and small fixed-wing crop sprayers, although the extent of this operation is understood to have been relatively modest for a spill of this scale. The focus of at-sea response operations was understood to have been the use of booms and skimmers and sorbents to attempt to recover floating oil.

From the early stages of the response ITOPF had recommended to Korean authorities that large-scale aerial dispersant application be considered as an effective means of mitigating the impacts to sensitive resources along the Korean coastline. However, agreement was not provided until a week after the incident, when OSRL was mobilised to the site with their Hercules aircraft and ADDS Pack aerial spraying system. A test spray was conducted at the time, and it is understood that the results were not encouraging, and the involvement of OSRL was ceased at that stage. By that stage, after a week of the oil spreading oil and weathering at sea, the window of opportunity for widespread spraying of dispersants had passed.

The shoreline contamination resulting from the HEBEI SPIRIT spill was widespread and severe in some areas, particularly within Taean County. The impact of the spill extended across three provinces and several hundred kilometres of coastline, both on the mainland and on numerous islands, along the western coast of South Korea. The west coast of Korea is an important area for fishing and mariculture, and thousands of hectares of seaweed cultivation facilities, particularly laver, and intertidal oyster cultivation were affected by the oil, with severe socio-economic implications. Many farms and facilities required removal and replacement to minimise further contamination of the surrounding area by oil trapped in the facilities. Large-scale hatcheries for laver, sea mustard, abalone, sea cucumber, and finfish were also affected by oil taken in through water intakes. In addition, the Taean-haean Marine National Park is an important tourist area in South Korea with ~21 million visitors annually to the beaches and coastal scenery. While the clean-up work reduced the effect of the oil on this industry, significant losses were nevertheless recorded by tourist businesses.

A major shoreline clean-up operation was undertaken with 21 separate clean-up contractor companies and numerous province-level and city authorities hiring many local villagers as labourers (up to 10,000 people per day). Significant numbers from the army were also deployed together with an immense volunteer effort (up to 50,000 per day).

Although it is not possible to conclude how successful a large-scale aerial dispersant spraying operation may have been in this case, with early intervention it may have been possible to mitigate the widespread shoreline contamination and associated damage to sensitive resources.

Key Lessons Learned

The four case studies discussed in the above sections help to demonstrate some of the key considerations associated with dispersant application as a strategy for dealing with oil spills at sea, such as the advantages of having comprehensive plans in place, including a clear dispersant use policy; the importance of considering the oil type and its properties; the usefulness of carrying out test sprays prior to widespread application of dispersants; the merits of balanced decision-making when taking account of the potential benefits and negative consequences of applying dispersants to oil at sea in sensitive areas; and the importance of making rapid decisions when faced with a short window of opportunity to act.

In ITOPF’s experience the decision whether or not to use dispersants is very rarely ‘clear-cut’ and typically a balance has to be struck between the advantages and limitations of different response options, cost-effectiveness and conflicting priorities for protecting different resources from pollution damage (e.g. from different government agencies, central government, the fishing community, environmental groups and the public). In most instances a balanced assessment of the net environmental and economic benefits will be necessary prior to application. The time available to use dispersants effectively is likely to be limited both by the weathering of the oil and its movement towards sensitive resources. To avoid delays at the time of a spill, the decision on whether dispersants can be used and if so, the precise circumstances under which they may be used, need to be agreed during the process of developing contingency arrangements for spill response.

Concluding Remarks

Dispersant use at oil spills can be a controversial topic, at times generating widespread debate in the media and public forums, particularly during the aftermath of the DEEPWATER HORIZON spill. Their use can be seen as adding another unwanted pollutant into the environment that may prove toxic to marine fauna and flora. In addition, it is recognised that dispersant application is not appropriate for some spill scenarios, depending on oil type, sea state and the proximity of resources that would be particularly vulnerable and sensitive to dispersed oil. However, from ITOPF's perspective there are considerable advantages to having dispersants as an available option to responders, albeit on the basis of a thorough Net Environmental Benefit Analysis (NEBA). In our view, the complete dismissal of dispersants at the contingency planning stage strips those charged with responding to spills of one of their most powerful tools, and thus limits their capability in situations when containment and recovery is likely to be highly ineffective or potentially unfeasible.

Operational experience has shown that mechanical recovery of oil at sea is severely hampered by strong currents and rough seas, and can be rendered unfeasible if conditions are particularly inclement, or if the equipment and/or expertise are insufficient. In ITOPF's experience, it is rare for containment and recovery operations to collect more than around 10-15 % of the spilled oil, even in the most favourable of conditions. Bearing this scenario in mind, it is also important to recognise that in many cases a large proportion of the oil that has not been recovered at sea will eventually drift ashore, sometimes in the form of a highly persistent water-in-oil emulsion, which can be more than three times the original volume spilled at sea. However, if the spilled oil is amenable to dispersion, and the circumstances are appropriate, a well-timed and suitably-scaled dispersant spraying operation may considerably reduce the extent and severity of damage to sensitive coastal resources, as was found during the response to the SEA EMPRESS spill.

There is also merit in recognising that in contrast with containment and recovery operations, dispersant application is typically more effective in choppy sea conditions, such as those which typify the North Sea. Indeed, the process fundamentally requires a certain degree of wave action, and when formulating a spill response strategy it is worthwhile considering that dispersants simply act to enhance the natural dispersion of oil. Provided that the oil is amenable to dispersion and the energy is sufficient, dispersed oil will be present to varying degrees in the water column even before dispersants are applied. Therefore, in such circumstances the decision on dispersant use may not necessarily be a case of deciding whether it is acceptable for oil to enter the water column, since such a scenario may be inevitable, as was seen during the TASMAN SPIRIT spill. In such situations, it may be more realistic to think of the decision to spray as relating to the acceptance and promotion of this natural process.

For many of the reasons outlined above, we suggest that there is considerable merit in giving appropriate thought to the role that dispersants might play in different spill response scenarios during the contingency planning process. While dispersants are not the panacea of oil spill response, having a number of key limitations in some situations, it should be recognised that there is no cure-all solution for dealing with spills, with all strategies having positive and negative implications. In the appropriate circumstances dispersants have been shown to be highly effective at reducing the environmental and economic impacts of oil spills, although there is a need for a rapid response due to the typically short window of opportunity. If a clear dispersant policy exists, with pre-approved areas for application drawn out on sensitivity maps, a quick and effective response is far more likely to occur than it would if the authorisation process needs to take place at the time of an incident.

Further reading

ITOPF Publications

ITOPF has a number of publications and also a film focussing on the subject of dispersant use during oil spills, and the following sections provide an overview of some of these resources and links to this relevant information.

ITOPF Technical Information Paper (TIP) – Over the years ITOPF has produced a series of Technical Information Papers (TIPs) to cover a range of specific subjects relating to spill response. The TIP on the *Use of Dispersants to Treat Oil Spills* provides an overview of some of the practical considerations associated with dispersant application, including the composition of the products and how they work, how they can be applied and the pros and cons of different techniques, calculating application rates and the logistics association with using dispersants, limitations of their use and how to monitor their effectiveness, environmental considerations and contingency planning. The paper can be downloaded from the following link on the ITOPF website: ITOPF Technical Information Paper (TIP)

ITOPF Response to Marine Oil Spills Series: At-Sea Response – In 2014 ITOPF released a series of seven educational films on the subject of *Response to Marine Oil Spills* which have since won awards at the International Oil Spill Conference (IOSC). The third film in the series focusses on *At-Sea Response* and provides an overview of some of the key considerations and practical issues associated with different response strategies, including the use of dispersants. It can be viewed online via the ITOPF website at the following link: [FILM] Response to Marine Oil Spills: At-Sea Response

Review of Practice & Research Needs in Europe – In 2007 ITOPF and the UK's national Centre for Environment, Fisheries and Aquaculture Science (CEFAS) jointly published an article in the peer-reviewed scientific journal Marine Pollution Bulletin [54 (7), July 2007] on the subject of dispersant use in Europe. The article summarises the findings of a desktop study focusing on the practice of dispersant use over a 10 year period from 1995 to 2005, looking in particular at variations between different regions and oil-types. The full paper can be downloaded from the following link on the ITOPF website: Dispersant Practice & Research

Research & Development Projects

Over the years ITOPF has been involved in a number of research and development projects related to dispersants, their applicability in different situations and their potential effects on marine life. The following two projects are particularly pertinent examples of such research.

DISCOBIOL Project – DISCOBIOL is a research project implemented by the Centre of Documentation, Research and Experimentation in Accidental Water Pollution (CEDRE) in Brest, France. This three year research project was conducted in collaboration with the French Agency for Food, Environmental and Occupational Health and Safety, the Fisheries and Ocean Department of Canada, the University of Western Brittany, the University of the Littoral Opal Coast as well as two manufacturers of chemical dispersants: Total and Innospec Ltd. ITOPF co-authored the paper which was presented at the International Oil Spill Convention (IOSC) in Savannah in the USA in 2014. The full paper can be downloaded from the following link on the ITOPF website: DISCOBIOL Report

FishHealth Project – The effect of dispersed oil on fish has been investigated in several studies and one of the more recent ones was supported by ITOPF's Research and Development Award in 2012. The FishHealth Project aimed at establishing a relevant methodology for the assessment of resilience of fish populations to pollution from oil spills. As part of the project, Professor Claireaux from the Université de Bretagne Occidentale and co-workers investigated the impact of mechanically and chemically dispersed light crude oil on the health of pelagic fish. Tolerance to hypoxia and heat as well as swimming performance of European sea bass were measured before and after 48 hours of exposure to mechanically and chemically dispersed oil and used as indicators of their fitness. Further information on the research can be found on the ITOPF Website: FishHealth Summary

12 Chemical dispersion as an oil pollution response solution – French Approach

Gilbert Le Lann

Centre of Documentation, Research and Experimentation on Accidental Water Pollution (Cedre), Brest, France

Qualification of chemical dispersants for use in national waters

The qualification of chemical dispersants for use in areas under French jurisdiction is based on three main tests:

- a test of efficiency, whose objective is to verify that the product allows good dispersion of hydrocarbons in the water column, and that the dispersion remains relatively stable;
- a toxicity test, to ensure that the product does not present a major hazard to the environment;
- and finally a biodegradability test to verify that the product will gradually disappear naturally from areas where it could be used.

The efficiency test is based in France on national standard NF T 90-345. It is carried out in a tank equipped with a stirrer to generate the necessary mechanical energy for the dispersion to take place. A reference oil, in the case of the standard a refined product having a viscosity of about 1300 mPa.s and a density of 0.97 at 20°C, is introduced into the tank with the dispersant to be tested in a ratio of 20 volumes of oil to one volume of a dispersant. After one hour of test, the hydrocarbon concentration in the water is measured. If there is more than 60 % of the initial oil quantity dispersed in water, the dispersant is considered as efficient enough. Other dispersant efficiency tests exist. These include notably the WSL (Warren Spring Laboratories) test used in the UK and based on the use of rotating conical separatory funnels. There is also the MNS (Mackay - Nadeau - Steelman) test used in Canada where oil and dispersant are placed in a cylindrical tank and the mechanical energy is introduced by an air flow which rotates the water. Finally the test SFT (Swirling Flask Test) used in the US is based on using Erlenmeyer flasks placed on a rotary shaker table. Cedre has the ability to implement all of these tests.

The toxicity test is currently performed in France on the basis of another national standard NF T 90-346. It involves comparing in a bench for measuring the LC50 toxicity of the dispersant with that of a reference surfactant, the N-alkyl dimethyl benzyl ammonium chloride (Noranium). The dispersant is considered as acceptable if its toxicity is at least 10 times lower than that of the reference toxic. Tests are conducted for six hours on shrimps. National considerations are currently underway to replace this purely national test by the OSPAR tests, respectively on juvenile turbot, copepods, amphipods and algae. These standardized tests have indeed broad international recognition and form the basis of toxicity studies on marine species in many countries.

Lastly, France makes a biodegradability test of chemical dispersants according to national standard NF T90-349. This test is performed over a period of 28 days, and the dispersant is accepted if its degradation rate at the end of this period is greater than 50 %. However, discussions are ongoing on whether to continue the test because its relevance is not proven. Indeed, the dilution of the product after 28 days is very much higher than the level of biodegradation, which calls into question the interest of this test that would apply more to the use of products in a confined environment, which is not the case in reality.

Chemical dispersants which have passed the above three tests are identified in a list of qualified dispersants which is available online on Cedre's website. Some of these dispersants were purchased by French authorities to build up a national emergency stockpile which is immediately available in case of oil spill following a maritime accident. Efficiency tests are regularly carried out on the dispersants in stockpiles to make sure that their performance does not degrade over time.

Decision to spray chemical dispersants is based on a cost / benefit analysis, the NEBA

The choice whether to use chemical dispersants on a drifting oil slick is guided by a cost-benefit analysis. The procedure is known and documented as the Net Environmental Benefit Analysis (NEBA). The principle is to compare the potential impact of non-dispersed oil slick with that of the oil plume after using chemical dispersants. The analysis is based both on the knowledge of the pollutant (the quantity, the toxicity, ...), on an atlas of environmental and economic sensitivity of areas potentially impacted by the pollution, on the particular sensitivity of elements identified in the atlas to the dispersed and non-dispersed oil, and finally the prediction of the oil drifts with or without dispersant use. The difficulty of the exercise is that in most cases such information is not readily available during the accident, or, if available, its accuracy may be low. In addition, the decision must be made quickly because the time window during which the oil can be treated with chemical dispersants is relatively short, a few hours after the spill to, at most, a few days.

The consequence is that, while the full analysis can be performed on small areas during the preparation of emergency response plans, it is much more complicated to do so in an accidental context of which we know neither the place nor the time it will happen. This led France to set up a decision-making process based on some simple criteria that are applied to all areas under national jurisdiction to enable a very quick decision to implement chemical dispersion as a pollution response action, while ensuring that the environmental benefit of this action will be positive.

A simpler approach for a quick decision

The decision process implemented in France is based on three scenarios of accident leading to the presence at the surface of the sea of oil slicks with respective masses of 10, 100 and 1,000 tons. No scenario beyond a 1,000 tons release was considered because the likelihood of having a single drifting slick of more than 1,000 tons of oil is extremely low. Similarly, offshore exploration and production of hydrocarbons are undeveloped in maritime areas under French jurisdiction, and therefore the decision process does not include the use of dispersants from underwater leaks. The decision process has been prepared solely for decisions related to the treatment of surface slicks. A new analysis would be necessary for the definition of decision criteria related to the use of chemical dispersant underwater, by which to ensure that the concentration of dispersed oil in the water column would remain permanently within acceptable limits.

Studies on the toxicity of dispersed oil carried out in the past have found that concentrations below 10 ppm do not have a significant and long-lasting toxic effect on marine species. This led to a study to determine under which specific conditions it is ensured, for the three scenarios considered, that the oil concentration in the water column remains below the toxicity limit.

Existing models are not able to represent in a reliable way dispersed oil concentration in the water column after treatment of a slick. Information on concentrations of oil below dispersant-treated slicks comes therefore mainly from field experiments in open waters or from measurements made during real accidents where dispersants were used. Immediately after application of the chemical dispersant on a slick, the concentration of oil in water just under it is high and may exceed by far 100 ppm. Under the effect of water movements and currents, the dispersed oil concentration falls down quickly, but the oil plume spreads in surface and in depth. The vertical profile shows however a rapid reduction of the oil concentration as depth increases. The seabed is the location of the most vulnerable ecosystems with a lot of sedentary species. These ecosystems are those which will take the longer time to recover their original functions if impacted by dispersed oil. The important point is therefore to make sure that the concentration of dispersed oil at the seabed will remain well below 10 ppm at any time after treatment of a slick with chemical dispersants. This leads to the definition of a minimum water depth, in order to make sure that the seabed will not be reach by the dispersed oil plume under the effect of its vertical expansion, but also to the definition of a minimum distance to the coast to ensure that the plume will not reach the seabed somewhere else under the effect of its horizontal expansion, to authorize the treatment of a slick with chemical dispersants.

From the considerations above and from experimental measurements of dispersed oil concentration, for each accident scenario a geographical limit has been defined in France for the use of chemical dispersants that meet the following constraints:

- the so-called "10 ton" limit for a floating slick of 0 to 10 tons of oil:
    - A water depth equal to or greater than 5 meters;
    - A distance to the coast equal to or greater than or 0.5 nautical mile;
    - Consideration of areas of specific interest as described below (virtual islands);
- the so-called "100 ton" limit for a floating slick of 10 to 100 tons of oil:
    - A water depth equal to or greater than 10 meters;
    - A distance to the coast equal to or greater than or 1 nautical mile;
    - Consideration of areas of specific interest as described below (virtual islands);
- the so-called "1000 ton" limit for a floating slick of 100 to 1000 tons of oil:
    - A water depth equal to or greater than 15 meters;
    - A distance to the coast equal to or greater than or 2.5 nautical miles;
    - Consideration of areas of specific interest as described below (virtual islands and excluding large protected areas of dispersion for a slick over 100 tons).

For some sensitive areas more restrictive measures are taken. Protected areas are considered in the above described process as "virtual islands" whose contour is taken as equivalent to a coastline. However, for some very large areas, such as Natura 2000 areas, and in consultation with relevant stakeholders, it was decided to simply ban the dispersion of slicks of more than 100 tons in these areas, dispersion of smaller slicks remaining possible, subject to the satisfaction of the criteria limiting the dispersed oil concentration at the seabed to 10 ppm. Estuaries are also treated in a particular way. An area is calculated at the mouth of the river where chemical dispersion is prohibited in order to be sure that under no circumstances dispersed oil may enter the estuary under the effect of tidal currents.

During an accident, when beyond these limits, the use of chemical dispersants is considered to be an interesting response option with a positive environmental benefit. Thus, the decision to treat an oil slick of 50 tons of oil may be taken as soon as the slick is located beyond the limit set for slicks of 10 to 100 tons ("100 ton" limit).

These elements are not however sufficient for making a decision. Depending on their nature, not all hydrocarbons can be treated with chemical dispersants. Authorities shall therefore ensure that the pollutant can be treated this way before starting operations. Another point is to examine alternative response options. One may indeed prefer different options, such as a mechanical recovery, in specific situations. This will be the case if the oceanic and weather conditions are particularly favorable. In this case, the surface mechanical energy would not

be sufficient to generate dispersion of the oil, while the efficiency of the mechanical recovery would be maximal.
Once all these points examined, if the decision to use chemical dispersants is taken, then one must proceed to implementation.

Implementation of the decision, availability of qualified dispersants and spraying platforms

Once the decision to treat an oil slick with chemical dispersants has been made, it is necessary to proceed quickly with the implementation of the decision, because the time slot during which hydrocarbons can be chemically dispersed is limited. In addition, as time elapses, even while remaining within the time slot, the efficiency of chemical dispersion decreases.

For an effective action, it is essential to have a quick access to qualified chemical dispersants from stockpiles and to the platforms for spraying the product, whether ships or aircraft. This can be achieved by implementing dispersant stockpiles at national level and by equipping ships for the application of dispersants. Fitting aircraft for this purpose is not impossible but is much more complicated because of aeronautical constraints.

Another solution is to rely, via partnership agreements or trade agreements, on structures able to provide the service very quickly. The British company OSRL offers this type of service and can provide equipped aircraft and dispersants from its own stocks within 24 hours from initial call. The European Maritime Safety Agency is currently setting up a dispersant spraying capability on its oil spill response stand-by vessels. It seems to be currently studying the possibility to set up chemical dispersant stockpiles to be made available to Member States in case of necessity. A consultation was launched recently for the procurement of chemical dispersants by the Agency.

Conclusion

The process used in France for the selection of qualified chemical dispersants and for making decision on the operational use of dispersants can inspire processes in other countries.

The first point is to define the criteria for qualification of products for use in areas under national jurisdiction. To do this, it is necessary to select an efficiency test from the existing ones and set the efficiency threshold beyond which the dispersant would be acceptable. An acceptable level of toxicity shall also be defined and the corresponding test shall be selected, keeping in mind that the OSPAR tests have a wide international recognition. Once some dispersants have been qualified, it is necessary either to constitute a national stockpile or to implement any other solution that would enable use of the products from a partner's stock.

The difficulty of conducting a full cost - benefit analysis in real time during an accident makes it necessary to define a simple process for decision making in emergency situations. The principle to keep in mind is that this process shall ensure that hydrocarbon concentration in the water column remains below a value for which no significant and lasting toxicity to marine species is observed. A concentration of 10 ppm seems to be reasonable. Any solution meeting this basic requirement and relying only on readily available data for decision making is acceptable.

Finally, it is important to consider the implementation phase of pollution response through the use of chemical dispersants. It is necessary to provide quick and easy access to platforms for the application of dispersants on oil spills at sea. Public service vessels may be fairly simply equipped, but if product spraying from aircraft is necessary, it seems preferable to rely on a service provider.

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13 Marine Management Organisation (MMO) – Dispersant use in UK waters Product Approval Process and Pollution Response

Bernard Christie

Marine Management Organisation (MMO), Newcastle upon Tyne, UK

Introduction

The MMO presentation that was delivered at the workshop in Berlin on 13th November 2015 is largely taken from training material that is directed at staff working in our coastal offices. It is intended to explain how MMO act in a Marine emergency situation and how we interact with different organisations to hopefully achieve the best possible outcome.

In the UK, the MMO has responsibility for both the control of the UK Approved Products (Oil Spill Treatment Product) and also for decision making on whether or not dispersant use can be allowed at the given location of a spillage in English/Welsh waters.

Product Approval

As prerequisite of product approval by MMO, all oil spill treatment products must be tested for their efficacy (effectiveness) and for toxicological hazard. The tests can be carried out within MMO-commissioned laboratories, or by independent laboratories, which must follow standard test protocols and have a recognised accreditation.

Efficacy is determined by a standard laboratory-based procedure described in annex 1 to appendix A WLS Report LR448. The efficacy test aims to assess the proportion of the total volume of treated oil that is dispersed into the water column. The minimum efficacy requirements depend on the type of dispersant being tested. Dispersants must achieve an efficacy of 30 % for type 1 (hydrocarbon solvent-based dispersant applied undiluted) and type 2 (concentrates diluted 1:10 with seawater before application) and 60 % for type 3 (high efficacy concentrates applied undiluted).

For the evaluation of toxicological hazards, 2 toxicity tests using marine species are used. The first test is called the Sea Test and is carried out using the brown shrimp (*Crangon crangon*). This test compares the relative toxicity of an oil dispersant mix to that of oil alone. In order to pass, the product must not increase the toxicity of the oil. The second test is called the Rocky Shore Test and is carried out using the common limpet (*Patella vulgate*). This test compares the toxicity of dispersant alone to that of the standard test oil. In order to pass, the product must not be more toxic than the oil alone. Offshore dispersants are not required to pass the Rocky Shore Toxicity Test, but may only be used in waters more than 12 nautical miles from the baseline.

In brief, applicants approach MMO with a request to include their product on the UK list of approved oil spill treatment products. They do this electronically by following the process detailed on the MMO website.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470085/ostp-application-new.pdf
Depending upon the type of product, the appropriate testing fee must be paid in order for MMO to arrange the necessary Efficacy and Toxicity testing. If MMO are asked to arrange the tests we currently use Ricardo Energy and Environment for Efficacy tests and Cefas (Centre for environment fisheries and aquaculture science) for Toxicity tests. Cefas act as scientific advisors to MMO.

It is possible for applicants to provide their own test result information from a different source but these results must be reviewed and agreed by Cefas before MMO could accept.
Further details of the UK testing process and also the relevant fees can be viewed here:
https://www.gov.uk/government/publications/get-an-oil-spill-treatment-product-approved-tests
https://www.gov.uk/government/publications/get-an-oil-spill-treatment-product-approved-fees
Applicants are updated throughout the testing process and only once MMO are satisfied that a product is proven suitable for the intended task, it is included on the Approved Product List for a period of 5 years from approval date.
https://www.gov.uk/government/publications/approved-oil-spill-treatment-products

Marine Emergencies

MMO operate a 24 hour pollution response via emergency number 0300 2002024 office hours which diverts to a Duty Officer on evenings and weekends.
Ordinarily Marine emergencies are notified to MMO either by telephone or by Pollution reports (Polreps) or Situation reports (Sitreps) by fax and email from UK coastguard offices. As we work closely with other organisations such as Environment Agency, Natural England and Natural Resources Wales, we often pass information regarding incidents to each other if we feel that the situation merits it.

Receipt of an incident notification

Once a call or a report has been received it depends upon the nature of the information as to the action MMO would take.
In the UK, the MCA (Maritime and Coastguard Agency) take the lead role in all significant Marine incidents.
If we use a Marine Emergency (perhaps a vessel in trouble with fuel and oil on board) as an example we need to make a judgement call on the potential severity of the incident. There is no easy answer to deciding the severity of an incident as it depends on factors like:

- How much has been spilled or has potential to be spilled?
- What has been spilled?
- Where it has been spilled (and what it is near)?

- If dispersants are used or a request for the authorisation of dispersant use is made, it is considered a significant incident.
- If protected areas/species/habitats are impacted or have potential to be impacted, the incident is likely to be significant.
- If the incident appears on the news or there is other media interest, it is likely to be significant regardless of the size, cargo, location etc.

MMO are often most heavily involved at the outset of an incident. This is primarily because we undertake to make a **decision on dispersant use within one hour** of such a request being received. This first hour can be extremely demanding and involves MMO liaising with other organisations (particularly Cefas) to consider their advice in our decision making process.

It depends upon the location of the incident as to which organisations we contact but as a rule, use of dispersant is not an automatic first choice. MMO will always consider whether from an environmental viewpoint it would be better to let any spillage disperse naturally. We would only authorise dispersant use if it was believed that this was likely to be more advantageous to the situation.

Natural Resources Wales carries out the same Marine Emergency function for Welsh inshore waters (out to 12 nautical miles) and MMO deal with Welsh offshore waters. Marine Scotland carries out the same Marine Emergency function for Scottish waters. Department for Energy and Climate Change (DECC) deals with offshore oil and gas incidents.

In any major incident the MCA takes the lead for dealing with Press enquiries. To avoid confusion or misrepresentation, the other organisations involved will only issue Press responses in line with MCA.

The process for MMO decision making on dispersant use is detailed within Figure 13.1.

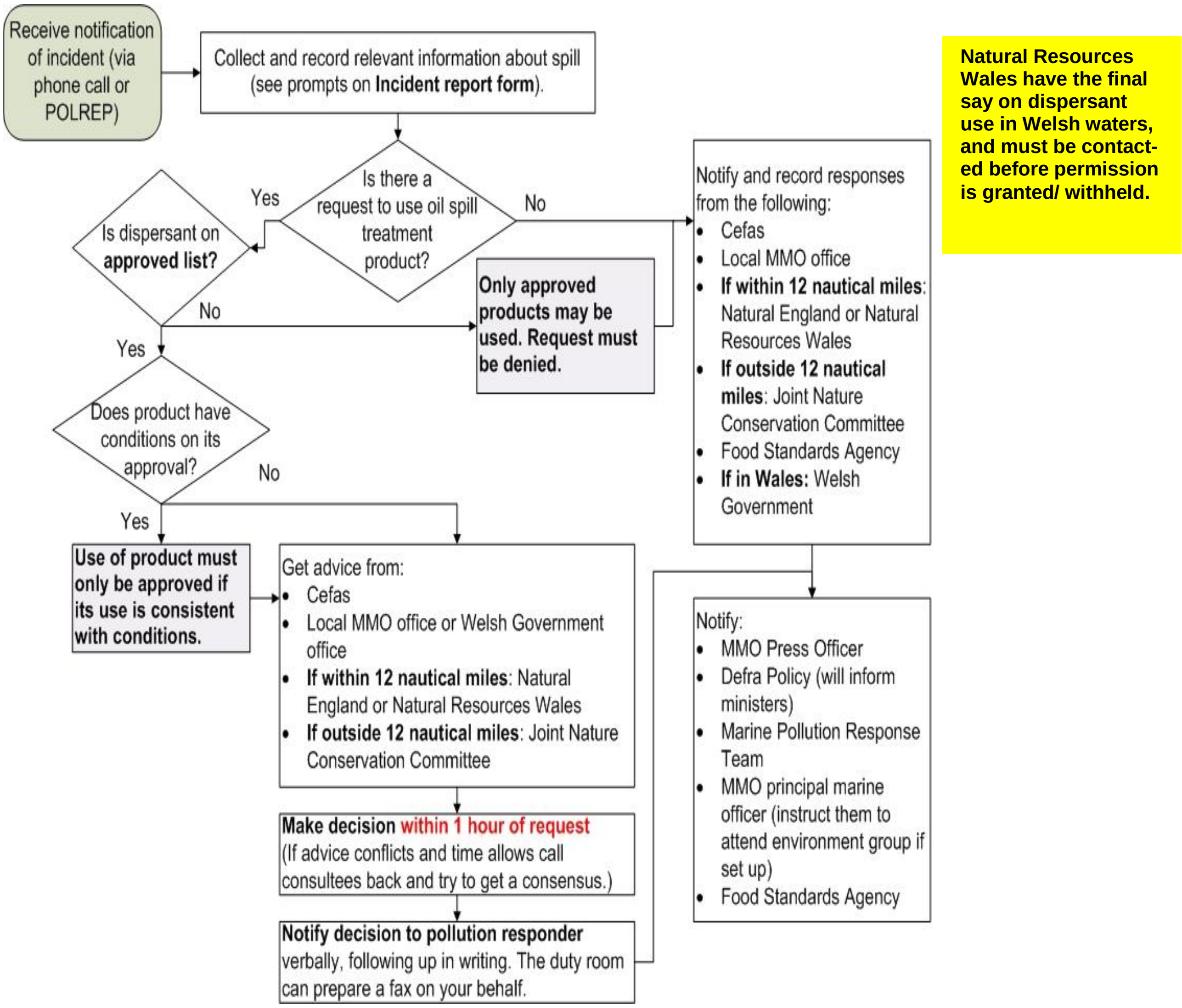

Figure 13.1: Flow chart for MMO decision making on dispersant use

Important points for consideration in decision making process:

- Ensure that identity of caller is verified and that accurate contact information is established.
- Record all information accurately to assist decision making process and audit trail.
- If a request for dispersant use is made or deemed likely to be made – establish the time with the caller and agree a response time. This is very important as MMO only have one hour from request receipt to make a dispersant authorisation decision.
- Establish dispersant type (product name and volume) – aerial spray or by boat?
- Approved oil spill treatment products are exempt from requiring a Marine Licence provided **each use** is approved.
- Only products which are on the UK Approved Products List can be considered.
- It is important that MMO gather as much information as possible to make informed decisions.
- Particular considerations are accurate co-ordinates of the incident, weather and tidal conditions, wind direction and strength, oil type and volumes, amount spilled or potential for spillage, accurate water depths.
- Sometimes depending upon the type of oil spill and weather conditions, it is preferable **not to use dispersants** and to let natural forces deal with the spill.
- Water depth at the spill site and within 1 nautical mile is very important to consider. This is because the dispersant itself can cause smothering of the sea bed if used within shallow waters.
- Use of **any** Oil spill treatment product(s) under the surface of the sea must be authorised.
- For offshore dispersants, approval is required for **any use**.
- The use of oil spill dispersant products in relation to offshore oil and gas exploration and production operations is specifically excluded from these legislative regimes and is regulated by DECC.

Once a decision on dispersant use has been reached we make contact with the caller to advise them accordingly within the agreed timescale.
If dispersant use is approved and if it is possible we would request a test spray with a limited volume of the dispersant.
Once feedback on the effectiveness of the test spray is received we would agree or disagree with further use.

MMO also take part in any **Standing Environment Groups** that may be called as a result of a Marine Emergency.
We act in an advisory capacity for environmental issues and fishing activities in the area(s) that have potential to be affected.

Standing Environment Groups (SEG):

- SEGs can be activated by individual chairperson(s) during an incident.
- SEGs are multi-agency bodies with responsibility for a particular area of coastline. Membership includes the Environment Agency, Natural England or Welsh Government, local authorities, MMO and others.
- SEGs provide environmental advice to SoSRep (Secretary of State Representative for Transport).
- 14 SEGs around England and Wales (plus Scotland and Northern Ireland).
- Hold regular meetings in person so members know each other as this makes it easier to work together during an incident.

14 Current and intended status for contracting of product stocks and technical equipment in Europe

Walter Nordhausen

European Maritime Safety Agency (EMSA), Lisbon, Portugal

The European Maritime Safety Agency (EMSA) is one of the EU's decentralized agencies. Based in Lisbon, the Agency provides technical assistance and support to the European Commission and Member States in the development and implementation of EU legislation on maritime safety, pollution by ships and maritime security. It has also been given operational tasks in the field of oil pollution response, vessel monitoring and in long range identification and tracking of vessels.

A major political impetus to the setting up of EMSA in 2003 was the fallout from the Erika (1999) and the Prestige (2002) accidents and their resulting oil spills. These incidents resulted in huge environmental and economic damage to the coastlines of Spain and France. They also acted as a reminder to decision-makers that Europe needed to invest in better preparation for a large-scale oil spill, i.e. above-and-beyond the resources available at individual Member State level.

Following the Macondo well / Deepwater Horizon incident in 2010, the European Commission undertook an evaluation of the preparedness in Europe to respond to a pollution incident from an offshore oil installation. Subsequently and based on the findings, EMSA's Founding Regulation (EU No. 100/2013) was revised adding the response to marine pollution from oil and gas installations to the Agency's tasks. An Action Plan identifying the status in the European Union with regard to offshore installation and proposed activities to implement the revised regulation was adopted by EMSA's Administrative Board in November 2013. In 2014 the Agency started implementing the Action Plan by enlarging the 'toolbox' to deal with oil spills originating from offshore installations.

More specifically, the Agency began the relocation of response arrangements for mechanical recovery of oil (oil spill recovery vessels including sweeping arms, booms, skimmers, etc.) to areas of higher risk of oil spill, i.e. the Adriatic Sea, the Northern North Sea, and the Canary Islands. In addition, oil pollution response vessels with Class Notation for recovery of oil with a Flash Point < 60° were selected at times of new contracts or upgraded.

In parallel, the Agency received approval from the Administrative Board to also develop an Equipment Assistance Service. This new service will include specialized oil pollution response equipment stored at locations in pre-identified regions, which can be used on vessels of opportunity. These systems are fully self-sufficient and can be transported containerized to any locations where needed.
In order to offer more response options in addition to mechanical oil recovery at sea, strategically located pollution response vessels have been, or are being, upgraded to add the capacity for seaborne dispersant spraying operations. This includes the stockpiling of limited quantities of dispersants. However, currently no equipment for aerial dispersant spraying are planned to be purchased or contracted.

Policies regarding dispersant use reside with the coastal states. This often includes an approval process including specific testing procedures for effectiveness and toxicity. EMSA has not established and is not intending to establish an approval process for dispersants. Currently, six countries have test procedures in place (France, United Kingdom, Norway, Spain, Italy, Greece). UK, France and Norway have the most experience in this field. In addition, some countries, which have not established their own test procedures, allow the use of dispersants approved in other countries. It has to be noted, however, that different approval procedures can be a hindrance for using each other's stockpiles.

Currently approximately 75 brands of dispersants are approved for use in certain countries of Europe, although they may not be tested and approved for use in the same way, i.e. in all national approval procedures. However, the majority of dispersant stocked is limited to five brands (Figure 14.1[6]).

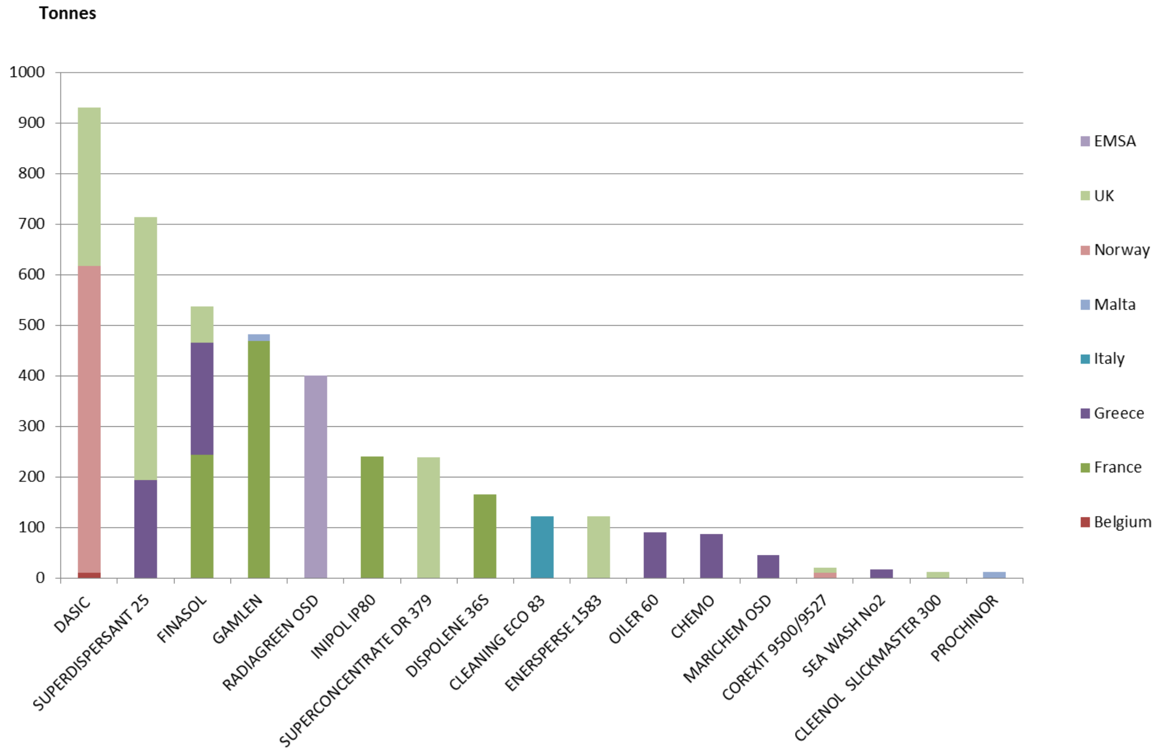

Figure 14.1: Brand and ownership of dispersant stockpiles in Europe (not including OSRL's resources)[7]

EMSA as an Agency of the European Union is bound to EU procurement rules. These rules obviously also apply to EMSA's purchase of dispersant stockpiles. The following Award Criteria were applied:

- Approval in many EU countries (e.g. in region of intended stockpile)
- Low toxicity, dispersants with no aromatic solvents were preferred
- High efficiency at broad range of oil viscosities
- Price

As a result of this procurement effort, EMSA established a 'Framework Contract in Cascade' with two dispersant manufacturers (Oleon and Dasic). These companies produce the dispersants Radiagreen OSD and Slickgone respectively. As both products are widely approved in Europe, EMSA can (easily) purchase dispersants with national approval(s) for nearly all European Sea areas[8].

[6] The figures are based on EMSA's Inventory of national policies regarding the use of oil spill dispersants in the EU Member States (2014b).
[7] Threshold used : > 10 tonnes)
[8] It is acknowledged that the Contracting Parties to HELCOM are not using dispersants to combat oil spills in the Baltic Sea.

Figure 14.2 shows the current distribution of EMSA's contracted oil spill response vessels and dispersant stockpiles. To date, the Agency has equipped two of its contracted vessels with dispersant application systems namely the *Alexandria* (Cyprus) and *Balluta Bay* (Malta). Both locations also have dispersant stockpiles (Radiagreen OSD) of 200 tonnes each. Currently ongoing is the improvement project for the vessel *Bahia Tres* (Sines, Portugal) to also install a dispersant application system. Once completed, dispersant (200 tonnes) will be purchased also for this location.

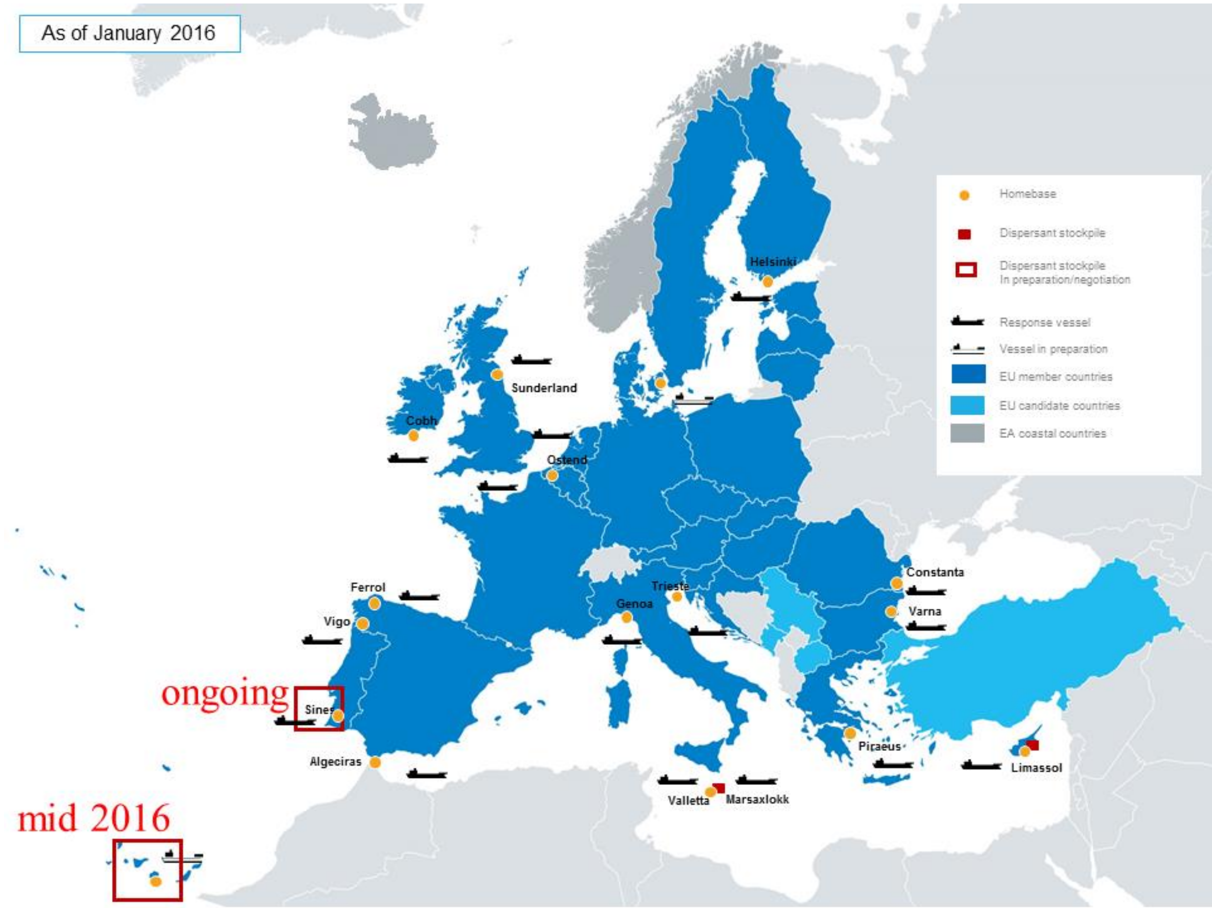

Figure 14.2: Distribution of EMSA's contracted oil spill response vessels and dispersant stockpiles

The EMSA handbook *Network-of-Stand-by-Oil-Spill-Response-Vessels-and-Equipment* (2014a) provides an overview on the current network of stand-by oil spill response vessels and equipment. For 2016, it is planned to also equip a new vessel based on the Canary Islands with dispersant spraying capability and a dispersant stockpile.

EMSA's new Equipment Assistance Service (EAS) could also include stand-alone dispersant spraying systems (tanks and spraying arms) including dispersant stockpile(s) to be used on vessels of opportunity, if the desire for such capabilities is clearly presented by countries of the region. As an equipment depot is planned for the North Sea region, Germany, if in favour of including dispersant spraying systems and dispersant in that area, could make such a request through the appropriate channels.

In addition to providing response capacity for oil spills, EMSA is also providing information tools to the member states. In this context, several workshops on dispersants have been held at the Agency's headquarter in Lisbon, Portugal. Furthermore a *Manual on the Applicability of Oil Spill Dispersants* (EMSA, 2010) was developed distributed to the EU Member

States maritime administrations, aiming to provide guidance to spill managers regarding the use of oil spill dispersants.

EMSA has also developed a specific software tool *Dispersant Usage Evaluation Tool* (DUET) which has been provided to the member states. The tool allows the user to compare scenarios with and without dispersant applications for spills of various types of crude oils and refined oil. The software models the fate and trajectories of oil and its components in space and time. This can provide guidance on the potential impacts of oil when spilled at sea and treated with dispersant or not. An updated version of the tool will be distributed to Member States in early 2016.

More information on EMSA's activities including its pollution preparedness and response activities can be found on our website: http://emsa.europa.eu/.

References

EMSA, 2010 Manual on the Applicability of Oil Spill Dispersants.
EMSA, 2014a EMSA-Network-of-Stand-by-Oil-Spill-Response-Vessels-and-Equipment-handbook.
EMSA, 2014b EMSA's Inventory of national policies regarding the use of oil spill dispersants in the EU Member States (2014).

Authors

Karl-Heinz (Carlo) van Bernem
Helmholtz-Zentrum Geesthacht (HZG)
Max-Planck-Straße 1, 21502 Geesthacht, Germany
karl-heinz.bernem@hzg.de

Ulrich Callies
Helmholtz-Zentrum Geesthacht (HZG)
Max-Planck-Straße 1, 21502 Geesthacht, Germany
ulrich.callies@hzg.de

Ivan Calvez
Centre de documentation, de recherche et d'expérimentations sur les pollutions accidentelles des eaux (Cedre)
715 rue Alain Colas, CS 41836, 29218 BREST CEDEX 2, France
ivan.calvez@cedre.fr

Bernard Christie
Her Majesty's Government – Marine Management Organisation (MMO)
Lancaster House, Hampshire Court, Newcastle upon Tyne, NE4 7YH, UK
bernard.christie@marinemanagement.org.uk

Kevin Colcomb
Maritime and Coastguard Agency (MCA)
105 Commercial Road, Southampton, SO15 1EG, UK
kevin.colcomb@mcga.gov.uk

Carolin Gräbsch
Bundesinstitut für Risikobewertung (BfR)
Max-Dohrn-Straße 8-10, 10589 Berlin, Germany
carolin.graebsch@bfr.bund.de

Matthias Grote
Bundesinstitut für Risikobewertung (BfR)
Max-Dohrn-Straße 8-10, 10589 Berlin, Germany
matthias.grote@bfr.bund.de

Alex Hunt
The International Tanker Owners Pollution Federation Limited (ITOPF)
1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, UK
alexhunt@itopf.com

Stéphane Le Floch
Centre de documentation, de recherche et d'expérimentations sur les pollutions accidentelles des eaux (Cedre)
715 rue Alain Colas, CS 41836, 29218 BREST CEDEX 2, France
stephane.le.floch@cedre.fr

Gilbert Le Lann
Centre de documentation, de recherche et d'expérimentations sur les pollutions accidentelles des eaux (Cedre)
715 rue Alain Colas, CS 41836, 29218 BREST CEDEX 2, France
gilbert.le.lann@cedre.fr

Almut Nagel
Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB)
Robert-Schuman-Platz 3, 53175 Bonn, Germany
almut.nagel@bmub.bund.de

Hartmut Nies
Bundesanstalt für Seeschifffahrt und Hydrographie (BSH)
Bernhard-Nocht-Str. 78, 20359 Hamburg, Germany
hartmut.nies@bsh.de

Walter Nordhausen, Ph.D.
Pollution Response Services
EMSA
Praça Europa 4, 1249-206 Lisbon, Portugal
walter.nordhausen@emsa.europa.eu

Jens Rauterberg
Havariekommando (HK)
Am Alten Hafen 2, 27472 Cuxhaven, Germany
jrauterberg@havariekommando.de

Fabian Schwichtenberg
Helmholtz-Zentrum Geesthacht (HZG)
Max-Planck-Straße 1, 21502 Geesthacht, Germany
fabian.schwichtenberg@hzg.de

Dierk-Steffen Wahrendorf
Bundesanstalt für Gewässerkunde (BfG)
Am Mainzer Tor 1, 56068 Koblenz, Germany
wahrendorf@bafg.de