Guidelines on the

Use of Dispersants for Combating Oil Pollution at Sea

INTERNATIONAL MARITIME ORGANIZATION

IMO

GUIDELINES ON THE USE OF DISPERSANTS FOR COMBATING OIL POLLUTION AT SEA

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Abbreviations

ADIOS	Automated Data Inquiry for Oil Spills
BAOAC	Bonn Agreement Oil Appearance Code
BSAM	Brigade de surveillance aéro-maritime (Aero-Maritime Surveillance Brigade) [France]
CEDRE	Centre de documentation, de recherche et d'expérimentations sur les pollutions accidentelles des eaux (Centre of Documentation, Research and Experimentation on Accidental Water Pollution) [France]
CERA	consensus ecological risk assessment
COOGER	Centre for Offshore Oil, Gas and Energy Research [Canada]
CRA	comparative risk assessment
CTD	conductivity-temperature-depth
DFO	Department of Fisheries and Oceans [Canada]
DOR	dispersant-to-oil ratio
IBC	intermediate bulk container
IFP	Institut français du pétrole (French Institute of Petroleum)
ISO	International Organization for Standardization
ITOPF	International Tanker Owners Pollution Federation
LC50	median lethal concentration
NEBA	net environmental benefit analysis
NOSCP	national oil spill contingency plan
OSCAR	Oil Spill Contingency and Response
OSRL	Oil Spill Response Limited
PPE	personal protective equipment
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
ROV	remotely operated vehicle

SIMA	spill impact mitigation assessment
SINTEF	Stiftelsen for industriell og teknisk forskning (Foundation for Scientific and Industrial Research) [Norway]
UKOOA	UK Offshore Operators Association
VOC	volatile organic compound
WSL	Warren Spring Laboratory [United Kingdom]

Preface

At its sixty-first session, the Marine Environment Protection Committee (MEPC) of IMO decided to review the *IMO/UNEP Guidelines on oil spill dispersant application, 1995 edition* to provide authorities, responders and the general public with pertinent information, documents and practical guidance.

In cooperation with Canada, France agreed to act as the lead country in the development of parts I to III of these Guidelines through the Centre of Documentation, Research and Experimentation on Accidental Water Pollution (CEDRE) and the Department of Fisheries and Oceans of Canada (DFO). The United States of America agreed to act as the lead Member State in developing part IV of these Guidelines.

Parts I to III of these Guidelines were drafted on the basis of the *Guidelines for the use of dispersants for combating oil pollution at sea in the Mediterranean region* prepared by the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC) through its Mediterranean Technical Working Group, with the technical support of CEDRE. The final draft documents submitted by France were reviewed by the IMO Working Group on the International Convention on Oil Pollution Preparedness, Response and Cooperation through a correspondence group chaired by François-Xavier Merlin from CEDRE and Kenneth Lee from DFO.

The Guidelines are divided into four independent parts addressing different issues. Each part has been developed with a specific objective and related aims for various end users:

- **Part I**, "Basic information on dispersants and their application", provides general information on dispersants and their application for any person interested in the subject.
- **Part II**, "Template for national policy on the use of dispersants", aims to assist coastal States in developing their national policy on dispersant use and to facilitate the implementation of national or local contingency plans for oil spills.

  This part has been designed to assist the authorities in charge of developing/revising national contingency plans and policies for combating oil spills, as well as the competent authorities involved in decision-making, when considering the application of dispersants at the time of an incident.

– **Part III**, "Operational and technical sheets for surface application of dispersants", highlights the various issues to consider when using dispersants. This part has been developed to provide operators and first responders with the required knowledge for efficient dispersant application.

– **Part IV**, "Subsea dispersant application", presents guidelines for the application of subsea dispersants and a framework for developing national policies on utilizing and applying subsea dispersants.

The Marine Environment Protection Committee of IMO expresses its appreciation to:

– the Government of France and CEDRE for leading the correspondence group to formulate these Guidelines; and

– the correspondence group members who contributed to the preparation of part or all of these Guidelines:

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GUIDELINES ON THE USE OF DISPERSANTS FOR COMBATING OIL POLLUTION AT SEA

Part I

Basic information on dispersants and their application

Part I

Part I of these Guidelines provides general information on the chemical dispersants used to combat surface oil spills at sea. The intention is to provide the reader with a solid foundation on chemical dispersants. The authors have designed these Guidelines to address questions faced by those concerned with dispersant use, such as first responders and regulators from the public and private sectors.

Information in this document is in agreement with the *Guidelines for the use of dispersants for combating oil pollution at sea in the Mediterranean region* (REMPEC, May 2011 edition), which were integrated as Part D ("Operational guidelines and technical documents") of the REMPEC Regional Information System.

Chapter 1 gives an introduction to dispersants and their use.

Chapter 2 presents the definition, composition and classification of dispersants, as well as information related to the mechanism of chemical dispersion with an analysis of the main parameters that affect the dispersion process.

Chapters 3, 4 and 5 discuss the use of dispersants in oil spill response, the factors that influence a dispersant's effectiveness and the physical characteristics of dispersants, respectively.

Environmental concerns related to the use of dispersants are described in chapter 6.

A comprehensive overview is provided in chapter 7 on the process of conducting a net environmental benefit analysis to support decision-making for the operational use of dispersants on a surface oil slick.

Chapter 8 presents the methods for measuring dispersants' performance, effectiveness, toxicity and biodegradability. These characteristics are relevant to the approval procedure for dispersants.

General considerations regarding dispersant stockpiles, application equipment, logistics and health and safety concerns are covered in chapters 9 to 13.

Figure 1 – *Large aircraft (Boeing 727 with Tersus system) completing a spraying exercise operation. (Source: OSRL)*

1 Introduction

Chemical dispersants can be used on oil slicks at sea to reduce environmental damage, particularly by reducing shoreline contamination. Since their first application on a large scale (in the aftermath of the **Torrey Canyon** oil spill in 1967), the use of dispersants as a response technique for oil spills has remained the subject of much debate. This is partly due to a lack of information and misunderstandings concerning the way dispersants work.

The use of dispersants, especially the related decision-making and application processes, must be planned carefully at the national level and be supported by an appropriate national policy.

A clear policy regarding dispersants and their use should be agreed upon and incorporated into the national emergency response strategy prior to an oil spill incident. Discussions or lack of clarity on whether/how to use dispersants during a spill can lead to delays in the application of a given dispersant, reducing its effectiveness.

The objective of these Guidelines is to provide relevant information on dispersants and their role in a coordinated oil spill response operation. These Guidelines will assist coastal States in creating their own policy for using such products to manage oil spills.

Generally speaking, a national policy for the use of dispersants should be based on the following:

- a full understanding of the action of dispersants;
- knowledge of currently available dispersant products and application methods;
- knowledge of operational practices;
- adoption of compatible and, as far as possible, standardized procedures for testing and assessing the effectiveness, toxicity and biodegradability of dispersants and oil-dispersant mixtures; and
- knowledge of areas in which dispersants may be applied.

2 Background information on dispersants

2.1 Definition

Oil spill dispersants are mixtures of surface-active agents (surfactants) in one or more organic solvents. These dispersants are specifically formulated to enhance the dispersion of oil into the water column by reducing the interfacial tension between oil and water. Natural or induced movement of water then causes rapid dissemination and dilution within the water mass of the very fine oil droplets formed by the action of the dispersant. This process enhances the biodegradation of the residual oil by increasing the surface area of the oil-water interface. Preventing oil from drifting towards the coast or other sensitive areas is one of the primary reasons for using dispersants. While natural dispersion of oil in water does occur, the addition of dispersants can prevent oil droplets from coalescing to re-form an oil slick.

2.2 History of dispersants

The history of dispersants,* at least in the public's perception, begins with the **Torrey Canyon** incident off the coast of Cornwall, United Kingdom, in 1967, which resulted in the loss of 95,000 tonnes of Kuwaiti crude oil (GESAMP, 1993). As part of the response, chemicals were used to remove oil from the shoreline. These chemicals are often referred to in the literature

* The text of this section is taken from chapter 3 of *Guideline for the Use of Dispersants*, published in 2005 by the Marine Environmental Emergency Preparedness and Response Regional Activity Centre (under the Northwest Pacific Action Plan), which was co-authored by IMO.

as “first-generation” dispersants and bear little resemblance to the modern chemicals developed for such use. Instead, they were degreasing agents containing 60% or more of aromatic solvents; their intended use was to clean oily residues from tanker compartments, not to respond to marine oil spills (Exxon, 1994). Their improper application, including direct shoreline application, resulted in extensive mortality of intertidal organisms (NRC, 1985; Exxon, 1994). According to Southward & Southward (1978), approximately 14,000 tonnes of weathered oil came ashore in Cornwall, and a total of 10,000 tonnes of chemicals were applied to remove it. The oil was not particularly toxic by the time it reached the shore. The stranded oil was sprayed with chemicals and then removed by hosing down the area. In some locations, multiple treatments were applied. While organisms were certainly killed by direct contact with the oil, almost all of the observed impacts were due to the chemicals applied. Animal mortality near or in chemical-treated areas was nearly total and many algae were killed or damaged. First-generation dispersants are no longer used in oil spill response.

Shortly after the **Torrey Canyon** incident, “second-generation” dispersants made up of less toxic surfactants and much less toxic low-aromatic or non-aromatic hydrocarbon solvents were developed. In the mid-1970s, the third generation of dispersants was developed, which contain a blend of surfactants, wetting agents and oxygenated solvents.

Despite its notoriety, the response to the **Torrey Canyon** incident was not the first use of chemicals on a significant spill. Just the year before (1966), the Norwegian tanker **Anne Mildred Brøvig** collided with the British **MV Pentland** in the vicinity of the Elbe estuary in the North Sea. Approximately 70 tonnes of a variety of dispersants were applied from workboats. Most was applied to oil escaping from the wreck or used to prevent the formation of large integrated oil slicks. In this case, no environmental damage was attributed to the use of the dispersants (Exxon, 1994). In the three years after the **Torrey Canyon** incident, dispersants were used seven times on major spills: thrice in 1968, once in 1969 and thrice in 1970. In none of these events was a significant ecological impact observed that could be attributed to the use of dispersants. Dispersants were used during the **Platform A** blowout off the coast of Santa Barbara, California, in 1969.

The use of dispersants on large oil spills has been infrequent. Such spills are rare and dispersant use has not always been feasible or desirable. Some of the largest oil spills (from the tankers **Erika** in 1999 and **Prestige** in 2002) involved very heavy fuel oil, where dispersant application would not have been effective. In other spills, such as from the **Exxon Valdez** in 1989, dispersants were considered and tried, but not applied on a large scale. Dispersants were a critical part of the response to the **Sea Empress** spill in February 1996

(Lunel, 1996), in which 445 tonnes of seven types of dispersants were applied over seven days. In this instance the effectiveness of the dispersants was difficult to determine, although their use was credited with significantly reducing shoreline stranding of emulsified oil and did not result in apparent harm to the water column community (SEEEC, 1998).

Through to mid-1996, 80 documented uses of dispersants in spill events have been identified in the literature, and dispersants were used on many more small spills that did not receive international attention. Since 1990, dispersants have been used on small spills several times in the United States (Henry, 2005). In other parts of the world, the use of dispersants on small oil spills has been more frequent but generally poorly documented (Steen & Findlay, 2008). A large volume of dispersant was used in the Gulf of Mexico in 2010 when 4.9 million barrels of oil were released from the **Deepwater Horizon** well. About 400,000 barrels (63,000 tonnes) of this oil are estimated to have been chemically dispersed (ISPR, 2011) using about 7,000 tonnes of dispersants.

Figure 2 – *Converted crop-spraying aircraft applying dispersant during the* ***Betelgeuse*** *oil spill. (Source: ITOPF)*

2.3 Nomenclature of dispersants

Since their first application, dispersants have been used during numerous oil spills of various sizes worldwide and have become an important tool in spill response. The development of new products continues to occur in tandem with the development of application techniques, technology and significant scientific research aimed at understanding the environmental effects of dispersants and dispersed oil.

Table 1 summarizes the nomenclature of dispersants in current use. There are two basic categories of dispersants: second and third generation. The UK authorities group dispersants into three types according to the generation and the application method for which the product has been approved :

– Type 1: second-generation dispersant (this type is now much less commonly used or stocked);

– Type 2: concentrates approved to be applied pre-diluted with seawater from vessels; and

– Type 3: concentrates approved to be applied neat (from vessels or aircraft).

Table 1 – *Comparison of dispersant classifications*

Dispersant type	Common name	Typical dispersant-to-oil dosage ratio	Type of solvent	United Kingdom	
				Type	**Approved application**
Second generation	Conventional dispersant	High ratio: 1:3 or 1:2.5 of the oil quantity	Non-aromatic hydrocarbons	1	Undiluted (neat), from vessels
Third generation	Concentrate	Low ratio: 1:20 of the oil quantity	Oxygenates (e.g. glycol ethers) and non-aromatic hydrocarbons	2	Diluted, from vessels
				3	Undiluted (neat), from vessels or aircraft

Current research on dispersant formulation is focusing on chemical formulae that aid the penetration of the dispersant into heavy and viscous oils through to the oil-water interface. The use of solvents that are less water-soluble and gel or paste formulations that stay associated with the oil for longer periods of time offers potential for future dispersant products. Approaches that rely on the physical interactions of oil and very fine mineral particles (oil-mineral aggregates) to break up the slick into small droplets are also being investigated and may provide an alternative or complementary response to chemical treatment. These developments have shown promise on a laboratory scale and require further validation in the field.

2.4 Composition of dispersants

Oil spill dispersants consist of two main groups of components:

- surfactants; and
- solvents.

Surfactants are chemical compounds with molecules composed of two distinct parts: a "water-loving" (hydrophilic) portion and an "oil-loving" (oleophilic) part. The surfactant molecules (carried by the solvent) migrate to the oil-water interface and reduce the interfacial tension between the oil and the water. Consequently, natural agitation (waves) can break up the oil into tiny droplets, which disperse as a plume into the top layers of the water column.

To improve the performance of the dispersant, several surfactants are often combined, although only non-ionic and anionic surfactants are used in modern formulations:

- Non-ionic surfactants:
  - sorbitan esters of oleic or lauric acid;
  - ethoxylated sorbitan esters of oleic or lauric acid;
  - polyethylene glycol esters of oleic acid;
  - ethoxylated and propoxylated fatty alcohols; and
  - ethoxylated octylphenol.
- Anionic surfactants:
  - sodium dioctyl sulphosuccinate; and
  - sodium ditridecanoyl sulphosuccinate.

Solvents (or their mixtures) are liquid chemicals used in dispersants to dissolve solid surfactants and to reduce the viscosity of the product (enabling uniform application), to enhance the solubility of the surfactant in the oil and/or to depress the freezing point of the dispersant. Solvents can be divided into three main groups: (a) water; (b) water-miscible hydroxy compounds; and (c) hydrocarbons. Hydroxy compounds used in dispersant formulations include ethylene glycol monobutyl ether, diethylene glycol monomethyl ether and diethylene glycol monobutyl ether. Hydrocarbon solvents used in modern dispersants include odourless, low-aromatic kerosene and high-boiling solvents containing branched saturated hydrocarbons.

Additives are also a component of dispersants.

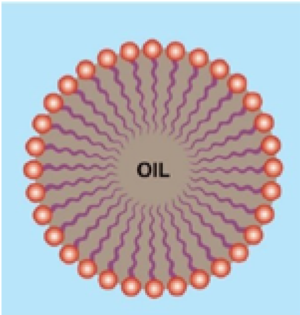

Figure 3 – *Surfactant-stabilized oil droplet. (Source: OSRL)*

3 Use of dispersants in oil spill response

Chemical dispersion is one of the primary response options at sea, along with mechanical recovery associated with containment, monitoring and evaluation, and in situ burning.

The use of dispersants in oil spill response has many advantages:

a When dispersed, oil is no longer subject to wind drift; therefore, when applied upwind of sensitive areas on the surface (e.g. the shoreline), dispersion reduces the amount of oil that might otherwise drift towards these locations.

b The prompt and effective application of dispersants can reduce shoreline contamination, reducing the need for, or the scale of, manual clean-up operations.

c It reduces the likelihood of an impact on valuable ecosystems sensitive to floating oil (surface slick), such as those that support marine birds and mammals.

d Dispersed oil does not generate oily waste requiring regulated disposal.

e The use of dispersants inhibits the formation of mousse (oil/water emulsion), which can be especially difficult to clean up and generates a greater quantity of oily waste.

f In terms of operational feasibility, it is often the quickest response option.

Figure 4 – *Aerial view of a fresh slick partly dispersed (brown dispersed plume (lower left) in the water column); picture taken during sea trials). (Source: IFP/CEDRE)*

g Dispersion can generally be used in higher sea-energy conditions (greater wind and/or current and sea state) than containment and recovery options.

h It enhances the natural biodegradation of oil in the marine environment, contributing to reduced oil toxicity.

i In very specific operational circumstances (such as a subsea blowout), it can be used to create a safer working atmosphere for personnel engaged in source-control operations. Reducing the amount of oil on the sea surface reduces the concentration of toxic or flammable volatile organic compounds in the immediate vicinity. The use of dispersants for this safety purpose overrides environmental considerations regarding dispersant use.

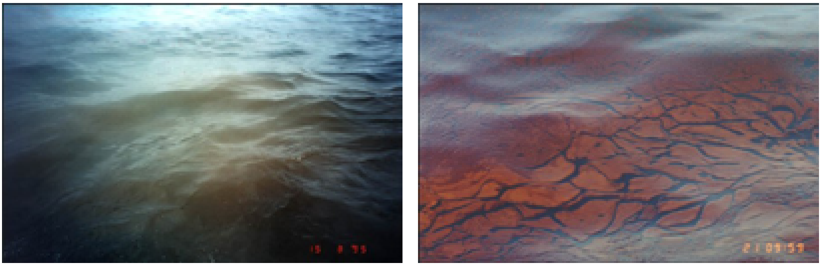

Figure 5 – *A freshly dispersed oil plume in the water column (left) and weathered oil emulsion on the water surface (right). (Source: SINTEF)*

The use of dispersants also has disadvantages:

a It is not effective for all oils, particularly those of high viscosity.

b It is only an effective response option within the first hours or days of the operation ("window of opportunity") before the oil becomes too weathered and viscous.

c It temporarily increases the local oil concentration within the upper few metres of the water column, resulting in dispersed oil being more bioavailable to pelagic organisms that would not otherwise be in contact with surface oil. If used on a discharge or oil slick containing high levels of volatile organic compounds, a chemical dispersant can enhance the solubility (bioavailability) of more toxic fractions that would otherwise evaporate.

d It is not an appropriate technique for use everywhere, particularly where the possibility of significant rapid dilution is reduced, such as in shallow water environments.

e If used near the shore or in very shallow waters, dispersants may increase the likelihood of oil being incorporated into the suspended sediment. It should be noted that oil incorporation into sediment is a risk associated with oil slicks in reduced water depth regardless of whether dispersants are used or not. (Please refer to section 6.4.1 for more information regarding the limitations of dispersant use in a near-shore or shallow water environment.)

f The use of dispersants is not an effective response option if the prevailing sea energy is too low.

g Chemically dispersed oil may continue to create an environmental impact if the conditions for rapid dilution are not present (see section 6.4.1 for more information).

h In cases where dispersant has been applied but dispersion is not achieved, the subsequent effectiveness of other response methods may decrease. For example, oleophilic skimmers and absorbents work best with untreated oil.

i Adding dispersant introduces extraneous substances into the marine environment.

The feasibility of assessing these advantages and disadvantages decreases when an emergency response is ongoing. There are tools available to help assess response options and trade them off against one another so as to determine whether dispersant application is appropriate to minimize impact from a spill scenario on environmental, cultural and socio-economic resources. Chapter 7 details the net environmental benefit analysis (NEBA) process and annexes 1 and 2 in part II provide further guidance on NEBA.

The use of dispersants and their place within a general response strategy for oil spills should be considered in advance. The circumstances and locations where dispersant use will be given priority over other available response techniques should be analysed and determined during the preparation of an oil spill contingency plan. By evaluating different priorities for different coastal areas, geographical boundaries may be defined within which dispersants may or may not be used.

As a general rule, dispersants should not be used in areas with poor water circulation or poor dilution potential, nor should they be used near fish spawning areas, coral reefs, shellfish beds, mariculture facilities, wetland areas and industrial water intakes.

When a national policy* for the use of dispersants has been adopted, decision-makers can then make a final decision on the use of dispersants based on the specific circumstances of the emergency (e.g. type of oil; environmental conditions; availability of equipment, products and personnel). Decision trees can guide responsible personnel on the use of dispersants as an emergency unfolds. Decision-making on the use of dispersants must be a priority during a spill since there is typically a very narrow window of opportunity for dispersion before the oil becomes too weathered and emulsified (see chapter 4 and part II, annex 2 for more information).

Once the decision to use dispersants has been made, some basic principles should be followed:

- Dispersants should be applied to the spill as early as possible.
- Dispersant spraying operations should be terminated when the oil reaches the degree of weathering (viscosity, mousse formation) at which it is no longer readily dispersed.
- If oil is approaching a sensitive area, dispersants should be applied to the part of the slick nearest to it.
- Dispersants should be applied to thick and medium-thick parts of the slick and not to the low-thickness areas (sheen).
- Dispersant application should be methodical, with the dispers-ants applied in parallel and contiguous or slightly overlapping runs.
- Treatment of the slick should take into account the prevailing wind – in most cases, by applying dispersants against the wind.
- Vessels are suitable to conduct treatment of smaller slicks near the shore, but aircraft usually permit a rapid response less than 24 hours after the spill and are particularly suitable where large offshore spills are concerned.
- Regardless of whether dispersants are sprayed from vessels or aircraft, spotter aircraft should be used to guide them and assess the results.

In the event of a significant oil spill affecting an extensive area, it is possible and often necessary to use a combination of spill response methods. In such situations, dispersants can be used on one part of the slick while oil is mechanically recovered elsewhere. Such an approach requires careful control to ensure that the different response strategies do not overlap and conflict (dispersed oil cannot be recovered).

* See part II, "Template for national policy on the use of dispersants."

Large oil spills also often necessitate international cooperation. The application of dispersants may be part of the assistance offered to a country managing such a spill. To optimize this support, some countries have agreed in advance to accept the application of products approved for use by neighbouring countries.

Figure 6 – *Oil slick at sea treated by a ship performing parallel spray runs during sea trials.*
(Source: IFP/CEDRE)

Visual aerial observation, complemented by fluorometry, photography, video recording or the application of remote sensing techniques, should be used to evaluate the effect of dispersant application. The resultant data is vital for decision-making and record-keeping purposes.

Finally, for practical reasons, countries considering the use of chemical dispersion in their response strategy need to pay particular attention to the following:

a storage of sufficient quantities of approved products;

b procurement and maintenance of adequate spraying equipment; and

c training of personnel on all aspects of dispersant use, including organizing regular practical exercises.

Figure 7 – *Remote sensing aircraft of the Swedish Coast Guard (view of the aircraft and inside). (Source: CEDRE)*

4 Factors affecting dispersant effectiveness

Dispersant effectiveness has been defined as the amount of oil that the dispersant transfers into the water column compared with the amount of oil that remains within the surface slick (Fingas & Banta 2009). Regardless of the application technique (chapter 10) and dosage (chapter 9), dispersant effectiveness will primarily depend on the following:

- oil type;
- dispersant contact with oil;
- mixing energy;
- weather conditions;
- water salinity; and
- suspended sediments.

4.1 Oil properties

The following characteristics determine how an oil will behave when treated with chemical dispersants. These properties vary according to the type of oil but also as the oil is affected by weathering processes.

4.1.1 *Viscosity*[*]

Oils that contain more significant amounts of heavier components, such as resins, asphaltenes, etc., are typically more viscous and less dispersible. Oils with a viscosity at seawater (ambient) temperature of up to 5,000 cSt (most fresh crudes, medium fuel oils) are considered to be chemically dispersible using currently existing dispersants. Chemical dispersion of oils with a viscosity between 5,000 cSt and 10,000 cSt may be reduced and oils above 10,000 cSt (heavy, weathered and emulsified crudes, heavy fuels) are often unaffected by dispersant.[†]

Even oils with low initial viscosity may no longer be dispersible as time passes from the time of spillage because of the effect of weathering processes. Whether these changes affect the dispersibility of the oil depends on many factors, including the oil's chemical properties and also environmental factors, and the time can vary significantly. The time during which oil remains dispersible is called the "window of opportunity" for dispersion. It varies according to the type of oil and the meteorological and oceanographic conditions (mainly sea temperature, wave action and wind). The more viscous the oil, the more agitation (wave energy) is required to aid the chemical dispersion.

4.1.2 *Pour point*

Oils with a significant paraffin (wax) content (i.e. a high pour point)[‡] can cease to be dispersible if the ambient temperature is lower than the oil's pour point.[§]

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[*] The viscosity of a liquid is defined as its resistance to flow. The unit most commonly used for quantifying viscosity can be the dynamic viscosity in centipoises (cP) or the kinematic viscosity in centistokes (cSt).

In this context, as dispersant density is not far from 1, especially for the concentrates, the units cP and cSt are roughly equivalent. Weathered oils on the sea surface are likely to be semi-stable or stable emulsions, and are non-Newtonian liquids. The viscosity may depend on the shear rates adopted during the viscosity measurement.

[†] These recommendations remain general and apply to a large number of oils; however, exceptions exist especially for oils that contain wax (paraffinic oil) whose dispersibility viscosity limits can be significantly lower.

[‡] Pour point is the temperature below which an oil no longer flows according to specific laboratory conditions (ASTM D97, "Standard test method for pour point of petroleum products"). The pour point of an oil is influenced by its wax content, with oils with greater wax content having higher pour points and kinematic viscosity (Majhi *et al.*, 2015)

[§] The difference between the ambient temperature and the pour point for which an oil remains dispersible is still in debate; it is dependent on the ambient mixing energy (wave), especially when the agitation is high enough to maintain the oil in a dispersed state, but generally ranges from a few degrees to 10°C to 15°C according to different scientific sources.

Table 2 – *Typical relationships between wax content and pour points of crude oil*

Wax content (%)	Pour point (°C)	Wax content (%)	Pour point (°C)
<5	<5	15	20
≥10	≥10	20	30

4.2 Emulsification

As a result of emulsification, oil viscosity increases and dispersants generally become ineffective. However, research has shown that dispersants can be effective when the emulsion is fresh (not entirely stabilized; Lewis *et al.,* 1995a & Lewis *et al.,* 1995b). In these cases, dispersant application can be performed in two stages: a first application to break the emulsion and thereby reduce oil viscosity, followed by a second application to carry out the dispersion itself. This approach entails operational and logistical challenges, requiring two separate dispersant application operations on the same oil area with enough time for the emulsion to break up sufficiently.

4.3 Weathering

To be effective, all dispersants must be applied as soon after the spill as possible. Weathered oil is significantly more difficult to disperse. Thus, dispersants become less effective over time during the incident.

4.4 Droplet size

Dispersant must be sprayed onto the slick in such a manner as to reach the oil surface without penetrating it (where the dispersant would then be lost into the water column with no effect). This is achieved through a combination of appropriate spraying technique (chapter 10) and suitable droplet size. The optimal droplet size is considered to be in the range of 350 µm to 700 µm (Lindblom & Cashion, 1983). Smaller droplets would be carried away by the wind and may never reach the oil, while larger droplets penetrate the oil layer and enter the water without having sufficient time to bind to the oil. The appropriate spraying system for dispersant application should be chosen accordingly.

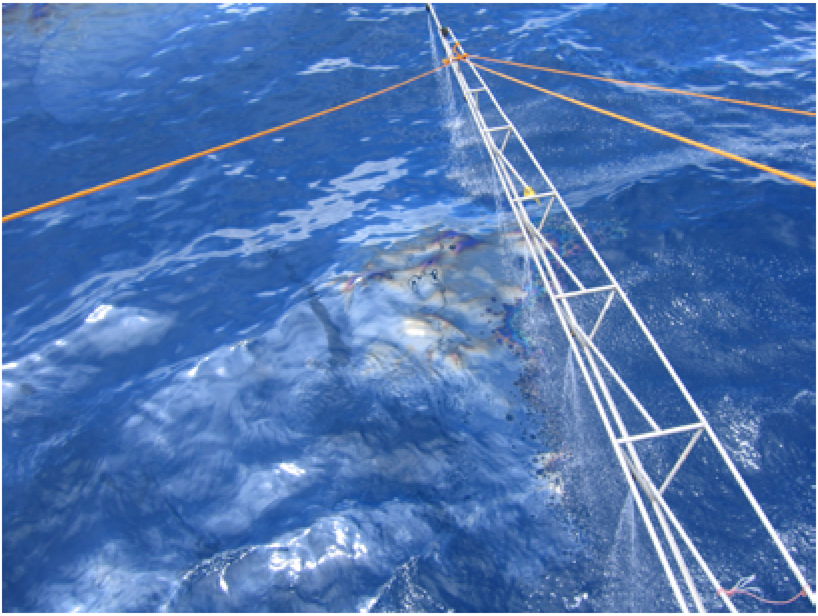

Figure 8 – *Close picture of the spray pattern from UKOOA spray arm. (Source: ITOPF)*

4.5 Mixing energy

The energy applied to the oil in the form of mixing is paramount to achieving dispersion. Natural agitation of the sea surface (waves) is required to complete this process. As a general rule, the more viscous the oil, the more energy is required to promote the dispersion process.

Once the dispersant has come into contact with the oil, the dispersant-oil mixture must be agitated to break the oil into small droplets to allow dispersal in the water column.

In some cases, if the mixing energy is insufficient (very calm sea), agitation of the dispersant-oil mixture with water can be achieved mechanically by navigating through the oil slick to stir it with bow wave and propeller action, and by using fire hoses from the deck of a vessel.

4.6 Weather conditions

The oil spill response technique of chemical dispersion is less affected by adverse weather conditions than other techniques (e.g. containment and recovery). In addition, weather conditions do not directly affect the physico-chemical process of dispersion but, rather, the application of the dispersant. Winds may blow the dispersant spray away from the targeted area, causing wastage of product. During aerial spraying, high winds may also affect the ability of an aircraft to carry out low-level spraying operations safely.

Wind and the resultant waves provide the required mixing energy to enable the dispersion process (the more energy, the better the dispersion). Large or breaking waves can render spraying operations difficult for vessels. However, weather conditions that are too severe to be suitable for dispersant application will likely result in considerable natural dispersion in the absence of chemical dispersants, purely owing to that significant mixing energy.

The interaction between dispersants and oil can be reduced if an oil slick is fragmented by wave action since a portion of the dispersant would be sprayed directly on the water surface rather than on the oil.

Poor visibility can also impede dispersant application by making it harder to locate spraying targets or monitor dispersant effectiveness.

4.7 Water salinity

Dispersant effectiveness is dependent on water salinity. Marine dispersants are specifically formulated for peak effectiveness in waters with a salinity of 20 to 40 parts per thousand. Alternative formulations have been developed to be effective in fresh water. Therefore, the ability of dispersants to function in an estuarine environment may be challenging to manage (especially when the salinity changes locally in relation to the tide and water depth).

4.8 Suspended sediments

High concentrations of suspended minerals or particulate matter in the water column may interact with oil to form oil-mineral aggregates. These relatively stable particles, mainly consisting of oil and suspended sediments, will eventually facilitate the transport of oil to the seabed over time. The use of dispersants is believed to reduce the size of the oil-mineral aggregate particles produced.

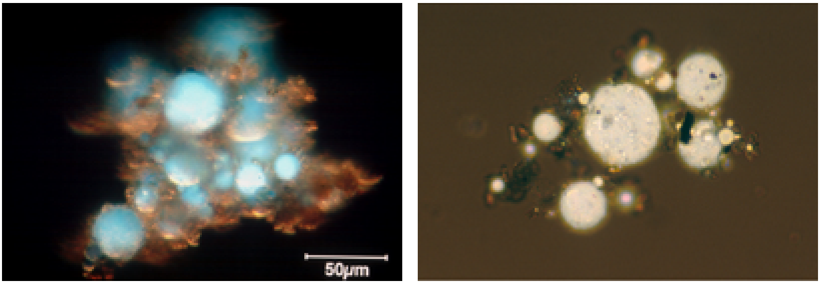

Figure 9 – *Magnified view of aggregates formed by the mineral fines around the oil droplets. (Source: Kenneth Lee, Department of Fisheries and Oceans, Canada)*

5 Physical characteristics of dispersants

Some physical properties of dispersants may have practical implications which affect their use (how they are applied, whether they pose a fire hazard, how they should be stored). For this reason, some countries include specific requirements in their approval procedure concerning the viscosity, specific gravity, pour point, flashpoint, and stability and shelf life of dispersants.

5.1 Viscosity

Viscosity is a measure that indicates a fluid's resistance to a change in its shape. The viscosity of dispersants will vary depending on temperature. Dispersant droplet size is directly affected by the viscosity of the dispersant. Some countries specify the dispersant viscosity parameters; for example, in France, dispersant viscosity must be below 80 cP at 20°C. Typical viscosity ranges are indicated in the table below:

Table 3 – *Typical viscosity range of dispersants at 0°C and 20°C*

Dispersant type	Viscosity (cP) at 0°C	Viscosity (cP) at 20°C
Second generation	10-50	5-25
Third generation	60-250	30-100

5.2 Specific gravity

Specific gravity is the ratio of a solid's or a liquid's weight to an equal volume of water at a specified temperature. Second-generation dispersants which require dilution usually have lower specific gravities (0.80 to 0.90) than third-generation ones (0.90 to 1.05).

5.3 Pour point

The pour point is the temperature below which a liquid will not flow. The pour point of most dispersants is well below 0°C (–40°C to –10°C), which should prevent the dispersant from solidifying in most regions of the world.

5.4 Flashpoint

The flashpoint is the lowest temperature at which a volatile substance's vapour will ignite in the air when exposed to a flame. Most dispersants have a flashpoint above 60°C and are therefore considered non-flammable. For practical safety reasons, some countries may set thresholds for the flashpoint (e.g. in France, the dispersant flashpoint must be higher than 60°C).

5.5 Stability/Shelf life

During the period declared by the manufacturer as the product's shelf life, its properties should not change. Most manufacturers claim the shelf life of a dispersant product to be five years but it can be maintained for much longer if stored correctly. The ongoing condition of the dispersant should be monitored through regular efficiency testing.

Certain components of some dispersants may cause corrosion to the packages (drums or containers) used to store the product. Regulations concerning dispersants in some countries require that the product should not contain such components.

Figure 10 – *Laboratory checking of dispersant quality.*
(Source: CEDRE laboratory)

6 Environmental effects

Environmental effects from dispersant use are mainly related to:

- the toxicity of dispersants or oil-dispersant mixtures;
- influence on microbial degradation of spilled oil; and
- the effect on seabird and marine mammal populations.

6.1 Toxicity

Toxicity is the degree to which a substance can harm a cell, an organ or an entire organism. Those adverse effects may be lethal (cause death) or sublethal (damaging the organism in some way without causing death). Toxicity depends on a number of factors, including the concentration of the substance, the duration of the organism's exposure and the innate sensitivity of the species in question throughout its various life-cycle stages.

Toxicity is usually expressed as the concentration that causes an effect during a specific time or the exposure time that induces an impact at a specific concentration. Most often, concentrations are expressed as parts per million (ppm) or parts per billion (ppb).* Sometimes toxicity can be described as the concentration that does not cause a negative impact on test organisms - the "no observed effect concentration" or NOEC.

Ideally, the toxicity of dispersants should be tested in situ and on endemic organisms that will be present. However, the impracticality of such field tests has led to the development of numerous laboratory testing procedures (Colvin *et al.* 2020). The results of such tests should be interpreted with caution as they do not fully or consistently mimic the fate and behaviour of dispersants during an incident and may lead to an overestimate of oil toxicity (Prince, 2023). Most tests use concentrations and exposure durations that substantially exceed expected field exposures (Coelho *et al.,* 2013). During testing, organisms are exposed to constant concentrations for several days; while in the sea, initial concentrations of dispersant or dispersed oil would be diluted progressively and usually rapidly (Bejarano *et al.,* 2014). Significant errors in interpreting laboratory test results may also arise from the fact that thresholds are most often reported as nominal concentrations. This means that the total amount of dispersant or oil divided by the total volume of water in the experimental chamber is considered, rather than the measured concentrations to which the organism is exposed. Oil toxicity tests are often

* These units are used interchangeably with mg/litre and μg/litre, respectively, minor differences in exact concentrations notwithstanding.

performed on fresh oil, whereas in real situations, the oil would be partially weathered for a few hours, losing its more toxic compounds (Redman & Parkerton, 2015; Lee *et al.,* 2013) (see section 6.1.2).

6.1.1 *Intrinsic toxicity of dispersants*

The actual toxicity of dispersants varies depending on the dispersant components and the species being tested on. Lethal concentrations of dispersants are the primary interest and most toxicity tests are aimed at determining these. Certain sublethal effects, including changes in reproduction, behaviour, growth, metabolism and respiration, may also occur when organisms are exposed to levels well below lethal thresholds. These responses have been noted in laboratory experiments where the duration of exposure is one to four days. This time frame is much longer than what would be experienced in most dispersant-use situations in open water. Exposure concentrations with reported sublethal effects usually are one or two orders of magnitude above the highest anticipated operational concentrations.

There are few reports of measurements of concentrations following the use of dispersants in the field (open water). Available data suggests that even initial concentrations (immediately after application) in the water column are below estimated lethal and sublethal concentrations derived from experiments (Bejarano, 2018).

The results of studies investigating dispersants' effects suggest that properly screened dispersants are used at recommended application rates; major toxicity effects should not occur in near-surface waters as a result of chemical dispersants alone (Bejarano *et al.,* 2014).

6.1.2 *Toxicity of oil*

Oils of different types contain a multitude of varying chemical components that may pose a risk to marine organisms. This inherent toxicity of oil exists without any addition of chemical dispersant. Regardless of the decision to spray dispersant, the toxic fraction has entered the marine environment through that oil spill event.

Some more acutely toxic compounds, particularly those of lower molecular weight (benzene, toluene, ethylbenzene and xylenes), are volatile and water-soluble. Hence, unweathered oil is generally more toxic than the same oil that has been weathered and lost the lighter compounds. It is commonly accepted that freshly spilled crude oils are much more acutely toxic than the modern oil spill dispersants used to treat them (NASEM, 2019)

Polycyclic aromatic hydrocarbons, present in low concentrations in many oils, often give rise to toxicity concerns. These higher molecular weight compounds are known to be carcinogenic and can have other detrimental effects through chronic exposure (ATSDR, 1995).

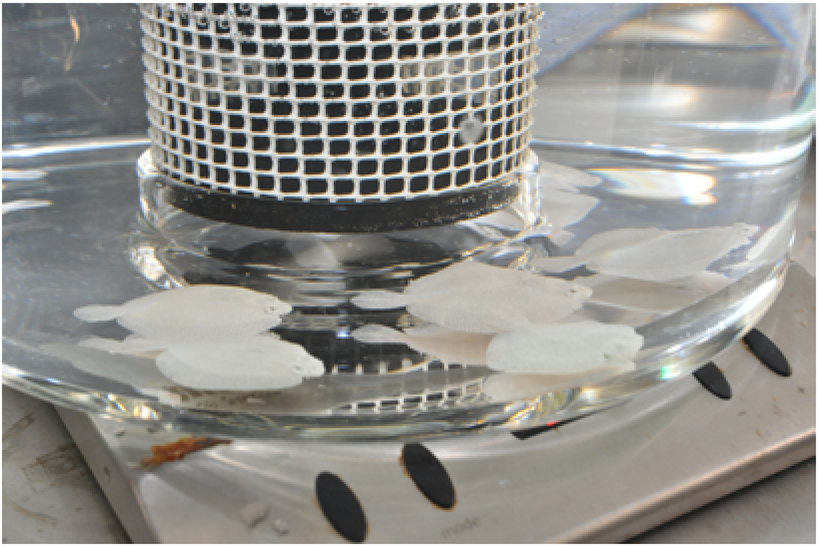

Figure 11 – *Toxicity test carried out on fish. (Source: CEDRE)*

6.1.3 *Toxicity of dispersed oil*

Dispersing spilled oil converts the oil from a surface slick to a plume or "cloud" of small oil droplets suspended in the top 10 m of the water column. These oil droplets could be ingested by filter-feeding organisms, such as copepods, oysters, scallops and clams. Most circumstances of dispersant application would occur in deep water (>10 m), ensuring minimal exposure of the aforementioned filter-feeding benthic fauna.

This large increase in the surface area of the oil amplifies the rate at which partially water-soluble chemical compounds in the oil are transferred into the water column. The ensuing temporary increase in concentration creates a short-term and localized increased toxicity which may be incorrectly used to argue against dispersant use. Effective use of dispersants will cause a temporary increase in the concentration of dispersed oil. However, this does not mean that the concentrations will be high enough or persist long enough to cause acute biological effects (Bejarano *et al.,* 2014; Prince, 2023). This localized increase in the concentration and bioavailability of dispersed oil is short-term and dilution will quickly dissipate the oil in an open-water environment. Most spilled oils will naturally disperse to some degree and the successful use of dispersants will obviously increase the concentration of dispersed oil in the water column, albeit over a short timescale.

As a result of the oil being dispersed, organisms living in the upper layer of the water column may experience short-term increased exposure, the extent of which will depend on their mobility and potential avoidance response. If the dilution of the plume of dispersed oil in the water column is rapid, exposure will be lower. Experience from both field trials and offshore dispersant operations at actual spills has shown that dispersed oil will dilute rapidly in an open-water environment, where water exchange is dynamic and not restricted by shallow water, enclosed water or low water exchange (NASEM 2022). The oil concentration in the water just below the spill decreases rapidly a few hours after treatment, from a maximum of 30 ppm to 50 ppm to concentrations of less than 1 ppm to 10 ppm total oil in the top 10 m to 20 m. See figure 12 below for the dispersed oil concentrations recorded during the **Sea Empress** oil spill.

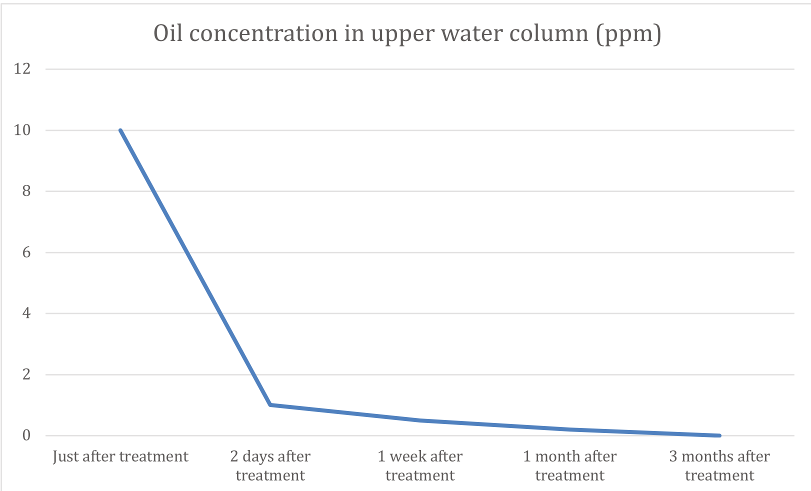

Figure 12 – *Oil concentrations were monitored in the upper water column during the* **Sea Empress** *oil spill (Wales, UK, 1996), where 72,000 tonnes of Forties crude oil was spilled and 440 tonnes of dispersant was applied.*

Figure 13 – *The* ***Sea Empress*** *oil spill (Wales, UK, 1996). (Source: ITOPF)*

Various studies have been conducted to devise toxicity testing methods that expose organisms to conditions closer to the actual conditions of an oil spill. Toxicity tests performed with more realistic "spike"- or "episode"-type exposure regimes show that the use of dispersants does not cause significant impact to embryos and larvae at dispersed oil concentrations lower than 5 ppm to 10 ppm. An exposure of 10 ppm/hours to 40 ppm/hours (concentration in ppm divided by exposure in hours) was found to produce no significant effect on higher forms of marine life, such as older larvae, fish and shellfish.

Studies have shown the following:

- Concentrations lethal to adults and juveniles are much higher than concentrations that have been observed in actual incidents.
- Sublethal effects such as bioaccumulation, metabolites in the liver and stress indicators can be observed in adults and juveniles after exposure. Most of these are reversible within a relatively short recovery period of up to two weeks, after which the observed effects disappear or are reduced to near-background levels (Le Floch *et al.,* 2010).

Provided that dispersants are used to disperse oil where there are adequate depth and water exchange for dilution, there is little risk of dispersed oil concentrations reaching levels for prolonged periods that could cause significant or ongoing impact to most marine creatures.

After incidents where large quantities of oil were dispersed at sea (e.g. **Sea Empress**), the environmental impact observed has generally been much lower than expected. Limited research has been conducted on the bioaccumulation and chronic toxicity of oil components after dispersion. However, evidence suggests that naphthalene, in particular, may pass up the food chain at a higher rate when chemically dispersed (Wolfe *et al.,* 1996). A high degree of sublethal stress has been noted in fish species having to deal with dispersed oil in the water column.

6.2 Microbial degradation

Dispersion of oil (whether chemically enhanced or not) renders oil more available to microorganisms present in the seawater.

Microorganisms capable of breaking down oil are present in seawater, and the rate of microbial degradation is directly related to the availability of oil (Lee, 2011; Swannell *et al.,* 1997; Varadaraj *et al.,* 1995). Paraffinic and high and medium aromatic fractions of oil are highly biodegradable. The same has not been proved for polyaromatic hydrocarbons (4, 5 rings) or asphaltenes.

Dispersants increase the rate of oil biodegradation by increasing the surface-to-volume ratio of oil, and they also increase oil bioavailability by reducing the tendency to form tar balls or mousse, and stabilizing the oil droplets in the water column, which prevents beaching or sedimentation.

With regard to toxicity, most of what is known about the biodegradation of dispersed oil is limited to the results of laboratory or other small-scale studies. Many laboratory and mesocosm studies have shown increased oil biodegradation rates when dispersants are used. Data from mesocosm studies strongly indicate that the effective use of dispersants would increase the biodegradation rate of spilled oil (Lessard & DeMarco, 2000; Tonteri *et al.,* 2023). However, the extent to which dispersants enhance biodegradation still requires further study (Morales-McDevitt *et al.,* 2020, Tonteri *et al.,* 2023).

It is known that the most toxic fractions of any crude oil are the benzene, toluene, ethylbenzene and xylene components, which are rapidly degraded by microorganisms because they lack structural complexity and are easily broken down. There is no current research evidence to suggest that increased degradation of these components is the result of dispersant use.

6.3 Effects on seabirds and marine mammals

Oil, whether dispersed or not, can affect seabirds and marine mammals as a result primarily of the following:

- toxic internal effects of either direct ingestion of oil from the sea surface, indirect ingestion through grooming or preening, and inhalation of volatiles and oil droplets from the surface; and
- external effects on the water repellency and thermal insulation of feathers or fur, direct damage to sensitive tissues from oil exposure, or inhibition of locomotion (swimming or flying) by external coating.

Many of these effects are specifically related to oil exposure experienced by animals either floating or surfacing at the air-water interface and can be directly related to a "dose-response" effect in relation to whether significant oil is at the surface. Most direct effects of oil on these species can therefore be reduced if the volume of oil on the water surface is reduced through dispersion (chemical or physical) into the water column. However, no extensive studies have been conducted on whether the use of chemical dispersants reduces those effects not directly related to external coating.

Figure 14 – *Dolphins passing through an experimental oil slick during the DEPOL-05 sea trials on dispersants. (Source: CEDRE)*

To date, studies have not indicated differences in the internal toxicity to seabirds of oil components in chemically and mechanically dispersed oil. Several studies exploring the external effects of chemically dispersed oil and dispersant alone have shown that dispersant can eliminate waterproofing and buoyancy in seabirds, but the effects are short-lived (Duerr *et al.,* 2011; Whitmer *et al.,* 2018). The same studies showed that external effects were not worsened through the chemical dispersal of oil versus oiling alone.

Marine mammals (especially heavily furred mammals such as sea otters, fur seals and polar bears) are also known to be affected by exposure to oil. The reported effects include dysfunction due to external coating (affecting, for example, thermoregulation and movement) and internal exposure (direct damage to respiratory and gastrointestinal tissues as well as impairment of organ systems and biochemical processes if toxic components are absorbed). Other overt effects, such as eye irritation and lesions, have also been reported. Exposure of marine mammals to oil can lead to changes in their ability to deal with the uptake, storage and depuration of hydrocarbons; acute exposures can result in mortality, particularly in the case of young mammals, which are more susceptible to the toxicological effects of oil.

Oiling can reduce the insulating capacity of fur in heavily furred mammals in a similar manner to seabirds. Dispersants, as surfactants, have been experimentally shown to damage the microstructure of fur or feathers, thereby allowing cold-water penetration and increasing thermal conductance as well as decreasing buoyancy. Animal deaths due to ingestion of oil during grooming have also been recorded.

One emerging concern for marine mammal health in connection with the use of chemical dispersants is the potential for increased volatiles and decreased oil droplet size at the water surface (Muriel *et al.,* 2021). As a consequence of the Macondo spill in the Gulf of Mexico in 2010, coastal bottlenose dolphins exhibited significant systemic health issues, with the likely cause being inhalation of toxins when surfacing through an oil slick (Takeshita *et al.,* 2017 and Takeshita *et al.* 2021). Whether chemical dispersant application increases the risk of petroleum and petroleum hydrocarbons being inhaled more deeply into the lungs is not yet fully understood; however, prudent deterrent activities to keep cetaceans away from dispersed oil are advisable.

Information on the influence of dispersants or dispersed oil on marine mammals is extremely limited. While the use of dispersants may not reduce the physical threat posed by spilled oil to some fur-bearing sea mammals, it has been reported that oil treated with dispersants significantly loses its ability to stick to skin and fur.

6.4 Basic considerations regarding the use of dispersants in specific environments

6.4.1 *Shallow waters*

Figure 15 – *Shallow coastal waters. (Source: CEDRE)*

Dispersants act by transferring oil on the water surface into the water column in the form of tiny droplets. Effective application of dispersant will result in initially elevated oil concentrations in the upper layers of the water column. Under the effect of water currents and turbulence, these elevated concentrations will decrease rapidly as dilution occurs. The dilution potential of the water mass into which the oil is dispersing is therefore an important consideration when deciding whether to use dispersants. Shallow water depth typically means lower dilution potential. The concentration of dispersed oil is somewhat confined and likely to diminish less quickly than in deeper, more extensive water masses. For this reason, caution is typically exercised when deciding whether or not to use dispersants in shallow coastal waters (see figure 15).

Dispersing oil from the water surface may minimize the risk of oiling of seabirds, boats and sensitive shorelines. However, the presence of dispersed oil in the upper layers of the water column may result in a limited period of exposure to pelagic marine organisms (and benthic organisms if waters are very shallow). The timescale and level of exposure of marine organisms to dispersed oil is dependent on a number of factors, including the dilution potential of the water mass. Therefore, in areas of diminished dilution potential, the presence of and risk to sensitive resources must be evaluated. This is typically done through the net environmental benefit analysis (NEBA) process, as detailed in chapter 7.

The use of dispersants in coastal and shallow waters also carries the risk of contamination of seabed sediments. Similarly, if suspended sediments are present, dispersants may facilitate the adhesion of oil to the particles, risking the exposure to oil of resources present on the seabed. It is important to note that regardless of dispersant use, oil adhesion to particulates will occur in shallow water (more turbid and particulate-laden environments). Ultimately, any remaining surface oil is likely to wash up on beaches and have an impact on shoreline biota.

The ability of many free-swimming fish species to detect and avoid oil in the water column should help to reduce their potential exposure (Maynard & Weber 1981; Bøhle, 1986; Ryder *et al.,* 2004, Claireaux *et al.,* 2018). However, the avoidance reactions of fish to hydrocarbons need to be more thoroughly studied as current study results often conflict (Claireaux *et al.,* 2018). In testing fish acutely exposed to chemically dispersed oil, Mauduit *et al.* (2016) noted that while the tested species remained impaired in terms of their hypoxia tolerance and swimming performance, temperature susceptibility was no longer impacted one month after exposure. Futhermore, the impairments observed did not seem to have subsequent ecological consequences under mildly selective environmental conditions, since growth and survival were not impacted during study. These effects were therefore reported to be temporary because re-testing 10 months post-exposure revealed no significant residual effects on hypoxia tolerance, temperature susceptibility and maximal swimming speed (Mauduit *et al.,* 2016).

Corals, seagrass and fish spawning areas may be susceptible to dispersed oil, and the use of dispersants is not recommended if there is a likelihood that these resources could be affected. Similarly, owing to the increased risk of stock being tainted, dispersant use is not advised in the vicinity of fish cages, shellfish beds or other shallow water fisheries (ITOPF, 2011).

6.4.2 *Tropical waters*

The distinctive habitats and generally warmer temperatures in the tropics can present different challenges from those found when responding to oil spills in more temperate or cold climates. In general terms, warmer temperatures can result in a change of behaviour in certain types of oil. There is likely to be a decrease in oil viscosity relative to colder temperatures and an increase in the rate of some weathering processes affecting oil, such as evaporation and biodegradation.

Figure 16 – *Tropical coastal waters. (Source: ITOPF)*

Habitats such as coral reefs, seagrass beds and mangroves are often found in tropical waters. Not only are these habitats vulnerable and sensitive to oil, but the diverse biological communities associated with them may also be adversely affected by the toxic or smothering effects of oil. Many fish nursery grounds in the tropics are found close to these habitats. Juveniles and eggs are more susceptible than adults to the toxic effects of oil or dispersants, and this should be taken into consideration when deciding whether to use dispersants in shallow waters (ASTM International, 2002).

The likelihood of oil affecting corals depends on factors such as the size of the spill and the type of oil, the type and depth of a coral reef, the local wave energy and the current stress state of the coral. The most significant damage is likely to occur if an oil slick is stranded on the upper parts of a reef at low tide. Submerged reefs may be exposed to oil droplets in the water column, especially if the oil is either physically dispersed through high wave energy, or chemically dispersed following the application of dispersants. If slicks float over submerged reefs without significant dispersal of oil into the water column, adverse effects are likely to be slight, and recovery rapid (IMO, 1997).

Similarly, subtidal seagrass beds, often found in the tropics close to coral reefs, are also at risk of contact with dispersed oil droplets. The application of chemical dispersants near these habitats should therefore be avoided unless the need to protect the shoreline landward of the seagrass beds is considered of sufficient importance as to warrant the risk of damage to this habitat.

Mangroves are particularly vulnerable to oil spills owing to their location at the land-water interface. Mangroves can be affected by the toxic and smothering effects of oil, which can cause stress and mortality to the trees. Manual recovery of oil from within mangroves is challenging without causing further damage to the habitat. Tidal action may moderately assist the natural cleaning processes by flushing oil from mangrove areas. In contrast, oiled mangrove forests with low water exchange can be affected for long periods.

Because of the difficulties associated with cleaning mangrove areas, prevention and protection measures are preferred. Effective chemical dispersion of oil in offshore waters before it reaches the mangroves is considered a viable response option. As mangrove areas are often found landward of coral reefs, any dispersant application should be carried out as far seaward of the reefs as possible to minimize the exposure of corals to the oil droplets in the water column. In some cases, dispersant spraying may be the only logistically feasible way of treating a slick passing over or near coral towards mangrove swamps. As the impact of oil can be fatal to mangroves and oiled mangrove sediments can be a source of chronic pollution, dispersant use in these circumstances could provide a net environmental benefit (IMO, 1997).

The 1984 Tropical Oil Pollution Investigations in Coastal Systems (TROPICS) study (Ballou *et al.* 1987) was a large-scale field study examining the short- and long-term effects of oil and dispersed oil on mangroves, seagrass and coral reefs. Of these habitat types, coral reefs were least affected by exposure to oil alone, showing minimal short-term (0 months to 20 months) and no long-term (10 years) effect on corals in an intentionally oiled zone. Mangroves were the most severely impacted, even 10 years after oiling (NOAA, 2010). This would appear to support the use of dispersants for the protection of mangrove areas, where feasible to do so effectively.

6.4.3 *Cold environments*

The global expansion of offshore oil and gas exploration and production, increased maritime traffic and climate change are leading to extended open-water seasons in the polar regions. The potential application of dispersants has been under consideration as a countermeasure for oil spills in cold-water conditions, including the Arctic.

Figure 17 – *Dispersant application using a remote-controlled spray boom in the icy Arctic environment. (Source: SINTEF)*

Environmental challenges to consider for dispersant use in these conditions include the efficacy of the dispersants at low temperatures, the impact of water salinity, the sensitivity of Arctic species, changes in the physico-chemical characteristics of the spilled oil (e.g. viscosity), and mixing energy levels. Research conducted on the impact of low temperatures seems to indicate that there is no significant drop in dispersant efficacy in very cold water (Belore *et al.,* 2009).

Another consideration when applying dispersant in ice is the salinity of the water. Traditional dispersants are most effective at salinity levels between 25 ppt and 40 ppt (API, 2012). The presence of sea ice can have a significant impact on the salinity of the surface water, either increasing the salinity through the process of brine rejection as the sea ice forms, or decreasing the salinity as the sea ice melts (Toggweiler & Samuels, 1995). Studies have found that variations in salinity had a much greater impact on dispersant efficacy than ice cover, so this should be taken into consideration prior to dispersant use (Faksness *et al.,* 2017).

Ice cover adds another dimension of challenge, as mixing energy is reduced by the presence of ice and existing methodologies for the application of dispersants may not be suitable. Numerous projects have been conducted to look into the effects of dispersant in conditions of broken ice. Such studies have shown that, ultimately, dispersants can disperse oil in ice-covered environments and are a viable response option; however, there are a number of factors which should be considered before their use.

In areas with less than 70% to 90% ice cover, decreases in wave energy do not limit dispersant effectiveness. However, in denser ice cover, additional mixing energy from complementary techniques such as mechanical agitation may be required (API, 2014). Although overall wave energy is reduced in moderate to heavy ice cover, the increased local energy created by the mechanical grinding action of the ice pieces somewhat makes up for this (API, 2012). In some cases, research has shown that the motion and interaction of broken ice pieces actually enhances the dispersion process by providing surface turbulence at higher levels than would occur naturally with non-breaking waves in open water (Lewis & Daling, 2007a).

Several studies have shown that the presence of ice can significantly slow down the rate of weathering, thereby lengthening the window of opportunity for the successful use of dispersants (Brandvik *et al.,* 2006). It has also been shown that in cases where dispersant was applied to oil which was subsequently trapped in frozen sea ice, once the ice had melted, the dispersant was still effective after three months, although it had reduced effectiveness when compared with fresh samples.

Another element to consider when applying dispersant in partially ice-covered waters is the availability of appropriate application methods. The presence of sea ice makes it challenging to target oil and not the ice. An innovation developed in Norway and tested as part of a SINTEF-led joint industry project in 2009 addressed this problem. The device was an articulated spray arm, similar to those used for aircraft de-icing operations, which allowed the delivery of the dispersant to the target areas (Lewis & Daling, 2007b).

Ultimately, dispersant use in ice-covered waters is a viable response option, though it may require additional examination.

6.4.4 *Sensitive areas with limited water exchange*

Some restricted marine areas have limited water exchange and strong salinity gradients (e.g. some fjords, lagoonal or estuarine environments). These limitations affect the ecosystem and species composition. A much smaller number of species can live in brackish water than in the habitats of true marine or freshwater species, which makes these ecosystems highly sensitive.

Marine areas with low water exchange may have stratified water bodies and deep basins, often with permanent anoxic conditions. Owing to the reduced dilution, repeated use of chemical dispersion in these areas can lead to a higher risk of dispersants and dispersed oil compounds accumulating in biota and sediments.

All these factors should be considered when performing NEBA, keeping in mind that the aim of using dispersants in areas with limited water exchange should be to minimize the damage to biota.

6.5 Use of dispersants on underwater oil releases (blowouts)

Dispersants can be used in underwater releases, such as a subsea wellhead blowout.

This situation was encountered in the **Deepwater Horizon** oil spill in the Gulf of Mexico in 2010, during which large quantities of oil were released at sea. Large quantities of dispersants were injected directly into the oil stream at the wellhead (at source), at a depth of approximately 1,300 m, in order to reduce the following:

– the amount of volatiles in the atmosphere close to the damaged well (health and safety issue); and

– the volume of surfacing oil that might drift to the sensitive coastal shoreline (environmental issue).

The formation of a large plume of dispersed oil at a depth between 1,100 m and 1,300 m with low oil concentrations was observed. At the time of writing, the efficacy and impact of this particular dispersant application were still being debated.

The preliminary consensus of the scientific community was that the "use of dispersants and the effects of dispersing oil into the water column [have] generally been less environmentally harmful than allowing the oil to migrate on the surface into the sensitive wetlands and nearshore coastal habitats" (CRRC, 2010).

It should be emphasized that the usual recommendations for regular dispersant application on surface slicks may not apply to a subsea blowout plume. In subsea application, the oil is fresh and still has its light ends (the most toxic fractions), while surface slicks are usually partly weathered. Given the ultra-deep environment, the conditions (e.g. temperature, ecological sensitivity and diversity) are so different from those of the surface photic zone that the usual impact assessment for chemical dispersion is not applicable.

Subsea dispersant application will be addressed in part IV of these Guidelines.

7 Net environmental benefit analysis

It is widely accepted and proven that spilled oil will have less impact on coastal environmental and socio-economic resources if it is recovered or treated in the open sea. Several response techniques exist, and the development of an appropriate response strategy requires careful consideration. Each response technique has particular strengths and weaknesses that must be evaluated in the light of the unique characteristics of each spill. In many cases, a combination of different techniques will be required.

Net environmental benefit analysis (NEBA) is aimed at comparing the environmental and socio-economic benefits of potential response techniques to inform an overall response strategy that will reduce the impact of an oil spill on the environment. An optimal response strategy will minimize a spill's adverse impact on a region's environment and economy. The results of a NEBA will determine the recommendations on which techniques are preferable and which techniques should be avoided for particularly sensitive receptors (IPIECA-IOGP, 2015a).

It is necessary to perform a NEBA, especially when using dispersants, because dispersion does not remove oil from the environment but transfers it to a more readily mixed and diluted state that is more susceptible to biodegradation. Before a spill occurs, it is recommended that potential oil spill scenarios be subjected to a NEBA to consider possible response techniques at the preparatory stage of oil spill response plans. Such preparation and stakeholder engagement to determine the optimal response strategy are meant to enable dispersant use within the window of opportunity if that is deemed an appropriate choice.

NEBA for dispersant application assesses the positive and negative consequences on the environment of dispersant use, relative to doing nothing. These consequences are compared with those associated with other response techniques while taking into account a region's biological resources and socio-economics, such as the season, state of fisheries, cultural and social values. Dispersants are used when the NEBA shows that their use will lead to less hazardous negative consequences for biological resources and economic receptors.

NEBA may be performed as a preparedness tool when an oil spill response plan is under development, or it may be required for a specific oil spill. A preparatory NEBA is beneficial to reduce the time needed for decision-making and stakeholder engagement in an actual spill. This would be performed on the basis of potential oil spill scenarios (including the worst credible case), in which the following must be addressed:

a Description of sources/locations where oil spills are possible. Potential oil spill scenarios and volumes of oil spilled, in addition to anticipated physical and chemical properties of the oil. Results of mathematical simulation of oil spill behaviour on water (considering spreading, possible drift directions, quantitative changes to oil when floating on the sea surface due to evaporation and dispersion, the amount of oil stranded onshore, oil remaining on the sea surface and oil dispersed into the water column).

b List of ecosystem components within the area covered by the oil spill response plan, depending on the priority of their protection at the time of potential emergency scenarios, from the point of view of preserving natural resources and taking into account their seasonal changes.

c List of economically and socially valuable assets which require protection.

d Prioritizing the environmental and economic resources identified above in consultation with the local stakeholders.

e Advantages and disadvantages of various available oil spill response techniques, including dispersant application. In principle, it is necessary to assess the expected results of each possible response technique: dispersant application, containment and recovery; in situ burning; and monitoring for action. In many circumstances, owing to operational limitations, the comparison may be restricted to only feasible response options – for example, chemical dispersion and monitoring for action, which involves comparing scenarios where dispersant is and is not applied.

f The impact of floating and dispersed oil on selected ecosystem components and the state of the environment in general.

There are three commonly used tools to help decision makers select the response option(s) most likely to minimize the impact of oil on sensitive resources (NASEM, 2019). The NEBA process must allow for the variable nature of oil spills and the broad range of natural and economic resources that could be impacted, and it must be flexible to align with real-time, changing response conditions.

One qualitative method or tool for implementing the NEBA process is spill impact mitigation assessment (SIMA). SIMA enables the consideration and weighting of environmental, socio-economic and cultural sensitivities (or receptors) in a particular scenario setting to guide the selection of the most appropriate response options. The SIMA methodology uses a single score for extent of exposure and duration of recovery for each receptor and adds a weighting factor for resource values based on local priorities established through a stakeholder consensus-building process for each response technique. The final matrix is used to select the preferred response option or options (IPIECA-API-IOGP, 2017).

Two other tools designed to support NEBA are consensus ecological risk assessment (CERA) and comparative risk assessment (CRA). CERA involves the use of a detailed, semi-quantitative risk-ranking square to perform comparative analyses of response methods, while CRA relies on an integrated model to simulate the fates and effects of a spill scenario and uses a weighting function to represent the relative exposure, susceptibility and importance of resources.

In general, endangered species, highly productive areas, sheltered habitats with poor flushing rates and habitats that take a long time to recover should receive a high priority rank for protection. However, sensitive habitats and resources should not be viewed in isolation from each other, since any response decision taken for a particular habitat or resource will affect adjacent ecosystems. For example, if oil is spilled above an area important for fishing and is moving rapidly towards a salt marsh, it may be advisable to disperse the oil within the fishery. This may increase the oil exposure of the fishery but would minimize the quantity of oil entering salt marsh sediments, from where it would continue to seep out, forming a chronic source of pollution for both the salt marsh and the nearshore fishery ecosystems for many years. It is crucial to examine these possibilities at the contingency planning stage, when there is enough time to consider such complex interactions.

The recommendation to plot valuable ecosystem components on environmental sensitivity maps and conduct mathematical modelling of spilled oil behaviour constitutes the basis for a NEBA (i.e. weighing the advantages and disadvantages of dispersant application and other available response techniques for the area, depending on the time of year). NEBA is a tool for decision-making. To reduce delays in decision-making during an oil spill, it is strongly recommended that a NEBA be conducted when oil spill contingency plans are being prepared. The results of such a NEBA are presented as a set of oil spill response scenarios. These scenarios are supplemented with recommendations on the practicability, from an ecological point of view, of dispersant usage or its prohibition. Approval for the use of dispersant is given if the NEBA demonstrates that this will lead to an overall positive outcome for the environment. At the time of a real spill, decisions will be made on the basis of this previously prepared NEBA, with adjustments if the actual spill situation differs significantly from the scenarios studied for the NEBA.

Analysts may immediately rule out certain response options because of their ineffectiveness in the given conditions, and rank others in terms of effectiveness and preference. They may recommend the use of different techniques for different parts of the operational area. With regard to dispersant application, the recommendations must indicate whether it is possible to use dispersants in a given situation and if so, which parts of the slick should be treated with dispersants. The NEBA results can be included in contingency plans, discussed with stakeholders (including the national environmental agencies) and used to inform dispersant pre-approval.

NEBA is used in some countries for mapping areas where dispersants should not be used in certain situations according to specific criteria (e.g. seasonal or critically sensitive time of year, tides or currents, water depth, weather conditions, or the spill's size).

During a spill, decision makers are expected to reach rapid and well-justified decisions about protecting sensitive resources, often based on limited information, and where conflict over priorities for protection exists. Effective pre-planning can significantly increase the likelihood of a successful response by discussing response priorities and options when there is still sufficient time to consider them thoroughly.

Without local input to resolve conflicts in priorities at the contingency planning phase, there will be delays to the decision-making at the time of an incident that could have severe consequences for the local environment and economy. During contingency planning, it is necessary to weigh up the advantages and disadvantages of all available response options, including whether or not to use dispersants in specific coastal waters at a particular time of year or whether other response options would be more suitable. It is recommended that NEBA scenarios be incorporated into any contingency plan that involves the use of dispersants. This approach ensures that good practices can be adopted. It is also proposed that dispersant pre-approval should only be implemented if the actual spill scenario follows one of the NEBA scenarios in the contingency plan. Planning scenarios need to be practical and realistic to ensure that such pre-approval is applicable.

8 Testing, assessment and selection of dispersants

Most countries that consider dispersant application as part of their oil spill response strategy have developed specific criteria that dispersants should fulfil. These specifications may be used for selecting the most appropriate products on an informal basis, while some countries have established formal approval criteria and processes.

For the moment, there are no international agreements on these criteria, despite efforts made by international bodies and mechanisms such as the

European Maritime Safety Agency or the Bonn Agreement. Instead of setting their own approval procedure, many countries simply approve dispersants already approved in other countries, accepting those countries' approval mechanisms. For instance, Croatia accepts certain products approved in Cyprus, France and the United Kingdom, while Israel accepts products approved by the French entity CEDRE.

Most often, specifications are based solely on dispersant product effectiveness and toxicity testing. In addition, some countries have set standards relating to the biodegradability of the product or dispersed oil. Some countries specify the physical characteristics of permissible dispersants. Drawing on these criteria, national authorities can develop lists of approved products to be used in conjunction with the approved response strategy.

All known testing procedures are based on laboratory tests. The tests are not aimed at simulating real field situations; they are designed, rather, to give relative values of tested properties. Field experience has shown no significant discrepancies between the relative laboratory test values and product behaviour in the field. The same applies to comparing the results of different tests. Although absolute values can differ considerably for a specific characteristic of a tested dispersant depending on the testing procedure used, products which show better results according to a particular method usually appear superior also when tested using another method.

While there is no agreement on testing methods among different national administrations, it remains possible to rank products with regard to their relative effectiveness, toxicity or biodegradability. The main concern in the early years of dispersant use was the toxicity of these products. With the development of new, low-toxicity formulations, attention has shifted to efficiency. At present, the effectiveness of dispersants is the most important selection criterion. The toxicity and biodegradability of an ineffective product are considered irrelevant; the objective is to select a product with the best possible combination of high effectiveness and low toxicity.

Regardless of the specific methodology, generally accepted testing follows several common steps. First, the product is tested for its effectiveness. Products that meet this criterion are then tested for toxicity and biodegradability. The results of these toxicity and biodegradability tests are compared, and the products fulfilling defined criteria are approved for use.

8.1 Effectiveness tests

Tests conducted in laboratory conditions can compare dispersant effectiveness if the energy applied, oil-to-water ratio, analytical methods and quality assurance are controlled. Most of these tests measure the degree and stability of dispersion (droplet size distribution) after mixing oil and dispersants under standard conditions. Measurement is either by visual observation or through some analytical technique. The lowering of interfacial tension between oil and water following the addition of a dispersant or the speed with which a dispersed oil resurfaces after mixing can also be measured to assess a dispersant's effectiveness. Differences in results and rankings often originate from differences in test parameters, such as type of oil, temperature, oil and water volumes, dose rates, contact between the dispersant and the oil by way of application or premixing, mixing energy, closed test tank versus continuous dilution, and test duration. See table 4 for a summary of the features of several dispersant effectiveness tests.

The following laboratory procedures are those most frequently used to test effectiveness:

- The IFP (flow-through) procedure is used in France. Performed in a test tank, the water is renewed to reproduce the dilution that would occur at sea, while a wave generator supplies gentle mixing energy.*
- The Labofina test (or WSL LR448 test) procedure used in the United Kingdom is run in a separatory funnel that is rotated to promote the dispersion. The UK regulator MMO (Marine Management Organization) accepts both this test and the modified baffled flask test which CEFAS (the Centre for Environment, Fisheries and Aquaculture Science) recently adopted (Sühring *et al.,* 2017).
- The swirling flask test used in North America is carried out on oil samples premixed with dispersant in a very small funnel, which is rotated gently to promote the dispersion process.†
- The Mackay-Nadeu-Steelman (MNS) test is a medium- to high-energy system used in Australia‡ and Norway§.
- The modified swirling flask test was developed by the State of California using a baffled flask and is derived from the original swirling flask test.

* French standard AFNOR NFT 90-345.

† ASTM F2059 - 06 Standard Test Method.

‡ In Australia, in addition to the MNS test, the completion of WSL (Warren Spring Laboratory) testing is mandatory.

§ Norway uses a combination of the IFP dilution (low energy level) and the MNS (medium/high, energy level 2 to 3) tests to study the effectiveness of dispersant (in connection with dispersant screening), the dose needed and dispersibility of the oils at various weathering stages.

Table 4 – *Main dispersant effectiveness test features*

Test	Energy source	Energy level	Water volume (L)	Oil-to-water ratio	Dispersant application method	Dispersant-to-oil ratio	Settling time
IFP (French Institute of Petroleum) dilution test	Oscillating hoop	Low	5	1:1,000 then drop	Drop-wise	1:20	Not recorded
Labofina rotating flask using WSL (Warren Spring Laboratory) LR448	Rotating vessel	High	0.25	1:50	Drop-wise	1:25	1 min
Swirling flask test – later modified to swirling baffled flask test	Shaker table	Low	0.12	1:1,200	Premix or drop-wise	1:10 to 1:25	10 min
MNS (Mackay, Nadeau and Steelman)	High-velocity air stream	High	6	1:600	Drop-wise	N/A*	5 min

* N/A = not applicable

It is difficult to obtain data in laboratory conditions that reflects the actual energy and dilution encountered in spill conditions.

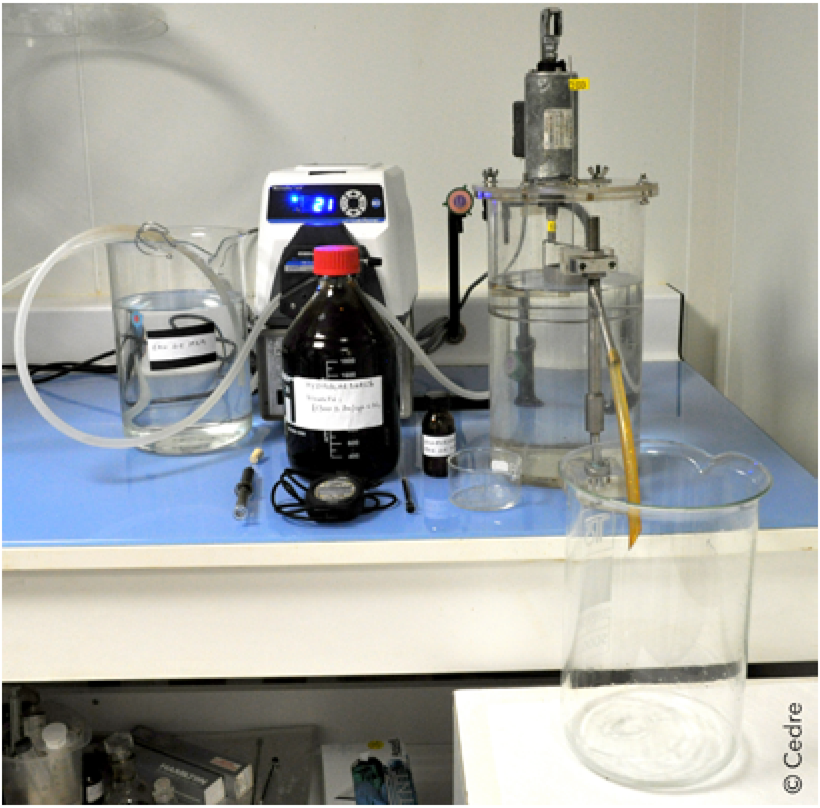

Figure 18 – *Dispersant effectiveness laboratory test method: IFP flow-through test used in France. (Source: CEDRE.)*

Tank tests offer a compromise between laboratory studies and field trials and are a vital step in understanding processes and refining test methods. The advantage of wave tanks is the ability to investigate droplet diffusion in a more realistic environment; however, the encounter rate may be higher than expected in the field owing to the confined environment of the tank. Droplet size, weathering, background levels of hydrocarbons, heterogeneity of the slick and accurate mass balance equations must also be considered.

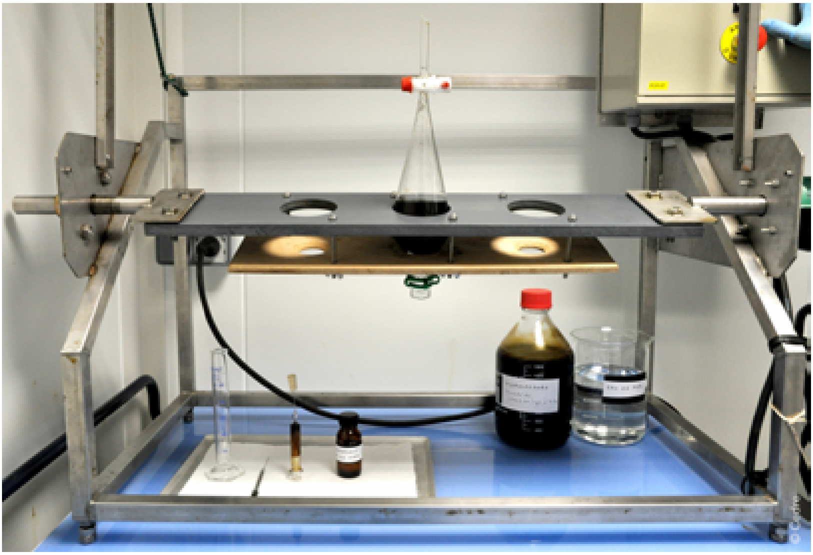

Figure 19 – *Dispersant effectiveness laboratory test: WSL-Labofina test method used particularly in the United Kingdom. (Source: CEDRE)*

Field tests have now been designed to assess oil dispersibility in open water, often at the beginning of or during the dispersant application. These tests are helpful to the oil spill responder in deciding whether to apply dispersant on weathered oil. Unfortunately, the tests are not very reproducible or quantifiable. Instruments such as fluorometers have been used to track dispersion in field tests and real spill scenarios. A fluorometer result is considered qualitative and should be used as an indicator of relative oil dispersion rather than as a precise determination (e.g. to compare naturally dispersed oil beneath a slick with dispersed oil following dispersant application, both relative to measurement in clean open water as a control sample). A protocol has been developed by the United States Coast Guard for monitoring in the field known as Special Monitoring of Applied Response Technologies (SMART) (USCG-NOAA-EPA-CDC-MMS, 2006). It has been used during several oil spill response operations, including **Montara** (2009) and **Deepwater Horizon** (2010). This protocol uses visual observations and in situ fluorometers to gauge the effectiveness of dispersant application and can be supplemented by in situ water samples that undergo laboratory analysis later on.

8.2 Toxicity tests

Test materials are usually dispersants, dispersed oil (oil-dispersant mixture), and sometimes oil alone. Test species could be fish, arthropods (typically decapod crustaceans), molluscs (pelecypods), annelids (polychaetes) and algae. Ideally, test species should be selected from local species of ecological or commercial significance. Tests may be acute (short term), lethal or sublethal and cover single or multiple species. The main goal of these tests is to determine the relative toxicity of a certain dispersant versus other previously tested products.*

Since toxicity increases with temperature, toxicity tests should consider expected changes in seawater temperature. A common criterion involves measuring the median lethal concentration (LC50; the concentration of test solution required to kill 50% of the test organisms) within a prescribed period (usually 24 or 48 hours).

Toxicity testing can be conducted using the following two different approaches:

1. checking the intrinsic toxicity of the dispersant in order to reject the most toxic ones, in which case only the dispersant is tested; or
2. checking that the dispersant does not increase the oil's toxicity, in which case the tests are performed both on the oil alone and on the oil-dispersant mixture.

Since the dispersion of the oil in the water column increases the exposure of pelagic marine organisms to oil, the toxicity of the oil-dispersant mixture will be temporarily higher than that of the oil alone. This effect is short-term because of active water exchange, a feature of open water environments. The more efficient the dispersant, the higher the proportion of oil droplets in the water and, therefore, the more toxic the oil-dispersant mixture may appear. This could lead to a rejection of the most effective dispersant, contrary to the goal of the approval procedure, which is to select the more effective but less toxic ones. This is the purpose of testing the intrinsic toxicity of the dispersant alone. The toxicity of the dispersed oil remains a concern when considering the policy on dispersant use. This concern is addressed as part of the NEBA to define the scenarios (environmental conditions) in which the use of dispersants would be environmentally optimal. NEBA acceptability requires data on the toxicity of the dispersed oil (the oil-dispersant mixture).

* As a complementary way to assess dispersion toxicity during a real pollution incident, monitoring the environmental effects of dispersant use (for example, by making observations of fish or mammals in the vicinity along with any mortalities), is a useful tool.

A standard toxicity test, the test for LC50, would measure the concentration of dispersant causing 50% mortality in a population of a typical test species over six hours. The smaller the LC50, the more toxic the dispersant tested. Most modern dispersants have maximum LC50 values of approximately 200 mg/L. Sensitivity to dispersants varies according to the species and life stage examined, with larval-stage organisms more susceptible than adults to dispersants and dispersed oil.

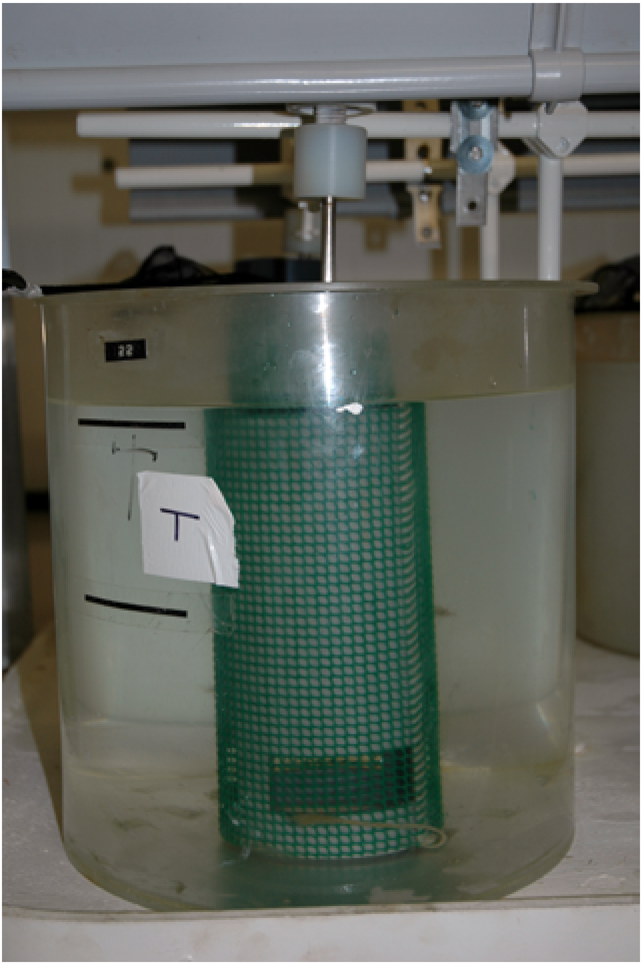

Figure 20 – *French toxicity test method conducted with the dispersant alone on shrimps. (Source: CEDRE)*

8.3 Biodegradability tests

Dispersants and dispersant-oil mixtures are often tested for biodegradability. There is no consensus on a standard methodology for testing the biodegradability of dispersants. Various adaptions of standard tests for organic materials are in use (e.g. the method used in France is the one described in the NF T90-346 standard).

8.4 Other tests

Standard analytical methods can be used if required to test other properties (density, viscosity).

9 Dosages and application rates of dispersants

The overall guiding principle for responsible dispersant application is to maintain the lowest effective dosage throughout the spray operation. To achieve this, a deliberate and dynamic approach is needed to adjust the quantity of dispersant in line with the changing conditions. The amount of dispersant to be applied depends on the dispersant type, degree of oil weathering, the oil thickness and environmental conditions (e.g. waves). Sometimes, the oil is easily dispersed; therefore, a low dosage (low dispersant-to-oil ratio, or DOR) may be sufficient. This was experienced during the **Sea Empress** oil spill in 1996. In other less favourable situations (low dispersibility of the oil), it may be appropriate to increase the dosage (SL Ross Environmental Research & MAR Inc., 2009).

For planning purposes, it is advisable to refer to the dosage rate recommended by the manufacturer (often 20:1 for ″third-generation", Type 2/3 dispersants), which can be adjusted during operations in the light of performance (typically ranging from 40:1 to 10:1). Dispersant effectiveness can be evaluated in the field through a test spray run and/or a field test using a glass jar (e.g. the Australian National Plan Oil Spill Dispersant Effectiveness Field Test Kit). Depending on the results of these tests, the dosage rate can be adjusted or the dispersant may be determined to be ineffective. Refer to part III, section 7.2, "Testing prior to large-scale spraying", for more information.

The older, non-aromatic hydrocarbon-based dispersants are now referred to as "second-generation" or "Type 1" dispersants. These are rarely used nowadays but historically were usually applied at a dosage rate of approximately 2.5:1.

"Concentrate" dispersants or "third-generation", Type 2/3 dispersants are usually applied at a dosage rate of around 20:1 for oils of up to 5,000 cSt. This may increase to between 20:1 and 10:1 in cases where the oil has a viscosity between 5,000 cSt and 10,000 cSt. Treatment of oils with viscosities of over 10,000 cSt is generally considered ineffective. For fresh, light, easily dispersible oils with a viscosity of less than 500 cSt, a dosage lower than 20:1 may be sufficient to maintain effectiveness.

Application rates can be calculated using generally accepted rules for assessing oil thickness (dark patches of oil are assumed to be at least 0.1 mm thick). Regardless of the spraying equipment used, the application rate is determined by the discharge rate of the dispersant pump, the speed of the vessel/aircraft and the width of the area covered by the spray (swath). The relationship between these variables is:

$$\text{Application rate} = \frac{\text{Discharge rate}}{\text{Speed x Swath}}$$

Consequently, knowing the constant swath width* of the available spraying equipment, the required application rate for each particular slick area can be achieved by:

a selecting the appropriate discharge rate of the dispersant pump; or

b selecting the appropriate speed of the vessel or aircraft.

Droplet size is a significant factor in achieving maximum effectiveness when applying dispersant. Droplets that are too small may be blown off target, and droplets that are too large may penetrate and pass through the oil. Refer to part I, section 4.4, "Droplet size", for more information.

10 Dispersant application systems

The selection of a suitable dispersant application system depends on several factors:

- type of dispersant available;
- spraying equipment available;
- spill's size and distribution (spread, patchiness); and
- location (distance from shore to ensure appropriate delivery mechanism).

Smaller vessel systems used in isolation to treat a large area of oil would take a long time and may miss the window of opportunity for dispersion. An aircraft-mounted system may be most suited to this situation. In contrast, a

* It should be noted that "swath width" refers to the width of deposition of dispersant on to the surface of the sea, and not the physical width of the spray booms.

sizeable aircraft-mounted system would not be as appropriate for managing a much smaller, broken-up oil slick.

Several dispersant spraying systems exist and they can be grouped according to the carrier for which they were designed, as in the following:

– aircraft-mounted; and
– vessel-mounted.

10.1 Aircraft-mounted spraying systems

The aerial application of dispersants offers many advantages. These include rapid response time, the possibility of flying multiple sorties in a day (depending on spill location), good control and targeting of dispersant application, rapid assessment of performance, high treatment rates and a wide operational window (less impacted by sea state than vessel-mounted systems). Accordingly, a number of small and large spray systems have been developed for use with both fixed- and rotary-wing (helicopter) aircraft. Existing units are either of a type that can be mounted in the "aircraft of convenience" or a type that is permanently installed. Standard inbuilt spraying systems, widely used in agriculture, can be adapted for the spraying of dispersants.

Aerial application of dispersants depends on the visibility over the slick area and relies on wave energy for mixing dispersant with spilled oil. Only neat concentrate dispersants are suitable for use with airborne spraying systems.

10.1.1 *Fixed-wing aircraft*

Crop-spraying aircraft may be readily available. However, it is necessary to modify the spraying nozzles because the application rate for dispersants is much higher than that for agrochemical products. These aircraft typically cannot be used far from the shore because of their limited range, small fuel load and the insufficient safety offered by a single engine.

Fixed systems for converted multi-engine aircraft comprise storage space for dispersants, a pump including a power pack, spray arms with nozzles and a remote control system. As an alternative, some independent systems (with a tank, a pump and spray booms) have been developed that can be clamped under the fuselage as a detachable pod. These systems make it possible to rapidly convert regular planes into spraying aircraft.

Pod spraying systems for small aircraft are self-contained spraying systems that can be rigged under a small plane. It is quick and easy to convert a regular freight or passenger aircraft into a spraying aircraft. The capacity of these systems is about 1.5 tonnes of dispersant.

Figure 21 – *View of the spray pattern seen from the inside of a large aircraft (C-130 Hercules). (Source: ITOPF)*

Figure 22 – *Medium-size aircraft equipped with a pod designed for dispersant application. (Source: CEDRE)*

Table 5 – *Application of dispersants: typical aircraft and workboat characteristics. (Source: ExxonMobil Research and Engineering Company)*

Characteristics	**Lockheed Hercules L-382/C-130 with ADDS[*] pack**	**Douglas DC-4**	**Air Tractor AT-802**	**Smaller planes, e.g. Beachcraft, CASA, Cessna, Bandeirante**	**Bell helicopter**	**Typical large workboats**
Payload (Litres)	20,000	7,600	3,000	800-1,900	680	2,100-6,500
Turnaround time with or without refuelling (minutes)	60-75	30-60	20	30-60	15	25-75
Max. average transit speed (km/hr)	350	350	310	370-400	210	10-17
Spray speed (km/hr)	280	260-295	210-260	300	200	2-15
Repositioning speed (km/hr)	325	295	360	300-370	200	4-17
Time to Initiate a 180° turn (minutes)	1	1	0.5-1	1-2	1	2-10
Neat dispersant pump rate (litres/minute)	2,400-3,000	1,890-2,270	570	760-1,900	400	60-150
Typical swath width (metres)	25-60	25-60	30-40	18-27	10-15	15-30

[*] ADDS: Aiborne Dispersant Delivery System

Characteristics	Lockheed Hercules L-382/C-130 with ADDS* pack	Douglas DC-4	Air Tractor AT-802	Smaller planes, e.g. Beachcraft, CASA, Cessna, Bandeirante	Bell helicopter	Typical large workboats
Minimum runway length required (metres)	1,830	1,525	580	790-1,500	N/A‡	N/A‡
Average number of missions per 12 hours for a 7.4 km (4 nm) slick / Litres of dispersant applied every 12 hours						
Distance (km)						
15	6 / 120,000	9 / 67,000	16/ 48,000	9 / 17,000*	23 / 16,000	3 / 20,000†
50	6 / 120,000	7/ 53,000	12 / 36,000	8 / 15,000*	14 / 9,500	1.5 / 10,500†
80	5 / 100,000	6 / 45,000	10 / 30,000	7 / 13,000*	10 / 7,000	1/ 6,500†
160	5 / 100,000	5 / 38,000	7 / 21,000	6 / 11,000*	6 / 4,000	N/A‡
240	4 / 80,000	4 / 30,000	5 / 15,000	5 / 9,000*	4 / 3,000	N/A‡

* Based on Bandeirante plane
† Based on 6,500 litre payload
‡ N/A = not applicable

Self-contained airborne spraying systems are built to suit large transport aircraft with rear cargo doors that can remain open during the flight. Units are self-contained, include tanks, power packs, pumps and retractable spray arms, and can easily be loaded into the cargo hold.

The most recent advancement in aerial dispersant application technology has involved developing purpose-built dispersant application equipment suitable for use with modified large cargo aircraft such as Boeing 727 and 737. Tanks capable of holding 15 tonnes of dispersant, power packs, pump systems and spray arms are self-contained and permanently mounted within the body of the aircraft and controllable from the flight deck.

Figure 23 – *Boeing 727 equipped with purpose-built pump systems and storage tanks. (Source: OSRL)*

10.1.2 *Helicopters*

Fixed spraying systems for helicopters are mounted under the fuselage and consist of much the same technology as the units on board the fixed-wing aircraft.

Helicopter spray buckets can be used with any helicopter equipped with a cargo hook for underslung loads. Units are self-contained and include tanks, power packs, pumps and spray arms and can be remotely operated by a control panel run to the helicopter cockpit.

Aircraft permanently equipped for dispersant spraying are rare because of the high costs involved, so using underslung helicopter buckets is often a good solution for many locations. Helicopters can be extremely manoeuvrable, but their carrying capacity decreases quickly when the distance to be covered increases.

10.2 Vessel-mounted spraying systems

Several types of vessel-mounted spraying systems exist, including units that are either permanently mounted on the vessel or removable.

10.2.1 *Systems for spraying Type 1 dispersants*

Systems for spraying second-generation (hydrocarbon-based) Type 1 dispersants are rarely used anymore since these dispersants were sprayed undiluted and, owing to the 1:1 or maximum 1:3 dispersant-to-oil ratio required, a large volume of dispersant needed to be carried on board. These systems comprised a fixed flow rate pump and two spray arms, usually with three nozzles each and were often stern-mounted.

10.2.2 *Systems for spraying concentrate pre-diluted into seawater*

The dilution of concentrated dispersants (Type 2 or 3) with seawater allows the use of high-volume spray systems. The dilution enables an increased flow rate and allows spraying using the same equipment but through large nozzles. These systems are usually designed to pre-dilute the dispersant to around 10%.

The following systems can be used to pre-dilute dispersants:

1 Eductor systems (fire monitor systems) are designed to work with the ship's inbuilt fire-fighting system. These systems, while simple, are known for their uneven application, which can lead to more inefficient spraying operations compared with other systems. The diluted dispersant is applied by a fire monitor or through nozzles mounted on spray arms attached to the vessel's side. This system tends to waste dispersant and has a limited encounter rate. Although it is found on most vessels, it should be used only if no other equipment is available.

2 Injection systems consist of two pumps: one for water and the other for the dispersant. The dispersant is applied through nozzles mounted on spray arms attached to the vessel's side. These arms tend to be 10 m to 30 m wide. Fixed and portable designs exist, and units are installed preferably on the vessel's bow to benefit from the mixing energy provided by the bow wave.

It should be emphasized that pre-dilution can reduce dispersant effectiveness, especially when the oil is viscous (>700 cSt). For this reason, neat dispersant application, as described next, is recommended where possible and always supported by a clear NEBA justification.

Figure 24 – *Dispersant application from a tugboat. (Source: ITOPF)*

10.2.3 *Systems for spraying neat dispersant*

Systems for spraying third-generation, neat concentrates (Type 2 or 3) are specifically designed for this purpose. These units are usually bow-mounted and have a pump with a variable flow rate, while the dispersant is generally discharged through nozzles mounted on spray arms. The latter are usually longer than stern-mounted arms, giving a greater oil encounter rate. Natural mixing energy is suplemented by the vessel's bow wave.

To increase the range of dispersant flow rates, some units are equipped with multiple spraying assemblies. By operating one or several assemblies, the flow rate can be adjusted to cope with variables such as ship speed, oil thickness and oil type.

In addition to custom-built, dedicated anti-pollution vessels, different vessel types may be used for spraying dispersants. These include tugboats, supply vessels, trawlers and small fishing vessels. The need to operate at low speeds with high manoeuvrability may exclude certain vessels. Suitable vessels should also have sufficient storage space for dispersants.

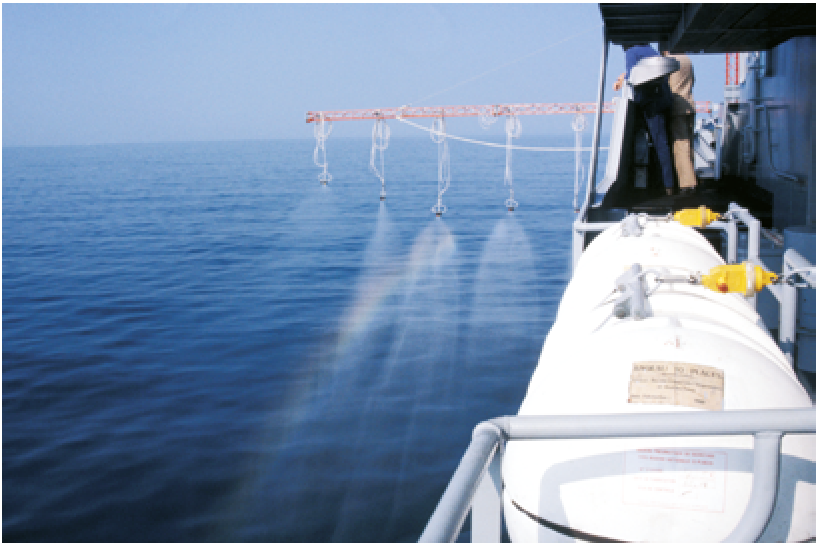

Figure 25 – *Neat dispersant application from a vessel.*
(Source: CEDRE)

11 Logistical requirements for the efficient use of dispersants

Regardless of the scale on which dispersants are applied, their use calls for well-organized logistical support. Dispersant effectiveness varies with the type of dispersant, accuracy of application and time taken to apply dispersant on the released oil (window of opportunity for dispersion). To maximize the benefits of this technique, it is better to apply dispersant as soon as practically possible before the oil increases in viscosity. Therefore, all the logistics should be pre-planned. This aspect is critical when dispersants are used for large-scale offshore spills given the large volume of dispersant required and the associated transport and storage arrangements. Since the mechanical recovery of oil also requires significant support, logistical constraints may be a decisive factor in whether to use one method or another. Through the application of NEBA principles, the correct technique (or combination of techniques) can be identified and prioritized. The availability of the necessary equipment, products and personnel will play a key role. Other factors, such as the size and location of the spill, the time required for mobilizing equipment and personnel, and prevailing sea and weather conditions, will also strongly influence the decision on which method to choose.

Figure 26 – *Refilling dispersant on a small crop-spraying aircraft (**Betelgeuse** oil spill). (Source: ITOPF)*

For maximum efficiency of dispersant treatment, particular attention must be paid to logistics and the resupplying of the dispersant.

Dedicated spotter aircraft should be poised to guide spraying aircraft or vessels over the thickest part of the slick to be treated.* The low height of visual perspective offered by vessel operations can make it challenging to determine the location of the thickest patches of oil. Support from the air is a critical factor to ensure that operations are effective and efficient. This intelligence should be made immediately available to the skipper so that he or she can adjust course rapidly or respond directly to instructions such as “spray on/spray off”.

* This aerial guidance can be conducted visually or, better, using remote sensing techniques such as those based on infrared sensors (e.g. forward-looking infrared video recording), which allow operations to be conducted without visibility (e.g. in darkness).

When treating oil with dispersant, product information such as oil viscosity* can assist one in making a more accurate calculation of the volume of dispersant needed. If Type 2 or 3 "concentrate" dispersant is to be used, a dispersant-to-oil ratio of approximately 1:20 will be required.

Many countries hold stockpiles of dispersants, but these are usually sufficient only for an initial response. It may be necessary to make arrangements with manufacturers and distributors or oil spill response organizations in advance, so that additional quantities of the product can be provided at extremely short notice. International, regional, subregional and bilateral agreements with neighbouring countries should be considered in advance to share national stockpiles in the region or in remote countries. Countries affected by a spill can request additional stockpiles and equipment within a pre-established framework to facilitate the coordination of regional assistance. Collaborative initiatives exist, such as the Global Dispersant Inventory database, which is held and maintained by OSRL and lists dispersant stockpiles located around the world known to the managers of the database.

Transportation of dispersant from storage and production sites or the airport of arrival to the spill site or base of operations must be planned and executed precisely. Air freight of dispersant in intermediate bulk containers (IBCs) may be the only option fast enough to bring dispersant to an affected country in time. However, air freight carries an increased cost and potential availability risk.

If large quantities of dispersant are required, transportation from storage to the operational staging posts in road tankers or liquid containers is often more efficient than in drums or IBCs. Transfer pumps, hoses, valves and fittings should be available to transfer dispersant in bulk storage or IBCs into vessels/aircraft tanks. Different types of dispersant should not be mixed.

The maintenance of the vessel/aircraft spraying equipment should be regular and planned. Supplies of the most critical spare parts should be available.

Fuel and logistics should be planned as part of the contingency planning process in order not to delay spraying operations.

Helicopter spray systems need minimal operating facilities. Landing sites for small rotary-wing aircraft can be improvised if proper airfields are unavailable; however, larger aircraft require long suitable runways and specific facilities.

* Sometimes, the actual dosage needed for the specific oil to be treated is documented in the contingency plan; such data can be obtained through a technical assessment previously conducted in a laboratory. As an example, some oils require a lower dosage rate (e.g. DOR < 1:200) when concentrates are used.

Accommodation for the crew must be provided near the base of operations. When larger vessels are used for spraying, the crew can often be accommodated on board.

Appropriate communication links are essential, particularly between spotter aircraft and spraying units. Very high-frequency radio communication systems appear to have advantages over other systems but, often, sourcing a communication channel from spotter aircraft to vessel can be a challenge. Permanent contact must be established with national aviation authorities to obtain clearance for planned operations without delay.

If requesting aircraft through international assistance, flight authorizations, infrastructure compatibility (e.g. runway specifications) and availability of specified fuel should be checked in advance, preferably while developing the contingency plan.

Crew flight time limitations should be considered when planning for ongoing aerial spraying operations.

12 Storage of dispersants

12.1 Storage

The volume of dispersants to be stored for emergency response should be assessed during the contingency planning process. The calculation should be based on the volume required to respond to the most credible worst-case oil spill scenario, taking into account the necessary time for sourcing and receipt of replenishment stock. Supplier replenishment times should be factored into the contingency measures as part of that planning process. Supplies of dispersant should be readily available in accessible and strategic locations such as a port, marine terminal, airfield or aboard dedicated vessels. Dispersant should be applied as quickly as possible after the oil spill incident. Any delay can lead to an increase in the oil's viscosity (as the oil undergoes weathering processes), which reduces dispersant effectiveness over time. Some oils have a very short window of opportunity for dispersion; therefore, the decision to apply dispersant should be prompt and the means readily available.

Most dispersant suppliers deliver dispersant in 1,000-litre IBCs. There are older stocks contained in steel drums, which should be stored in warehouses to avoid corrosion. Stockpiles should be protected from direct sunlight and significant temperature fluctuations to avoid deterioration of the dispersant. Drums can be palletized, but this storage method does not allow the most efficient use of space. Moreover, drums can present loading and unloading challenges, which may slow down response times.

Steel-caged IBCs are easily stacked, giving a more convenient and space-saving configuration, are easier to inspect and transport, and are usually cost-effective.

Depending on the response, dispersant is sometimes contained in bulk in road tankers for transport, ISO tanks for aviation storage or vessel tanks for either spraying operations or subsea injection. This approach risks leading to the evaporation of solvent and oxidation of surfactant. Most large tanks are not airtight to allow for temperature and pressure fluctuations. Vessel tanks also entail the risk of seawater contamination. Some dispersant suppliers and maintenance procedures recommend a nitrogen blanket for the container (IBC) void space and a cap without a vent, providing an inert environment for the dispersant inside. Bulk storage containers usually have vents, which means that solvent can escape over time, as well as creating the risk of external contamination of the dispersant.

Dedicated anti-pollution vessels may opt for storage in the vessels' integral tanks. ISO tanks, IBCs or other deck storage options may also be suitable depending on the size and capability of the vessel.

High-capacity portable pumps made of dispersant-resistant materials must be available to transfer products from storage containers to spraying units.

Figure 27 – *Dispersant stored in drums in an emergency stockpile. (Source: CEDRE)*

12.2 *Shelf life*

Dispersants are a complex mixture of various components. The effectiveness of a dispersant may be impacted if it is incorrectly stored. Components may separate from the solution during prolonged storage in layers or even crystallize. Usually, dispersant deterioration is a result of inadequate storage conditions. Dispersant quality may be altered if dispersants are contaminated by external chemicals or by reaction to the container material. This is especially a risk if containers are subject to temperature fluctuations or directly exposed to sunlight. Most often, deterioration manifests itself in a loss of product effectiveness. It is, therefore, advisable to carry out periodic checks on product quality. A monthly visual inspection is recommended to check for signs of container leak, damage, seepage, or sedimentation, to verify the legibility of labels and to check that the appearance and colour are consistent with the manufacturer's description. The presence of fine particulates does not necessarily impact on the performance of the product or spraying system. However, any changes or abnormalities should be recorded and a discussion with the manufacturer is recommended. Further investigation may be required (e.g. testing of effectiveness). The findings of these routine inspections should be recorded and photographs may be taken to allow the monitoring of dispersant state over time.

Countries with established approval or acceptance procedures regularly require information on shelf life from the product manufacturer. Regardless of the manufacturer's declaration, the most reliable method for discovering changes in the original quality of the stored dispersant is to periodically test its effectiveness and compare the results with those obtained using the same method and the same product when it was fresh. Such tests are easy to perform and are recommended to be carried out five years after manufacture and then every subsequent five years on 10% of the containers making up a numerically referenced "batch" at each storage location. This testing involves examining the physical properties of the dispersant (density and viscosity) and comparing them against those stated in the product's safety data sheet (SDS). The effectiveness of the product is also considered. The testing process should mirror that used when the original product was approved (to be comparable). Many regulators will stipulate the methodology to be used. Where this is not the case, most laboratories can offer several widely recognized methods, such as the LR448/EXDET test protocol. Different test methodologies represent different energy/mixing environments, so using the same methodology is very important to obtain comparable results. Regulatory jurisdictions set a pass mark for effectiveness results as part of their initial dispersant approval process. It is accepted up to a point that some loss of effectiveness will occur over time. As a result, many regulators accept a lower "retest" pass mark than the original threshold for approval.

12.3 *Disposal of dispersant stockpiles*

As with industrial waste, outdated dispersant stockpiles should be disposed of through specialized waste providers. Alternatively, an additional clause in the contract with the dispersant supplier could require the supplier to remove outdated stock at the time of replenishment. Dispersants are an expensive product and, therefore, only usually considered for disposal when laboratory tests demonstrate a significant deterioration in effectiveness (according to regulatory guidance). Stock can often be transferred or sold if dispersant is no longer required. It is recommended that, when seeking to dispose of dispersant stock, the manufacturer be contacted for advice.

13 Health and safety considerations regarding dispersants

13.1 Human health

Response operators should avoid direct contact with dispersants under appropriate operational conditions by using adequate personal protective equipment (PPE). Brief contact with a small amount of dispersant should not cause harm, and long-term repeated exposure to dispersant is unlikely. The components of dispersants are not considered to cause chemical sensitization, and most dispersants contain proven biodegradable, low-toxicity surfactants. Despite the low health risk, following proper application procedures and wearing appropriate PPE remain essential to protect human health (King & Gibbins, 2011). The operator should avoid breathing the dispersant spray by wearing properly fit-tested respiratory protection. Direct skin contact with the dispersant should be avoided by wearing gloves and protective coveralls, while safety goggles should be worn to protect the eyes. Spraying operations should be organized in such a manner as to prevent the possibility of exposing the public or other operators to the dispersant.

13.2 Seafood contamination

During the **Deepwater Horizon** incident in the Gulf of Mexico in 2010, substantial quantities of dispersant were applied both beneath and at the sea surface. The United States Food and Drug Administration reported that the overwhelming majority of seafood tested during the incident showed no detectable residue, and that none of the samples had a residue level harmful to humans. Undoubtedly, Gulf of Mexico seafood coming to the market was and is safe from oil or dispersant residue. However, as a precautionary principle, it is often advisable to ban temporary fishing activities near significant dispersant treatment operations.

13.3 Flammability of dispersants

Since dispersant formulations include hydrocarbons, dispersants are flammable in principle, but the flashpoint is high, often over 60°C, and the fire hazard is low. In the event of a dispersant fire, a regular extinguisher product, such as water, carbonic snow or chemical powder, are suitable for fighting the fire.

Figure 28 – *Example of personal protective equipment to protect the eyes and the respiratory tract. (Source: CEDRE)*

Figure 29 – *Dispersant spraying operation performed with a large multi-engine aircraft. (Source: ITOPF)*

Part II
Template for national policy on the use of dispersants

Part II

This part of the Guidelines proposes a template for a national policy on the use of dispersants, which would be used in conjunction with the national oil spill contingency plan (NOSCP). The template has been prepared as a single coherent document to be used separately from other parts of the Guidelines. It is designed to assist competent authorities (regulators and managers) to define, develop and revise their country's policy document on the use of dispersants. National competent authorities in charge of developing and revising the national policy for the use of dispersants can adapt the template to suit their national requirements. In that regard, the template offers the possibility to "fill in the blanks", indicated by square brackets [EXAMPLE BLANK TEXT], according to national structure and requirements.

The success and effectiveness of a dispersant operation depend on the degree of preparation. The following template provides a list of what should be prepared in the planning stage in terms of scientific (dispersibility studies, principles for NEBA analysis, geographical limits), technical (selection of product and equipment) and logistical (pre-authorization for flights, monitoring) data and procedures.

Considering the environmental constraints on dispersant use, the template proposes parameters such as minimum depth and proximity to the shore. These parameters are a reasonable synthesis of current knowledge of dispersants and can be adapted to address specific scenarios or concerns at the national level.

Basic practical recommendations are given on conducting a NEBA, which will inform the decision on whether or not to use chemical dispersants.

This template also facilitates decision-making procedures when considering dispersant application at the time of the incident. The decision scheme considers three key variables: oil dispersibility, potential impact and logistical capability.

The template also addresses the preparations needed to manage the operation properly, including the use of foreign resources.

Template for national policy on the use of dispersants in the marine waters of [COUNTRY NAME]

1 Preamble

Chemical dispersion is one of the response options for an oil spill at sea. This technique is suitable for offshore use and brings many clear operational advantages. This document sets out [country name]'s national policy on the use of dispersants, which is to be referenced in conjunction with the NOSCP.

2 Objectives of chemical dispersion

Chemical dispersion aims to minimize the impact of oil pollution by breaking the oil down into tiny oil droplets, to be dispersed and diluted into the marine environment, enhancing natural degradation processes (particularly biodegradation). The objective of using dispersants at sea is to reduce the amount of oil reaching the coastline, environmentally sensitive areas or economically important areas.

3 Chemical dispersion process

Dispersant functions by reducing the interfacial tension between water and oil, allowing the natural mixing energy generated by waves to split the oil into small droplets. Wave and current energy work to dilute and disperse oil droplets throughout the water column, with local oil concentration quickly falling to normal levels after just a few hours.

Removing oil from the sea surface reduces the effect of the wind on the oil's movement, which may otherwise push the slick towards sensitive areas (often the shoreline).

Dispersants also prevent the coalescence of oil droplets and the re-formation of the oil slick.

4 Role of the dispersant application technique in an offshore response strategy

Several response techniques are available when managing an oil spill in an offshore environment. These techniques include containment and mechanical recovery, chemical dispersion, in situ burning, and monitoring the fate and behaviour of the oil slick to determine whether action is necessary (refer to the IMO *Manual on Oil Pollution: Section IV – Combating Oil Spills*). In the decision-making process, the feasibility and effectiveness of each option, whether in isolation or combined, should be examined to determine the best course of action or response strategy.

Chemical dispersion is generally incompatible with other response techniques, particularly if oleophilic skimmers are used for oil recovery. However, using multiple techniques simultaneously may be very effective if operational sites are zoned and recovery operations are well coordinated.

5 Dispersant formulations and types

Oil spill dispersants are composed of the following two main components:

- surface-active agents (surfactants); and
- solvents.

There are two basic categories of dispersant available:

Second-generation dispersants: products with a low content of surfactant (between 15% and 25%). These products are applied neat at a high dispersant-to-oil ratio (DOR) of around 1:2.5 to 1:3. In the United Kingdom, these products are classified as Type 1 dispersants. This type is now much less commonly used or stocked.

Third-generation (concentrate) dispersants: products with a high content of surfactant (between 25% and 60%). They are much more effective than the second generation. These products are applied at a much lower dosage, typically at a DOR of around 1:20. Some oils may require less dispersant. They can be applied neat or pre-diluted (usually 1:10) with seawater, but the neat application is recommended as more effective. These dispersants contain a type of water-soluble alcohol/glycol.*

* These products are classified as Type 2 dispersants in the United Kingdom when approved to be applied pre-diluted, and as Type 3 dispersants when approved to be applied neat (LR448 specification, 1983).

Table 6 – *Classification, application and dosage rate of second- and third-generation dispersants*

Dispersant type	UK classification	Approved application	Typical dispersant-to-oil ratio
Second-generation	Type 1	Undiluted (neat) from vessels	1:2.5 to 1:3
Third-generation concentrates	Type 2	Pre-diluted with seawater from vessels	1:20
	Type 3 (self-mixing dispersant)	Undiluted (neat) from vessels or aircraft	

6 Process for dispersant pre-approval in [COUNTRY]

If already in place, indicate the process for approval application, the responsible regulatory body/bodies and the frequency of re-approval. Involve manufacturers to ensure the availability of testing certification. If not already in place, work through the requirements above and provide the resulting details here. Note to template user: refer to part I, section 8 for further information about pre-approval processes.

7 Pre-approved dispersant for use in [COUNTRY] waters

The list below details the dispersant types that are approved for use in [COUNTRY] waters. Dispersant pre-approval is regulated by [GOVERNMENT DEPARTMENT NAME]. Registration of products is achieved through application by dispersant manufacturer with [GOVERNMENT DEPARTMENT NAME], following the registration requirements of [GOVERNMENT DEPARTMENT NAME].

(Note to template user: regulatory requirements and testing methodology and criteria vary according to government body. Please check country requirements; if no country requirements exist, refer to section 6 above. Refer to part I, section 8 for further information about pre-approval processes. Some countries state that they automatically approve dispersants that have been approved by another country (e.g. France or the United Kingdom) under its criteria. Please note that, in these cases, approval is therefore impacted if that country registration process or dispersant approval status changes. This should be clearly indicated as a precaution in this section).

Dispersant name	Manufacturer	Approval expiry (if applicable)	[OTHER RELEVANT INFORMATION]

8 Advantages and disadvantages of chemical dispersants

The lists below present several advantages and disadvantages of using dispersants to mitigate an oil spill.

8.1 Advantages

- When dispersed, oil is no longer subject to wind drift effects; therefore, when applied upwind of sensitive areas (often the shoreline), dispersants reduce the amount of oil that might otherwise drift towards these locations.
- The prompt and effective application of dispersants reduces shoreline contamination, reducing the need for, or the scale of, manual clean-up operations.
- It reduces the likelihood of an impact on valuable ecosystems sensitive to floating oil (surface slick), such as those that support marine birds and mammals.
- Dispersed oil does not generate oily waste requiring regulated disposal.
- The use of dispersants inhibits the formation of mousse (oil/water emulsion), which can be especially difficult to clean up and generates a greater quantity of oily waste.
- In terms of operational feasibility, it is often the quickest response option.
- Dispersion can generally be used in higher sea-energy conditions (greater wind and/or current and sea state) than containment and recovery options.
- It enhances the natural biodegradation of the oil in the marine environment, contributing to reduced oil toxicity.

– In very specific operational circumstances (such as a subsea blowout), dispersion can be used to create a safer working atmosphere for personnel engaged in source-control operations. Reducing the amount of oil on the sea surface reduces the concentration of toxic or flammable volatile organic compounds in the immediate vicinity. The use of dispersants for this safety purpose overrides environmental considerations regarding dispersant use.

8.2 Disadvantages

– The use of dispersants is not effective for all oils, particularly those of high viscosity (see section 9.1.1 below).

– It is only an effective response option within the first hours or days of the operation ("window of opportunity"), before the oil becomes too weathered and viscous.

– It temporarily increases the local oil concentration within the upper few metres of the water column, resulting in dispersed oil being more bioavailable to pelagic organisms that would not otherwise be in contact with surface oil. If used on a discharge or oil slick containing high levels of volatile organic compounds, a chemical dispersant can enhance the solubility (bioavailability) of more toxic fractions that would otherwise evaporate.

– It is not an appropriate technique for use everywhere, particularly where the possibility of significant rapid dilution is reduced, such as in shallow water environments (see section 9.1.2 below).

– If used near the shore or in very shallow waters, dispersants may increase the likelihood of oil being incorporated into the suspended sediment. It should be noted that oil incorporation into sediment is a risk associated with oil slicks in reduced water depth regardless of whether dispersants are used or not.

– The use of dispersants is not an effective response option if the prevailing sea energy is too low.

– Chemically dispersed oil may continue to create an environmental impact if the conditions for rapid dilution are not present.

– In cases where dispersant has been applied, but dispersion is not achieved, the subsequent effectiveness of other response methods may decrease. For example, oleophilic skimmers and absorbents work best with untreated oil.

– Adding dispersant introduces extraneous substances into the marine environment.

9 Recommendations for the use of dispersants

9.1 Importance of prearranged dispersant policy

As dispersants are most effective on "fresh oil", it is of the utmost importance that the decision to use dispersant be taken quickly and efficiently. The speed of that process will depend on the level of preparedness measures put in place and on decision-making criteria developed in advance.

9.1.1 *Dispersible or non-dispersible oil*

The effectiveness of chemical dispersion depends on the properties of the oil. The viscosity of the oil at ambient temperature is one of the most critical factors. Chemical dispersion is usually effective on oils with a viscosity below 5,000 cSt (with some exceptions, such as oils with a high paraffin content). Where viscosity exceeds 5,000 cSt, the probability of successful dispersion decreases significantly. Dispersion is not generally suitable for oils with a viscosity greater than 10,000 cSt.

Following an oil spill, the oil's viscosity increases with exposure time since the release, as a result of weathering (evaporation, emulsification), which means that its dispersibility decreases. In general, an oil pollutant is dispersible only within a certain time frame referred to as the "window of opportunity" for dispersion. To obtain an idea of the viscosity of an oil pollutant, and of the corresponding window of opportunity for dispersion, certain data-processing models can be used that estimate the evolution of a pollutant according to its nature and the environmental conditions. For an oil of high viscosity, the greater the mixing energy (wave action, sea state), the higher the probability of dispersion.

Less persistent, light refined oils, such as petrol, diesel oil and kerosene, do not require the application of dispersants as they usually evaporate and self-disperse when released at sea. Moreover, these products contain toxic light ends that would cause a more significant impact if dispersed into the water column. For these products, chemical dispersion would be considered for safety reasons only (reduction of fire or explosion hazard).

Oil that has a high paraffinic content exhibits a high pour point.* When the ambient temperature is lower than the pour point, the oil ceases to be fluid and becomes non-dispersible.†

Table 7 – *Dispersibility ranges*

Generally accepted dispersibility ranges	
Light refined products (petrol, kerosene, diesel oil)	No chemical dispersion
viscosity <500 cSt	Dispersion is generally possible with a concentrated dispersant, applied neat or pre-diluted with seawater
500 cSt < viscosity <5,000 cSt	Dispersion is usually possible with a concentrated dispersant
5,000 cSt < viscosity <10,000 cSt	Uncertainty as to the result: dispersion might be possible with a concentrate dispersant; performance of dispersant application should be carefully monitored
viscosity > 10,000 cSt	Dispersion is generally not possible

Note: In order to assess the window of opportunity for dispersion and to prepare the dispersion response option for oils frequently transported inside or in the vicinity of [COUNTRY NAME] waters or regularly imported in [COUNTRY NAME] harbours, it is recommended, where possible, to conduct the following specific studies:

– a weathering study using modelling; and

– laboratory tests to assess oil dispersibility in relation to the oil weathering stage or oil viscosity.

* Pour point is the temperature below which an oil no longer flows according to specific laboratory conditions (ASTM D97 / IP 15). Oil pour point is correlated to the wax content; as a rule of thumb, the pour point can be roughly estimated as follows:

Wax content (%)	Pour point (°C)	Wax content (%)	Pour point (°C)
<5	<5	15	20
≥ 10	≥10	20	30

† The difference between the ambient temperature and the pour point for which an oil remains dispersible is still in debate; it is dependent on the ambient mixing energy (wave) especially when the agitation is high enough to maintain the oil in a dispersed state, but generally ranges from a few degrees to 10°C to 15°C according to different scientific sources.

The results from these studies are given in the document [TO BE SPECIFIED] in the form of tables showing the oil viscosity and the corresponding window of opportunity for dispersion of each oil according to different environmental conditions (temperature, wind) to be done by [ADMINISTRATION OR INSTITUTE IN CHARGE] in collaboration with [LIST OF ADMINISTRATION, INSTITUTES ETC. INVOLVED].

9.1.2 *Locations where chemical dispersion can be undertaken*

The toxicity of the dispersed oil can affect marine fauna and flora. Hence chemical dispersion is not advantageous at all locations. Chemical dispersant is not generally applied near ecologically vulnerable or sensitive areas or where the renewal and mixing of water do not offer conditions for rapid dilution of the dispersed oil. If used in very shallow water, the dispersion process may contribute to the penetration of oil into the sediments (it should be noted that if surface oil enters a shallow water environment, natural sedimentation processes will occur, with or without the addition of dispersant).

Identifying areas where chemical dispersants can be used is a relatively long and complex process as it is necessary to consider different local environmental parameters and data (e.g. on current and biological diversity). Such a task would be challenging to complete quickly during an incident. Areas where dispersant application can be employed as an oil spill response technique should be pre-established as part of the contingency planning process and have clearly defined geographical limits for dispersant use. Pre-approval/pre-authorization of dispersant use subject to specific criteria can be essential in enabling rapid application as soon as possible after an oil spill has occurred.

The choice of these areas should be based on studies of scenarios that aim to compare the environmental and socio-economic impacts of dispersed versus undispersed oil (see annex 1, "Net environmental benefit analysis"). The NEBA process should consider all local characteristics, including sensitive ecological and socio-economic resources (e.g. species of environmental value, marine protected areas, fishery resources, life cycles and seasonal variations, migration of the marine species of interest and currents).

The geographical limits must be defined for spill scenarios corresponding to various magnitudes of spills.

The following restrictions should be applied in conjunction with specific environmental criteria and taking into account the net environmental benefit that dispersed oil can provide. As a general rule, dispersion operations could be carried out where a water depth of [XX] m and distance from shore of [XX] nautical miles can be achieved. (These parameters are often defined as ranges of 10-20 m water depth and 1-2 nautical miles from the shore, but they should be agreed in conjunction with, and under guidance from, the technical committee described below.) This ensures sufficient water volume to allow the dispersed oil to be diluted to concentrations below that which could have a significantly negative impact on marine organisms.

However, a technical committee should be assembled, led by [NAME OF THE ADMINISTRATIVE BODY IN CHARGE], and composed of: [LIST OF THE ADMINISTRATIONS, LABORATORIES, INSTITUTES, HARBOUR AUTHORITY, PRIVATE BODIES INVOLVED]

1.
2.
3.
…

in consultation with: [LIST OF THE ADMINISTRATIONS, LABORATORIES, INSTITUTES, HARBOUR AUTHORITY, PRIVATE BODIES INVOLVED]

1.
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whose technical secretary is under [NAME OF THE ADMINISTRATIVE BODY IN CHARGE]. This committee should examine and study areas of particular interest, such as a harbour entrance (high-risk area) and marine protected and sensitive areas (those of high environmental interest, such as fisheries and critical marine habitats), and modifications of these general limits at a local scale to take into account local conditions (environmental and socio-economic). This technical committee can draw on the expertise of consulting non-governmental organizations dealing with marine conservation and environmental science.

With regard to the following areas: [LIST OF THE AREAS OF CONCERN], the possibility of dispersant use should be examined using scenarios that are realistic in terms of the quantity of oil involved in expected spill incidents, locations where the risk of an incident is high, prevailing weather conditions and analysis of tidal stream, currents and surface agitation. Studies of these scenarios will involve a realistic comparison (subject to the available equipment) of the possibilities for containment and recovery, chemical dispersion and extensive clean-up of the shoreline. The environmental damage and associated costs will be compared for each option to determine the most appropriate one (see annex 1, "Net environmental benefit analysis").

[NAME OF THE ADMINISTRATION IN CHARGE] is responsible for conducting these investigations.

The charts with the limits for dispersant use should be integrated into the contingency plan. They assist the responsible party in making a decision as quickly as possible (while the pollutant is still dispersible) on whether or not to use dispersant. The specific local regulations for the dispersant use are presented / described as charts in [ANNEX TO BE SPECIFIED].

These charts are regularly updated by [NAME OF THE ADMINISTRATION IN CHARGE], under the supervision of the technical committee described above.

9.1.3 *Logistics for dispersant application*

Logistical requirements for the application of dispersants include resources such as spraying systems, dispersant products and ancillary items. Requirements are outlined in the contingency plan (storage and mobilization location, quantities/volumes, characteristics, compatibility, availability, operational limitations and mobilization requirements, and deployment time frames). An example list of the required resources would be as follows *(delete if not appropriate or required)*:

1 operational stocks of dispersant;

2 onboard spraying systems;

3 vessels on which spraying equipment can be used;

4 vessels equipped with inbuilt spraying systems;

5 aerial spraying aircraft;

6 facilities/staging posts for the deployment of resources (airports, ports);

7 aerial surveillance aircraft dedicated to monitoring and guiding the operations;

8 water column monitoring/sampling equipment

9 communication equipment; and

10 transportation vehicles (trucks, forklifts) and suitable drivers.

The plan must also include specifications, performance ratings, requirements and conditions of the equipment likely to be mobilized for the following:

- at the national level (public and private equipment);
- at the regional level (equipment available through bilateral or regional agreement(s) with neighbouring countries); and

– at the international level (equipment available through global, regional, subregional or bilateral agreements or contracts with international companies).

The plan details those in charge of the equipment (contact persons).

[NAME OF THE ADMINISTRATION IN CHARGE], in cooperation with the stakeholders (private companies, ports), is in charge of keeping the inventory of equipment and related logistics up to date.

9.2 The decision-making process

At the time of the incident, the decision-making process should compare the feasibility and overall benefit of the various possible response options. With regard to the use of dispersant, the decision should be based on the following three questions:

Q1) Is dispersion feasible from a physico-chemical point of view? Is the viscosity of the pollutant compatible with chemical dispersion? This question refers to the recommendations outlined in section 9.1.1 above.

Q2) Is dispersion environmentally beneficial? Is the spill located in an area where the application of dispersant is recommended by net environmental benefit analysis? This question refers to the recommendation outlined in section 9.1.2.

Q3) Is dispersion logistically feasible? Are the logistics (products, equipment, personnel) available and sufficiently mobile to conduct the operation within the window of opportunity for dispersion? This question refers to the recommendation outlined in section 9.1.3.

At the time of an incident, the decision on using dispersant is taken by [NAME OF THE ADMINISTRATION IN CHARGE]. For this decision [NAME OF THE ADMINISTRATION IN CHARGE] can request the assistance of other relevant institutions.

See annex 2, "Decision tree", for the decision-making process.

9.3 Selection of dispersant products

Dispersant products should be pre-approved through [GOVERNMENT DEPARTMENT NAME/REGULATORY BODY] to ensure that they meet defined effectiveness and toxicity standards. These controls are carried out through laboratory testing.* In line with national policy, a specific approval process with its own testing procedures can be established, or a process from another country can be followed, which implies approving dispersants that have already been approved in other countries.

The dispersants used in [COUNTRY NAME] controlled waters must be approved for use as a pollution countermeasure by the authorities.

Note: Such acceptance (or approval) does not exempt a dispersant from complying with the general regulations on chemicals.

For efficiency purposes, third-generation "concentrate" dispersants (Type 2 or 3) are recommended for use in [COUNTRY NAME] controlled waters. For safety reasons, the flashpoint of dispersant products should be above 60°C. The dispersant product should be appropriately documented by the manufacturer. The dispersant manufacturer should guarantee that the product remains stable and effective for a minimum of five years when stored properly. Approved products are to be registered on an approved list that is periodically revised. This list should be regularly maintained and readily available.

In the event of a spill involving neighbouring countries, decisions on the use and application of dispersants must consider existing bilateral (or regional) agreements with those countries. Such agreements may cover the following:

- dispersants approved by those countries;
- application equipment that could be made available under a cooperative arrangement; and
- integration of response resources from the countries involved within [COUNTRY NAME].

As a guiding principle, in a joint operation at the regional level, dispersants approved in the partner countries will be acceptable if they have undergone successful testing for effectiveness and toxicity. In the event of a significant spill requiring international assistance, dispersants will, at a minimum, have been proven to be acceptable for effectiveness and toxicity.

The approval procedure and its revision are under the responsibility of a technical committee led by [NAME OF THE ADMINISTRATIVE BODY IN CHARGE] and composed of: [LIST OF THE ADMINISTRATIONS,

* Additional specific information on dispersant testing procedures can be found in part I, chapter 8, "Testing, assessment and selection of dispersants".

LABORATORIES, INSTITUTES, HARBOUR AUTHORITY, PRIVATE BODIES INVOLVED].

1.
2.
3.
...

in consultation with: [LIST OF THE ADMINISTRATIONS, LABORATORIES, INSTITUTES, HARBOUR AUTHORITY, PRIVATE BODIES INVOLVED].

1.
2.
3.
...

The role of technical secretary of the technical committee is performed by: [NAME OF THE ADMINISTRATIVE BODY IN CHARGE].

9.4 Choice of application equipment

Specialized or converted equipment is used for the application of the dispersants (e.g. agricultural plane equipped with nozzles suitable for dispersant application or mobile spraying equipment to be fitted to transport planes). The equipment ensures a regular spray pattern and distribution of the dispersant (diameter of the dispersant droplets, rate of application). The equipment must be regularly maintained (with written and scheduled maintenance procedures in place) and is tested periodically through exercises (see section 11.1 below).

The choice of application equipment should be approved by [NAME OF THE ADMINISTRATIVE BODY IN CHARGE] or delegated to [EXPERT ORGANIZATION NAME] with possible technical advice from [LIST OF THE ADMINISTRATIONS, INSTITUTES AND/OR PRIVATE BODIES INVOLVED].

9.5 Logistics related to the application of dispersants

The application of dispersants requires a detailed understanding of the necessary logistics for the operation. In addition to the spraying equipment, it is necessary to plan the logistics for transporting this equipment (ships, helicopters and planes), the required consumables (in particular, fuel and dispersant), adapted facilities (port, airport and runways) and other related provisions (e.g. transportation of the equipment or products).

Aircraft can be based in [COUNTRY NAME] or nearby [COUNTRY NAME]. They can belong to the public sector or private companies. In the case of aircraft owned by external private or public bodies, contracts should be in place to ensure the availability of the equipment at the time of an incident (e.g. availability within six hours after the call for mobilization).

The suitability and compatibility of the equipment and dispersant deployed must be verified to guarantee the reliability of the whole logistical chain (e.g. compatibility of the spraying systems with the ships and compatibility of planes or helicopters with the local facilities). The various authorizations required under civil aviation regulations should be obtained in advance to allow rapid deployment of the aircraft at the time of an incident.

To ensure prompt application, dispersant stockpiles must be established. These stockpiles should be quickly deployable and/or located near the spraying systems. They should be sufficient to enable a day of dispersion with the spraying system available at the location. Vessel-mounted spraying system equipment and the associated dispersant stock should be based preferentially in the ports where the vessels are located. Aerial spraying equipment and stockpiles should preferably be available at the airport.

The date of manufacture of the product must be given by the supplier. The dispersant must be stored according to the manufacturer's instructions and material safety data sheet.

The batches of operational dispersant stockpiles should be tested periodically (physico-chemical parameters; aspect, viscosity, density; effectiveness) to verify their condition. (The suggested intervals are five years after purchase if the product has been kept in its original tank or drum and every two years after that.)

Disposal of unusable dispersants is the responsibility of the dispersant owner. The dispersant must be disposed of in accordance with the environmental regulations, as with the disposal of any other chemical substances.

An up-to-date inventory of dispersant stockpiles and spraying systems should be kept. This inventory should also reference the stocks and industry capacities of the countries or entities with which bilateral agreements or agreements on assistance are in place, including the contact details of those parties.

Public stockpiles of dispersants are under the responsibility of [NAME OF THE ADMINISTRATIVE BODY IN CHARGE] or have been delegated to [EXPERT ORGANIZATION NAME].

For aerial application equipment, [NAME OF THE ADMINISTRATIVE BODY IN CHARGE] makes an inventory of the possible available resources at the regional level (e.g. existing spraying aircraft) or has delegated this task to [EXPERT ORGANIZATION NAME]. Considering that private resources will be needed, contracts must be drawn up with the bodies that own this equipment.

[NAME OF THE ADMINISTRATIVE BODY IN CHARGE] is in charge of establishing contracts with the private/external bodies that own the application equipment that may be mobilized as part of the contingency plan.

[NAME OF THE ADMINISTRATIVE BODY IN CHARGE] keeps the inventory of public and private sector equipment and products up to date or has delegated this task to [EXPERT ORGANIZATION NAME].

10 Application procedures

10.1 On-site testing and monitoring of dispersant effectiveness

The degree of weathering of the oil may be unknown, leading to uncertainty about its dispersibility after the dispersion operation begins. For this reason, any operation should begin with careful monitoring of the effects of the treatment. A test spray run should be conducted to determine whether to continue dispersant application. Such test runs should be periodically repeated throughout the operation to monitor dispersant efficiency.

Monitoring may be performed through visual observation, with an experienced and trained observer monitoring and documenting the results after dispersant application using georeferenced photography or videography. Observation of a brown "coffee-coloured" plume under the sea surface signifies the presence of dispersed oil.

Where possible, visual monitoring should be supplemented with the use of water column monitoring techniques such as fluorometry. The latter should be carried out by trained personnel using specialized equipment (USCG-NOAA-EPA-CDC-MMS, 2006). The technique measures fluorescence emitted by oil droplets in the water column. A fluorometer is towed from a vessel at predetermined depths, usually a number of metres below the water-oil surface, and indicates the relative prevalence of dispersed oil in the water column at the time of the measurement. Measurements are semi-quantitative, meaning the method relies on relative readings. It is necessary to obtain background readings in unoiled areas near the spill, oiled areas that have not had dispersant applied to them (to ascertain the rate of natural dispersion) and oiled areas that have been treated with dispersant. If the dispersant works effectively, the fluorometry readings from the chemically dispersed transect would be expected to be significantly higher than those recorded in the control transect.

If available, aerial remote sensing techniques such as infrared imaging can be used to confirm the reduction of surface oil resulting from the dispersion process.

If a ship is on location, it is possible to assess oil dispersibility on an oil sample collected from the slick following a field test procedure. This method compares the dispersion of the oil sample in a glass jar with and without dispersant as the jar is shaken gently by hand (e.g. the Australian National Plan Oil Spill Dispersant Effectiveness Field Test Kit or the Norwegian field effectiveness test).

[NAME OF THE ADMINISTRATIVE BODY IN CHARGE] must designate the person on location who will complete these checks of application effectiveness or delegate this to [EXPERT ORGANIZATION NAME].

[NAME OF THE ADMINISTRATIVE BODY IN CHARGE], in consultation with the Ministry responsible for the environment and/or [EXPERT ORGANIZATION NAME], will decide whether or not to continue the treatment.

10.2 Dispersion application procedure

Successful dispersant application is dependent on operations following correct procedures and taking place in the proper circumstances. Dispersant should be applied:

- on the thick parts of the slick (brown to black colour) while ignoring the thinnest parts (iridescence, shine);
- systematically, taking into account the wind; and
- in accordance with reference documents and industry good practice, for example:
  - the *IMO/UNEP Guidelines on Oil Spill Dispersant Application, Including Environmental Considerations,* Appendix 6 – "Dispersant application at sea: operational procedure" (IMO-UNEP, 1995);
  - the IPIECA-IOGP guidelines entitled *Dispersants: Surface Application* (IPIECA-IOGP, 2015b);
  - the CEDRE guide *Using Dispersant to Treat Oil Slicks at Sea* (CEDRE, 2005); or
  - part III of these Guidelines.

Wherever possible, treatment operations should be guided by a spotter aircraft. This aircraft's purpose is to identify optimal treatment locations and guide dispersant application to the targeted area. When necessary, these target areas can be marked with buoys. The low height of visual perspective offered by vessel operations can make it challenging to determine the location of the thickest patches of oil. Support from the air is a critical factor to ensure that operations are effective and efficient. This intelligence should be made immediately available to the skipper so that he or she can adjust course rapidly or respond directly to instructions such as "spray on/spray off".

As discussed in section 10.1, dispersant application should be carried out in conjunction with monitoring to assess the technique's effectiveness. Monitoring may also be supported by the use of information from the spotter aircraft to guide the monitoring equipment to the dispersed oil plume. Information gathered from the monitoring of dispersant effectiveness can be used to justify the decision to apply dispersant.

[NAME OF THE ADMINISTRATIVE BODY IN CHARGE], with the help of other institutions as necessary, is responsible for organizing the monitoring of dispersion efficiency or has delegated this responsibility to [EXPERT ORGANIZATION NAME].

10.3 Assistance from foreign experts and operators

For significant incidents (Tier 3) involving teams made up of foreign experts and operators, it is necessary to appoint contact personnel to welcome these external teams and facilitate their involvement in national operations. An example would be a contact person at the airport to arrange accommodation and any necessary authorizations or permits for a foreign team in charge of spraying aircraft.

Foreign exchanges and cooperation can be pre-planned through formal agreements at the regional level between neighbouring countries, or at the international level, as with specialized international service companies.

10.4 Impacts on fisheries

The dispersion of a significant amount of oil can impact on certain environmental resources such as fisheries (e.g. tainting of seafood following contact with oil droplets). For public health and safety reasons and to aid the management of claims for compensation, water and seafood should be monitored for oil levels. In some circumstances, it may be necessary to ban fishing temporarily. Additional information can be found in the *IMO/FAO Guidance on Managing Seafood Safety during and after Oil Spills* (IMO-FAO, 2003).

Monitoring water and seafood quality, as well as making the relevant decisions (e.g. imposition of a fishing ban), is the responsibility of the [NAME OF THE ADMINISTRATIVE BODY IN CHARGE] or is delegated to [EXPERT ORGANIZATION NAME]. This task can be done in consultation with [LIST OF THE ADMINISTRATIONS, INSTITUTES AND/OR PRIVATE BODIES INVOLVED].

10.5 Public perception and media communication

During a pollution incident, there will always be many and various stakeholders involved, for example, the ship manager, charterer, insurer, protection and indemnity club, local and national authorities, representatives of fisheries, aquaculture and related industries, the tourist industry, environmental non-governmental organizations, response operators, and local communities and the general public.

These parties may have conflicting perceptions of events and sometimes diverging interests. Such a situation may be exacerbated when the selected response option does not attract unanimous support, which is sometimes the case with the use of dispersants.

Negative reactions towards dispersant use are often caused by a lack of knowledge of this response technique and of the effect it can have. A very common confusion is between the toxicity of the dispersant and that of the dispersed oil in the environment. The NEBA process (see annex 1), which forms the basis for justifying the use (or non-use) of dispersants, is generally unknown to the public. It is important to bear in mind that people tend to be wary of things they do not fully understand. Oil spills are often widely publicized by the media and can generate highly emotional reactions among the general public. Recent major spills have demonstrated that communication is fundamentally important to a successful response and can be a real challenge.

At the preparation stage, education remains the best way to avoid conflicts over the use of dispersants. Ideally, this approach should be initiated before the spill through training and information programmes for the stakeholders involved and the heightening of public awareness by producing informative documents and multimedia channels, including dedicated websites.

At the time of the spill, communicating via a website dedicated to the incident is a very efficient way to inform people of the spill and its impact and explain why the various response techniques chosen are the most appropriate. In the case of chemical dispersion, information specifying how the use of dispersants will minimize the environmental and economic consequences of the incident can also be given.

This information must be written clearly to be easily understandable by all (experts and the general public). It should be honest and balanced about the advantages and limitations of the technique used. The environmental and economic advantages expected from the use of dispersants should be clearly explained.

Communication with the general public and the media is under the responsibility of [NAME OF THE ADMINISTRATIVE BODY IN CHARGE].

11 Precautions and operational recommendations

11.1 Exercises

Exercises should be organized periodically to validate operational procedures, train responders and verify the effectiveness of the contingency plan. The availability of personnel to be mobilized can be checked through a desktop exercise. Practical field exercises involving realistic simulations that mobilize people and equipment on site are used to examine the applicability of the equipment for a response.

One annual tabletop exercise should be organized in each coastal district, and one annual deployment exercise should be scheduled at the national level in a different coastal district. The deployment exercise could be organized in the framework of the whole NOSCP covering a number of techniques, including dispersant application.

Amendments to plans and policies should be undertaken in accordance with the observations made during the exercises.

Exercises are coordinated by [NAME OF THE ADMINISTRATIVE BODY IN CHARGE] in collaboration with the organizations concerned.

11.2 Training

Personnel responsible for the operation of dispersant application equipment should undergo regular and specialized training. This training can be integrated with the general training plan in the NOSCP.

The [NAME OF THE ADMINISTRATIVE BODY IN CHARGE] coordinates and supervises the training.

11.3 Protection of people and equipment

Responders involved in dispersant spraying operations must be protected from dispersant exposure through PPE (e.g. mask, eye protection, impermeable clothes and gloves). If spraying is carried out close to the shore, precautions must be taken to ensure that the public is not exposed to dispersant droplets. Wind direction should be considered when identifying treatment zones.

Solid surfaces (especially ship decks) that may be exposed to dispersant spray should be flushed with water to prevent slipping.

Material and equipment in contact with the dispersant should be flushed with water to avoid any deterioration of paint, rubber seals or similar materials. Spraying equipment should be rinsed with fresh water after use.

Annex 1
Net environmental benefit analysis

The objective of any oil spill response is to minimize overall impact on environmental and socio-economic resources. The decision on the use of a response option (i.e. dispersant and/or mechanical recovery) should be based on an assessment of what would be the impact of the spill following intervention as opposed to "no intervention".

This comparison process is called NEBA* and is based on the known sensitive resources, behaviour of the oil, the response option(s) considered, as well as the feasibility and the expected efficiency of the response options.

The analysis assists decision makers in considering whether the use of dispersants will minimize environmental and economic damage. NEBA can support a comparison of damage caused by the oil dispersed at sea with the damage caused by a slick that drifts ashore. In most cases, less damage is caused at sea by the dispersed oil than that caused by the weathered (often persistent) oil stranded on the shoreline. When the oil is approaching and likely to impact on the shore, decisions become more difficult and may require weighing the resources to be preserved and those to be sacrificed. The NEBA process with stakeholder engagement is intended to aid these decisions.

Cultural, natural and economic resources should be considered. In general, it can be said that endangered species, highly productive areas, sheltered habitats with poor flushing rates and habitats that take a long time to recover should receive top priority for protection. The list should take into account factors such as possible seasonal variations as well as the time needed by each impacted resource to recover (damage to a resource that can regenerate quickly is often more acceptable than damage to one which needs a very long restoration time). These factors will affect prioritization.

Habitats and resources should be considered as a whole and not independently, as the decision to apply dispersant may benefit particular habitats or resources and at the same time affect adjacent ecosystems. For example,

* NEBA is sometimes referred to in the literature by other names, such as NEEBA (net environmental and economic benefit analysis) or NEDRA (net environmental risk and damage assessment).

if an oil spill occurs in shallow water above a submerged coral reef with current and wind conditions leading the slick towards a mangrove swamp, it is generally advisable to disperse the oil above the reef, because of the recovery time of a mangrove impacted by oil. Although this may increase the exposure of the corals to oil, it will prevent the oil from being incorporated into the mangrove sediments, from which it would constantly seep out over many years, causing long-term chronic pollution in both ecosystems.

Generally, in terms of priority, it is better to protect the habitat before the species themselves, as the species are dependent on the preservation of their habitat. With regard to species, the objective must be to protect the reproductive potential.

Completing the NEBA process takes time and such analysis should be carried out in advance when preparing oil spill contingency plans. It should be conducted on a scientific basis by a team of stakeholders that preferably includes specialists from several fields (e.g. ecology; bird, mammal, fish and benthic biology; socio-economics; mathematical modelling of the behaviour of spilled oil) industry representatives, government entities, subject matter experts, oil spill response organizations and representatives of potentially affected stakeholders and communities.

The NEBA methodology should be defined and the tool to undertake the NEBA agreed on by the stakeholders for the selected scenario(s). Possible tools include spill impact mitigation assessment (SIMA), consensus ecological risk assessment (CERA) and comparative risk assessment (CRA).

Principles of environmental considerations regarding the use of dispersants

1 Consider the use of dispersants in the open sea, offshore and upstream of sensitive resources to prevent oil from reaching the shoreline or sensitive resources (where water quality must be preserved).

2 Avoid the use of dispersants on, or in the immediate vicinity of, resources that are sensitive to dispersed oil.

3 In coastal areas where several sensitive resources are of concern, a NEBA based on realistic scenarios is required.

4 When a NEBA is required:

- **a** Consider the behaviour (drift and weathering) of the treated oil (drift according to the current and speed of dilution of the plume) and of the untreated oil (drift according to the current and wind).

b Identify resources potentially affected by the treated oil or by the untreated surface oil.

c Assess the possible sensitivity of these resources.

d Consider these resources according to their sensitivity and/or importance and decide on the priorities (what must be preserved, what could be sacrificed).

e Predict the possible impacts for the different response options (e.g. chemical dispersion or not) and make a decision on the use of dispersants.

f In case of conflicting conclusions:

- preserve the habitat before the species; and
- preserve reproductive potential.

5 In areas where local birds are concentrated, the application of dispersants is of particular concern when the wind is blowing in the direction of flocks of birds (direct contact between dispersants and the feathers of seabirds should be absolutely avoided).

Note: Dispersants should be used in response to accidental pollution. In sheltered areas, chronic usage during repeated incidents can lead to chronic contamination.

Annex 2
Decision tree for the use of dispersant as an appropriate response technique

The decision-making process for dispersant use is described through the decision tree below and its three corresponding flow charts.

The decision on whether to use dispersant is reached by successively addressing three independent and basic questions:

1 Is dispersion possible? (Is the pollutant itself dispersible?)

2 Will dispersion be beneficial? (Is it appropriate or acceptable with respect to the environment and related issues?)

3 Is dispersion feasible? (Is it logistically possible to conduct?)

In the three flow charts that aim to answer these questions, the decision-making process can be followed through the blue boxes. The yellow boxes represent the information needed for the process. The yellow boxes outlined in bold blue indicate information that needs to be predefined and included in the NOSCP to facilitate the process. Yellow boxes containing black text indicate information related to spill-specific circumstances.

The decision to use dispersants can be taken if the three questions elicit a positive answer. If one of these questions gives a negative answer, it is necessary to consider other response options.

Each of these questions is detailed in the corresponding flow chart further down.

1 Is the oil dispersible from a physico-chemical viewpoint? (This question refers to table 7, “Dispersibility ranges”.)

Note: This question is answered considering the use of third-generation (concentrate) dispersants. Dispersibility limits according to oil viscosity refer to concentrate dispersants.

There are two possible ways to assess the dispersibility of the oil:

- Carry out a dispersibility test on an oil sample to directly determine the oil dispersibility; or
- Assess the oil viscosity (at the time of treatment) using three principle questions:
  - Is the oil initially dispersible at the ambient sea temperature (before weathering) and is its viscosity below the generally accepted dispersibility limits? If it is over 10,000 cSt, other response options should be considered.
  - Given its pour point and the ambient sea temperature, is the oil liquid or does it solidify? If the oil is not fluid, other response options should be considered.
  - After having assessed the actual oil viscosity according to its weathering stage (possibly using oil weathering models), is the oil dispersible at the time of dispersant application?
    - **i** If an oil weathering pre-study is available, use data from that to determine whether the oil is dispersible.
    - **ii** If an oil weathering pre-study is not available, dispersibility can be estimated from the actual oil viscosity using the simplified table below the flow chart (this table takes into account both oil viscosity and sea state/surface agitation).

If the oil is not dispersible, consider other response options. If the oil is dispersible, proceed to the next question.

2 Will dispersion be beneficial from an environmental or economic viewpoint? (This question refers to section 9.1.2.) In other words, will dispersant use lead to more advantages than disadvantages considering the environment and cultural and socio-economic sensitivities?

The first step is to observe if the oil spill is sufficiently far from the coast or from oil-sensitive resources so as not to cause damage.

If geographical limits for the use of dispersants have been defined previously, it will be easy to gauge whether the spill is outside these limits. If it is, there is no reason not to consider the use of dispersants, and you should move to the next question; however, if the oil is within the limits, or if there are no predefined limits, it is necessary to conduct a NEBA to compare the impact of the oil when dispersed (in the water column) and not dispersed (on the surface).

NEBA (in orange) conducted in parallel for surface and dispersed oils involves four steps:

1 determination of the drift of the dispersed and undispersed oil (using the meteo-oceanic data, wind and current);

2 identification of the sensitive resources of concern using drift calculations and the inventory of sensitive resources previously compiled for the NOSCP;

3 among the sensitive resources of concern, identification of the highly sensitive resources; and

4 among the identified sensitive resources, determination of the resources which should be preserved as a priority, using the priority list previously defined in the NOSCP. The decision on whether or not to use dispersants is made depending on which is the most appropriate of these priorities.

If dispersant is beneficial, move to the next question. If it is not, consider other response options.

3 Is dispersion feasible from a logistical viewpoint? (This question refers to section 9.1.3.) In other words, are the means available and sufficient to conduct the dispersant treatment properly?

The first step is to check that there is enough dispersant available to treat the spill using the dispersant stockpile inventory previously established in the NOSCP. If there is no dispersant, consider other response options. If there is not enough dispersant to treat the entire spill, it would be preferable to target that part of the spill which, if treated, would lead to the greatest environmental benefit (especially the part of the spill that threatens the most sensitive areas, or is the most amenable to dispersion).

The second step is to verify that there is sufficient application equipment, and that conducting the treatment is logistically sensible. This can be done by considering the size of the spill and using the application equipment inventory and related logistical information that has been previously established in the NOSCP. If there is not enough equipment, or it is not possible logistically to treat the entire spill, it is preferable to target that part of the spill which, if treated, would lead to the greatest environmental benefit (especially the part of the spill that threatens the most sensitive areas).

The third step is to check whether the product and equipment can be mobilized so that they are ready to act on location within the window of opportunity for effective dispersion of the oil. This can be determined by comparing the mobilization time and the capabilities of the equipment or related logistical information previously reported in the NOSCP with the distance to be covered and the prevailing sea state. If timely mobilization is not possible, consider other response options.

The final step is to check if the dispersant application can be conducted properly bearing in mind the capabilities of the equipment (previously reported in the NOSCP) and the prevailing weather. If not, consider other response options. If all the answers are positive, plan and implement the dispersant application operation.

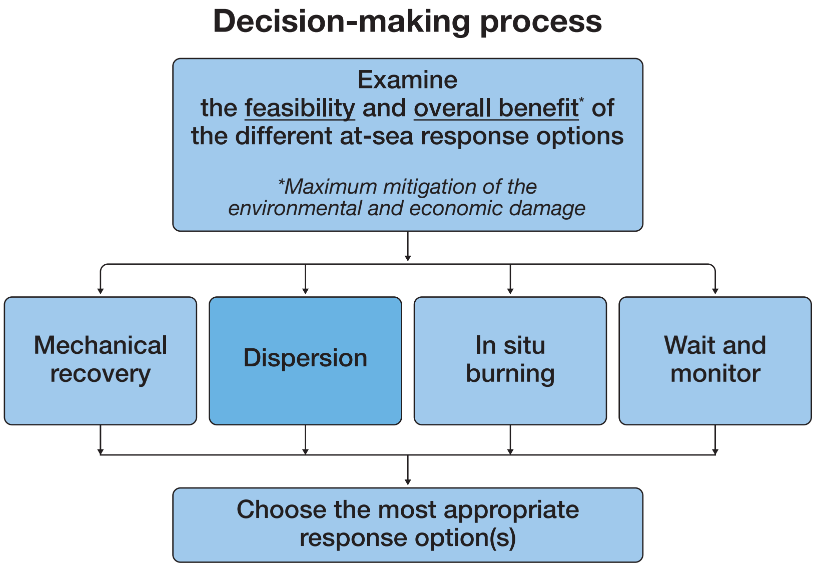


Figure 30 – *Decision-making with regard to different oil spill response options.*
(Source: François-Xavier Merlin (CEDRE) & Kenneth Lee (COOGER))

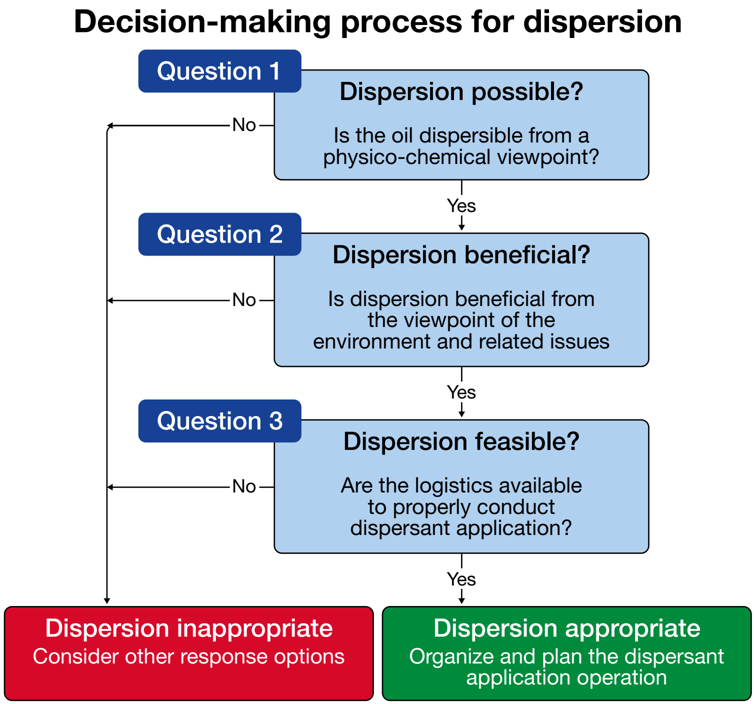
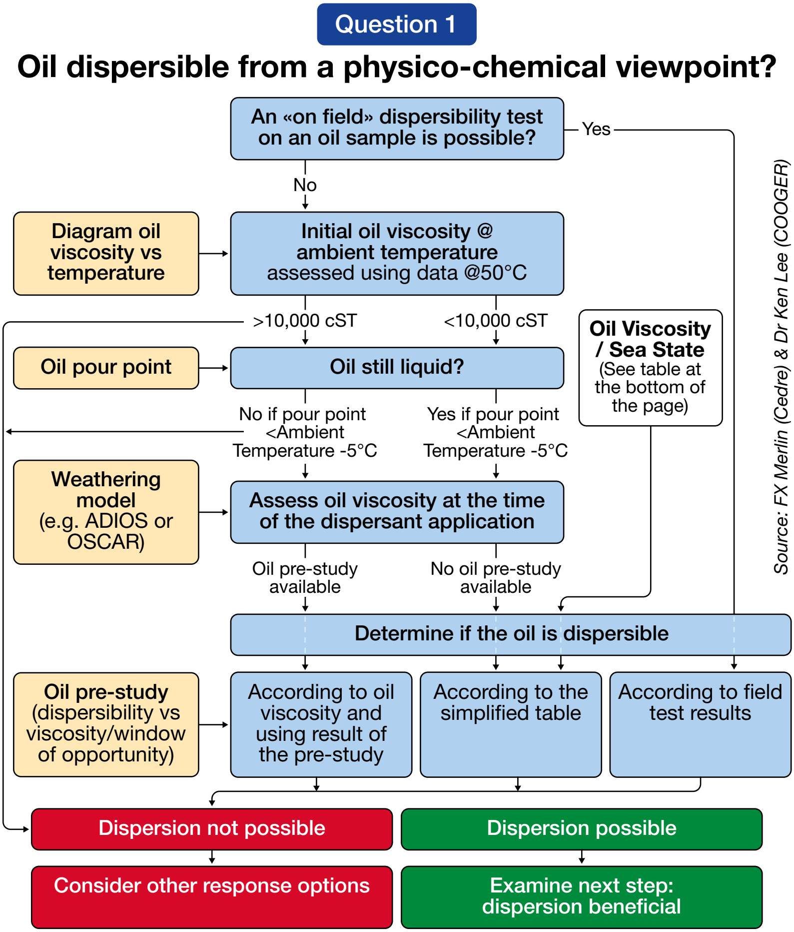


Figure 31 – *Decision-making process for the use of chemical dispersant. (Source: François-Xavier Merlin (CEDRE) & Kenneth Lee (COOGER))*



Oil Viscosity / Sea State	<500 cST	500-5,000 cST	5,000-10,000 cST	>10,000 cST	>>10,000 cST
0-1	possible on limited spill with mixing energy	no	no	no	no
2-3	easy	possible	uncertain	no	no
>3	easy	easy	possible	uncertain	no

Figure 32 – *Assessing whether oil is dispersible from a physico-chemical viewpoint. (Source: François-Xavier Merlin (CEDRE) & Kenneth Lee (COOGER))*

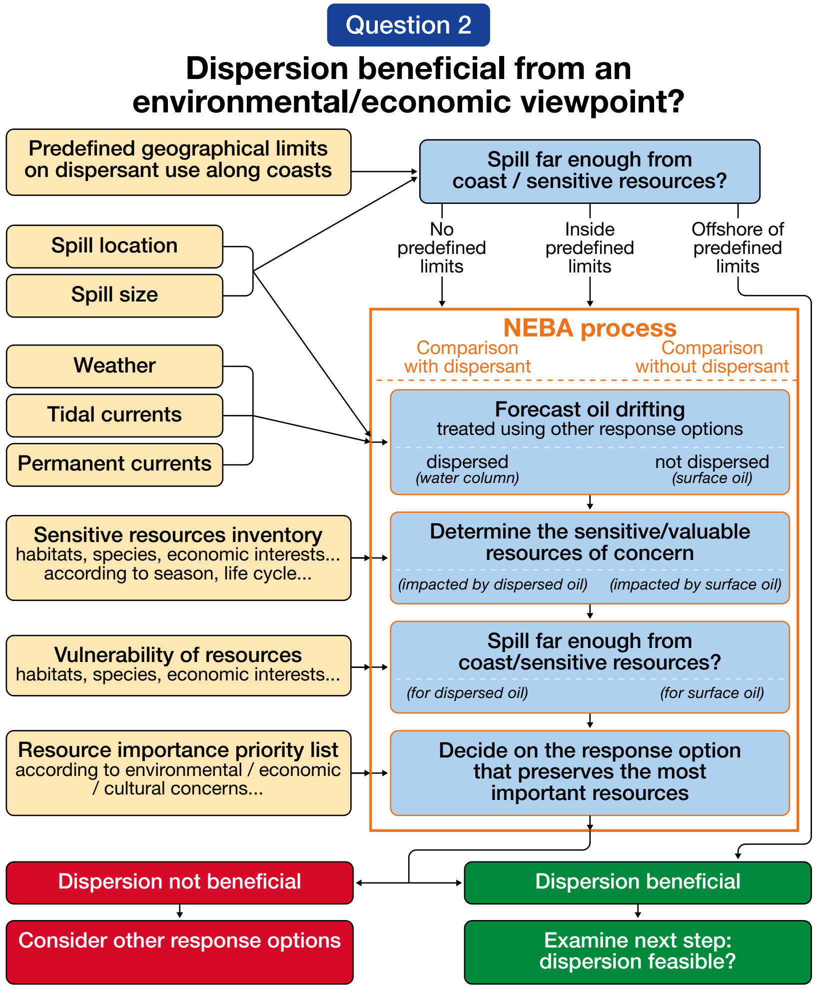


Figure 33 – *Assessing whether treatment of spilled oil with chemical dispersants will be beneficial from an environmental and/or socio-economic viewpoint. (Source: François-Xavier Merlin (CEDRE) & Kenneth Lee (COOGER))*

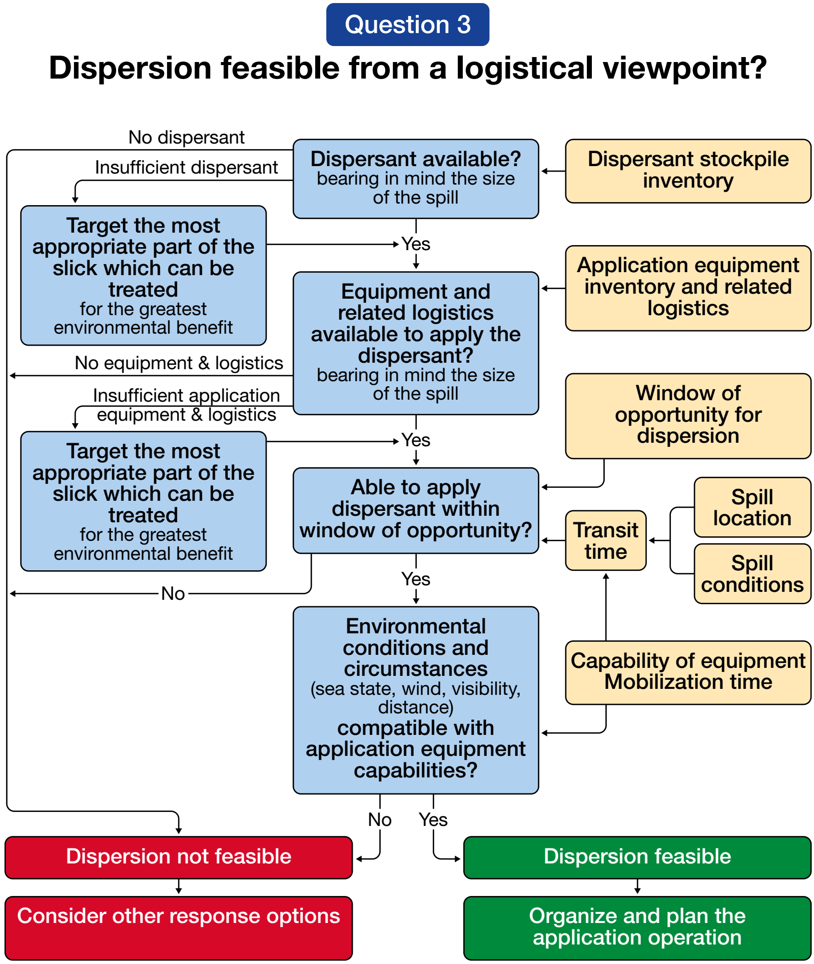


Figure 34 – *Assessment of the feasibility of application of chemical dispersants from a logistical viewpoint. (Source: François-Xavier Merlin (CEDRE) & Kenneth Lee (COOGER))*

Part III
Operational and technical sheets for surface application of dispersants

Part III

This part of the Guidelines addresses the practical issues that an operator needs to consider when applying dispersants and is therefore devoted to providing guidance for the personnel in charge of aerial or vessel-mounted dispersant application (e.g. coastguards).

The following areas are discussed:

- managing the operation;
- conducting dispersant application;
- defining the dispersant dosage;
- operating the equipment;
- health and safety considerations and precautions; and
- monitoring effectiveness.

Practical advice is given to facilitate the work (recommendations on nozzles, safety procedures, etc.).

The requisite items to run the operation are listed.

Recommendations are proposed to assess the efficiency of the treatment (pretest before spraying and during the application), and a set of photographs are included to help the reader identify, analyse and understand what might be observed on site (e.g. formation of a plume of dispersed oil).

This part is arranged as a practical handbook that can be readily consulted by both operators and responders.

1 Health and safety and precautionary measures

1.1 Response crew

The material safety data sheet should be consulted before handling and using any chemical.

Dispersants can irritate eyes and mucosa, so avoid all contact with the eyes and the skin. When handling dispersants, always wear protective clothing (e.g. disposable chemical coveralls), goggles and gloves (recommended: rubber, nitrile; always avoid latex). If dispersants come into contact with eyes or skin, wash the affected area immediately with plenty of fresh water.

When carrying out spraying operations, always wear a personally fit-tested respirator mask to protect the respiratory tract. Do not breathe in aerosols.

Dispersants can make some surfaces (e.g. ship's deck) slippery and present dangerous working conditions. It is advisable to set continuous water flushing on the decks to prevent crew members from slipping and injuring themselves. This can be done using fire-fighting equipment or a hawser hole washing system. It will also be necessary to routinely use deck wash-down systems on both the port and starboard sections of the deck, including catwalks.

1.2 Equipment

Dispersants are natural solvents for products such as paints, elastomers, certain plastics, tar and asphalt. The treated material will either soften, swell or detach (e.g. coatings do this).

Dispersants also have a wetting effect and can soak through the smallest cracks. If dispersant leaks and covers the hull or the deck, use a fire hose to wash it off with as much salt water as possible.

When spraying from a vessel abeam of the wind, never spray from the windward side.

When spraying from an aircraft, check that the dispersant is not jeopardizing the lubrication of moving parts (such as the rotors) or any part of the flight and control system.

At the end of each day, use fresh water to rinse spraying equipment. Immediate surroundings such as the aircraft, runway or taxiway should be rinsed after every spray run.

WARNING: Using a fire hose (i.e. equipment not designed for the express purpose of dispersant application) to apply dispersants can cause damage to the hose, particularly if it is not adequately rinsed after use.

1.3 If a fire breaks out

Dispersants are flammable. Their flashpoint is usually over 60°C. If a fire breaks out, use dry chemical extinguishers, carbon dioxide, foam or water spray and cool the dispersant storage drums and tanks.

2 General features of dispersant application

2.1 General features

For effective treatment, the dispersant must be applied to the oil in sufficient quantities and using a spray that ensures a uniform distribution of dispersant over the oil and facilitates good dispersant-to-oil contact.

This can only be achieved by using specialized equipment that has been routinely well maintained.

2.1.1 *Dispersant application rate*

Achieving an appropriate dosage rate to ensure effective chemical dispersion without overspraying is a key consideration. In order to perform the necessary calculation to determine dosage or dispersant-to-oil ratio (DOR), surveillance should be conducted and a quanitification exercise carried out using the Bonn Agreement Oil Appearance Code (BAOAC) to obtain the volume of dispersant per hectare. Refer to part I, chapter 9 for details of dispersant dosage and application rates.

2.1.2 *Dispersant droplet size*

Achieving a fine spray of dispersant is essential to ensure an even distribution and maximum dispersant-to-oil coverage. In that regard, droplets with an average diameter of 400 μm to 700 μm are usually recommended; these have been, described as resembling "light rain" (Lindblom & Cashion, 1983).

Dispersant droplets larger than 1 mm in diameter are likely to pass through the oil layer and be lost into the water beneath the slick.

Smaller dispersant droplets are likely to be caught by the wind and deflected away from the targeted oil.

2.1.3 *Dispersant application methods*

The newer "third-generation" dispersants (concentrates) can be applied neat (defined by the UK authorities as Type 3 dispersants) or sometimes pre-diluted with seawater (defined as Type 2 dispersants). However, neat application is strongly recommended as it is more efficient.

Stocks of the older-style "second-generation" dispersants are rarely used now as they are being phased out by the industry. These were always applied neat at a high dosage rate.

2.2 Modes of application: planes, helicopters, vessels

Dispersants can be applied by planes, helicopters or vessels.

2.2.1 *Type of dispersant and application method*

Aircraft always use neat Type 3 dispersant.

Vessels can use neat or pre-diluted concentrate dispersants depending on the type of equipment they are fitted with, as described below.

The old spraying units were originally designed to spray second-generation/Type 1 dispersants at a high application rate of up to 1,000 L/ha. To apply concentrate at much smaller application rates (50 L/ha to 100 L/ha) using the same spraying assembly (i.e. nozzles), the dispersant is pre-diluted into seawater in order to obtain a large global sprayed volume (up to 1,000 L/ha of dispersant and water mixture). This dilution process can be achieved with the use of an eductor system or with dedicated pumping units.

More recent equipment is designed for concentrate dispersants and can spray at low application dosage (usually 50 L/ha to 100 L/ha). If possible, neat dispersant should be given preference over pre-diluted.

2.2.2 *Advantages and disadvantages of aerial dispersant application*

Advantages:

– An aircraft can get to the scene of operations very quickly. This is an important factor as dispersant application must occur within the time window during which the oil is still amenable to dispersion (not yet weathered).

– High aerial coverage allows a large area to be sprayed quickly.

– Aircraft are more versatile than vessels and can continue spraying in weather conditions that prevent vessel-mounted dispersant application.

Disadvantages:

– Uneven spraying, with a greater risk of overspray. As dispersant is sprayed at a height of anywhere between 10 m and 30 m above the sea surface, some dispersant will be lost and not reach the slick.

– Limited payload for helicopters: the payload capacities are reduced further as transit distance increases.

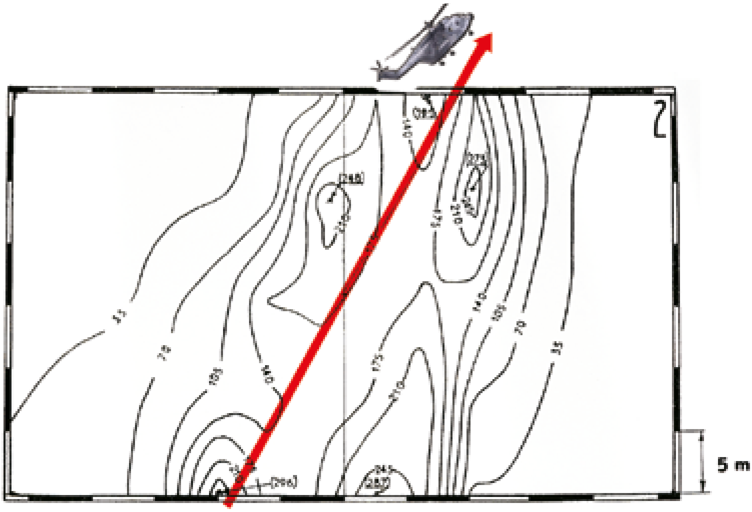


Figure 35 – *Map of a spray pattern completed by a dispersant spraying bucket: the iso-spraying curves are in litres per hectare, the grid of the map is 5 m. (Source: CEDRE)*

2.2.3 *Advantages and disadvantages of vessel-mounted dispersant application*

Advantages:

- The passage of the vessel provides mechanical agitation, aiding the dispersion process.
- Generally good availability of suitable vessels and relatively simple vessel-mounted spraying systems.
- Flexibility and manoeuvrability of vessels (especially if assisted by aerial guidance) allowing fragmented slicks to be treated effectively.
- One can control and adapt dispersant spray rates by changing vessel speed or using specialist spraying equipment (multiple-boom spraying arrays) where flow rate can be controlled.
- Vessels are able to remain on station for extended periods.
- Greater ability to treat smaller or fragmented surface oil spills than is the case with fixed-wing aerial options.
- Closer proximity to the oil allows more direct adjustments to spray pattern and dosage.

Disadvantages:

- Slow transit times, meaning that the length of resupply missions or the time taken to reach the spill may impact the duration of the operating window during which chemical dispersion is a viable response option.
- Low area coverage rate (compared to aircraft-based application) simply because vessels cannot manage more than 3 to 6 (rarely 8) knots while spraying.
- Personnel safety considerations. The closer proximity to the oil and spraying operations can create a heightened risk of exposure, which should be mitigated through correct processes, competence requirements and PPE.
- Sea state limitation: increased pitch and roll of a vessel reduces the ability to properly target the oil, especially with certain nozzle configurations where the distance from the nozzle to the water surface is an important factor to ensure droplet size consistency and correct dosing of dispersant.

2.3 Spraying equipment

Spraying equipment usually involves:

- A dispersant storage system (e.g. ISO tank, drums, IBC, ship's inbuilt tanks);
- A pump and hoses (for pre-diluted application, two pumps or a pump and an eductor system for the seawater and the dispersant, respectively);
- Nozzles that can be fitted on a spray boom. Generally, the nozzles produce flat jets. When fitted on a spray boom, the nozzles must be placed at an angle of anywhere between 10° and 15° in relation to the spray boom in order to generate non-crossing, parallel, flat jets.
- Non-drip check valves are often mounted on the spray system upstream of the nozzles. These valves close when the system pressure in the spray boom drops, preventing leaks and keeping the spray system under pressure and full of dispersant when the spraying operation stops. This allows finer and more immediate control when treating fragmented slicks, enabling instant "spray-on" and "spray-off" to be achieved with minimal lag and hence less wastage.
- Filters are sometimes set upstream of the pump to protect the pump from clogging.

3 Aerial dispersant application

3.1 Amount of dispersant to be used when spraying from an aircraft

3.1.1 *Average quantities*

Average doses are of the order of 5% to 10% in relation to the amount of oil to be treated (DOR 1:20 to 1:10). In this case, treatment rates are related to estimated oil thickness. (See the annex, section 1.1 on slick characteristics and the Bonn Agreement Oil Appearance Code.)

Table 8 – *General trends of amenability to chemical dispersion (and potential dosage rates) in relation to oil viscosity*

<table>
<tr><td>Oil viscosity
(in centistokes (cSt) at sea temperature)</td><td>< 500</td><td>500-5,000</td><td>5,000-10,000</td><td>> 10,000</td></tr>
<tr><td>Amenability to dispersion</td><td>very likely</td><td>usually possible</td><td>sometimes possible</td><td>usually impossible</td></tr>
<tr><td>Second generation – Type 1</td><td colspan="4" rowspan="2">never sprayed by aircraft</td></tr>
<tr><td>Concentrate dispersant.
Third generation – Type 2 used diluted 10% in seawater</td></tr>
<tr><td>Concentrate dispersant.
Third generation – Type 3 sprayed neat (in % dispersant to oil)</td><td>5%</td><td>5% to 10%</td><td>10% (possibly 15%)</td><td>ineffective</td></tr>
<tr><td colspan="5">Note: In the case of a fresh emulsion: it may be necessary to treat the slick by spraying dispersant twice, with an interval of around 30 minutes to one hour. The first spraying operation should use low percentages of dispersant (1% to 2%) so as to break up the emulsion and reduce viscosity. The subsequent spraying operation will effectively disperse the slick (Lunel et al., 1997).</td></tr>
</table>

Except for special cases such as thick slicks (e.g. those that are 250 µm to 500 µm thick), the treatment rate can be adjusted by changing pump speeds, nozzle type and, to a lesser extent, aircraft ground speeds (for helicopters). The treatment rate R (L/ha) can be calculated using the following equation:

$$R \approx (10^3 / 3) \times (D / (L \times V))$$

where:

D is the dispersant flow rate (L/min)

V is the aircraft ground speed during treatment (knots)

L is the width (metres) effectively treated by the system; usually 1.2 to twice the length of the spray boom depending on the aircraft and height

In practice, slick thicknesses are unknown and the usual treatment rate is 50 L/ha to 100 L/ha, meaning the average slick thicknesses are from 50 μm to 200 μm, defined as BAOAC Code 4.

Spray drift may affect some of the dispersant applied. Pilots should fly directly into the wind to minimize the effects of wind on dispersant droplets. Spraying should be carried out in conjunction with dispersant effectiveness monitoring to provide real-time feedback on the success of the dispersant application operation (refer to chapter 7 below).

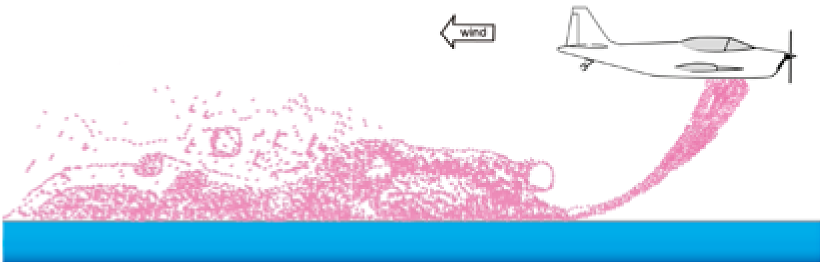


Figure 36 – *Schematic representation of the pattern of the spray of dispersant issued from an aeroplane. (Source: CEDRE)*

3.1.2 *Adjusting dispersant rate*

The most effective manner of adjusting dispersant application rate on the ground is to choose the appropriate nozzles and by changing pump speed. Once the spray system has been adjusted, note the delivery pressure. This will be very useful for ensuring that subsequent applications are consistent. Pressure variations can lead to system malfunction.

To adjust dispersant rate during flight, change the flying speed. This can be done more easily when spraying from a helicopter. Some systems have several booms and the spray rates can be changed by feeding only one of them – for instance, in a twin-boom spray system where either boom can be operated independently.

3.2 How to treat a slick

3.2.1 *What to do*

During treatment operations, always fly upwind or downwind at the height recommended for the type of plane.

When flying low over the water, it may be difficult to identify the outline of a slick, not to mention determining slick thickness. It is important to approach dispersant application methodically. After the bulk of the oil has been treated, undispersed thick patches can be revisited.

DO	DO NOT
Begin treatment from the edges of a slick to the border of medium-thickness areas. Treat the slick by parallel close passes (the only way to cover all the slick). Treat upwind or downwind to facilitate consistent spraying conditions and optimum dispersant-to-oil contact. Remember equipment response times when starting the spraying operation, and droplet drift caused by the wind when you may need to stop spraying. ***See section 3.2.5, "Start and stop cues"***	Cut up and fragment a slick. By ploughing through it in all directions, it will soon be impossible to spot the slick and treat it effectively.

3.2.2 *Areas to treat*

Average to thick patches in a slick are treated by adjusting the quantity of dispersant sprayed. Thin areas are not sprayed (i.e. BAOAC Codes 1 ("sheen") and 2 ("rainbow"); see the annex). (See section 3.1 above, "Amount of dispersant to be used when spraying from an aircraft".)

After weathering for a few days, the oil will be patchy and more viscous. By this stage, the oil is often so viscous as to render it impossible to disperse. Careful observations (visual through aerial surveillance, and where possible through in situ effectiveness monitoring and sampling using techniques such as fluorometry) should be carried out. Dispersant application should be ceased when monitoring indicates that dispersant is no longer effective.

3.2.3 *Standard approach*

The preferred approach is either upwind or downwind.

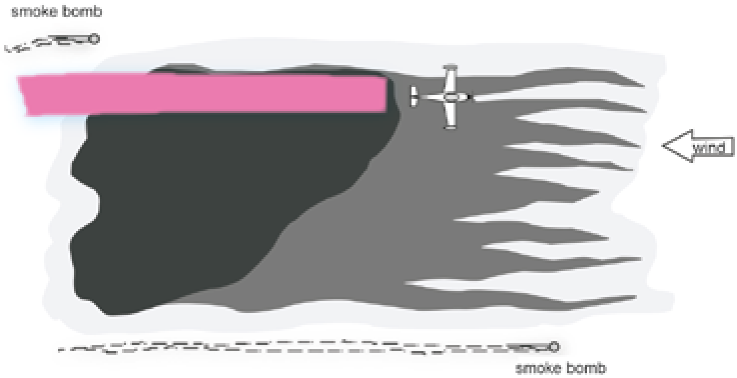


Figure 37 – *Aircraft application with the standard approach. (Source: CEDRE)*

3.2.4 *Special case*

If the slick is a thin strip abeam the wind, the preferred treatment approach should be to fly several passes into the wind, or possibly, to treat abeam the wind, not forgetting that the dispersant will tend to drift sideways with the wind (see figure 39).

3.2.5 *Start and stop cues*

The start and stop spraying cues have to include the following considerations:

– Equipment response times: for spraying to start once the cue has been given. This usually causes a delay of only a few seconds.

– Wind effect: as dispersant droplets fall onto the slick, the wind will blow them away. Droplet drift (d) in metres can be estimated as follows:

$d = (v \times h) / 12$

where:

v is wind speed in knots

h is height at which the aircraft is spraying

– Flying into the wind, droplet drift will occur once the slick has passed. Flying downwind, it will occur as soon as the aircraft reaches the edge of the slick.
– Regardless of response time, always start spraying at a distance of 60 m from the edge of the slick, even if wind speed is low.

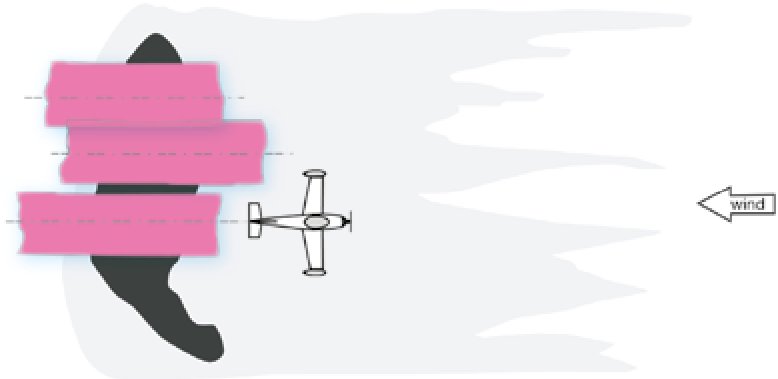


Figure 38 – *Aircraft flying into the wind to treat a strip of oil. (Source: CEDRE)*

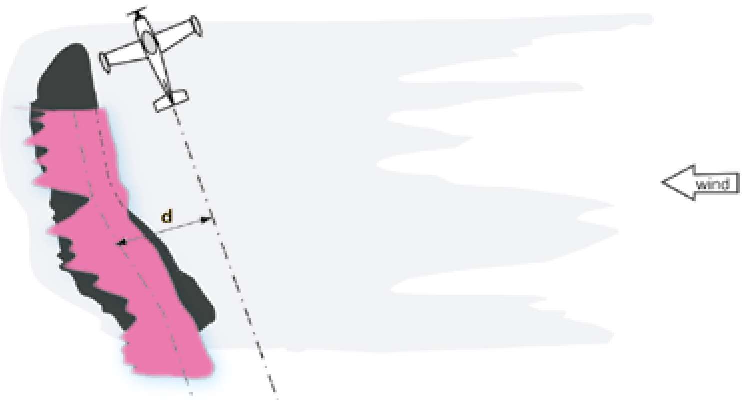


Figure 39 – *Aircraft flying in a crosswind direction to treat a strip of oil. (Source: CEDRE)*

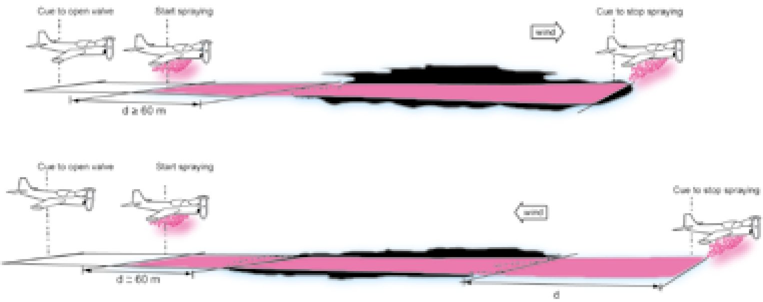


Figure 40 – *Spraying dispersant on the sea surface: spray downwind, spray upwind. (Source: CEDRE)*

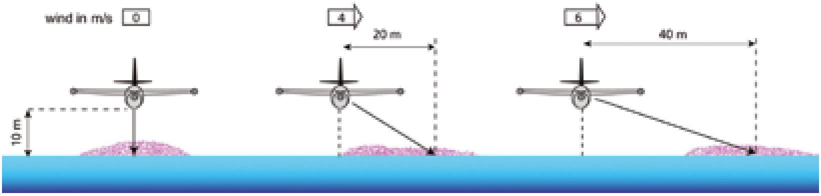


Figure 41 – *Drifting of the sprayed dispersant according to the wind. (Source: CEDRE)*

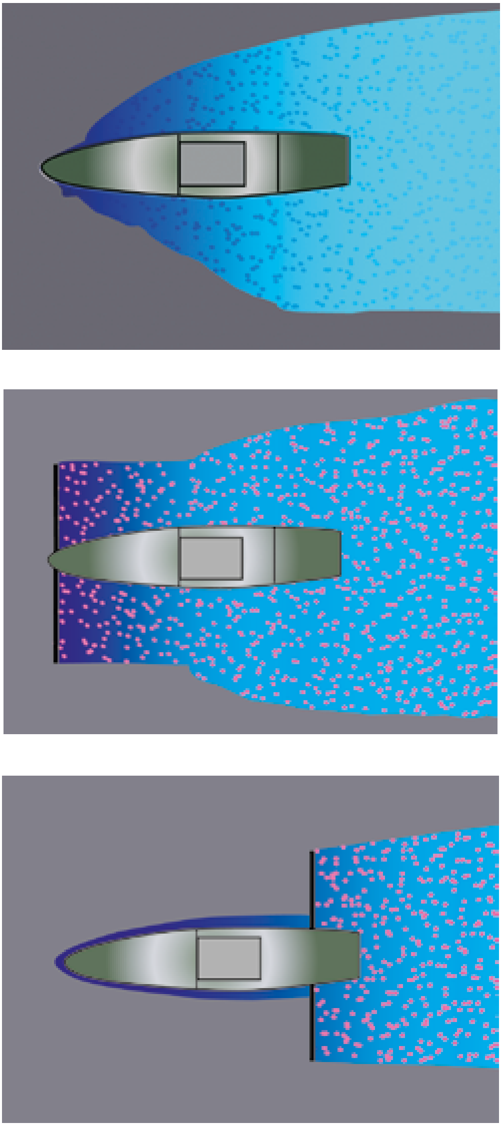
Wind conditions can make spraying difficult and ineffective because dispersant droplets are blown by the wind as they are dropping onto the slick and a crosswind will push the dispersants away from the slick that is being targeted.

4 Vessel-mounted dispersant application

4.1 How to apply dispersant from a vessel

4.1.1 *Vessel spraying speed and spray arm positioning*

If the vessel speed is too high, the bow wave generated can cause the oil to be pushed away from the vessel and from the reach of the dispersant sprayed from spray arms. It is also possible that the bow wave could have a "herding" effect on the dispersant before it has had a chance to penetrate the oil. The more viscous the oil, the longer it will take the dispersant to penetrate through to the oil-water interface. This impact can be managed by altering the positioning of spray arms or reducing the spraying vessel speed while passing through the slick.



(a)

(b)

(c)

Figure 42 – *The bow wave pushes the oil away from the vessel (a). Either treat from the bow section in front of the bow wave (b) or slow down to reduce the bow wave (c). (Source: CEDRE)*

4.1.2 *Effect of the wind on spray distribution*

When using spray arms (also referred to as spray booms), strong wind can compromise spraying quality by altering the shape of the spray, reducing spray swath width and even causing it to miss the targeted oil altogether. This kind of effect will be more marked when dispersant is sprayed from high above the slick.

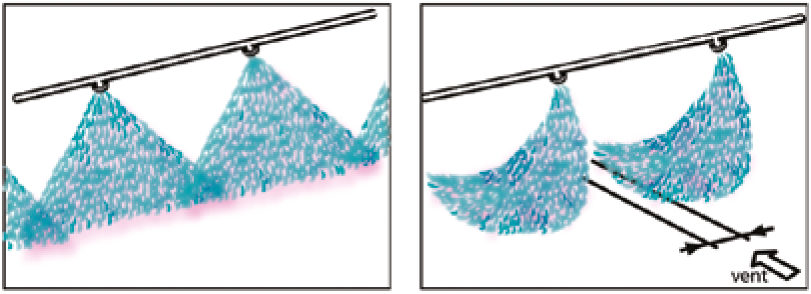


Figure 43 – *Deformation of the spray pattern of a spray boom due to the wind. (Source: CEDRE)*

Similarly, wind can considerably reduce the range of spray nozzles (or systems such as fan air blowers).

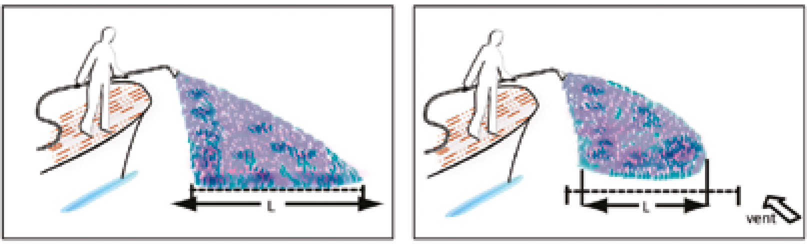


Figure 44 – *Deformation of the spray pattern of a spray jet due to the wind. (Source: CEDRE)*

As a rule, the preferred spraying direction is into the wind (upwind). However, if the wind is so strong that it compromises spraying operations and adequate droplet dispersion, an attempt can be made to spray downwind. Under these conditions the slick is more likely to fragment, making effective application more difficult.

Important safety note: If spraying from a crosswind position, only spray from the leeward side.

4.1.3 *Herding effect of dispersant*

If, owing to adverse conditions, it is necessary to spray in a downwind direction, an effect known as "herding" may be observed.

Figure 45 – *Observed "herding" effect after application of chemical dispersant. (Source: CEDRE)*

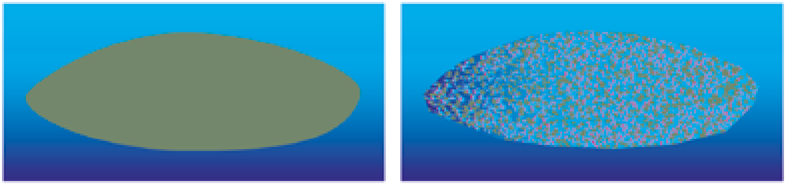


Figure 46 – *Illustration of the herding effect of the dispersant on the oil. (Source: CEDRE)*

This is where the slick is concentrated into smaller and thicker patches by fine dispersant droplets that are blown forward in front of the vessel by the wind. When the spray arms then pass over the broken slick, the majority of sprayed dispersant is applied onto the water surface in between the small oil patches.

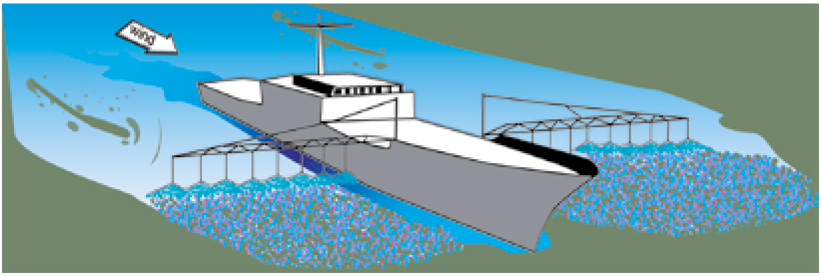


Figure 47 – *Dispersant application completed downwind, leading to herding effect. (Source: CEDRE)*

When this effect occurs, spraying a second time may be superfluous. It is always better to spray dispersant in one pass and adjust the dose accordingly. This effect does not occur if oil is thick, emulsified and viscous.

4.1.4 *Dispersant dilution limitation*

If dispersant pre-diluted with seawater is used, the percentage of dispersant in the mixture should be at least 10%.

4.2 Amount of dispersant to be used when spraying from a vessel

4.2.1 *Average quantities*

The average dosage when applying dispersant from a vessel is of the order of 5% to 10% (DOR 1:20 to 1:10) in relation to the amount of oil. In this case, treatment rates are related to estimated slick thickness. (See the annex on slick characteristics and the Bonn Agreement Oil Appearance Code.)

Table 9 – *General trends of amenability to chemical dispersion (and potential dosage rates) in relation to oil viscosity.*

Oil viscosity (in cSt at sea temperature)	< 500	500-5,000	5,000-10,000	> 10,000
Amenability to dispersion	very likely	usually possible	sometimes possible	usually impossible
Second generation – Type 1	30%	30% to 50%	up to 100% slightly effective	ineffective
Concentrate dispersant. Third generation – Type 2 used diluted 10% in seawater*	5% to 10%†	ineffective	ineffective	ineffective
Concentrate dispersant. Third generation – Type 3 sprayed neat (in % dispersant to oil)	5%	5% to 10%	10% (possibly 15%)	ineffective
Note: In the case of a fresh emulsion, it may be necessary to treat the slick by spraying dispersant twice , with an interval of around 30 minutes to one hour. The first spraying operation will use low percentages of dispersant (1% to 2%) so as to break up the emulsion and reduce viscosity. The subsequent spraying operation will effectively disperse the slick (Lunel *et al.* 1997).				

* The dispersant dilution must not be less than 10% (dispersant).

† e.g. a 50% to 95% dispersant to water solution, or 100% dispersant only.

In reality, it can be difficult to estimate the slick thickness owing to enormous variation across an area:

- Thicker patches described as "true oil colour" (continuous or discontinuous) can be categorized under the Bonn Agreement Oil Appearance Code as anywhere from 50 µm to a few millimetres;
- Very thin layers, often described as "sheen" or "rainbow", can cover huge areas geographically but may only be between 0.04 µm and 5 µm thick.

The chosen treatment rate will be about 50 L/ha to 100 L/ha, which would mean an average slick thickness of 100 µm.

To optimize the effective use of dispersant, treatment rate can be varied, depending on slick thickness.

4.2.2 *Adjusting dispersant rate*

4.2.2.1 *Standard approach*

To achieve a treatment rate of 50 L/ha or 100 L/ha, vessel speeds will have to be adjusted to suit spray system requirements.

$$V_{(50\ \mathrm{L/ha})} = D\ /\ (0.6 \times L)$$

$$V_{(100\ \mathrm{L/ha})} = D\ /\ (0.3 \times L)$$

where:

V is vessel speed (knots);

D is the pumping rate of the dispersant (neat) delivered by the system (in L/min); and

L is the width (in metres) of the swath effectively treated by the system (distance from one spray arm tip to another including vessel width at spray boom location).

4.2.2.2 *Special cases*

- Non-adjustable spray system

Where flow rate cannot be adjusted mechanically, the thicker areas of a slick (oil thickness > 100 µm) should be sprayed at a slower speed or possibly several times to increase dispersant delivery quantities (> 100 L/ha).

– Adjustable spray system

With a small adjustment range (1 to 4 times the flow rate), vessel speeds should still be varied so as to deliver at least 100 L/ha.

$$V = D_{minimum} / (0.3 \times L)$$

Adjustable systems can facilitate the treatment of thick patches (>100 μm) by increasing delivery rates (pump rate) so that such patches can be treated with one pass.

With a large adjustment range (1 to 10 times the flow rate), it is best to set the vessel speed so as to deliver at least 50 L/ha.

$$V = D_{minimum} / (0.6 \times L)$$

The unnecessary use of dispersant should be avoided when traversing thin patches (BAOAC Codes 1 ("sheen") and 2 ("rainbow"); see the annex, section 1.1) that can stretch for miles. Thick "true oil" patches (> 100 μm) can be treated with a single pass by increasing delivery rates.

4.3 How to treat a slick

4.3.1 *What to do*

Average to thick slick patches are treated by adjusting the quantity of dispersant sprayed. Thin areas are not sprayed (BAOAC Codes 1 ("sheen") and 2 ("rainbow")).

From a ship deck, it will be difficult to identify the outlines of a slick, not to mention determining slick thickness. This must be done methodically. After the bulk of the oil has been treated, undispersed thick patches can be revisited.

DO	DO NOT
Begin treatment from the edges of a slick to the border of medium-thickness areas. Treat the slick by parallel close passes (the only way to cover all the slick). Treat upwind so as to ensure the right spraying conditions and an optimum dispersant-to-oil contact.*	Cut up and fragment a slick. By ploughing through it in all directions, you will soon find it impossible to spot the slick and treat it all properly. Treat downwind.

* Spray into the wind to avoid the herding effect (see section 4.1.3 above), unless the slicks are very thick and weathered, in which case the herding effect does not occur.

4.3.2 *Areas to treat*

Average to thick patches in a slick are treated by adjusting the quantity of dispersant sprayed. Thin areas are not sprayed BAOAC Codes 1 ("sheen") and 2 ("rainbow"); see the annex, section 1.1.

4.3.2.1 *Standard approach*

The preferred approach is upwind.

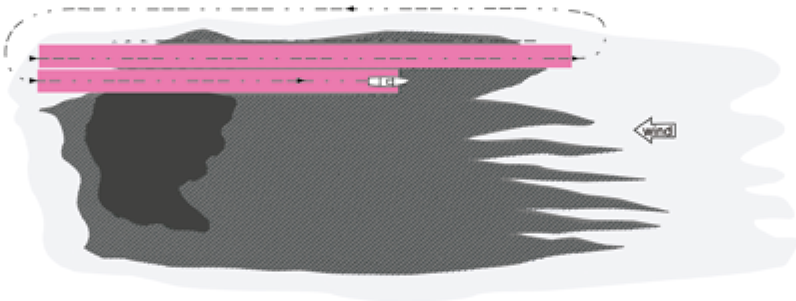


Figure 48 – *Standard application procedure. (Source: CEDRE)*

4.3.2.2 *Special case*

If the slick is made up of a number of thin strips within windrows that are abeam of the vessel, it should be treated to the leeward side of the vessel.

Figure 49 – *Application procedure when the oil is gathered in strips across the wind. (Source: CEDRE)*

Refer to section 4.2, "Amount of dispersant to be used when spraying from a vessel".

After weathering for a few days, the oil will become patchy and more viscous. By this stage, the oil is often so viscous as to render it impossible to disperse. Careful observations (visual through aerial surveillance, and where possible through in situ effectiveness monitoring and sampling using techniques such as fluorometry) should be carried out. (Refer to chapter 3 on aerial dispersant application for further discussion of dispersant application methodologies.)

5 How should treatment of the slick be guided

5.1 Reconnaissance, guidance and marking

When flying at low altitudes (recommended for treatment) it is not easy to identify the slick's edges or thickness. It is advisable to have a second aircraft flying above to guide the spraying aircraft on to the slick and to give the cues to start and stop spraying with each pass.

If no other aircraft is available, the spraying aircraft must undertake its own reconnaissance of the area at higher altitude, before descending to an altitude suitable for dispersant spray runs. The pilot should take bearings to assist in the conduct of spray runs, taking note of ships in the vicinity, platforms, shorelines and buoys.

5.2 Using marker buoys and developing surveillance technology

The location of the oil slick can be marked by the following:

- marker buoys (traditional and satellite marker buoys) deployed from a vessel that has been guided by a spotter aircraft; and
- surveillance technology (if available on board the spotter aircraft) to detect and georeference spill location.

5.3 Aerial guidance procedure

Whenever dispersing or recovering oil, vessels will normally require some form of aerial guidance to the slicks for the application of dispersant to be effective, as crew on board the vessels will have great difficulty spotting oil on the water surface. Locating the slick can be made easier if the crew are told where to drop marker buoys.

The preferred method is to provide, in advance, a detailed description of the slick (including maps) where the vessel or flotilla will start spraying. This obviates the need to engage a spotter aircraft for the entire day. When this is not possible, navigational guidance should be provided to direct a vessel to the thickest parts of a slick by giving the helmsman a bearing and a distance. For instance: "The slick is 20 m wide and 200 m long. The bearing is 30° and 300 m from your current position."

The plane (or helicopter) should indicate the slick's position, shape and the location of the thickest parts for spraying. Guidance can be given directly over the radio. When response time is limited, it is best to give the crew on board the response vessel an exact description of the slick together with the GPS coordinates.

6 Technical considerations before treatment

6.1 Pre-flight spray system checks

Before commencing aerial spraying operations, personnel should be fully briefed and the required safety equipment and PPE defined. The relevant standard operating procedures for the spraying equipment must be followed. These procedures will vary depending on the equipment and must be followed to ensure its safe and effective use.

6.2 Spray system checks before a shipborne operation

Before commencing spraying operations, the following should be undertaken:

- Ensure that the crew and operators have been fully briefed, that safety equipment is available and properly worn, and that any unnecessary personnel are kept clear of the operations.
- Ensure that any ship ventilation systems are properly isolated.
- Ensure that the relevant standard operating procedures for the equipment are available, and that they are understood and followed.

7 Monitoring and assessment procedures

7.1 How to assess treatment effectiveness

7.1.1 *Visual observation*

The dispersion operation can be visually assessed as effective if a brown-orange or even brown-black plume (with some heavy fuel oils) can be seen beneath the surface. This is often described as a "coffee-coloured" plume. This kind of plume can usually be seen upwind of a slick of medium to large thickness. The surface slick driven by the wind will drift slowly away and leave the plume of dispersed oil behind.

It is important to be aware that the plume of dispersed oil may not form immediately, particularly when the oil has weathered and emulsified a little and where wave/mixing energy is low. Additionally, the plume may not be easy to see and often will not last long. The plume of dispersed oil will dilute and become less apparent once the oil mixes and disperses through the water column. When spraying dispersant from an aircraft, the oil plume may be harder to spot owing to flight altitude.

When dispersant is used effectively, the oil slick will begin to reduce. This can occur quickly (within minutes) or become evident hours later as the slick breaks up. Surface areas thickly covered by oil will gradually shrink.

As thick oil slicks recede, much thinner zones appear (BAOAC Codes 1 ("sheen"), 2 ("rainbow") and 3 ("metallic"); see the annex, section 1.1), which spread over large areas before shrinking and disappearing within a few hours or days.

It is important to know that dispersion could be confused with the herding effect. This is another visible and well-known effect that occurs with fresh and thin oil slicks. If, after the dispersant has been sprayed, the oil suddenly disappears, it may actually be that the dispersant has pushed the oil sideways instead (herding effect). This is not true dispersion because after a little while, the oil film reappears (refer to section 4.1.3 for more information).

7.1.2 *Infrared remote sensing*

If dispersant application is effective, thick patches of oil will gradually disappear from the sea surface. Spotter aircraft with infrared monitoring capability will be able to verify this reduction in oil thickness and spread as the infrared scan will detect fewer and smaller white patches.

Figure 50 – *Dispersion trial. Note the brown colour of the plume immediately after spraying. (Source: CEDRE)*

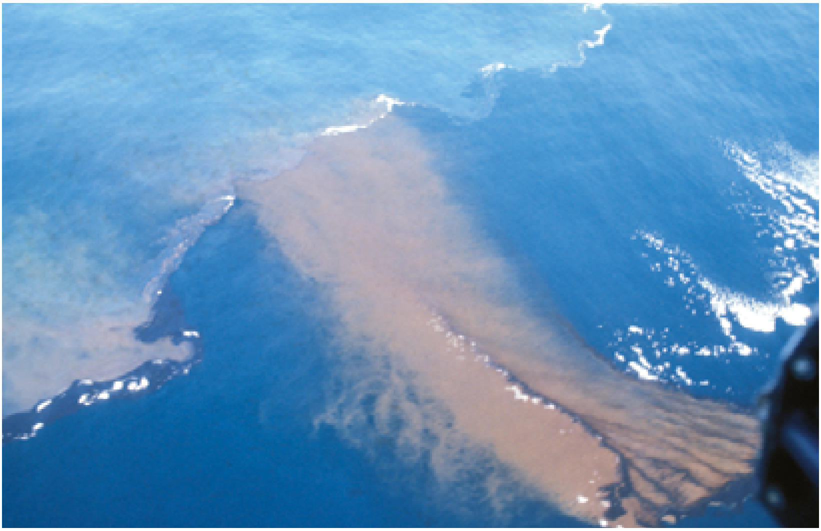


Figure 51 – *When the wave goes through the treated slick, the additional agitation assists by placing the oil in suspension and the brown plume of dispersed oil forms. (Source: CEDRE)*

Figure 52 – *Dispersed oil in the wake of a vessel engaged in dispersant spraying operations. (Source: CEDRE)*

Figure 53 – *What the pilot sees: plume of dispersed oil (brown/beige) appears quite distinct from the surface oil (which is black or metallic). Note the presence of cloudy/white patches in some areas, which indicates that too much dispersant may have been sprayed or that targeting was inaccurate. (Source: CEDRE)*

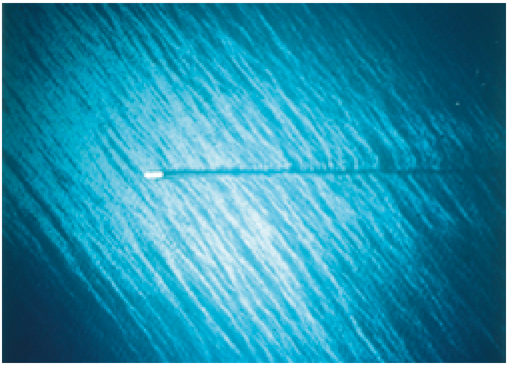


Figure 54 – *Appearance of a slick that has been treated some time ago. This thick part disappeared and what remains is only the thin parts (mainly sheen) progressively dispersing. (Source: CEDRE)*

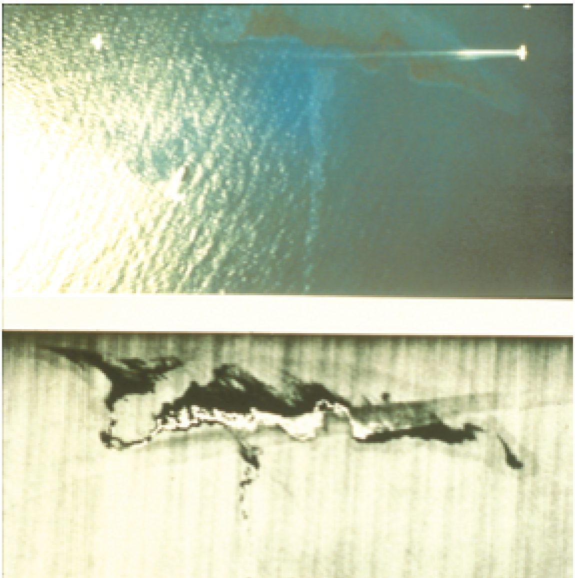


Figure 55 – *A Canadian aircraft starting to spray. The lower picture shows the same slide in a thermal infrared scene taken by the remote sensing aircraft (the thickest layers are in white). (Source: CEDRE)*

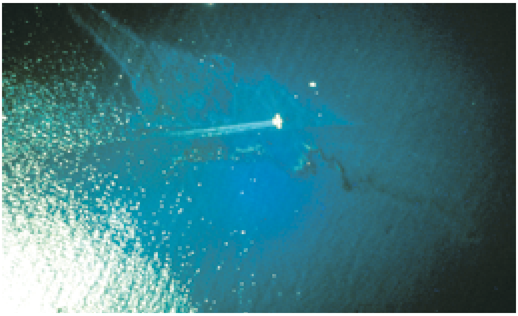


Figure 56 – *Continuation of treatment. Note the appearance of a plume of dispersed oil (beige yellow; top half of photo) upwind of the thicker patches (black). Below the aeroplane, note the temporary disappearance of thinner patches due to the herding effect that a dispersant can produce – this is not real dispersion). (Source: CEDRE)*

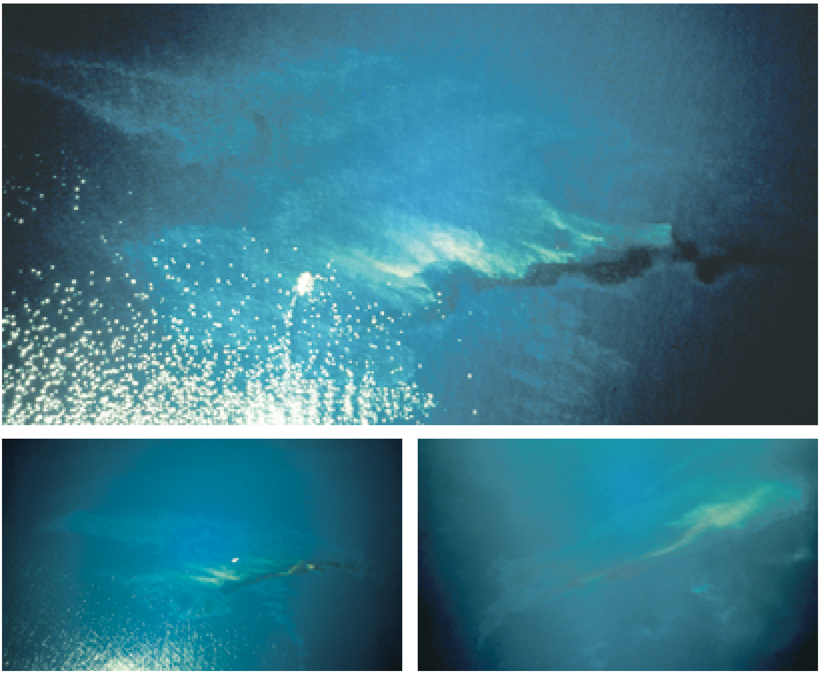


Figure 57 – *Gradual disappearance of thicker patches that turn into dispersed oil patches (yellow-brown plume). (Source: CEDRE/IFP)*

Figure 58 – *The same slick a day after being sprayed. The dispersion plume has dissolved into the background. All that is left is sheen which is waning and disappearing. (Source: CEDRE)*

7.1.3 *In situ monitoring techniques*

Monitoring the dispersed oil in the water column through in situ measurements is possible. The most commonly used technique (with the most readily available equipment and trained personnel) remains fluorometry (spectrofluorometry; Levine *et al.,* 2011).

Parts of oil compounds can absorb specific wavelengths of light and almost instantaneously emit a longer wavelength of light. This phenomenon is known as fluorescence. This property is used for measuring oil concentrations in the water column (especially dispersed oil concentrations). This is carried out by towing a fluorometer from a vessel at predetermined depths, usually a few metres below the water surface, and indicates the relative prevalence of dispersed oil in the water column at the time of the measurement.

Fluorometry relies on relative readings. It is therefore necessary to obtain background readings in unoiled areas near the spill. As another comparison reading, fluorometry is carried out in the oiled but untreated area (before dispersant has been applied). This ascertains the rate of natural dispersion occurring (i.e. dispersion through natural mixing processes). Finally, measurements are taken in the oiled area that has been treated with dispersant. If the dispersant is working effectively, the highest readings will be from the chemically dispersed transect. It should be noted that when using fluorometry, readings will vary widely, reflecting the patchy distribution of a dispersed oil plume. When considering this data, trends and patterns should be looked for to provide a good indication of increased hydrocarbon concentrations above background and naturally dispersed levels.

The fluorometer measures the degree of fluorescence detected, indicating the relative amount of dispersed oil in the water column at the time of the measurement, with the background reading and the natural dispersion reading used to provide the baseline. Baseline readings must be taken at each location as readings will also be impacted by factors such as turbidity (particles in the water column).

7.2 *Testing prior to large-scale spraying*

Tests should be conducted on part of the slick as soon as operationally possible to check that the spraying operation is likely to succeed and be effective.

Spraying should continue while visually monitoring ongoing dispersant effectiveness from:

- the spotter aircraft, but remote sensing can also be used;
- a vessel in the vicinity (e.g. the spraying vessel); or
- in the case of aerial spraying, the sprayer aircraft may provide the feedback after it has finished spraying the entire dispersant payload or possibly before it starts a second spray run.

These observations should confirm the presence of a brown-coloured plume or the gradual disappearance of thicker oil patches. As an alternative to the visual assessment, the dispersibility of the oil can also be assessed on-site using a rudimentary test (e.g. the jar test: a small quantity of the oil, taken from the spill, is put in a jar with seawater and dispersant and then shaken; the observed result will indicate dispersibility).

In the event of an extended response operation, checks should be performed several times each day to ensure that the oil is not weathering too much and is still amenable to dispersion.

If there is no indication that dispersion is working, spraying may be stopped and three questions should be asked to determine whether the suitability of that response technique has now ceased:

- **Is this due to the nature of the oil?** Has it weathered too much and become too viscous to be dispersed? If the answer is yes, then dispersion may no longer be a suitable response technique.
- **Is this due to low or no wave energy (is the sea too calm)?** If the answer is yes, and the slick is large, dispersion can only

really be continued if the (very) short-term weather report forecasts rougher weather, which would provide more wave energy. If the slick area is small, mechanical agitation (such as propeller wash from the sprayer ships) may provide the necessary mixing energy.

– **Is this because the dispersant type/brand used is not effective on the type of oil?** In that case, try another approved dispersant if available.

7.3 Good practices

The United States Coast Guard has developed a protocol for monitoring in the field known as Special Monitoring of Applied Response Technologies (SMART) (USCG-NOAA-EPA-CDC-MMS, 2006). It has been used during several oil spill response operations, including **Montara** (2009) and **Deepwater Horizon** (2010). This protocol uses visual observations and in situ fluorometers to gauge the effectiveness of dispersant application and can be supplemented by in situ water samples that undergo laboratory analysis later on.

It is advised that water column samples be taken from the area whenever dispersants are applied. This is useful for comparing treated and untreated areas of water, assessing water quality for health purposes and/or justifying the use of dispersants.

Annex
Slick characteristics

1.1 Bonn Agreement Oil Appearance Code

To optimize the response, it is necessary to appraise the thickness, shape and nature of the oil to be treated. This standardized approach uses the appearance of the oil as a quantification tool (providing an estimate of oil volume).

Research conducted under the framework of the Bonn Agreement has led to the adoption of an oil appearance code. This code is based on scientific studies seeking to determine spilled oil quantities on the basis of aerial observation and should be used in preference to any other approach.

Table 10 – *Categories (codes) in the Bonn Agreement Oil Appearance Colour Code and corresponding oil thicknesses*

Code and description of appearance	Layer thickness interval (μm)	Litres per km^2
1 Sheen (silvery/grey)	0.04 to 0.30	40 to 300
2 Rainbow	0.30 to 5.0	300 to 5,000
3 Metallic	5.0 to 50	5,000 to 50,000
4 Discontinuous true oil colour	50 to 200	50,000 to 200,000
5 Continuous true oil colour	200 to more than 200	200,000 to more than 200,000

1.2 Topography of oil slicks

For relatively fresh slicks (from a few hours to a few days), the shape and the thickness distribution (small, average, large) depend mainly on the wind, which spreads and lengthens slicks and even cuts them into parallel swaths, fragmenting them. Larger oil thicknesses (BAOAC Codes 4 and 5) will be found downwind. If the wind is strong, sheen areas (silvery grey, rainbow and metallic: BAOAC Codes 1, 2 and 3) tend to disappear.

When slicks have had a chance to weather (for a week or more), the silvery grey, rainbow and metallic films (BAOAC Codes 1, 2 and 3) disappear (via evaporation, natural dispersion, biodegradation, etc.). All that is left are very thick patches of weathered and often emulsified oil floating on the water's surface (BAOAC Codes 4 and 5).

Very weathered slicks are often found mixed with floating debris.

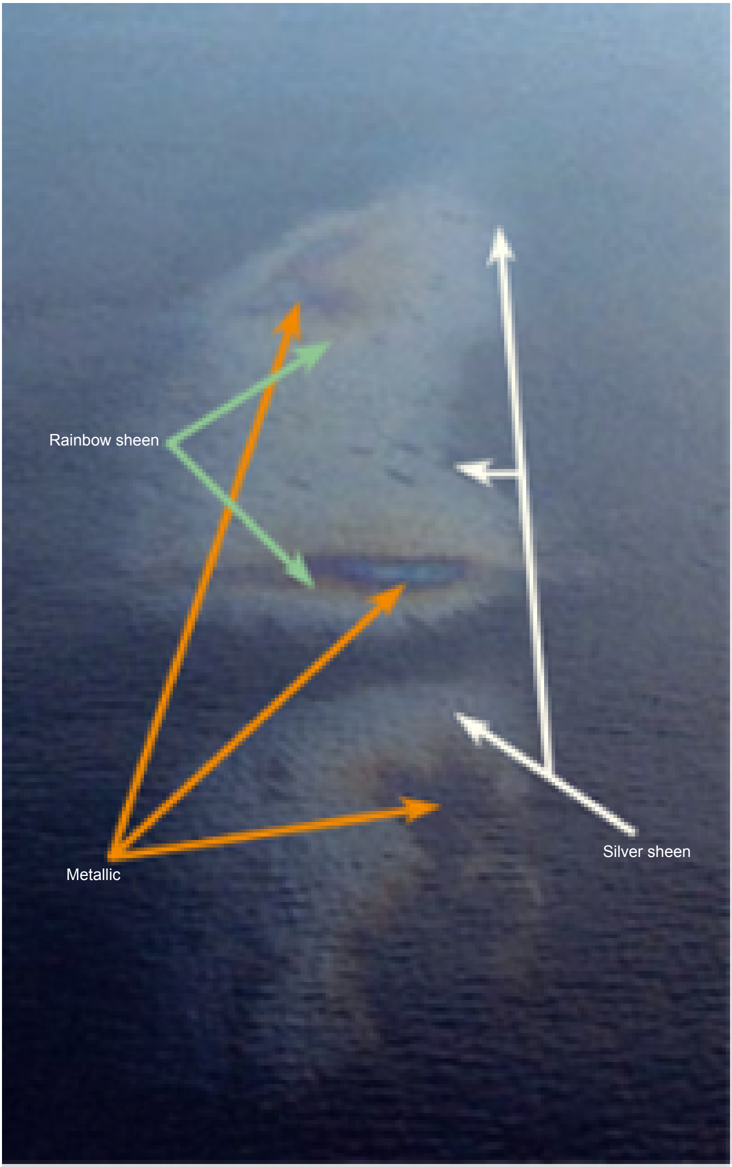


Figure 59 – *Illustration of elements of the Bonn Agreement Oil Appearance Code. (Source: Bonn Agreement Photo Atlas)*

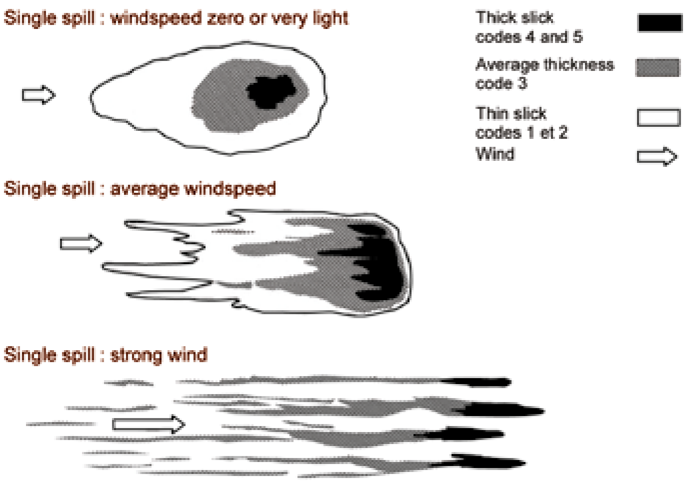


Figure 60 – *Effect of wind on an instantaneous oil spill. (Source: CEDRE)*

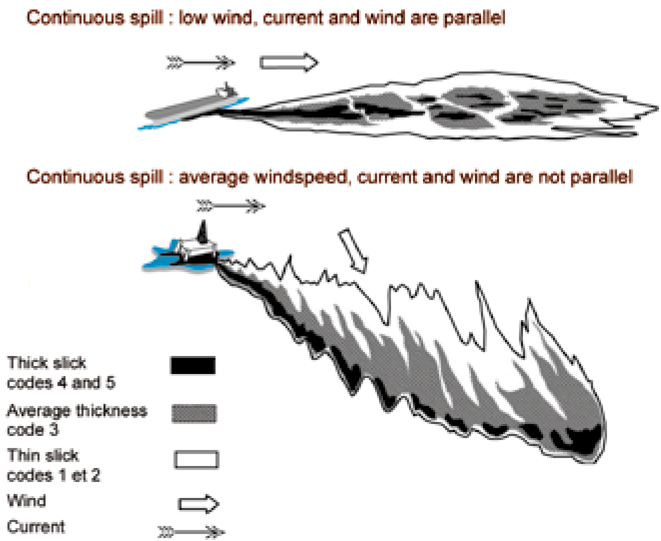


Figure 61 – *Effect of wind on a continuous oil spill. (Source: CEDRE)*

Part IV
Subsea dispersant application

Part IV

This part of the Guidelines presents guidance and information on the preparations for, and use of, subsea dispersant application during an offshore oil discharge. Subsea dispersant application was first employed during the **Deepwater Horizon** event in the US Gulf of Mexico, where the response method was applied through novel and adaptive techniques. During that oil spill approximately 771,272 US gallons of dispersant were injected subsea at the source of the discharge at depths of nearly one mile. This accounted for around 42% of the 1.841 million gallons (approximately 7,000 m^3) of the dispersant used during the response.

Part IV has been prepared taking into account the information provided in other parts of the Guidelines and should be used in conjunction with these. The document focuses on subsea application procedures and is divided into several chapters. The first three chapters provide an introduction to subsea dispersants, an overview of the objectives of subsea dispersant application, and health and safety considerations relating to dispersant use. The following four chapters discuss the overarching role of subsea dispersant application, conditions of use and decision-making procedures. The remaining chapters highlight multiple facets of the preparations that are required prior to subsea dispersant application, subsea dispersant response operations, monitoring requirements, information management and recommended preparedness measures.

The information in these Guidelines is based on lessons learned from the **Deepwater Horizon** oil spill and practices identified by government entities, industry groups and academic institutions.

1 Introduction

While dispersants applied on the sea surface have been used as a response method for several decades, the subsea application of dispersants is a relatively new approach that continues to be informed by research and the development of new technologies and procedures. Like other response options, subsea dispersant application has distinct operational advantages but requires certain precautions to be taken before use and a clear understanding of its limitations. Historically, decision-making models, monitoring programmes and use plans have focused on surface dispersant application and have not sought to capture the conditions, challenges and complexities of applying dispersant in the subsea environment. These specific aspects are highlighted here and integrated into the overall context of the Guidelines.

2 Objectives of subsea dispersion

Subsea dispersant use generally shares the same overall goal of surface chemical dispersion, namely to facilitate the movement of oil into the water column by promoting the formation of smaller oil droplets. These small submerged oil droplets are then subject to transport by subsurface currents and other natural removal processes (NRC, 2013), such as microbial degradation of the oil. Dispersant use, surface or subsea, is intended to minimize the potential impact of an oil spill on surface and coastal habitats and resources. However, a key objective of subsea dispersant use that distinguishes it from surface chemical dispersion is the potential to increase the effectiveness of dispersant application by achieving and maintaining a high encounter rate directly at the source and preventing the oil from ever coming to the surface. In addition to the potential environmental advantages, prevention or reduction of oil surfacing at a spill site may also have a critical benefit in protecting the health and safety of responders and enabling source control operations by reducing harmful volatile organic compounds (VOCs) in the atmosphere (Zhao *et al.,* 2021).

3 Health and safety considerations

As with any response technique employed during oil discharges or hazardous substance releases, various health and safety issues need to be taken into account in the application of subsea dispersant. Part I, chapter 13 and part III, chapter 1 of the Guidelines set out information on health and safety considerations when using and handling dispersants.

Considerations of general occupational health and safety are critical during a response. Safety operators evaluate administrative and engineering mechanisms to mitigate risks. It has been suggested that potential reductions in VOCs around the well site may result from subsea dispersant use (Zhao *et al.* 2021). Responders and safety operators must continue to evaluate the site-specific conditions, including the potential inhalation exposure to the combination of crude oil, dispersants, combustion products and other contaminants that could be expected in crude oil spill situations. Taking into account the potential for exposure to VOCs, responders must then consider which compounds are of concern, the potential harm attributed to exposure to the compounds identified, and the levels that would trigger concern.

Ultimately, it is prudent to reduce the potential for adverse health effects by the responsible use of engineering controls, administrative controls and personal protective equipment, including respirators, where appropriate.

Safety issues during subsea well blowouts, including potential effects arising from the injection of subsea dispersants, are discussed further in chapters 5 and 6. Subsea dispersant injection is achieved through a closed-loop system with the dispersant applied at depth, significantly reducing responder contact with dispersant. The much greater encounter rate achieved through subsea dispersant application at source is of additional benefit. Effective use of this response technique can reduce or eliminate the requirement for offshore or shoreline surface response activities, thereby removing the associated risks.

While outside the scope of these Guidelines, general safety plans that address safety concerns during a subsea response operation should be addressed by the administration or entity in charge of the response.

4 Role of subsea dispersant application in oil spill response

The purpose of any response is to protect human health and safety and minimize the damage caused by the oil spill. Chapter 3 in part I of the Guidelines describes the role of dispersant use in oil spill response and highlights the importance of considering chemical dispersion as a response option, along with other response technologies, such as mechanical recovery and in situ burning. Dispersant application, whether by surface or subsea methods, is one of a number of options for reducing an incident's potential effect, mitigating the impact of oil on sensitive resources and habitats on the water's surface and along shorelines. The objective of subsea dispersant application is similar to that of surface dispersant use. In a blowout scenario, a high encounter rate can be achieved by applying the dispersant subsea directly at the point of discharge. The dispersant is injected at the source before the oil rises and spreads horizontally and vertically within the water column. The use of this method can ensure continued access to the spill site by removing surface oil and improving the safety of surface working conditions (reducing workers' exposure to VOCs) (National Commission, 2011 and NASEM, 2019). This method is also not subject to many of the weather and daylight constraints that apply to surface application methods.

While the advantages and disadvantages of subsea dispersant application are discussed in detail in chapter 6, it is first essential to understand the characteristics, conditions and potential impacts of subsea well blowouts and why these factors are important when considering the use of subsea dispersants.

5 Characteristics, conditions and impacts of subsea oil releases

When deciding whether to apply subsea dispersant in response to a well blowout, it is important to consider the properties of the oil, how it will weather and behave in the subsea environment and how the application of dispersant will influence that behaviour. Predicting the fate and behaviour of dispersed oil requires an understanding of the subsea oceanographic conditions and the oil's physico-chemical properties. An essential part of the decision-making process is to consider the potential effect on all aspects of the environment that could be impacted by the oil spill. This assessment is referred to as a net environmental benefit analysis (see part I, chapter 7 for more information on NEBA).

5.1 Sources of subsea oil releases

Subsea oil may be released from a range of sources that include the following:

- subsea well blowouts from offshore exploration and production oil wells, supporting subsea infrastructure, or risers connecting the wells to the offshore installation or drilling rig;
- pipeline failures; and
- sunken vessels.

This chapter will primarily focus on subsea well blowouts but the information is applicable to all forms of subsea oil release.

5.2 Behaviour of subsea oil spills

Every subsea release source will exhibit a distinct set of variables (e.g. high or low pressure/volume) and those variables influence the oil's behaviour. How the oil will behave depends on the following factors:

- the type of source and the characteristics of the discharge;
- the oil and gas pressures and flow rates;
  - under high pressures and low temperatures, the natural gas may convert to a solid hydrate;
  - the free gas, and certain condensates and/or VOCs can dissolve into the surrounding water body;
  - the gas bubbles can create a pumping action which results in the development of a plume of oil, gas and water that rises to the surface. At certain velocities, this can override the effects of prevailing water currents.
- gas-to-oil ratio;

- the size and geometry of the discharge;
- the water and current conditions into which the oil is discharged;
- the water depth and hydrostatic pressure;
- the water temperature and the oceanographic conditions at the discharge site; and
- the physico-chemical properties of the oil that was released.

These factors play an important role when assessing the viability of particular response options during a subsea well blowout and how the oil will behave with or without chemical dispersion. They also influence the decision-making process regarding the effectiveness of subsea dispersant application.

5.3 Importance of oceanographic characteristics

As mentioned in the preceding section, understanding the water temperature, density and oceanographic conditions at the discharge site is vital for planning and decision-making.

A convenient and simplified method of visualizing the sea is to divide it into layers in much the same way that the atmosphere is divided. Bathythermographic data (temperature versus depth profiles) displays the oceans as a basic three-layered structure. The surface zone, sometimes called the "mixing layer", consists of fairly constant temperatures and is the least dense. The salinity and temperature of this layer vary depending on the location. However, within the layer, salinity and temperature are constant throughout because waves and currents keep the layer well mixed.

The middle zone is called the "pycnocline". It is an area where density changes rapidly with depth. This rapid change in density is directly related to the progressive change in temperature and salinity.

The last zone extends from the bottom of the pycnocline to the seafloor. In this zone, temperature and salinity vary little with depth. Because of the cold temperatures and, to a lesser degree, the salinity, this zone contains the densest seawater.

How does this relate to subsea well blowout scenarios?

During a high-energy loss of well control (e.g. subsea well blowout), oil droplets are rapidly released into the ocean. Since certain properties of the oil (e.g. density) are generally different from those of the surrounding seawater, oil droplets will begin to rise through the zones of water (described above). Therefore, understanding the water temperature, salinity and current (direction and velocity) profiles and the potential water column stratification helps scientists in determining the fate and transport behaviour of the chemically and physically dispersed oil droplets.

5.4 Physico-chemical characteristics of subsea well blowouts

When assessing whether to use subsea dispersant application during an oil spill, it is critical to understand the physico-chemical characteristics of the subsea well blowout. While there are many such characteristics, this section will focus primarily on the behaviour of the oil droplets as they are discharged and transported through the water column (Socolofsky *et al.* 2016; Boufadel *et al.* 2020).

Jet phase:

During a subsea well blowout, the oil and/or gas is released from the source under considerable pressure. The pressure differential between the oil inside the well and the ambient water generates a jet. In the absence of obstructions or debris, the oil/gas is released at a high velocity in a narrow, expanding cone. The jet of oil and methane gas will be broken up into oil droplets and gas bubbles by the intense turbulence of the release conditions. It is important to note that any obstructions, debris or uneven breaks from the well site may alter the release profile during the jet phase (NASEM, 2022).

Buoyant plume phase:

As the jet dissipates, oil droplets and gas bubbles will continue to rise as a buoyant plume, where expanding gas bubbles provide the dominant source of lift and buoyancy. The plume begins to be impacted by the oceanographic characteristics described in section 5.2; in deep water (more than 500 m in depth), the methane gas will dissolve into the sea (owing to its solubility at high pressure), which reduces the buoyancy of the plume, thereby slowing its ascent through the water. Currents and stratification in the water column begin to separate the oil droplets and gas bubbles (if not already dissolved). The oil will also entrain dense water to a point where the aggregate density of the oil-gas-hydrate-seawater suspension is no longer buoyant. Once the plume sheds some of its heavier components, it may re-form. This process can occur numerous times (known as “peeling”). Whether or not a plume reaches a terminal level (or “trapping height”) will depend on the depth of discharge, the plume buoyancy (flow rate and composition of oil, gas and hydrates) and the strength of the ambient stratification. Moreover, cross-current profiles may complicate the plume, causing it to bend and/or sieve.

If the cross-flow current is strong enough, the sieving process will disrupt the establishment of the plume, and the oil will then rise in accordance with the buoyancy of the individual droplets (NASEM, 2022).

Droplet rise phase:

Once the plume reaches its final terminal level, the oil's rise is driven purely by the balance between the buoyancy of the individual droplets and their hydrodynamic drag. The larger oil droplets will continue rising slowly to the sea surface under the effect of their buoyancy. The rise velocities of these larger individual droplets are slower than the velocity of the buoyant plume. Smaller oil droplets will rise more slowly and will be carried horizontally in the water column by ambient currents. These droplets will take considerably longer to reach the surface and will be transported farther from the discharge site. Research has shown that oil droplets smaller than 100 microns should remain suspended in the water column, where they can be degraded by naturally occurring microbes (Johansen *et al.,* 2003) and other processes (NASEM, 2022).

5.5 Environmental considerations associated with subsea well blowouts

In conjunction with the behaviour of oil and gas during subsea oil spills and the importance of understanding the oceanographic conditions of a particular marine environment, the environmental impact of subsea well blowouts is a critical variable for decision-makers to consider when evaluating the potential use of subsea dispersant application.

The potential impact on a resource within the marine environment depends on the proximity of the resource to the initial subsea oil release, the subsea oil plume and surfacing oil from the subsea release. This section highlights the potential effects of subsea oil releases in the water column and on the sea surface and their impact on benthic and shoreline habitats. Table 11 summarizes important areas of potential impact due to a subsea oil discharge.

Seabed benthic zone:

The deep-sea environment, specifically the benthic zone (seabed), is a vital reservoir of biodiversity and plays a critical role in the development of life in the sea, enabling productivity from the sea floor to the surface waters of the ocean. During deep-water blowouts, the seabed is at risk of being impacted by oil through various oil transport pathways. Much of the material (trophic energy) reaching the sea floor comes in the form of "marine snow", a mixture of sediment and biological debris that generally falls from the water column to the seabed (Grassle 1991).

Oil may be sedimented following different pathways. Sedimentation may occur where oil comes into contact and then binds with suspended sediment in the water column, e.g. particulates from a disturbed sea floor or drilling muds etc. These sediments may sink and can form "tar mats" on the surface of the sea floor. One phenomenon reported during the **Deepwater Horizon** incident was the formation of marine oil snow, which is marine snow with a high hydrocarbon content. Marine oil snow occurs when marine snow incorporates oil. It may form through several pathways (Passow & Ziervogel, 2016; UNH/CSE, 2013). Depending on the degree of oil weathering (e.g. biodegradation), the formation and settling of marine oil snow may have far-reaching implications for the distribution pathways of certain oil fractions (not limited to resins and asphaltenes) and for the benthic zone (seabed). However, the impacts of marine oil snow vary, and more research is required to truly understand the implications (Gregson *et al.,* 2021). Studies of the **Deepwater Horizon** spill have reiterated the need for accurate quantification and understanding of local sedimentation rates and processes to inform the net environmental benefit analysis (NEBA) used in operational decision-making, especially when considering whether and to what extent to apply subsea dispersants (see part I, chapter 7 for more information on NEBA). Sediment traps and cameras are valuable components of a monitoring programme (see chapter 9 for more information on subsea dispersant monitoring).

Water column:

The release of oil droplets into the water column poses a risk to marine organisms in the demersal (just above the seabed) and pelagic zones of the water column. When considering the use of subsea dispersant application, assessment of the potential risk must include identifying the marine organisms that can potentially be exposed to dispersants and dispersed oil and whether dispersant use affects the bioavailability of oil compounds that are toxic to them.

The durations and concentrations of exposure for organisms in deeper waters will depend on the degree to which the oil is dispersed, the mobility of the organisms and how long the plumes of smaller oil droplets are retained in the water column by stratified water layers.

Sea surface and shoreline habitats:

As the oil reaches the sea surface and spreads, it poses a risk to animals and marine organisms on the sea surface and in shoreline habitats, including seabirds, marine mammals and sea turtles. Many breeding grounds for fish and invertebrates are to be found in the coastal waters and along shorelines.

Moreover, fish eggs and larvae tend to float near the surface and are relatively more sensitive to impacts from oil.

The extent to which the oil travelling to the surface through the water column has weathered will depend on several factors, including release depth. Weathered oil is expected to be different in composition and original mass from the oil released. To the extent that VOCs like benzene have not dissolved during ascent, concerns may remain regarding potential exposure to these compounds for the animals and marine organisms at the sea surface during deep-sea blowouts.

Table 11 – *Potential impacts to resources within each environmental compartment*

Seabed benthic zone		Marine organisms in the benthic zone are most abundant in the coastal waters, especially along continental shelves. The benthos lives on the sea bottom and includes benthic fauna such as deposit and filter feeders (including barnacles, bryozoans, sponges, mussels, hydroids, pycnogonid sea spiders and stalked crinoids).	Subsea oil may form an underwater plume or flocculate onto marine snow and be deposited on the seabed, which may adversely impact benthic resources or cause long-term exposure and toxic effects to benthic and demersal organisms. The same long-term exposure and toxic effect issues highlighted below for nearshore sediments and shoreline also apply to the extent that oil is deposited on the seabed.
Water column	**Near seabed demersal zone**	The demersal zone is the body of water near (or significantly affected by) the seabed and the benthos. Marine organisms within this location typically live along seamounts or continental rises.	
	Deep water pelagic zone	Zooplankton, meroplankton and fish (large/small pelagic) are vital ecosystem components living in deep open waters.	Organisms may be exposed to oil plumes or droplets in the water column.
	Nearshore zone	Shallow nearshore habitats such as coral reefs, seagrass beds etc.	Habitat would be susceptible to damage from exposure to naturally or chemically dispersed oil in the water column.
Sea surface		Oil which reaches the sea surface poses a risk to resources such as seabirds, sea turtles, marine mammals and fish eggs/larvae present in the uppermost water column.	Floating oil may be persistent and serve as a long-term source of hydrocarbon contamination in the upper water column.

Nearshore sediments	Nearshore sediment forms a habitat for burrowing and stationary (anchoring) organisms such as crabs, snails, limpets, worms and shrimp.	Oil droplets that become naturally dispersed or negatively buoyant can become incorporated into nearshore sediments and result in long-term exposure for the organisms that inhabit the sediments in the littoral environment.
Shoreline	Oil that reaches the sea surface will drift with prevailing wind and current and may contaminate coastal habitats, including marshlands, beaches and other sensitive areas.	Oil may smother shoreline organisms and impact the coastal breeding grounds and juvenile life stages of fish – even those that live offshore as adults. Oil trapped in shoreline substrates can be a source of long-term exposure for shoreline organisms and may cause long-term toxic effects.

6 Advantages and disadvantages of subsea dispersant application

During a deep-sea well blowout, there are several response tools to consider, and each technique possesses advantages and disadvantages depending on the circumstances of the incident. These strengths and weaknesses must be evaluated in light of the unique characteristics of each spill. In many cases, a combination of different response techniques may be required. While chapter 5 addressed the characteristics, conditions and impacts of subsea release of oil into the marine environment, this chapter will strictly focus on the advantages and disadvantages of subsea dispersant use under such conditions.

Note: These advantages and disadvantages are primarily based on the experience gained during the **Deepwater Horizon** oil spill. Our understanding will evolve if this technique is used further, particularly at different well types and depths.

With subsea application the dispersant has the potential to encounter the oil at the source directly. This is in contrast to a response to floating oil, where the large area of fragmented and scattered oil on the sea surface is often a limiting factor. However, it is important to understand that the actual process of chemical dispersion resulting from subsea dispersant application on the periphery or edge of a blowout should not be assumed to be complete and is unlikely to disperse all of the oil released. Nevertheless, given the right conditions, subsea dispersant injection remains a potential response option, given the right conditions, that reduces the impact of oil at the surface by chemically dispersing oil droplets within the water column, where they will be subject to natural processes.

The following sections will examine the advantages and disadvantages of subsea dispersant application during a subsea well blowout.

6.1 Advantages of using subsea dispersant application

The advantages of subsea dispersant application include:

- Mitigation of the oil at the source of the discharge:
  - It can reduce VOCs at the surface and enable source control operations.
  - Large volumes of released oil can be treated efficiently and from one manageable location.
  - It may reduce the amount of dispersant required in comparison to surface dispersant application, where application ratios are higher.
- Subsea dispersant application may eliminate or reduce the need for surface or shoreline response techniques.
- It promotes the formation of small oil droplets within the water column, maximizing the dilution effect and oil exposure to natural fate processes, such as dissolution and biodegradation.
- It reduces the amount of oil reaching the water's surface and not captured by other response technologies, thereby:
  - reducing long-term damage and disruption to specific resources, such as sensitive wildlife and mitigating the effect on coastal waters and shorelines,
  - reducing potential impacts on ecosystems and species that are sensitive to the floating oil (surface slick), such as seabirds and marine mammals; and
  - preventing certain oil constituents (e.g. VOCs) from reaching the surface (for more information on health and safety issues, see part I, chapter 13; part III, chapter 1; and part IV, chapter 3).

- It reduces the amount of oily waste material that must be disposed of relative to other response techniques.
- Dispersant applied subsurface can be injected almost continuously (subject to available dispersant stocks) since operations are not constrained by certain operational requirements (i.e. flight hours, distance), weather or sea state conditions, and are not dependent on daylight hours, as with surface applications. Autonomous subsea injection systems may provide more flexibility to responders by operating even in severe weather. However, the associated subsea resources required, such as subsea monitoring, control and dispersant supply vessels, may limit this advantage.
- Most subsea dispersant application systems are designed to integrate with other subsea response techniques, such as subsea capping.

6.2 Disadvantages of using subsea dispersant application

The disadvantages and challenges of subsea dispersant application include the following:

- It does not physically remove oil but changes its fate in the marine environment, potentially increasing exposure for certain marine environmental compartments (e.g. water column, benthos).
- Extraneous chemical substances (dispersant) are introduced into the marine environment, potentially resulting in additional exposures.
- Past use in the field is limited to a single event (**Deepwater Horizon**), which means that:
  - understanding of the contribution of dispersants to deep plume formation and fate mechanisms is still evolving; and
  - there is limited operational experience in comparison with other oil spill response methods.
- Uncertainty remains regarding the role of dispersants in the formation of marine oil snow sedimentation and flocculent accumulation, as well as regarding the role of oil-mineral aggregates, which may result in sedimentation.

- Subsea dispersant deployment times may be as long as, or longer than, those of other response options:
  - as the logistics required to mobilize the equipment and personnel to the site of the oil release and deploy the equipment to the seafloor can be complex and burdensome (adverse weather conditions could also have an impact);
  - because additional time may be required to remove subsurface debris/obstructions from the oil discharge site;
  - as managing the supply and resupply of large volumes of dispersant entails logistical and manufacturing challenges; and
  - as operators need to consider release rate and injection volume and determine whether the supply chain is adequate to meet needs.
- Depending on the condition/orientation of the damaged wellhead and/or the presence of debris, it may not be possible to position the dispersant injection nozzle adjacent to the discharge point. Some subsea dispersant application systems may not be capable of being deployed to or of operating at the water depth at which the discharge occurs.
- The response may need to address multiple points of subsea discharge.
- Subsea dispersant injection operations may require advanced water column monitoring equipment and procedures.
- There may be challenges associated with public perception and communication of scientifically complex information to stakeholders.

7 Decision-making procedures

After considering the characteristics, conditions and potential impacts of subsea oil releases along with the advantages and disadvantages of subsea dispersant application, the next step involves establishing decision-making procedures for countries to follow when determining whether subsea dispersant application would be an appropriate response option. This process involves understanding the importance of subsea modelling and conducting pre-incident planning and real-time, incident-specific assessments to determine the feasibility and suitability of recommending subsea dispersant use. Finally, the process should also recognize the different roles and responsibilities of oversight agencies when it comes to authorizing the use of certain oil spill response techniques. All potential response options must be considered for planning purposes, given that subsea dispersant use may not always be authorized or may be authorized subject to conditions.

As the potential oil spill-related damage to the seabed (benthic zone), water column, shoreline and coastal regions during a subsea well blowout can be extensive, expediting the decision-making process is of the utmost importance. The speed of the decision will depend on the degree of pre-spill preparation in which decision criteria are established and validated by the appropriate stakeholders.

7.1 Use of modelling to support decision-making for preparedness and response

Modelling often supports both preparedness planning and operational decision-making during a spill. Models developed for oil spills on the surface can provide real-time and projected horizontal movements of oil slicks, based on the real-time and forecast winds and currents for set durations. Normally, for oil spill responses on the surface, models are recommended to be run for 24-72 hours so that they can provide conceptual and predictive data for planning purposes, in particular indicating potential resources at risk. Subsea 3-D models, which include projections with and without subsea dispersant use, may consist of both vertical and horizontal transport modelling. These models depend on many of the same factors as a surface model but also take into account droplet size, gas content, depth, stratification, oil constituent concentrations, etc.

Good practice guidance recommends that modelling be conducted as a preparedness measure before an event, using well blowout scenarios to assess the oiling extent and risk for a given circumstance. Operational modelling during an actual response provides responders with access to the most current trajectories and exposure predictions based on the specific characteristics (e.g. location, volumes, oil type, weather/ocean conditions, etc.) of the event. The outputs from the operational modelling can be used to inform decisions relating to worker safety, resource prioritization, intervention methods, allocation of equipment, guidance for monitoring missions and other critical response decisions.

Lastly, it is essential to note that the accuracy of oil spill hydrodynamic trajectory models depends on the quality of the input information, the skill of the modeller and the hydrodynamic model itself. It is therefore important to include uncertainty analyses in the modelling output. For modelling dispersed oil at depth, detailed information on water column velocity near the spill site should be a priority, along with oil characteristics and droplet size, as well as a baseline conductivity, temperature and depth (CTD) cast to provide boundary conditions for the modelling. Predictions using this information usually have a 24-72 hour trajectory forecast. It is also important to understand that different oil spill trajectory models using the same spill conditions can result in variability among model predictions because of their differing solution strategies. Thus, collecting relevant field data during a response, particularly in the near field, is critical to improve confidence in model predictions.

7.2 Identification of resources at risk

Whether in the planning process or during a response, the identification of the environmental resources potentially at risk from an oil spill, including their socio-economic and cultural importance, is essential for evaluating which response techniques may best mitigate the risk (refer to part I, chapter 7, "Net environmental benefit analysis", for further information). These resources are often associated with the examples listed in table 11 but can include other ecological values, such as those of economic importance. Among the sources of information that may be used to identify resources at risk, ideally during contingency planning, are the following:

- environmental impact statements;
- exploration plans;
- plans associated with the development, production and operations of a subsea well;
- population and community-level ecology data;
- relevant models (e.g. circulation, ecological, trajectory);
- subject matter experts; and
- any other relevant documents in which biological resources are identified.

During an incident involving a subsea well blowout, subsea dispersant application would be one of the response techniques considered. Modelling can forecast the levels at which different resources may be at risk for all oil spill response techniques, including subsea dispersant application. Planning and operational decision-making often use risk assessments and include processes such as NEBA.

7.3 Consideration of subsea dispersant use

As discussed in part I, chapter 7 of these Guidelines, the purpose of risk assessment processes, such as NEBA, is to inform recommendations for choosing the oil spill response techniques that focus on protecting environmental resources at risk. An ecological risk assessment for a subsea well blowout would include an evaluation of the positive and negative consequences of subsea dispersant application and other response techniques, taking into account the region's environmental resources, the timing, location and severity of the incident, and environmental conditions.

Given the complexity of these analyses, it is recommended that scenarios involving subsea well blowouts contained in regional contingency plans be subjected to an ecological risk assessment process (e.g. NEBA or SIMA). The risk assessment process, whether conducted as a planning measure or in an incident-specific situation, should include, at a minimum, the following elements:

- **Assess and evaluate the risks, including those identified in relevant contingency plans.** Include a description of where subsea well blowouts are possible. Include potential oil spill scenarios and volumes, including worst-case discharge scenario of oil spilled, and the physical and chemical properties of the oil.

    - Modelling oil contact with the environment using site-specific input parameters. Consider where the subsea and surface oil will be transported under the influence of subsea and surface currents and wind. It is also helpful to understand how the physico-chemical properties of the oil will change as it "weathers" in the environment. The weathering is important to the fate and toxicological nature of the oil as it is transported in the environment.

    - List of resources at risk or ecosystem components within the areas of potential impact. This should be done from the point of view of preserving resources and habitats, considering seasonal changes and patterns.

    - List of environmental resources at risk, including those with socio-economic and cultural importance, which require protection, if applicable.

- **Consider the feasibility and effectiveness of various response options identified in relevant contingency plans.** Consider the associated advantages and disadvantages and assess the feasibility and effectiveness of using different combinations of response techniques under various conditions, including subsea dispersant application. Consider the encounter probability of the dispersant application and the likelihood of the dispersant becoming incorporated into the oil.
  - Consideration should include response techniques listed in relevant contingency plans, including the practicalities of their utilization and how much oil they can mitigate in the time that is likely to be available.
  - For all potential response strategy outcomes, including those for subsea dispersant use, contingency plans should ensure the availability of response resources and the time necessary to deploy response equipment.
  - In considering a response to a subsea oil release, a decision must be made on the scope of the response, including activities conducted subsea (e.g. capping, containment and recovery, subsea dispersant use) and activities at the sea surface (e.g. mechanical containment and recovery, controlled burning, surface dispersant use). The particular characteristics of the subsea oil release scenario and the behaviour of the released oil and gas will inform the selection of response techniques.
- **Compare the expected mitigation potential of various response options to protect resources at risk.** Assess the overall risk of short- and long-term toxicological effects on marine organisms arising from their exposure to oil on the surface, dispersed oil and the partially water-soluble components released from the oil in the water column. Toxicological effects may include a variety of exposure routes (e.g. ingestion, inhalation, fouling) and organism effects (e.g. mortality, growth inhibition, reproductive failure).
  - Consider how the continuous release of large amounts of oil and gas from a point source will produce high concentrations of naturally dispersed oil, water-soluble components from the oil in the water column, and oil accumulating on the water's surface close to the release. Consider the increase in oil concentrations in the water column by transferring oil that would otherwise rise to the surface.

Note: Before subsea dispersant use, field measurements, as described in part IV, chapter 9, should be taken to characterize the naturally dispersed oil plume.

- Assess and compare the potential impact on resources from exposure to floating or stranding oil, chemically dispersed oil and naturally dispersed oil resulting from using and not using dispersants in the subsea environment. Additionally, assess and compare to what extent subsea dispersant application would be used and how it would be combined with other response options.
- Consider exposure as a function of concentration and duration.
- The regime of exposure to dispersed oil and water-soluble oil compounds in the water column experienced by marine organisms will depend on their proximity to the discharge, the direction of a plume's drift and exposure duration. Organisms close to the release may be exposed to relatively high concentrations of dispersed oil for prolonged periods, even if subsea dispersant application is not used.
- Subsea dispersant use at a blowout will cause the dispersed oil concentration in the water closer to the discharge to be increased. This exposure will continue at least as long as the blowout and subsea dispersant use continue. Depending on the release conditions, exposure in the water column may occur over an extended distance and at lower concentrations. Correspondingly, oil floating on the water should decrease in the areas where the oil plume rises to the surface. However, this oil may become unavailable for removal by other response options (e.g. mechanical recovery).
- Exposures and recovery times of affected species should be considered and compared on a species population-level basis throughout the region and compared with exposures and recovery times if subsea dispersants were not to be used.

- **Select the optimum response techniques for the planning or response scenario or the prevailing incident conditions.** Recommend if subsea dispersant application should be incorporated into the overall response. This stage of an ecological risk assessment relies on planners and/or responders, with input from stakeholders, establishing priorities for protection and the acceptable balance of trade-offs, and ensuring compliance with applicable regulations. It is important to include a description of the uncertainties and knowledge gaps.

8 Planning and preparation for subsea dispersion and logistics

The response to a well blowout scenario typically requires the mobilization of large amounts of specialized equipment and many vessels to conduct subsea source-control operations. The mobilization of specialized personnel is also necessary to ensure an effective response. Logistics plans should identify the logistical concept of operations, organization, processes, requirements and resources.

If subsea dispersant use is determined to be included in the overall response, strategy requirements for such operations and their ancillary components should be detailed in appropriate contingency response plans (e.g. location, quantities, characteristics, compatibility, availability, operational limit conditions, mobilization procedures and deployment time frame), as with the requirements for other response techniques, such as:

- operational stocks of dispersant products;
- vessel – dispersant storage;
- vessel – subsea dispersant application system components;
- vessel – subsea dispersant and water column monitoring;
- remotely operated vehicles (ROVs);
- facilities for deployment (airports, ports);
- aerial surveillance aircraft;
- points of contact (responsible for the equipment); and
- communication equipment.

The plan must include characteristics, performance, requirements and conditions of availability for all response equipment likely to be mobilized: at the national level, public and private equipment; at the regional level, equipment available through bilateral or regional agreements with neighbouring countries; and at the international level, equipment available through international, regional, subregional or bilateral agreements, or through contracts with international companies.

Table 12 – *Resources involved in subsea dispersant operations (Source: IPIECA-IOGP, 2015c)*

Resource type	**Specific equipment, supplies and other items**
Vessels	– Suitable vessels to transport and deploy subsea dispersant injection equipment and dispersant supplies and to transport dispersant supplies for restocking
	– Subsea dispersant injection vessel – dynamic positioning capability, crane capacity, gas detection, deck space
Chemical supplies	– Dispersant
Operating equipment	– Multiple remotely operated vehicles (ROVs) that are pressure rated to assist in installation/operation – Coil tubing unit or dispersant delivery system – Subsea manifold – Dispersant pumping system – Vessel-to-vessel hose and equipment for refilling dispersant storage tanks
Subsea dispersant monitoring kit	– ROVs that are pressure rated to assist with monitoring operations – Specialized instrumentation for the monitoring of subsea dispersant operations – Scientists to support monitoring team – Research vessel for monitoring activities
Procedures	– Installation/operation procedures customized to the responder's vessel(s)
Planning/ Procedures	– Dispersant deployment plan (e.g. transfer from ISO tanks to vessel) – Dispersant injection rate (ratio of dispersant injection rate to oil discharge rate or dispersant-to-oil ratio) – Plan for dispersant restocking operations – Health and safety plan (addresses overarching concerns for the entire response) – Dispersant monitoring plans
Operational plans	– Staging/sequencing plan for the arrival of dispersant tanks at shore base – Ensure that vessel charter agreements cover dispersant operations

8.1 Global dispersant stockpiles

Lessons identified from the **Deepwater Horizon** oil spill prompted a joint industry project highlighting the need for a global dispersant stockpile to be available. During the **Deepwater Horizon** event, unprecedented amounts of dispersant were deployed for use on the surface and through subsea injection systems. Dispersant suppliers required time to produce dispersant and it was challenging to acquire some of the raw materials required for manufacture (Carter-Groves, 2014). There is often a regulatory requirement for operators to subscribe to the services of companies that provide access to global dispersant stockpiles. The subscription service provides access to a large volume of readily accessible dispersant that can be mobilized immediately. Knowledge of the locations of global dispersant stockpiles is vital for a country's or organization's marine environmental planning and preparedness.

8.2 Logistical requirements

As explained in part I, chapter 11, subsea dispersant application systems require more time to deploy than aerial systems. While subsea dispersant equipment is not considered a type of source-control or containment equipment, it is typically co-located and deployed alongside such equipment (BSEE, 2016).

A report published by the Bureau of Safety and Environmental Enforcement of the US Department of the Interior defined optimal mobilization times as the shortest period of time required to carry out subsea dispersant application and source control given minor delays caused by adverse weather conditions and subsurface debris removal near the wellhead, among other factors. The report estimates suboptimal and optimal time frames for well capping and subsea dispersant operations to be between 7 and 60 days (BSEE, 2016).

However, subsea dispersant systems can be deployed within 3 to 12 days depending on location and destination. By comparison, aerial dispersant systems can be mobilized within several hours to one day. Furthermore, ancillary subsea dispersant-related equipment (e.g. dispersant manifold, dispersant supply vessels, dispersant stockpiles), ROVs and monitoring equipment must already be at the location before the commencement of operations. At a minimum, two ROVs are needed to complete the setup procedures for subsea dispersant application.

Unlike other response options, which are limited to daylight hours for aviation and vessel safety purposes, subsea dispersant injection can be maintained continuously around the clock as long as a dispersant stockpile is available and active monitoring can be conducted.

Note: A disruption to the dispersant supply chain can occur during extreme sea states, when dispersant storage transfers cannot be conducted safely.

8.3 Specialized staff

In addition to the equipment and personnel required to conduct monitoring, subsea dispersant injection operations involve the assembly of specialized equipment and require qualified personnel for that purpose. ROVs are the primary underwater platform used for subsea dispersant injection operations. In addition, shipboard operators trained to handle coiled tubing winches and dispersant pumps from the stern of a vessel are necessary. Careful coordination is essential to ensure optimal dispersant injection rates. As a result, the personnel needed to staff such an operation include shipboard dispersant equipment specialists, flow engineers, ROV specialists, representatives of the dispersant manufacturer(s), dispersant-use specialists and specialists in the monitoring of such operations.

8.4 Equipment deployment procedures

Once the subsea dispersant equipment arrives at the incident location, following all appropriate health and safety protocols, a dispersant supply vessel should be positioned nearby. Because of the other ongoing operations (e.g. capping and containment activities, debris removal, relief well drilling, etc.), all vessels and activities should be carefully coordinated through a central coordination system known as the SIMOPS ("simultaneous operations") command. This system is intended to coordinate all activities on the ocean surface and in the subsea environment so as to ensure the safety of all vessels operating in close proximity and better organize subsea operations.

After the vessel is in position, coiled tubing is attached to the vessel's dispersant supply tanks. If the tanks are deployed to the sea floor, hoses are used to connect the supply tanks to the other equipment. The dispersant manifold and clump weights with the other end of the coiled tubing attached are subsequently deployed from the vessel. Once in place on the sea floor, ROVs connect the various components of the subsea dispersant injection system.

Dispersants are transferred from a surface ship or a dispersant storage tank on the sea floor and applied directly at the point of release by an ROV with a dispersant injection nozzle or wand, or via some other subsea assembly, such as a fixed connection into a blowout preventer.

8.5 Dispersant-to-oil ratio

With surface or subsea application of dispersants, it is important to manage the relative dispersant-to-oil ratio (DOR). In surface application, a DOR of 1:20 has been found to be effective, depending on multiple factors, including dispersant product, mixing energy, oil characteristics and weathering. The same factors would apply to subsea dispersant application, but the DOR would be expected to be considerably reduced to 1:100, 1:200 or lower owing to the higher encounter rate that can be expected to be achieved when applying dispersant at the source. In surface application, experience and observation can allow the DOR to be estimated on the basis of the colour and thickness of the surface layer with reasonable accuracy. The rate of application of dispersant can be derived to treat a surface area at a set DOR, which is then adjusted to ensure that the application is carried out at the highest effective DOR (keeping dispersant use to an effective minimum). For subsea application, the volume being released will be less well-defined. It will vary depending on the characteristics of the reservoir and the release point, and will change over time with changes in the flow and the progress of measures to control the outflow. Therefore, the volume of dispersant introduced in subsea application will be less than needed to treat a surface slick. The application rate should be adjusted on the basis of, and in parallel with, ongoing observations and measurement of the effects to achieve an optimal DOR. The resources and capability to manage this must be incorporated into response planning.

8.6 Dispersant application procedures

Subsea dispersant application procedures abide by a set of fundamental principles. First, as mentioned in section 8.4 above, the dispersants are pumped from a supporting dispersant storage vessel to the first component in the system. Depending on the depths, coiled tubing, a pump and an injection head are normally used to accomplish this task. The inner diameter of the coiled tubing can range from 1.25 inches to 2 inches. It is important to note that increasing depths require tubing of smaller diameter owing to constraints related to weight and limited reel size. The hose or coiled tubing attaches to:

- a suspended, free-standing manifold, coiled tubing connector attached to a coiled tubing termination head;
- a chemical hose with a clump weight; or
- a distribution panel on the seabed.

Chemical hoses are a conduit between the coiled tubing and the distribution panel or manifold. From there, the dispersant is discharged from single or multiple sources. If ROVs are used, the ROV positions the dispersant injection nozzle (or application wand) immediately adjacent to the oil and gas discharge jet. A second ROV would assist the first ROV by providing lighting and video surveillance on the sea floor. Depending on the component, one or two arrays may be attached to and extend from the distribution panel or manifold to enable dispersant injection into the rising oil plume. Once this equipment is in position, dispersant pumping will be initiated from the dispersant vessel. Once the oil discharge rate at the incident site has been determined, the injection rate for the dispersant operation will be subsequently adjusted to maximize dispersant effectiveness, as indicated by in situ operational monitoring.

Recent industry developments include various forms of arrays, such as "hot stabs", which connect to the capping stack or Joint Industry Council fittings, to increase adaptability and more efficiently inject dispersant directly into the source (Coelho *et al.,* 2013).

Lastly, the following good practices, as identified by international oil and gas associations, should be kept in mind when conducting subsea dispersant injection:

– If injecting dispersant into the oil and gas before a release (e.g. injecting dispersant into a broken riser pipe), the dispersant should be injected no more than about six well pipe diameters, or four milliseconds flow time, before the release (IPIECA-IOGP, 2015c).

– If the dispersant is to be added to the energetic jet at the oil and gas discharge point, the dispersant should be added only slightly above that point and at a maximum distance of 10 well pipe diameters (IPIECA-IOGP, 2015c).

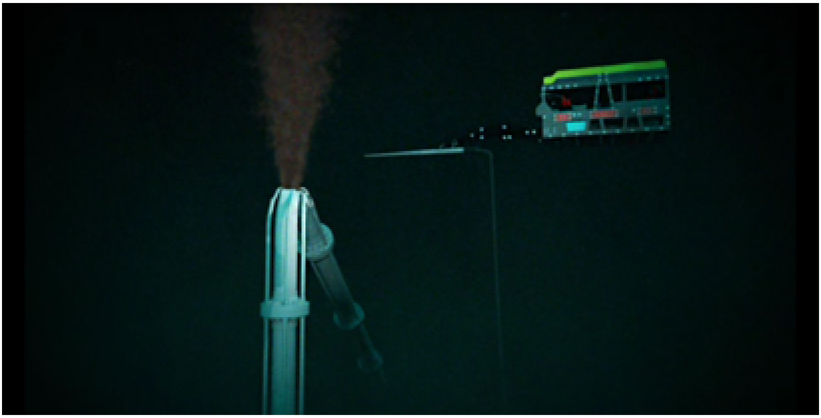


Figure 62 – *Subsea dispersant injection into a broken riser. (Source: Wild Well Control)*

9 Subsea dispersant monitoring

Monitoring efforts during an oil spill help to provide responders and government entities with an ongoing stream of information necessary to inform operational decision-making throughout the incident. It is crucial that government officials and stakeholders agree on the monitoring objectives, goals and associated procedures and plans early on in an incident.

The overall functions of dispersant monitoring, whether at the surface or subsea level, are to assess the dispersant's effectiveness at the source, assess the fate and transport of any dispersed (surface or subsea) oil plumes, and provide data on potential ecological impacts as they relate to operational decision-making. One of the key objectives of subsea dispersant monitoring is to assess the operational, chemical and transport effectiveness of the dispersant injection methods, including evaluating, validating or adjusting operational aspects such as the application ratio, injection point and injection pressures. Guidance on the monitoring of surface dispersant application can be found in part III, chapter 7 of these Guidelines.

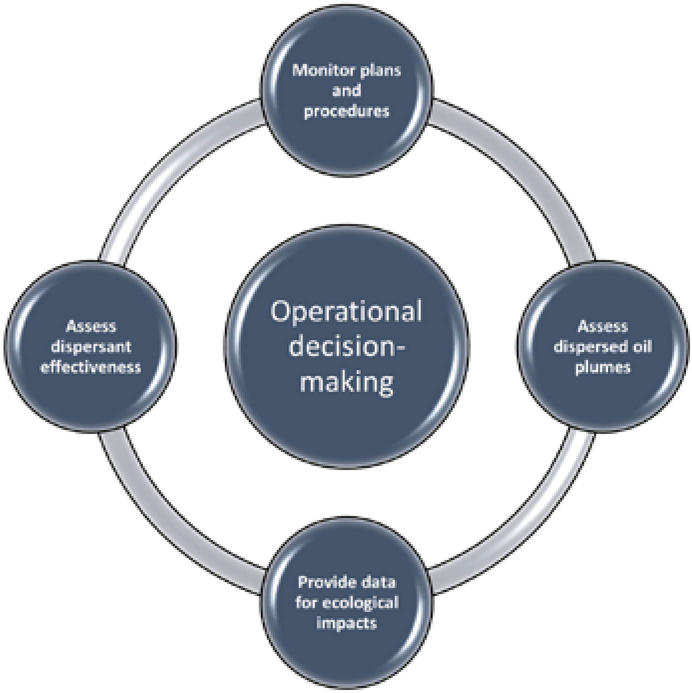


Figure 63 – *Dispersant monitoring functions and their relationship to operational decision-making*

Spill response plans should consider environmental management policies or frameworks and environmental monitoring guidance, including those for monitoring the ecological impacts of subsea dispersant use. These may include national water quality management strategies (e.g. ANZECC-ARMCANZ, 2000) or relevant regulatory guidance materials (e.g. NOPSEMA, 2020). Monitoring elements that inform ecological risk assessments (see part III, section 7.3) and operational decision-making should also be considered in preparedness arrangements. These include, for example:

- the location of the area of interest (e.g. at the dispersant application site and at any other location that may be at risk or where the potential impact may occur);
- physical conditions at the location of interest (e.g. water depth, water column temperatures, ocean stratification and currents, wind and wave climate);

- the diversity and distribution of sensitive receptors (e.g. water and sediment quality, sensitive habitats and the flora and fauna that they support, fisheries resources), including seasonality, where relevant;
- the range of environmental impacts and risks associated with subsea dispersant use to understand the relationships between oil exposure and toxicological effects of potential receptors and to inform the selection of indicators to monitor; and
- approvals/permits that may be required for the monitoring activity or to allow access to undertake the monitoring activity.

This chapter will provide an overview of monitoring functions unique to subsea dispersant operations and their relationship to operational decision-making.

9.1 Monitoring plans and procedures

Procedures and plans associated with dispersant monitoring operations help to identify the supplies, equipment, staff and activities required to use subsea dispersant injection effectively. Dispersant monitoring plans and procedures may have several subordinate plans structured around specific objectives. For example, a quality assurance project plan addresses sample collection methodology, sample handling, chain of custody and decontamination procedures to ensure that the highest-quality data will be collected and maintained.

While specific subsea dispersant monitoring packages may vary slightly in configuration and outfitting, certain fundamental, high-level operational requirements and methods exist for such equipment. In a similar way to that described in part III, chapter 7, the logistical elements and specialized personnel required to conduct subsea dispersant monitoring operations should be conceptually planned in advance given the duration of deployment times and the need to ensure that resources and personnel are available.

Dispersant monitoring team members may consist of personnel specially trained not only for the technical operation of the equipment but also for the interpretation of the data to support operational decisions.

9.2 Assessing dispersant effectiveness at the source

The initial priority of subsea dispersant monitoring should be to complete a site characterization of the subsea oil release before subsea dispersant injection. This should include but not be limited to droplet size distribution for naturally dispersed oil, estimates of oil and gas flow rates, and the behavioural characteristics of the released oil. This information provides the decision-makers with vital background data. It is used to guide the selection of dispersant injection methods and application rates, and to provide site-specific input data for trajectory modelling. This background data can be used later on to diagnose whether dispersant application is effective. By employing water column monitoring, water column sampling, acoustics and air monitoring techniques, decision-makers can synthesize and corroborate the data to determine the effectiveness of subsea dispersant application. None of these techniques used individually can directly quantify dispersant effectiveness, but collectively the data produced can provide sufficient evidence to support decisions on whether to continue or modify dispersant use.

9.2.1 *Release characterization*

Obtaining release characterization data is crucial to understand the nature of the subsea oil release and determine the released oil's properties and behaviour. Gathering the information below, at a minimum, should help to provide sufficient background data (i.e. on the situation before dispersant application), guide operational decision-making and inform the assessment of dispersant effectiveness:

- the best estimate of the oil discharge flow rate, periodically re-evaluated as conditions dictate, including a description of the method, associated uncertainties and materials;
- the best estimate of the discharge flow rate for any associated volatile petroleum hydrocarbons, periodically re-evaluated as conditions dictate, including a description of the method, associated uncertainties and materials;
- the identity of and rationale for the dispersant identified for use, including the recommended DOR for the intended application; description of the methods and equipment to be used for dispersant injection and application, including a plan for monitoring, sampling and observation (not limited to visual);
- the actual injection rate of the dispersant in cubic metres per second; and
- the estimated duration of dispersant injection.

9.2.2 *Source oil sampling*

It is helpful for responders to have specific chemical data on the source oil and any samples collected for profile analysis ("fingerprinting"). Furthermore, source oil sampling can be used to determine the estimated rise rate through the water column for non-dispersed oil and distinguish between the oil associated with subsea discharge and other potential sources of oil. It should be noted that the standard on-site sampling methods used in surface dispersant application are less relevant to subsea dispersant injection since the application is not taking place at surface conditions. Understanding the possible range of oil properties is important, but observation of a test application of subsea dispersant should be conducted.

9.2.3 *Visual assessment*

Although part III, chapter 7 of these Guidelines provides an overview of how to assess treatment effectiveness visually, there are certain distinctions to bear in mind in the case of subsea dispersant application. Visual assessment of subsea dispersant effectiveness is a qualitative measure that includes using ROVs (separate from the ROV conducting the dispersant injection) equipped with underwater video cameras.

The following monitoring can be conducted to ensure that dispersant is being applied at an appropriate rate and with the desired droplet size so that surface VOCs and surfacing oil are minimized:

- Visual assessment based on colour or appearance/shape changes of the oil plume when dispersant is injected. Conducted by ROVs, the data feed provides analysts with the initial tools to assess the shape or colour of the oil and how it changes when dispersants are added.
- Analysis of VOC data collected by surface vessels stationed in close proximity.
- Monitoring of surface expression of oil using aerial imagery comparison to confirm successful subsea dispersant application (API, 2020).

9.3 Assessment of the dispersed oil plume

In conjunction with monitoring the effectiveness of subsea dispersant application at the source, it is important to characterize dispersed oil plumes in the subsea environment. The techniques used for that purpose are water column monitoring and sampling, which aim to inform operational decision-making by:

- determining the position, scale and characteristics of the dispersed oil within the water column;
- characterizing the lateral and vertical movement of the dissolved and dispersed oil; and
- documenting changes in the concentration of the oil as it moves away from the source.

By obtaining water column sampling and monitoring data and supporting data from oceanographic measurements, oil droplet size distribution and hydrodynamic models, responders can determine the likely direction of movement of the subsurface oil and assess the effectiveness of subsea dispersant operations.

It is important to note that while this data can be used to assess ecological impacts as part of natural resource damage assessment, this chapter is focused specifically on the monitoring of subsea dispersant application and its relationship with operational decision-making.

9.3.1 *Modelling to support monitoring*

Before conducting an assessment of a dispersed oil plume, oceanographic data should be used to provide decision-makers with particular areas or grids where sampling or water column monitoring should be conducted. These areas or sample grids should be based on information from subsea oil and dispersed oil models. Such models can assist decision-makers by providing them with critical subsea information, notably on dispersant effectiveness, subsurface circulation, oceanographic conditions and water column concentrations. Oceanographic data combined with model information can guide the selection of sampling locations (see section 9.3.2 below for more information). If such models are unavailable, the sampling grids should be centred on the spill location (API, 2020).

Note: Subsea plume behaviour forecasting and sample collection targeting may be improved by installing acoustic Doppler current profilers on the ocean floor with real-time telemetry capabilities.

9.3.2 *Water column monitoring and sampling*

Water column monitoring informs operational decision-making by providing information on dispersant effectiveness and should be used to re-evaluate the incident-specific response objectives. Water column monitoring seeks to determine the dispersed oil plume's location, extent and characteristics at depth. As with all dispersant operations, data retrieved and analysed from water column measurements is intended to help decision-makers and critical stakeholders in considering dispersant operations as part of the broader oil spill response effort and in weighing the risks associated with continuing the operation against the environmental impacts that the operation is intended to minimize.

The primary monitoring strategy employed during the **Deepwater Horizon** incident involved using a research vessel outfitted with an A-frame and winch to conduct sampling casts using a conductivity-temperature-depth (CTD) instrument and rosette sampler. The CTD equipment was supplemented with a fluorometer, a dissolved oxygen sensor and a deep-water laser light scattering particle size analyser. This remains the recommended approach, with suitable equipment packages available through subscription agreements.

Water samples are collected using the rosette sampler and stored for subsequent detailed chemical analysis from depths determined by the results of the CTD casts for selected stations. Water samples for shipboard dissolved oxygen measurements should be collected at depths above, in and below any observed increase in fluorometric response.

A laser light scattering particle size analyser provides real-time in situ measurements of the dispersed oil droplet size distribution. A significant shift from larger to smaller droplet sizes may indicate oil dispersion and inform operational decision-makers about the effectiveness of the application approach.

9.3.3 *Oil droplet size distribution*

As mentioned above in section 7.1, oil droplet size distribution can be used to inform plume modelling. Observations of relative changes in the droplet size range may indicate dispersant effectiveness when compared with measurements taken before dispersant injection (e.g. measurement of naturally dispersed oil droplet size).

A droplet size analyser, such as, but not limited to, a LISST (laser in situ scattering and transmissometry) instrument, is capable of reaching the sea floor from the vessel(s) for continuous sampling of surface water during transits. These tools can provide information on droplet size counts, potentially distinguishing between dispersed and non-dispersed oil.

A SilCam (silhouette camera) can also be used to detect particle size and is useful in verifying the effectiveness of dispersant application close to the source.

Based on lessons learned from the **Deepwater Horizon** incident, a particle size distribution analysis should focus on droplet sizes ranging from at least 2.5 µm to 500 µm, with measurements for droplet size distribution between 2.5 µm and 2,000 µm, if practicable, for trajectory modelling analysis. A baseline analysis should determine droplet size distribution before dispersant application.

Note: Observations of relative significant changes in the droplet size range serve as an indication of dispersant effectiveness.

9.3.4 *Sediment sampling and monitoring (e.g. physical, chemical and biological)*

Under certain circumstances, sediment sampling and monitoring may be necessary for operational response decision-making. Sediment sampling can be used to gather additional information on the potential effects of subsea dispersant use on oil transport by means of sedimentation. As mentioned in section 5.5, **Deepwater Horizon**-related studies on marine oil snow have reiterated the need to accurately quantify sedimentation rates and processes during and after spills to inform operational decision-making, especially when considering whether and to what extent to apply dispersant in the subsea environment. The sampling and monitoring plan should include appropriate sediment sampling for quantitative analysis, including, but not limited to, oil when applicable.

Sediment sampling and monitoring should cover sediment analysis from reference areas to serve as benchmark information. This information should be collected before any oil exposure or direct application of dispersant.

The analysis of reference data should include water and sediment in the immediate vicinity of the discharge, in the direction of likely transport (e.g. a direction that may periodically shift because of changes in the subsea currents), and in any direction towards the shoreline(s).

Note: Observation of relative differences between samples for reference areas and potentially impacted areas should be recorded.

9.4 Monitoring data for ecological impacts

Subsea oil spills and the use of subsea dispersants may call for environmental trade-offs. Considerable effort is needed to design and implement an appropriate monitoring programme aimed at mitigating and measuring ecological impacts. Ecological monitoring should occur concurrently with sampling of dispersed oil (e.g. fluorometry, particle size, water quality). Spill response plans (developed in advance and in readiness for an oil spill event) should identify ecological monitoring elements, including appropriate preparedness arrangements, to inform operational decision-making when implemented.

Ecological monitoring methods and strategies should be determined in consultation with subject matter experts to help identify, measure and minimize the effects of subsea dispersant application on various receptors. These ecotoxicity testing methods and strategies should assess the toxicity associated with whole-water samples, including in areas where no dispersant has been applied, to allow determination and comparison of ecotoxicity from physically and chemically dispersed oil (CSIRO, 2016; US National Response Team, 2013). For example, ecotoxicity may be assessed by comparing total petroleum hydrocarbon concentrations in water samples collected at appropriate depths against ecotoxicity benchmarks using a sensitive species distribution approach based on representative oils (US National Response Team, 2013). Safety factors may be applied to ecotoxicity benchmarks developed using acute toxicity values to account for any chronic toxicity concerns, with input from appropriate technical specialists. Relevant aspects of ecological monitoring methods and strategies include, for example:

- collection of baseline data from areas where no dispersant has been applied to support detection, determination and comparison of the extent, severity and duration of any impacts to the environment from both physically dispersed and chemically oil, using the selected standard methods;
- mechanisms to ensure that operational monitoring during the response phase covers ecological impacts, which will make the data collection efficient and targeted (e.g. monitoring for ecotoxicity occurs concurrently with the sampling of dispersed oil for fluorometry, particle size and water quality);
- collection and testing of samples following standardized sampling and test protocols, with the chain of custody clearly documented (e.g. use of common techniques among monitoring teams, known standard time frames between sample collection and analysis that will be adhered to); and
- requirements related to personnel, services and equipment (e.g. personnel with specialist chemical, ecological and oceanographic skills; field personnel with relevant

competencies and training to undertake work safely and effectively; accredited laboratories; and specialized sampling equipment).

10 Recommended preparedness measures

As indicated in part II, chapter 11 of these Guidelines, preparedness measures such as research, drills, exercises and training are essential to establish and maintain an appropriate level of awareness within a country or geographic region regarding the level of planning required to determine whether to consider subsea dispersant operations. These preparedness measures also serve as an important bridge between researchers, practitioners and operational decision-makers.

Exercises/Drills:

Subsea dispersant application-oriented exercises and drills should be planned and organized periodically to validate operational procedures and resources (authenticating contracts), train responders, inform the public and critical stakeholders, and evaluate the contingency plan.

After-action reports should be drawn up and corrective actions implemented according to the observations made during the exercises.

Note: The outcomes of subsea dispersant application-oriented exercises and drills should not be interpreted as a guarantee that subsea dispersant use would be appropriate or authorized for an actual response.

Training:

Subsea dispersant operations and monitoring require personnel specially trained and educated on the science, procedures and process of subsea dispersant application. Their roles and responsibilities must be understood and integrated into national oil spill contingency plans.

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