# The Use of Dispersants in Marine Oil Spill Response

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## ABSTRACT

Each marine oil spill presents unique circumstances and challenges that require careful consideration of which response options are most appropriate for mitigating impacts to local communities and the environment, which may include the use of dispersants. Dispersants are chemical countermeasures that reduce the amount of floating oil by promoting the formation of small droplets that remain or become entrained in the water column, where they are subjected to greater dissolution and dilution. During the Deepwater Horizon oil spill, an unprecedented volume of dispersants was used at the surface and in the deep ocean. The spill stimulated interest and funding for research on oil spill science, especially regarding dispersant use. Building on two previous reports and using this new information, a committee of experts convened by the National Academies of Sciences, Engineering, and Medicine (NASEM) conducted a review and evaluation of the science on dispersant use. The committee's review focused on various aspects of dispersant use in offshore marine oil spills, including dispersant and oil fate and transport, human health considerations, biological effects, decision making, and alternative response options, among others. The findings and recommendations of the committee were published in the recent report, The Use of Dispersants in Marine Oil Spill Response (available for free download at https://www.nap.edu/catalog/25161/the-use-of-dispersants-in-marine-oil-spill-response). The presentation summarizes the committee’s findings and recommendations within the context of oil spill response science and technology. A key area of consideration is how they

relate to and support a robust decision making process in the event dispersants are considered for use in future spills.

## INTRODUCTION

Every oil spill, whether the result of an oil well blowout, vessel collision or grounding, leaking pipeline, or other incident at sea, presents unique circumstances and challenges. In determining the optimum response, many factors must be considered, including the type of oil, location, time of year, water depth, occurrence of living marine resources, environmental conditions, and potential community impact. A variety of response options exist, including mechanical recovery of oil using skimmers and booms, in situ burning of oil, monitored natural attenuation of oil, and dispersion of oil by chemical dispersants. Each method has advantages and disadvantages, and it is important to understand specific scenarios where a net benefit may be achieved by using a particular tool or combination of tools. Often, it is a combination of approaches and adaptability to the particular circumstances that affords the best outcomes. Having a variety of response options available in the "tool kit" provides responders with alternatives in the face of operational limitations. Dispersant use can be one such option.

The objective of dispersant use is to prevent or reduce the formation or thickness of surface oil slicks. Dispersants work by reducing the oil-water interfacial tension, and, with sufficient mixing energy, forming smaller oil droplets that become or remain entrained in the water column with minimal recoalescence. The smaller droplet size slows or eliminates surfacing, allowing for greater dilution, dissolution, and degradation of the oil while it is within the water column.

The National Academies of Sciences, Engineering, and Medicine (NASEM) recently assembled a committee of experts to address several key considerations in the decision of whether or not to use dispersants in response to a marine oil spill (see Box 1). The resulting consensus report of the Committee, titled *The Use of Dispersants in Marine Oil Spill Response*, was released in April 2019 and includes the Committee's findings and recommendations. This report builds from two prior reports by the National Research Council regarding dispersants. The first was released in 1989 and the second in 2005.

**Box 1**

**Statement of Task**

This study will assess the effects and efficacy of dispersants as an oil spill response tool through review and evaluation of domestic and international research reports and results, including both field and laboratory studies. The study will evaluate trade-offs associated with dispersant use, in part through use or review of net environmental benefit analyses conducted for past oil spills.

This evaluation will include comparison of chemically dispersed oil with the fate and effects of *untreated* oil. As part of this study, the committee will review research on the use of dispersants during actual spills, both for surface and subsurface applications (e.g., the 2009 Montara oil spill off the Australian coast and the 2010 *Deepwater Horizon* oil spill in the Gulf of Mexico) to assess the net benefit of dispersant use in these cases. Specifically, the study will:

1. Assess the state of our knowledge about dispersant effectiveness (including comparisons across a range of dispersant formulations) and the fate, including short- and long-term fate, of untreated oil (no chemical dispersant applied), chemical dispersants, and chemically dispersed oil and the influence of dispersants on deposition (including marine snow), biodegradation, and/or transport of oil;
2. Evaluate and summarize research on the acute and chronic (sub lethal) toxicity of chemical dispersant formulations of comparable efficacy, chemically dispersed oil, and untreated oil at realistic environmental exposure levels. This will include characterization of the relative risks to wildlife health of untreated oil and chemically dispersed oil, taking into consideration exposure to volatile compounds, ingestion, and absorption of naturally versus chemically dispersed droplets;
3. Compare the benefits and limitations of dispersant application to the use of other clean-up methods (e.g., no-action, mechanical recovery, burning, and chemical herders in combination with burning);
4. Compare the relative human health risks for the use of dispersants with the use of other clean-up methods (exposure of response personnel and residents in Gulf coastal communities to oil and dispersants, and contamination of seafood);
5. Identify the research protocols and standards that would: i) increase the applicability of lab-based measurements to the field and ii) improve the comparability of research findings from different laboratories;
6. Assess the adequacy of the existing information to support risk-based decision-making or net environmental benefit analysis of response options under a variety of spill scenarios and recommend a "roadmap" of research and modelling to address identified information gaps.

In 2010, the *Deepwater Horizon* (DWH) oil spill resulted in an unprecedented use of dispersants, including for the first time, the use of subsea dispersant injection (SSDI) at the wellhead. The DWH spill and the resulting funds from litigation and penalties catalyzed a rapid increase in the science and literature on spill response and dispersant use in particular. Further, the use of SSDI in particular raised additional questions and challenges, which have further spurred research on this topic.

The recent NASEM report expands on the earlier reports by incorporating and highlighting the new information on this topic. The Committee sought to provide as much current and complete information as possible, while recognizing that dispersant use, and oil spill response generally, remain areas of ongoing research. The Committee also acknowledges that much of the recent literature focuses on the DWH oil spill; however, their report is not intended to be a retrospective evaluation of that event.

As context for the report, it is important to consider the circumstances for which dispersants would be considered as a potential response option. For example, for small spills or in particular sea state conditions, dispersant operations may not be logistically feasible. Similarly, in the United States, preauthorization zones for dispersant use are generally limited to areas greater than 3 nautical miles from shore and in depths greater than 10 m. In other parts of the world, these zones may differ. Also, although a few freshwater dispersant products are available on the market, they are not currently approved for use in freshwater in the United States. Therefore, the Committee interpreted the Statement of Task as limited to marine oil spill scenarios in which dispersants would be considered a potential response option.

What follows is a high-level summary of the topic covered in the NASEM report with a selection of the key findings and recommendations.

# FATE AND TRANSPORT OF DISPERSANTS, UNTREATED OIL, AND CHEMICALLY DISPERSED OIL

## Fate and Transport of Dispersants

The modern dispersant products considered in the NASEM report (e.g., Dasic Slickgone NS, Finasol® OSR 52, Corexit® EC9500A) are mixtures of solvents and surface active agents (surfactants) with different physicochemical properties, which influence their potential fates in the environment. Once introduced to the aquatic environment, dispersants become subject to dilution, dissolution, and degradation (e.g., biodegradation and photodegradation). As a result, the window of time within which ocean biota may encounter the full dispersant formulation is brief. When dispersants are injected at depth, the various components of the dispersant will differentially dilute and dissolve, with some of the components being retained at depth. In this circumstance, biota at those depths may encounter dilute concentrations of the more persistent and water-soluble components.

## Fate and Transport of Untreated and Chemically Dispersed Oil

Throughout this report the term “oil” is used as a general term referring to complex crude and refined chemical mixtures of hydrophobic compounds derived from geological sources. The chemical composition of an oil typically includes thousands of different compounds (Chang et al., 2011; Reddy et al., 2003) and can vary significantly. The composition of an oil dictates its physical properties, its behavior in the environment, and its initial physical interactions with an applied dispersant. Dispersants tend to be more effective on lighter oils than on high-viscosity oils.

The fate and transport of oil are dictated by the laws of physics and chemistry, but the application of these laws can be strongly modulated by the composition of the oil, the spill environment, human intervention, biological processes, and time. The processes identified in Figure 1 can influence and be influenced by the application of dispersants. For example, dispersants may enhance processes such as dissolution, while evaporation or emulsification may hinder dispersant efficacy.

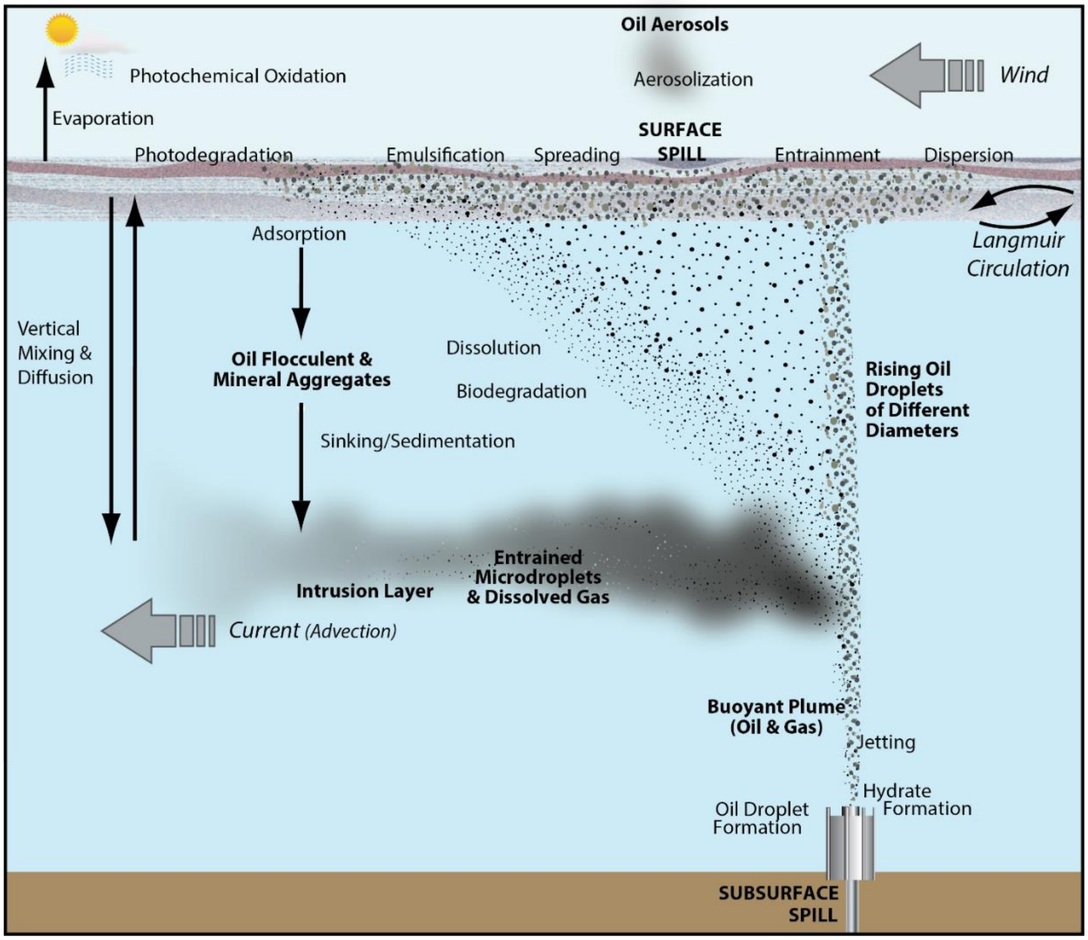

**Figure 1** Summary of the important components (bold font) of an oil spill and the processes (normal font) that affect them. Dispersants may exert an influence on all processes shown except for jetting, wind, current, and Langmuir circulation. Surface gravity waves are not explicitly shown for the sake of clarity. SOURCE: Modified from Hazen et al. (2016).

A key determinant of oil transport in both the surface and subsurface is droplet size. With regard to surface oil, droplets form when turbulence drives oil beneath the surface. The depth of penetration and the resurfacing time depend in part on the droplet size. In a deepwater release, droplets form at the source and rise through the water column as a function of their size. Oil type and the densities of the oil and surrounding seawater will influence rise velocity, but generally, larger droplets have greater buoyancy and hence rise more quickly than smaller droplets do.

Because they rise to the surface more slowly, smaller oil droplets will lose more soluble components before surfacing and thus release fewer volatiles to the atmosphere. Smaller oil droplets may also be transported further from the source and surface over a broader area, potentially reducing atmospheric concentrations of volatiles. Because inhalation of volatile organic compounds (VOCs) is a major health concern for responders, this can have important implications for response efforts. Under favorable conditions, small droplets may also promote greater biodegradation because of the increased surface area and longer residence in the water column. The purpose of using dispersants is to enhance the formation of these small oil droplets and thereby increase dissolution and biodegradation while decreasing exposure.

Models and experiments have been developed that can provide insight on droplet formation and distribution and together serve as valuable tools for understanding the driving factors and the sensitivity of systems to particular parameters. However, sources of uncertainty remain, and for any particular spill, unforeseen factors may impact droplet size and complicate reconstruction of the actual conditions. Therefore, field trials and observations during accidental spills (spills of opportunity) could help reveal processes beyond those incorporated in current models and experiments.

**Recommendation: Additional observations of droplet formation are needed as close to field scale as possible. An extensive, dedicated field study would be highly desirable; but, should cost and permitting prove prohibitive, a spill of opportunity should be considered. Field experiments will be inherently restricted in the phenomena that can be studied because of logistical challenges and open boundaries. They will also face legal and regulatory challenges. Thus, it would be highly desirable to develop a large-scale laboratory facility with the ability to include high ambient pressure and observation of droplets as they evolve over time.**

## AQUATIC TOXICITY AND BIOLOGICAL EFFECTS

Oil can present an immediate hazard to ocean life, both at the surface and below. At the surface, oil can harm animals such as seabirds, turtles, and marine mammals through physical smothering from direct contact, ingestion, inhalation, and aspiration of oil. Dispersants have been used in part to reduce the hazards of surface oil, both at the offshore site of the spill and through wind-driven transport to nearshore habitats. However, the action of dispersants in a surface spill increases the amount of oil in the water column, both as dissolved oil constituents and as small droplets, where fish and other species may be exposed through absorption or ingestion.

### Dispersant Only Toxicity

Modern dispersants (e.g., Dasic Slickgone NS, Finasol® OSR 52, and Corexit® EC9500A) have been formulated with less toxic chemical constituents, employing ingredients found in common consumer products such as cleaners and cosmetics. Further, toxicity is a function of exposure and based on operational dispersant application rates at the surface, the dispersant-only concentrations are expected to be well below the HC5[1] determined by species sensitivity analyses within minutes to hours. As underscored in the previous NRC reports, the concern with dispersant use is whether dispersed oil is more toxic than untreated oil, not the toxicity of current dispersant formulations.

## Dispersed Oil Toxicity

Laboratory experiments have been conducted to compare the solutions of oil equilibrated with seawater to oil and dispersant mixtures equilibrated with seawater in order to determine the relative toxicity of dispersed oil. However, the results of these studies have been equivocal, at least in part due to the lack of consistency in the methodologies. Toxicity testing protocols consist of three main elements: media preparation, exposure, and chemical characterization. Media preparation is complicated by the fact that oil components vary in solubility and partition into both the oil and the aqueous phase. Two methods of media preparation have typically been employed: variable loading and variable dilution.

### *Variable Loading*

In variable loading experiments, a water-accommodated fraction (WAF; aqueous phase separated from the oil after mixing) is prepared for each concentration of oil to be tested. When a dispersant is included, a chemically enhanced water-accommodated fraction (CEWAF) is produced at the same oil concentration. Both WAFs and CEWAFs contain microdroplets, but CEWAFs contain a higher concentration of microdroplets for the same initial loading of oil. WAF and CEWAF have the same dissolved oil concentration because at equilibrium the

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[1] Acute HC5 refers to the concentration at which 5% of the tested species have their LC50 (concentration lethal to half of the test population for a 96-hour exposure). At this or lower concentrations, 95% of the species have an $LC_{50}$ above the HC5. Note that toxicity is greater when the LC50 or HC5 is lower.

dissolved concentration depends on the oil-to-water ratio, not the amount of oil present in microdroplets. An analysis using available variable loading toxicity tests comparing CEWAFs to WAFs shows that the higher concentration of microdroplets in the CEWAF does not increase toxicity until the oil loading is above approximately 100 mg oil/L. Hence, variable loading experiments indicate that at or below approximately 100 mg/L, dispersed oil is no more toxic than is untreated oil. Above approximately 100 mg oil/L the increase in toxicity with dispersants is due to increased generation of oil microdroplets.

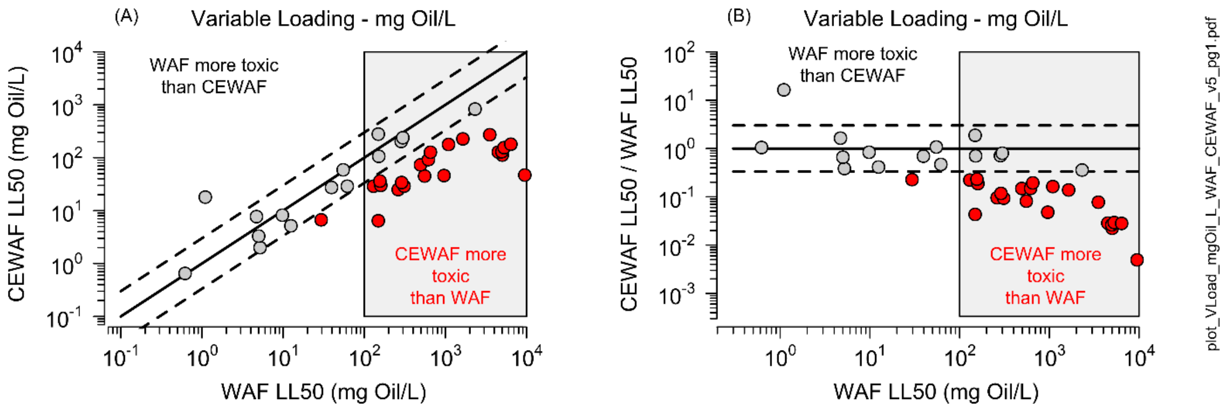

**Figure 3.5** (A) Comparison of the median lethal (LL50) or effects-loading concentrations (EL50) for chemically dispersed CEWAF to physically dispersed WAF. (B) Ratio of CEWAF to WAF LL50 concentrations versus WAF LL50 concentrations. Only data from 1:10 and 1:20 dispersant-to-oil ratio are included. Dashed lines span a factor of 1/3 to 3 around the solid 1:1 line. Note the scale change on the vertical axis between figure (A) and figure (B). SOURCE: Data from Bejarano et al. (2014) and the Committee's meta-analysis (Appendix F).

### *Variable Dilution*

An alternative approach, commonly applied in oil toxicity tests, uses a single stock solution prepared at a high oil loading that is serially diluted to create a set of decreasing concentrations. However, there is a fundamental problem with this test design. When the WAF or CEWAF is diluted, the concentration of the dissolved oil components decreases and is no longer in equilibrium with the oil in the microdroplets. This causes further dissolution of oil components from the microdroplets until the solution reaches equilibrium. However, the dissolved concentration will be higher than predicted by the proportion of the dilution. Because dispersants create more microdroplets, the dissolved concentration in the CEWAF dilutions will be higher than in the equivalent WAF dilutions. This mismatch in the dissolved oil concentrations and composition can be corrected by direct measurement of the dissolved oil concentration in each dilution. However, without correction for the actual dissolved oil concentrations, a direct comparison of WAF and CEWAF toxicity will not produce meaningful results.

**Recommendation: Funding agencies, research consortia, and other sponsoring groups should require that research teams use standardized toxicity testing methods, such as those developed by the Chemical Response to Oil Spills Ecological Effects Research Forum (CROSERF) program, and analytical chemistry protocols to fully characterize hydrocarbon composition and concentrations in the exposure media. For testing the effect of dispersant, the variable loading test design is recommended.**

### *Phototoxicity*

Another consideration for assessing the use of dispersants is phototoxicity. When oil is exposed to sunlight, the toxicity of certain polyaromatic hydrocarbons (PAHs) that are absorbed by the organism can undergo a 10-100 fold increase in toxicity. Use of dispersants to reduce oil at the surface would therefore lower the potential aquatic toxicity of the oil. Exposure to sunlight can produce new compounds that have to be considered.

## HUMAN HEALTH CONSIDERATIONS

The NASEM report considers three primary means by which dispersants can influence or alter the health risks associated with an oil spill:

(1) adverse effects result from oil dispersant mixtures;

(2) dispersant use directly causes adverse effects; and

(3) indirect effects of dispersants altering the extent or duration of the spill.

During a spill response, the primary exposure pathways of concern are inhalation and dermal exposure of response workers. Direct effects to response workers may be mitigated through proper worker health and safety programs that focus on personal protective equipment and monitoring. Community health concerns arising from exposure to oiled shorelines; socioeconomic effects, such as disruption of commercial and subsistence fisheries; and concerns over contaminated seafood also need to be considered as factors in oil spill response.

### Human Exposure and Toxicity of Oil

The primary constituents of crude oil that can affect human health are the volatile organic compounds (VOCs) (benzene, toluene, ethylbenzene, and xylene [BTEX]) and PAHs. The carcinogenicity of benzene and PAHs, particularly benzo(a)pyrene, are well characterized. Dispersants may reduce exposure to these oil constituents by altering their fate, transport, and biodegradation. In a deep-water blowout, subsea use of dispersants could reduce the potential for inhalational exposure by increasing the dissolution of VOCs during the slower transit of dispersed oil droplets to the surface. Dermal exposure to oil constituents has been shown to cause skin irritation and skin cancer. At present, there is insufficient evidence to determine if dispersant use changes the transdermal absorption of crude oil components.

Although responders may be exposed to oil and/or dispersants through accidents or improper use of protective equipment, exposure of the broader community to dispersants or dispersant-oil mixtures is much less likely because dispersant use in the United States is generally limited to offshore spills. Possible routes of exposure include ingestion, inhalation, and dermal contact. Exposure via ingestion could occur through consumption of seafood contaminated with PAHs or dispersant components during or after an oil spill. Protocols for closing and reopening fisheries during and after an oil spill are designed to protect public health from this exposure route.

If a response tool, such as dispersants, shortens the intensity and duration of a spill and hence response activities, and proper health and safety measures are in place, exposure risk would be lower, particularly for responders. This factor merits inclusion as part of the tradeoff considerations with regard to decisions on dispersant use.

### *Epidemiological Studies*

Two studies of DWH spill responders have attempted to disentangle the direct effects of dispersants from other worker health risks. While these studies noted similar adverse effects associated with dispersant exposures, both have limitations in their ability to validate exposure to dispersants based on self-reporting of workers. In both of these epidemiological studies, limitations in the exposure assessment for dispersants affect the strength of the conclusions. The protracted initiation of the studies and the lack of a dispersant/dispersed oil biomarker necessitated reliance on self-reporting, making it difficult to accurately estimate exposures and hence the effects of dispersant/dispersed oil versus untreated oil.

### *Indirect Human Health Effects*

Often, the adverse health effects noted in studies of communities near an oil spill have been associated with psychosocial and economic impacts rather than toxicity associated with direct exposure to chemicals. A spill can also lead to prolonged closure of fisheries, causing secondary effects on community psychological and socioeconomic well-being.

**Recommendation: Selection of biomarkers to improve human exposure assessment should consider the toxicity of dispersant and oil components and degradation products (produced by both biological and photodegradation), persistence in the environment, and bioaccumulation potentials. Biomarkers and analytical protocols should be established for each dispersant formulation listed on the U.S. Environmental Protection Agency's (EPA's) National Contingency Plan Product Schedule.**

**Recommendation: In advance of the next significant oil spill, the reporting requirements for details of injury and illness reporting for worker health and safety should be improved, with a clear focus on whether workers were exposed to dispersant. To that end, publication and ready availability of well-defined DWH worker health and safety statistics is needed. Exposure assessment and toxicological evaluation should recognize that response workers may not be from a healthy worker population and may not know how to minimize exposure.**

## OIL SPILL RESPONSE DECISION-MAKING

Immediate human life is the first priority in marine oil spill response. The next priority is the development of a response strategy that most effectively reduces environmental consequences, offers the greatest protection, or promotes the fastest recovery. Crafting this strategy and determining whether or not dispersant use is appropriate for a given scenario requires decision-making tools for assessing the relative benefits of available response options. A number of approaches, collectively known as Net Environmental Benefit Anlaysis, are available to assist decision-makers in selecting the response option(s) most likely to minimize the net environmental impacts of oil spills. Three specific tools commonly used to support the NEBA approach are the Consensus Ecological Risk Assessment (CERA), Spill Impact Mitigation Assessment (SIMA), and Comparative Risk Assessment (CRA).

All three decision-making tools (CERA, SIMA, and CRA) have value for supporting contingency plan development, strategic planning during the initial stages of a spill response, or tactical execution during the active phase of a response. Because a CRA relies on an integrated model adapted for a particular spill scenario, it takes considerable time before results are available; hence, it typically has more value for contingency planning.

Importantly, each tool can be used to engage stakeholders, an essential element for providing input on local or regional priorities, expanding awareness, and building confidence and trust in the decision-making process. With further development, the NEBA process also could be used to estimate human health and socioeconomic impacts.

**Recommendation: Decision makers should further evaluate surface and subsea spill scenarios using NEBA tools (i.e., CERA, SIMA or CRA) to better define the range of conditions (e.g., oil type, sea state, depth, location, resources at risk) where dispersant use may be an appropriate and/or a feasible response option for reducing floating oil.**

**Recommendation: The NEBA tools (CERA, SIMA, and CRA) should be expanded to consistently address the health of response personnel, community health, and**

**socioeconomic considerations (e.g., beach closures). Further, these tools should be used to gain stakeholder input on local or regional priorities, expand awareness, and gain trust in the decision-making process.**

## SELECTION OF RESPONSE OPTIONS

It can be difficult to make trade-off decisions during an on-going spill based on field data, because observations may be limited. Efforts to ensure human safety, contain the oil, and minimize environmental damage take priority over monitoring and scientific studies. Pre-spill planning and scenario development prior to a spill provide the knowledge base on which decisions can be made during a spill event as long as human health considerations are included in the NEBA tools as discussed above.

### Comparative Studies

Each response option has a complex suite of advantages and limitations, many of which are presented in the NASEM report. However, a limited number of comparative studies have evaluated the relative effectiveness, benefits, and limitations of various response methods. The NASEM report identifies five such comparative studies.

The first, Tropical Oil Pollution Investigations in Coastal Systems (TROPICS), established three shallow-water study sites from 1983 to 2015 in Panama to evaluate the impacts of untreated and dispersed oil relative to a control site. The purpose of the TROPICS study was to evaluate the relative health of the ecosystem at each site.

The second set of studies involved two CRAs. The CRAs rely on integrated numerical modeling to predict which environmental and human health impacts may arise in various response scenarios.

The third study involves a comparison of VOCs emitted to the atmosphere near the well during a DWH-like blowout using an integrated oil-fates model for the ocean and a numerical model for the atmosphere to compare SSDI with no response.

The fourth comparison study of note used an alternative integrated fate and effects model to evaluate the effectiveness of SSDI during the DWH relative to no dispersant use. The model was validated using observed concentrations of oil constituents. It was then used to estimate the distribution of oil through the water column with and without SSDI.

The fifth comparison involved a SIMA prepared for an exploration drilling project in offshore Nova Scotia that focused on a source control event (Slaughter et al., 2017).

Our understanding of the impacts of dispersants as a response tool has been greatly advanced by laboratory experiments and modeling but these efforts are often limited by their inability to capture the complexity or scale found in the field. Important issues that are best answered in a field study or spill of opportunity (SOO) include validation of models, especially scaling of droplet size, better understanding health impacts on response workers, validating response-decision making approaches, and discovering previously unknown linkages in complex ecosystems affected by oil.

## Other Considerations

Selection of the appropriate response option(s) may also depend on other facts. Some specific factors identified by the NASEM study include: dispersant regulatory approval processes, transboundary considerations for spills that extend beyond a single country's jurisdiction, and the unique conditions associated with oil spills in the Arctic.

## CONCLUSION

The NASEM Committee recognized the importance of having a variety of response options available to responders so that response efforts can be tailored to the particular circumstances of a specific spill scenario. The Committee further recognized the potential value of dispersants as one such response method. Three NEBA tools (SIMA, CERA, and CRA) are available to assist decision-makers in their determination of which response methods best minimize the environmental harm associated with an oil spill. These tools incorporate available information on the likely fate and transport of oil and dispersant components, as well as information regarding the potential effects associated with human and environmental exposure. The Committee reviewed what is known regarding oil and dispersant fate and transport, aquatic toxicity and biological effects, and human health considerations. The Committee provided recommendations as well as suggested protocols for advancing our knowledge in these areas and also for enhancing the decision-support tools, for example, by expanding the considerations of human health.

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