Subpart J Proposed Rule

REVISED DRAFT Comment Summary

IV.1 General (300.900 and Removal of 300.905 – NCP PS)
and
IV.2.a General (Authorization of Use, 300.910)

(v. January 19, 2016)

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IV. SUBPART J - USE OF DISPERSANTS, AND OTHER CHEMICAL AND BIOLOGICAL AGENTS

IV.1. GENERAL (300.900 AND REMOVAL OF 300.905 – NCP PS)

Commenter Name: M. Swanson, A. Bauer, T. Miller, et al.
Commenter Affiliation: Prince William Sound Regional Citizens
Document Control Number: EPA-HQ-OPA-2006-0090-0266-A1
Comment Excerpt Number: 1

DRAFT

After years of observing dispersant trials, dispersant effectiveness monitoring, advising and sponsoring independent research regarding chemical dispersant use, it is the position of the Prince William Sound Regional Citizens' Advisory Council (the Council) that dispersants should not be used on Alaska North Slope crude oil spills in the waters of our region. Until such time as chemical dispersant effectiveness is demonstrated in our region and shown to minimize adverse effects on the environment, the Council does not support dispersant use as an oil spill response option. Mechanical recovery and containment of crude oil spilled at sea should remain the primary methodology employed in our region.

Comment Excerpt Number: 8

While it is important to ground oil spill response policy and decision-making in science, it is equally important that EPA acknowledge areas where the foundational science contains uncertainties. In the wake of the Deepwater Horizon spill response, there has been significant effort among federal agencies and leading researchers to clarify areas where there is consensus about chemical treating agents (primarily dispersants), and areas where uncertainty prevails. In light of this fact, we encourage EPA to be as transparent as possible about areas where scientific data is sparse or consensus is lacking. In order for the public to have confidence in oil spill response decision-making, there must be clear and plain acknowledgement of scientific uncertainty.

Comment Excerpt Number: 26

Comment Excerpt:

Throughout the proposed rule, requirements are proposed for testing and monitoring to be conducted by the Responsible Party, (RP) at the time of a spill, or the Chemical Agent manufacturer (for listing agents on the

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Schedule). PWSRCAC strongly urges the EPA to consider all possible opportunities to require independent science or rigorous peer review of all studies that are conducted by the RP or vendor. When a spill occurs, the RP faces significant civil and criminal liability based on environmental damages, including damages caused by spill treatment decisions. This creates a conflict of interest for assessing potential adverse impacts from treating agents. Similarly, the product manufacturers and vendors have a financial interest in selling their product, and therefore have a motive to present results that might overestimate potential effectiveness or understate toxicity. We recommend that the EPA consider opportunities to audit or independently vet studies to ensure fairness and transparency.

Commenter Name: Riki Ott, PhD
Commenter Affiliation: ALERT Project, a project of Earth Island Institute
Document Control Number: EPA-HQ-OPA-2006-0090-0520-A1
Comment Excerpt Number: 1

Comment Excerpt:

First, we find that EPA has made a critical attempt to clarify its duties under the Clean Water Act to prepare a Schedule identifying chemical and biological agents, and other spill mitigating devices and substances that may be used in carrying out the NCP; to identify in the Schedule the waters in which such products may be used; and to identify the quantities of such products that can be used safely. 33 U.S.C. § 1321(d)(2)(G). Inclusion of the third duty, in writing, is missing from the proposed rule yet this duty is what tethers the Schedule and everything in it to a solid legal foundation and to sound science and public health principles.

The government has a fiduciary duty to protect public health, public trust resources that support health and wellbeing of present and future generations, and public access to our collective public assets. In essence, this means that federal, state, and local governments are trustees, charged with managing trust assets on behalf of the citizens who are trust beneficiaries. It also means that the government – all levels and all branches – is responsible for creating, implementing, and enforcing laws and policies to protect trust assets by holding polluters who despoil trust assets accountable to the laws and policies.[1]

This is especially relevant during responses to discharges or releases of oil and hazardous substances because the despoiler – the spiller – is duty-bound to its shareholders to minimize its liability, which often comes at the expense of human safety and health and the environment. The fiduciary duties of government to protect public assets during spill response conflict with the fiduciary duties of the spiller to protect its private assets. Therefore, it is critical that public trustees in government recognize this inherent conflict of public versus private interests and establish, implement, and enforce regulations that protect public health and welfare and the environment.

The current laws and regulations are weak, in that they do not recognize the toxic and hazardous nature of crude oil; nor do they recognize the potential harm from products alone or in combination with oil. By not recognizing the hazardous nature of oil spills and the response activities necessitated by them, nearly all of the risk to the public and its assets and resources falls on society to bear. The risks manifest to individuals as debilitating health issues, as devalued or destroyed homes, and as lost livelihoods, among other things. The risks manifest to society as health and reproductive issues that damage our unborn and young, as loss of productivity from chronically sick adults, as undrinkable or contaminated fresh water, and as degraded ecosystems incapable of supporting diverse and thriving life, among other things.

In our comments to the proposed rulemaking, we advocate rules that force the spiller to internalize more of the inherent risk of using dispersants and other chemical and biological products, rather than rules that continue to allow the spiller – and the oil and gas industries more broadly – to externalize these risks to society and the

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environment. We need rules that specify how products can be used safely in waters of the U.S.

Footnotes:

[1] Wood, Mary Christina, 2014, Nature's Trust: Environmental Law for a New Ecological Age (Cambridge University Press, 2014), p. 207.

Commenter Name: Riki Ott, PhD
Commenter Affiliation: ALERT Project, a project of Earth Island Institute
Document Control Number: EPA-HQ-OPA-2006-0090-0520-A1
Comment Excerpt Number: 32

Comment Excerpt:

SUBPART J — USE OF DISPERSANTS AND OTHER CHEMICALS

Title of Subpart J

JUSTIFICATION
We find this title inaccurate and somewhat misleading. There is a redundant emphasis on dispersants. Dispersants are chemical agents that in their current formulations, arguably, do not mitigate spill impacts (see Dispersant definition). There is no mention of biological agents, substances such as sorbents that are not considered to be agents, or ignition devices that are used with burning agents.

RECOMMENDATION (edits)

We recommend using language consistent with the proposed language in §300.900(c) as follows: Subpart J – Use of ~~Dispersants, and Other~~ Chemicals and Biological Agents and Other Spill Mitigating Devices and Substances

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§300.900 General.

JUSTIFICATION for paragraph (a) (edits)
We find this paragraph to be vastly improved from the current rules, but we are concerned that one key phrase has been left out. Under the Federal Removal Authority, the President is bound to "ensure effective and immediate removal of a discharge, and mitigation or prevention of a substantial threat of a discharge, of oil or a hazardous substance…" Section 3100(c)(1)(A). The sole focus of this section is to remove and mitigate or prevent harm from the oil or hazardous substance itself. It implies that any method may be used to achieve the stated purpose.

However, the President has to prepare a National Contingency Plan for removal of oil and hazardous substances and, as part of that plan, a schedule identifying agents and substances, if any, that may be used on oil spills; the waters in which such agents and substances may be used; and the quantities of agents and substances "which can be used safely in such waters" (emphasis added). Section 311(d)(2)(G).

We find the phrase "if any" important because it implies that not just any product may be use, but rather only those in certain waters, "which can be used safely in such waters." The latter phrase is twice stated in law and worth repeating in the rules, because it modifies the goal of removal and mitigation or prevention of oil or hazardous substances from using any method or product to using only methods and products that can be used safely in such waters. The word "can" denotes ability, making this word key in preparing a Schedule to identify not only what products "may" be used (denoting permission), but the products that "can"; i.e., have the demonstrated ability, be used safely. Taken together, this phrase is the basis for all the screening and environmental monitoring tests, and the process to remove products that are found to be unsafe; i.e., do more harm. We interpret this phrase as a directive to do no more harm to the waters and adjacent shoreline or to the aquatic environment and

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human life in the vicinity of the spill.

In short, we support restating the three duties delegated to EPA by the President, including these key phrases. We also recommend using language to describe the agents and substances that is consistent with the title for reasons stated above.

RECOMMENDATION for (a) (edits)
Section 311(d)(2)(G) of the CWA requires that EPA prepare a schedule of ~~dispersants, other~~ chemicals and biological agents and other spill mitigating devices and substances, if any, that may be used in carrying out the NCP; ~~and~~ the waters in which such agents, devices, and substances may be used; and quantities ~~in which they~~ which ~~may~~ can be used safely in such waters. This subpart establishes a schedule identifying chemical and biological agents and other spill mitigating devices and substances, and procedures
that, when taken together, identify the waters and quantities in which such ~~dispersants, other chemicals~~ agents or other spill mitigating devices and substances ~~may~~ can be used safely.

JUSTIFICATION for (c)
For reasons stated above for paragraph (a), we find it necessary to state that this paragraph applies only to agents and substances that may be used to remove, control or otherwise mitigate oil discharges, providing they can be used safely. Further, we recommend specifically stating that use must be consistent with the provisions of Subpart J.

RECOMMENDATION for (c) (edits)
This subpart applies to the use of chemical and biological agents as defined in Subpart A of this part, or other substances that may be used to remove, control, or otherwise mitigate oil discharges, providing they can be used safely, consistent with the provisions of Subpart J.

DRAFT

Commenter Name: Unsigned
Commenter Affiliation: The International Tanker Owners Pollution Federation (ITOPF)
Document Control Number: EPA-HQ-OPA-2006-0090-0403-A1
Comment Excerpt Number: 8

Comment Excerpt:

Subpart J - Use of Dispersants, and Other Chemical and Biological Agents

The proposed Revision of the heading of Subpart J as listed above does not match the text of (a) Revised Definitions of B. Subpart A – Introduction in which dispersants are to be included within the general heading of Chemical agents. The proposed revised text of Subpart J refers in general terms to both Biological and Chemical agents. On this basis, ITOPF suggests that the heading is edited to read Subpart J – Use of Chemical and Biological Agents.

Commenter Name: Marianne Engelman Lado
Commenter Affiliation: Earthjustice
Document Control Number: EPA-HQ-OPA-2006-0090-0522-A1
Comment Excerpt Number: 7

Comment Excerpt:

WHILE FLEXIBILITY SHOULD BE ACCORDED DECISION-MAKING AT AREA AND REGIONAL LEVELS, THE CWA REQUIRES THE PRODUCT SCHEDULE TO SPECIFY WATERS AND QUANTITIES THAT CHEMICAL AND BIOLOGICAL

AGENTS MAY BE USED SAFELY.

General (40 C.F.R. § 300.900)

As noted above, the Clean Water Act plainly requires EPA to specify in the Product Schedule "the waters in which… dispersants, other chemicals, and other spill mitigating devices and substances may be used" and "the quantities of such dispersant, other chemicals, or other spill mitigating device or substance which can be used *safely* in such waters." 33 U.S.C. § 1321(d)(2)(G) (emphasis added). We therefore support EPA's proposal to add language to the general provision at § 300.900(a) that clarifies EPA's duties under the Clean Water Act. But the current proposed language that EPA must specify the "waters and quantities" in which oil-spill response products may be used fails to reflect the operative word in the statutory provision— "safely." EPA's duty is not merely to specify the waters and quantities in which these products may be used; rather, EPA must specify the waters and quantities in which these products may be used *safely*. The addition of the word "safely" to § 300.900(a) would better reflect the statutory language and Congressional intent, and provides support within the regulatory text itself for the toxicity standards that EPA proposes to implement in other sections of Subpart J.

Commenter Name: Catherine Kilduff
Commenter Affiliation: Center for Biological Diversity, Pacific Environment and Surfrider Foundation
Document Control Number: EPA-HQ-OPA-2006-0090-0600-A1
Comment Excerpt Number: 7

Comment Excerpt:

4. Improve Transparency in the Listing Process. 40 C.F.R. § 300.915.

The EPA proposed rule fails to require identification of waters in which dispersants may be used or quantities in which they may be used safely. Instead, the *Federal Register* notice states that "the waters and quantities in which a dispersant, or other chemical or biological agents may be safely used are to be determined in each case by the [on-scene coordinators]."[25] The statute requires this information in the Product Schedule, not to be determined later.[26] In order to address this requirement, first the Product Schedule should specify for which waters (as described by geography or physical characteristics like temperature, salinity or pressure) dispersants are recommended based on EPA's testing, not the manufacturer's recommendations. Second, while we support the EPA's publishing ingredients of the dispersants, the process of listing should be more transparent by establishing criteria for assessing impacts on human health or the environment.

First, in order to meet the Clean Water Act requirement that the product schedule identify the waters and quantities in which dispersants may be safely used,[27] the Product Schedule should allow listing of a dispersant only in the environments for which it was tested and met the efficacy and toxicity listing criteria. The *Federal Register* notice for the proposed rule discounts this idea – for example, listing dispersants based on temperature – by saying that while "these more specific listing approaches would provide more information on effective product choices, the Agency is concerned about how such specific listing approaches may contribute to [on-scene coordinators'] confusion in an emergency, the cost of stockpiling multiple types of dispersants, or the immediate availability of the appropriate dispersant in an emergency."[28] While perhaps valid concerns, EPA fails to rationally explain how a Product Schedule with less information addresses them. Having to check supplemental references for the necessary information on external factors will not simplify the on-scene coordinators' decision. The cost of stockpiling dispersants and availability of the appropriate dispersant should be addressed now, by responsible parties, not at the time of the emergency.

Currently the burden falls on the applicant to identify waters in which the dispersant may be used, but EPA cannot

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discharge its mandatory, statutory duty so easily. The proposed rule requires the applicant to recommend product use procedures, and address as appropriate "weather, water salinity, and water temperature."[29] These recommendations, along with results of efficacy and toxicity tests, which should also be specific to these variables, can and should inform the EPA's listing decision, specifically in which waters and at what quantities the dispersant can be used safely. Delegating to the regions tests and analyses of manufacturer's recommendations is infeasible and does not meet the requirements of the Clean Water Act.

Footnotes:

[25] 80 Fed. Reg. 3386-87.

[26] 33 U.S.C. § 1321(d)(2)(G).

[27] ID.

[28] 80 Fed. Reg. 3404.

[29] 80 Fed. Reg. 3380, 3424 (proposed to be codified at 40 C.F.R. § 300.915(a)(10)).

Comment Excerpt Number: 8

Comment Excerpt:

We also support EPA's proposed clarification at § 300.900(c) that Subpart J applies not only to products used to "remove or control" oil discharges, but also to those used to "otherwise mitigate" oil discharges. The toxic effects of these products arise from their application to the sea surface or subsea, and are not dependent on the ultimate outcome desired by the product user. Indeed, oil, oil-spill response products, and product/oil mixtures are likely to be all the more toxic if the oil and other chemicals are not removed from the sea surface but rather "mitigated" into the water column.

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Comment Excerpt Number: 9

Comment Excerpt:

We disagree with EPA's assertion that the Proposed Rule's "schedule . . . and procedures [*e.g.*, the authorization procedures of § 300.910], when taken together" are sufficient to meet EPA's responsibility under the Clean Water Act to "identify the waters and quantities in which such dispersants, other chemicals, or other spill mitigating devices and substances may be used." While flexibility should be accorded decision-making at area and regional levels, the listing on the Product Schedule must be made in accordance with the law and should provide local decision-makers, including the OSC, with needed information about each product. EPA proposes, instead, to defer "authorization of use procedures . . ., the waters and quantities in which a dispersant, or other chemical or biological agents may be safely used" to the OSC. 80 Fed. Reg. at 3386-87. The plain language of the Clean Water Act clearly requires determinations regarding the waters and quantities as part of the listing.

As described above, the Clean Water Act explicitly requires that the President prepare "in cooperation with the States," a product schedule that specifies the waters and quantities with which the products can be used safely. EPA's Proposed Rule, however, sub-delegates the specification of waters and quantities to Regional Response Teams ("RRTs"), Area Committees, On-Scene Coordinators ("OSCs"), and other entities that are external to EPA. Given that the specification of waters and quantities on the Product Schedule is a responsibility of the President that has been delegated to EPA only, EPA's sub-delegation of that responsibility to external entities contravenes the plain language of the Clean Water Act. The plain language requires that specification of waters and quantities in which dispersants or chemicals can be used safely in those waters be included in the Product Schedule itself.

Moreover, including information about waters and quantities for which products are *eligible* for use in the listing on the Product Schedule also advances sound policy. The listing identifies dispersants and other products eligible

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for use, which in turn provides a foundation for decision-making at area and regional levels. Manufacturers apply for listing on the Product Schedule in accordance with the requirements of Subpart J, and the law does not require a parallel comprehensive process for area and regional authorities to require the submission of additional tests from the manufacturers of each product. Neither are area and regional planners likely to have the time or resources to develop testing protocols and review applications for particular products. If the Product Schedule provides information about the waters and quantities of which products can be used safely, however, area and regional authorities will be better able to base plans on data and, also, to make timely and informed decisions should oil spill events occur.

IV.1.A. SCOPE OF EPA AUTHORITIES FOR SUBPART J

Commenter Name: M. Swanson, A. Bauer, T. Miller, et al.
Commenter Affiliation: Prince William Sound Regional Citizens
Document Control Number: EPA-HQ-OPA-2006-0090-0266-A1
Comment Excerpt Number: 3

Comment Excerpt:

PWSRCAC applauds EPA for clarifying, through this proposed rule, that the agency has the responsibility and authority under the Clean Water Act not only to establish a Schedule for oil spill treating agents, but also to identify the waters and quantities in which they may be safely used.

Commenter Name: Marianne Engelman Lado
Commenter Affiliation: Earthjustice
Document Control Number: EPA-HQ-OPA-2006-0090-0522-A1
Comment Excerpt Number: 11

DRAFT

Comment Excerpt:

All provisions of § 300.910 should be amended to apply to the use of "substances" and not merely "agents." EPA is proposing to define sorbents as "substances . . . that are not combined with or act as a chemical or biological agent," but, aside from the prohibition of sinking agents under § 300.910(e)(1), all of the authorization provisions of § 300.910 apply only to chemical or biological agents but not to the broader category of "substances" that would include sorbents. Though EPA proposes to create a Sorbent Product List separate from the Product Schedule, it is unclear what practical effect the Sorbent Product List would have absent any regulations concerning the authorization process for sorbents. Under the proposed regulations, it is unclear whether any authorization is even required before a responsible party may begin to use sorbents. Moreover, no explicit requirements exist that only listed sorbents may be used, nor are there limitations on the waters, quantities, and toxic effects of sorbent use. Such an interpretation is in clear contravention of the Clean Water Act provisions concerning the Product Schedule, which clearly apply to all "substances," and not just chemicals, dispersants, or other agents. 33 U.S.C. § 1321(d)(2)(G). EPA has provided no rational basis for why the authorization of sorbents, unlike the authorization of all other spill response substances, may or should be left unregulated. EPA should amend its proposed authorization provisions in § 300.910 to make clear that its safeguards apply to all substances, including sorbents.

Commenter Name: Anonymous
Commenter Affiliation: Unknown
Document Control Number: EPA-HQ-OPA-2006-0090-0590-A1

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Comment Excerpt Number: 14

Comment Excerpt:

In conclusion, the proposed rule is in conflict with the CWA, Executive Order EO 12777 and interagency regulations inserting the Administrator and EPA's RRT representative into pre-planning and field decision making authority of the Coast Guard. It also removes the planning and operational authority from the OSC and gives it illegitimately to

the EPA in the coastal zone. In this rule, EPA uses no known short - term or near-term scientific support for new

proposed requirements to substantiate the changes to the NCP for dispersant monitoring. This rule is an unwarranted affront to responsible future dispersant use by adding additional approval layers, creating escape clauses for government agencies despite strong science that dispersants are effective and the likely of preemption of any preauthorization plans tenuous based on political expediency. It subverts rules for Coast Guard and BSEE response planning efforts and undermines current regulatory and policies in place by these agencies. Ultimately, it is the OSC's decision to use or not to use dispersants. In the heat of battle and in a politically charged environment, this proposed rule as written, makes it improbable that an OSC would consider dispersant use in the future or give he/she the confidence that they would have the backing of the agencies that have approved a preauthorization plan. If that was the Agency's goal, I believe you've achieved it in this proposed regulation. Unfortunately during the next major oil spill requiring dispersant use, there will be much more shoreline impact and environmental damage as the result of a spill because of an OSC's reluctance to use this major response tool due to these onerous requirements. EPA will be off the hook because dispersant use will not be considered.

DRAFT

Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1
Comment Excerpt Number: 2

Comment Excerpt:

API, NOIA, and our respective members understand that through this Proposed Rule, EPA's goal is to develop a regulation which protects people and preserves natural resources. We too wish to accomplish the same goal, based upon sound scientific research and grounded in real-world, outside-the-laboratory scenarios and taking into account incident-specific risk. While the original intent of the dispersant rule was simply to provide for a schedule of dispersants and other chemicals that may be used in carrying out the National Contingency Plan (NCP), the Proposed Rule would essentially expand its purpose to an operational rulemaking which would significantly alter operational procedures.

In summary, the Proposed Rule, if implemented, would be substantially problematic for all stakeholders, including the response community, which is required to carry out an effective spill response. The Proposed Rule would also be problematic for the Federal and state agency community interests, as well as the public with regard to increasing environmental and community impacts. Although the Agency indicates that it seeks to "encourage the development of safer and more effective spill mitigating products, and would better target the use of these products to reduce the risks to human health and the environment" and "ensure that On-Scene Coordinators (OSCs), Regional Response Teams (RRTs), and Area Committees have sufficient information to support agent preauthorization or authorization of use decisions," API, NOIA, and our respective members submit that the Proposed Rule falls short of these

objectives and in many cases would have the opposite effect.

Comment Excerpt Number: 4

Comment Excerpt:

The Proposed Rule covers activities broader than mere scheduling criteria for dispersants. The added complexity resulting from the Proposed Rule in authorization, monitoring and product listing, in addition to unfounded and overly corrective assumptions about dispersant effects described in the Proposed Rule, will not assist the Unified Command during an oil spill. Instead, it will likely complicate and limit its ability to respond in the most effective manner to ensure the health and safety of people and minimize environmental and community impacts. Also, prohibiting the application of dispersants during an oil spill response or delaying their use will significantly increase the economic and environmental damage of oil spills.

Comment Excerpt Number: 127

Comment Excerpt:

The Agency's suggested toxicity testing changes in the Proposed Rule do not take into account the essential role of NEBA in considering the potential benefits and risks of dispersant use as a response option for an offshore oil release. The Product Schedule should focus on the basic testing to compare the efficacy and toxicity of the dispersants against each other with the sole purpose of screening good products that should be listed. The Proposed Rule should not attempt to translate any laboratory data into possible real-world implications. This process should instead be defined by full stakeholder NEBA discussions specific to a given spill scenario.

IV.1.B. CONFLICTS WITH OTHER REGULATIONS/AGENCIES

DRAFT

Commenter Name: Philip B Smith
Commenter Affiliation: Shell Offshore Inc. (Shell)
Document Control Number: EPA-HQ-OPA-2006-0090-0391-A1
Comment Excerpt Number: 4

Comment Excerpt:

Proposed revisions conflict with other regulations with established approval policies and processes which require availability and rapid deployment of dispersants for environmental protection

There have been many advances in spill response planning and regulatory instruments available to enforce spill preparedness in the last decade. The proposed rule does not acknowledge the requirements in 33 CFR 154/155 which rely on the establishment and maintenance of dispersant stockpile bases as well as training/ exercising of resources and personnel. Shell believes that the unnecessary impacts of duplicative regulation should be avoided, especially in cases in which they may delay response actions. Given existing compliance with 33 CFR 154/155, the provision of detailed dispersants logistics and a requirement to assess dispersant manufacturing capability during the initial response are unnecessary.

The proposed rule specifies monitoring sufficient to provide a comprehensive assessment of environmental impacts and goes beyond those required to inform operational decision-making, crossing into the realm of Natural Resource Damage Assessment (NRDA) monitoring. NRDA is a process established by the Oil Pollution Act to assess the damages to natural resources resulting from a spill, and to develop o plan for the restoration, rehabilitation, replacement or acquisition of equivalent resources lost. Sampling and monitoring conducted in support of this assessment is comprehensive, requires considerable resources and its goals are substantially different from the monitoring efforts supporting fast-paced NEBA-focused dispersant use decision-making. Recognizing that the primary issue in a spill scenario is oil in the environment (not dispersants in the environment) and that operational

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monitoring efforts should concentrate on evaluating how well the response option (or options) mitigates the negative effects of the oil on sensitive environmental resources, Shell recommends that any comprehensive, detailed environmental impact monitoring instead fall under the purview of NRDA, and be excluded from this proposed rule.

The agency should reevaluate the impact of the proposed revisions to other regulations and plans (national, regional, facilities) where existing plans rely on the availability/use of dispersants and none are approved by the Agency either because manufacturers opted not to apply for approval due to the need to disclose confidential information or increased data requirements, or because none of the tested dispersants were able to pass the new rigorous testing regime. Information provided by EPA is not sufficient to determine how many (if any) dispersants will be approved under these revised rules. EPA should also consider the impacts on response efficiency and preventable environmental impacts related to reduced opportunity for US to access global dispersant stockpiles if those dispersants are not approved under the proposed rules.

Commenter Name: Greg DeMarco
Commenter Affiliation: Exxon Mobil Corporation (ExxonMobil)
Document Control Number: EPA-HQ-OPA-2006-0090-0402-A1
Comment Excerpt Number: 9

Comment Excerpt:

The proposed rule changes appear to be inconsistent with polices and approaches supported in other government organizations (e.g., USCG, BSEE) that require dispersant stockpiles, delivery systems, and trained personnel and also serves to reduce the long standing role of the Federal On Scene Coordinator (FOSC) in operational decision-making during a spill response. The USCG requires that facility and vessel response plan holders (in dispersant pre-authorization zones) maintain the capability to apply certain quantities of dispersants in certain timeframes. Similarly BSEE has established an expectation that plan holders be capable of using subsea injection of dispersants to combat a subsea well release. Industry has developed these capabilities through substantial investment. EPA's proposal to limit/remove this tool from the toolbox will require these other agencies to re-assess their policies accordingly. Industry urges thorough interagency review of the NPRM to avoid such regulatory conflicts.

Commenter Name: Stephen Ricks, Don Toenshoff
Commenter Affiliation: Marine Spill Response Corporation (MSRC)
Document Control Number: EPA-HQ-OPA-2006-0090-0505-A1
Comment Excerpt Number: 1

Comment Excerpt:

1) Customers of MSRC (plan holders submitting response plans to the USCG, BSEE, and/or applicable states) have determined that dispersants are a key response option that should be in MSRC's toolkit to minimize the impacts of environmental damage from a spill, whether by vessel, pipeline, platform, or a facility.

The U.S. Coast Guard supports the view of our customers with mandated regulations, which went into effect in 2011. Finally, BSEE supports this view through its review and acceptance of response plans for offshore operations that include aerial dispersants as a response tool.

MSRC has developed its robust capability as outlined in the introductory comments to meet both its customer views from a response mitigation perspective as well as to meet regulatory requirements.

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Commenter Name: Stephen Ricks, Don Toenshoff
Commenter Affiliation: Marine Spill Response Corporation (MSRC)
Document Control Number: EPA-HQ-OPA-2006-0090-0505-A1
Comment Excerpt Number: 2

Comment Excerpt:

The EPA Proposed Rule is in direct conflict with the standing FOSC pre-authorization processes presently in place. Loss of FOSC pre-authorizations, which would negate the planning requirements of the applicable Coast Guard regulations, would provide no rationale for MSRC's customers to continue to fund MSRC to retain dispersant capability in its oil spill response toolkit.

Commenter Name: John Temperilli
Commenter Affiliation: public citizen
Document Control Number: EPA-HQ-OPA-2006-0090-0569-A1
Comment Excerpt Number: 5

Comment Excerpt:

It is inconsistent with policies in other parts of the US government (USCG, BSEE)

Commenter Name: David McBride
Commenter Affiliation: Anadarko Petroleum Corporation (Anadarko)
Document Control Number: EPA-HQ-OPA-2006-0090-0572-A1
Comment Excerpt Number: 4

DRAFT

Comment Excerpt:

Inconsistent with requirements from other agencies such Coast Guard and BSEE

The Proposed Rule appears to directly conflicts with existing Coast Guard Response Plan requirements to include surface dispersants as well as with existing BSEE drill permit requirements to have subsea dispersant injection equipment. The drill permit requirement for subsea injection equipment offers no alternative, thus, this conflict may negatively impact industry's ability to obtain drill permits for operating offshore.

Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1
Comment Excerpt Number: 24

Comment Excerpt:

The Proposed Rule Conflicts with Current Facility and Vessel Oil Spill Response Plans

Effective September 30, 2009, facility and tank vessel plan holders were required to update their response plans to include planning for responding to discharges using dispersants under a USCG rulemaking. Specifically, dispersant equipment is required in areas where it has been pre-determined that dispersants would be a viable oil spill mitigation technique and pre-authorizations have been established. Previously, with regard to dispersants for facilities located in areas with pre-authorization, a mechanical recovery equipment credit for up to 25% could be obtained for certain persistent oils.

However, since 2009 facilities handling certain persistent oils in areas with pre-authorization must ensure, through contract or other approved means, the availability of dispersant response resources and the commencement of dispersant-application operations within 7 hours of the decision by the OSC to use dispersants. Dispersant response resources must include: (1) sufficient volumes of dispersants to meet specified regulatory requirements, (2) dispersant application platforms and systems sufficient to meet planning standards, and (3) trained personnel.

Similarly, vessels transporting certain persistent oils in areas where dispersants are pre-authorized have been since 2009 required, through contract or other approved means, to have dispersant-related response resources meeting dispersant planning standards, including appropriately trained dispersantapplication personnel. The dispersant resources must include the identification of each primary dispersant staging site used by each dispersant-application platform and the corresponding distance to the associated stockpile. Similar requirements were adopted for non-tank vessels in 2013.

There are also aerial tracking requirements under the current response plan requirements, and there are now pre-authorization zones for the use of dispersants outlined in the applicable Area Contingency Plan throughout the nation for every state except for Alaska and Connecticut whereby the OSC has the authority to expedite the authorization for the use of dispersants. Although there are no specific dispersants requirements under Bureau of Safety and Environmental Enforcement's (BSEE) response plan requirements for offshore facilities, it is clear based on experience with the Deepwater Horizon that dispersants are a key response tool that must be available on an expedited basis to respond both to a spill on the surface of the water and subsea in case of a blowout.

The Proposed Rule, however, appears to directly conflict with Coast Guard response plan requirements and raises a host of questions related to the continued validity of facility and vessel response plans. It is unlikely that any dispersants will pass both the efficacy and toxicity tests required by the Proposed Rule as a precursor to being listed on the NCP Product Schedule. For example, the EPA proposal may have the practical effect of virtually eliminating the entire stockpile of available dispersants nationwide that will be able to be listed on the NCP Product Schedule following full implementation of the Proposed Rule. In addition, it could have the practical effect of eliminating the usefulness of preauthorization zones. This could result in invalidating response plans.

Furthermore, the Proposed Rule, if implemented, would require significant additional requirements for information needed and monitoring required before dispersants use approval is granted, which may prevent a plan holder from being able to deploy dispersants in the desired/required amount of time. For some spills it may mean that dispersants cannot be used at all due to limited window of opportunity. Thus, the Proposed Rule raises significant issues related to USCG and BSEE facility and vessel oil spill response plan compliance and could result in unnecessary and increased environmental damage and corresponding spill claims as a result of increased damages. In this regard, we note that although the President delegated to EPA the responsibility for the amendment of the NCP, the Proposed Rule may extend beyond the limits of EPA's authority under that delegation or the applicable law. Furthermore, amendments to the NCP must be coordinated with members of the NRT, including the USCG and other relevant agencies, prior to publication for notice and comment. 40 C.F.R. § 300.2. It appears this coordination may not have been accomplished sufficiently to avoid the conflicts discussed above. Accordingly, we recommend that EPA further coordinate with the USCG and BSEE to ensure that the Proposed Rule does not adversely affect USCG and BSEE response planning procedures and requirements.

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Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1
Comment Excerpt Number: 43

Comment Excerpt:

The USCG and Bureau of Safety and Environmental Enforcement (BSEE) already regulate logistical aspects of dispersant use.

There is no reason for the Agency to regulate logistical matters related to dispersant usage because they are already regulated by other agencies. In Section § 300.910(a)(1), the Agency makes the following statement:

"...and logistical factors including inventory, storage locations and manufacturing capability of available agents, availability of equipment needed for agent use, availability of adequately trained operators, and means to monitor agent use in the environment."

There have been many advances in regulations and spill response planning in the past decade. The regulations should acknowledge that there are now requirements in 33 CFR Parts 154 and 155 that have established a surface dispersant capability throughout the U.S. to apply up to 55,000 gallons (daily) of dispersant out to 50 nm offshore. These new regulations resulted in the development of 44 strategically located dispersant stockpile bases. Further, these regulations require training and exercising of equipment and personnel. Given existing compliance with 33 CFR Parts 154 and 155, preauthorization plans do not have to restate all of these assets but should be able to refer to this regulated capability. With current U.S. stockpiles containing close to 1 million gallons of dispersant and international stockpiles containing over 1.5 million gallons (as established via the Global Dispersant Stockpile), the requirement to assess dispersant manufacturing capability during the initial response is unnecessary.

We recommend that the Agency revise this section of the regulation to not require specific information on stockpiles, spray equipment, personnel, training or manufacturing and acknowledge that the USCG and the BSEE are regulating these aspects of spill response.

IV.2. AUTHORIZATION OF USE

IV.2.A. GENERAL

SUPPORT

Commenter Name: Gary B. Folley
Commenter Affiliation: Alaska Department of Environmental Conservation (ADEC)
Document Control Number: EPA-HQ-OPA-2006-0090-0457-A1
Comment Excerpt Number: 2

Comment Excerpt:

300.910 Authorization for agent use
The format and content is improved. This section now has headers for main subjects making it much easier to identify the references.

ED_001324_00007556-00014

OPPOSE

Commenter Name: John Temperilli
Commenter Affiliation: public citizen
Document Control Number: EPA-HQ-OPA-2006-0090-0569-A1
Comment Excerpt Number: 10

Comment Excerpt:

It largely ignores the current state of operational and monitoring activities that have evolved through drills and events since Deepwater in 2010.

IV.2.A.I. EPA AUTHORITY OVER USE

SUPPORT

Commenter Name: Anonymous
Commenter Affiliation:
Document Control Number: EPA-HQ-OPA-2006-0090-0127
Comment Excerpt Number: 1

Comment Excerpt:

Clarify that the Environmental Protection Agency has the ultimate authority over product use in any spill. This would allow the Environmental Protection Agency to be able to immediately stop the use of any product if concerns arise.

Commenter Name: Anonymous
Commenter Affiliation:
Document Control Number: EPA-HQ-OPA-2006-0090-0314
Comment Excerpt Number: 2

Comment Excerpt:

During the BP Deepwater Horizon (DWH) disaster, the US Coast Guard (USCG) asserted authority over EPA regarding the use of dispersants. The USCG is unfortunately not qualified nor authorized to preside over decisions for product use during oil spill response. By Executive Order, the President delegated this ultimate authority under the Clean Water Act to EPA to establish a Schedule listing what products may be used, waters in which products may be used, and quantities of products that can be used safely in such waters. EPA should clarify its existing authority to make the final call on any product use. I would suggest that ideally EPA should ban the use of these products or significantly control their use. They should never again be used at the toxic levels that were permitted during the Gulf Oil Spill.

Commenter Name: Mrs. Judith Keeling
Commenter Affiliation:
Document Control Number: EPA-HQ-OPA-2006-0090-0107
Comment Excerpt Number: 1

ED_001324_00007556-00015

Comment Excerpt:

1) The EPA should be in the driver's seat, not the oil company and not the Coast Guard, when an oil spill occurs, whether it is in the ocean or fresh water. The EPA should have a PLAN to monitor the volume and damage, as should the oil company, but the EPA should be in the manager. The EPA needs to already know the local experts who can be counted on in the event of a spill. The EPA should have already decided on mitigation and if they must use dispersants, which chemicals can be used and how much.

2) The local experts need to include people who are local public health experts willing to work in the event of a spill.

Commenter Name: Riki Ott, PhD
Commenter Affiliation: ALERT Project, a project of Earth Island Institute
Document Control Number: EPA-HQ-OPA-2006-0090-0520-A1
Comment Excerpt Number: 33

Comment Excerpt:

§300.910 Authorization for Agent Use.
"One of the things we complained about the most was the rampant use of the Coast Guard to do what BP wanted. That was out of the box... The government and BP claimed dispersants were not used near shore, but oil slicks that were reported near shore "disappeared" overnight. Oil don't leave that quick. Microbes don't eat it that quick. Trust me." ~ George Barrisch, Louisiana fisherman[121]

"The Coast Guard was not there to do what was best for the waterways, the birds, or the people. They were there to cover BP's butt." ~ Billy Nungesser, Plaquemines Parish president

"The government and business collusion has been so troubling in this. The way the oil spill acts and response plans are written, they leave BP with far too much power. The government was basically acting like security for BP. The Coast Guard, every agency, seemed to be deferring to BP. BP's messaging is what the public is hearing." ~ Aaron Viles, Gulf Restoration Network

JUSTIFICATION for lead paragraph
EPA considered language to it make clear that the EPA Administrator and senior EPA NRT representative and their delegatees have existing authority under section 311(d)(2)(G) of FWPCA and Executive Order 12777, along with the OSC, to make decisions to authorize use, quantity used, duration of use, and limitations on use, including cessation of use, for any chemical or biological agent or other spill mitigating devices and substances. However, the Agency decided that situations, in which it may have to exert authority over the On Scene Coordinator (OSC), were rare and possibly limited to such events as a spill of national significance or extended duration. The Agency decided that this is an existing authority that did not need to be reiterated in the rules. Therefore, the Agency did not propose a regulatory amendment to clarify the EPA Administrator's authority, but it is requesting comment on this issue.

We find the Agency's decision to not clarify the Administrator's authority surprising, given the public perception of uncertainty that clouded the Administrator's existing authority during the BP DWH disaster, and the precedent set by the manner in which the uncertainty was resolved. Specifically, we are referring to the widespread public perception that the FOSC – the US Coast Guard – was in charge and directing response efforts at the whim and will of the spiller. Supporting evidence relative to agent use is as follows. (For other examples, see Suggestions for Future Rulemakings, Subpart B.)

On May 20, 2010, EPA directed BP to identify within 24 hours, and to begin using within 72 hours, less toxic

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alternatives to the Corexit dispersants that had already been used for nearly a month.[122] EPA stated concerns about quantities of dispersants being used, extended use, and scientific uncertainty about underwater use and long-term effects on aquatic life. BP supplied a short list as requested – and went right on using Corexit 9500 at the surface and Corexti 9527 at the wellhead, saying it had not conducted independent tests to evaluate the issue. Although EPA and the Coast Guard stated this response was insufficient,[123] EPA started its own testing and evaluations.

On May 26, 2010, EPA ordered BP to reduce the total amount of dispersant applied to the minimum amount possible with the overall goal of reducing dispersant application by 75% from the maximum daily amount used.[124] Specifically, EPA's directive mandated that BP "eliminate the surface application of dispersants" except in rare cases where there may have to be an exemption." To obtain an exemption, BP had to submit a written request providing justification to the FOSC – the USCG – who would have to approve the request and volume of dispersant prior to initiating use. EPA also limited subsea application to no more than 15,000 gallons a day. Records obtained subsequently by Congressman Ed Markey, chair of the House Energy and Environment Committee, revealed that BP went right on using the Corexit dispersants, near daily, with the Coast Guard's approval – sometimes retroactively. In no instance was a request by BP to use dispersants denied. In all, 74 exemptions were approved in 48 days, of which all but 10 were fully approved, despite EPA's order.[125]

It was abundantly clear to the public that the Federal OSC/ USCG exercised authority over EPA by ignoring EPA's order and concerns regarding extended dispersant use and subsurface dispersant use. In hindsight, it is also clear that authority uninformed by science – and biased by the spiller's conflict of interest – has led to long-term injury to the Gulf ecosystem and the exposed human populace (see Dispersants). Most importantly and unfortunately, precedent was set for future spills, where the FOSC/USCG-spiller block may and can override EPA's existing authority.

In short, we request that EPA specifically adds the EPA Administrator and the senior EPA representative to the NRT (e.g. NRT Chair) to § 300.910(a) and other paragraphs as needed to clarify the Administrator's authority.

RECOMMENDATION for lead paragraph (edits)
Use of chemical or biological agents and other spill mitigating devices and substances in response to oil discharges to waters of the U.S. or adjoining shorelines must be authorized by the OSC in accordance with the provisions of this section, unless otherwise directed by the Administrator in accordance with concurrent authority under section 311(d)(2)(G) of FWPCA and Executive Order 12777:

Footnotes:

[121] Hopkins, Bryan, producer, 2013, Dirty Energy. Interviews with George Barrisch, Billy Nungesser, and Aaron Viles).

[122] US EPA, 2010, News Releases – BP spill, EPA: BP Must Use Less Toxic Dispersant, May 20, 2010. http://yosemite.epa.gov/opa/admpress.nsf/9cee789b9acd64168525772000595 1b7/0897f55bc6d9a3ba852577290067f67f!OpenDocument

[123] EPA, 2010, Letter from EPA Administrator Lisa Jackson to David Rainey, Vice President of Gulf of Mexico Exploration, BP Exploration and Production, May 26, 2010. http://www.epa.gov/bpspill/dispersants.html#directives http://www.epa.gov/bpspill/dispersants/Rainey-letter-052610.pdf

[124] EPA, 2010, Dispersant monitoring and assessment directive, May 26, 2010. http://www.epa.gov/bpspill/dispersants/directive-addendum3.pdf

[125] Fox, James, 2014, Pretty Slick, a documentary film distributed by Specialty Studios/ Video Project.

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Wald, Matthew, 2010, Despite rule, BP used dispersant, panel finds, New York Times, July 31, 2010. http://www.nytimes.com/2010/08/01/science/earth/01dispersants.html?_r=0

OPPOSE

Commenter Name: M. Swanson, A. Bauer, T. Miller, et al.
Commenter Affiliation: Prince William Sound Regional Citizens
Document Control Number: EPA-HQ-OPA-2006-0090-0266-A1
Comment Excerpt Number: 21

Comment Excerpt:

PWSRCAC has strong concerns about the proposed language that would give the EPA Administrator, under Subpart H, unilateral authority to bypass both Subpart J and regional preauthorization plans. As a national political appointee, the EPA Administrator should not be in the position to override consensus decisions or policies developed by local natural resource trustees. This option undermines both Subpart J and the preauthorization planning process. PWSRCAC does not believe that decisions about local application of spill treating agents in Alaska should be made in Washington, D.C. by a single agency head. We therefore recommend removing this provision from the proposed rule. If it is retained, we suggest that the EPA Administrator should be required to obtain concurrence from his or her counterpart within federal trustee agencies – i.e. the NOAA Administrator, DOI Secretary, etc. PWSRCAC recommends that EPA require that in any case where exceptional decisions are made to use oil spill treating agents – whether that decision originate with the OSC or the EPA Administrator – a transparent public record must explain these decisions and their scientific rationale.

DRAFT

CONFLICTS WITH OSC AUTHORITY

Commenter Name: Anonymous
Commenter Affiliation: Unknown
Document Control Number: EPA-HQ-OPA-2006-0090-0590-A1
Comment Excerpt Number: 2

Comment Excerpt:

§ 300.910 Authorization for Agent Use

Prioritization of Response Tactics

In the preamble, the EPA made the following statement, "During the Deepwater Horizon (DWH) response, a priority countermeasures scheme was established to first use mechanical recovery via skimming/booming or in-situ burning followed by subsea dispersant and lastly surface dispersant use." I disagree with this assertion as the response record shows that the prioritization for the use of several response methods (e.g., mechanical, ISB, dispersants) during DWH was determined each day by the Unified Command at the Incident Command level (USCG Federal On Scene Coordinator's Representatives) and approved or affirmed at the Area Command level (USCG Federal On Scene Coordinator) . For the use of subsea and surface dispersants during DWH, those spill countermeasure s were approved by RRT VI with the concurrence of EPA RRT Rep, USCG RRT Rep and OSC, the

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states affected, natural resource trustees as required by RRT VI Dispersant & In situ - burn Guidelines and the NC.

In many instances, weather conditions and equipment capabilities dictated the response method, not the idealistic priorities as listed in the EPA's preamble. In several instances during DWH, despite consensus by the unified command, area command, and RRT VI, the OSC's priorities to use dispersants were capriciously over-ruled or at a minimum needlessly delayed by the EPA, without written explanation, consensus by the resource trustees, scientific data or reasoning. In addition, the EPA pressured the USCG to use joint "Directives" during the DWH that arbitrarily limited the use of dispersants circumventing the desires of the OSC, RRT and the States. This was in direct conflict with the OSCs authority under Executive Order (EO) 12777 that gives the following authority to the USCG OSC in the coastal zone:

"(a) 2. National Response System. (a) The functions vested in the President by Section 311(j)(1)(A) of FWPCA, **respecting the <u>establishment of methods and procedures</u> for the removal of discharged oil** and hazardous substances, are **delegated to the Secretary of the Department in which the Coast Guard is operating for the coastal zone** and

(b) Sec. 3. Removal. The functions vested in the President by Section 311(c) of FWPCA and Section 1011 of OPA, **respecting an effective and immediate removal or arrangement for removal of a discharge and mitigation or prevention of a substantial threat of a discharge of oil or a hazardous substance, <u>the direction and monitoring of all Federal, State and private actions</u>, the removal and destruction of a vessel, the <u>issuance of directions</u>, <u>consulting with affected trustees</u>, and <u>removal completion determinations</u>, are delegated to the Secretary of the Department in which the Coast Guard is operating for the coastal zone."**

My rationale for keeping the decision-making authority/priorities to the OSC and the RRT without EPA concurrence is well documented in the DWH OSC report and the Incident Specific Preparedness Review (ISPR). During DWH, the OSC received authorization to use subsea dispersants and was preauthorized to use aerial dispersants by Regional Response Team VI. After these decisions were made by the OSC and RRT VI, the subsequent actions by the EPA and its Administrator limiting dispersant use resulted in more shoreline impact and environmental damage to the coastal areas of the Gulf States (DWH ISPR). Finally, this commentary ignores the lessons learned during DWH. Dispersant use as a response option was used to great effect until limited by the EPA through pressure on the National Incident Commander and the OSC (USCG F OSC report). This is one example of why the EO 12777 delegates this responsibility to the OSC in the coastal zone, to ensure he/she, the expert, provides the direction of all public and private agencies/resources as it pertains to the spill response. It is also why the RRT provides

guidelines, NRT provides guidance, the EPA/Administrator approves the types of dispersants and quantities (pre

- spill) to be used, and the OSC provides direction to public and private parties. This is how the NCP has worked

for more that 24 years and the EP A should have a compelling reason for making these regulatory changes. As noted in the ISPR:

"The Coast Guard and EPA should clarify NCP provisions regarding Federal Agency roles and responsibilities in

using dispersants as a response option."

I humbly submit that the EPA should remove this statement and prioritization because it is contrary to the

directives in EO 12777 and CWA, places unneeded complexity and delays into the response decision - making

process; and enshrines misguided tactical policy in regulation by inappropriately prioritizing mechanical recovery over other viable response options that undermine the sole responsibility and prerogatives of the expert in the field, the OSC to direct an oil spill response, as documented in the DWH OSC report and ISPR.

Comment Excerpt Number: 5

Comment Excerpt:

§ 300.910(B) USE OF AGENTS IDENTIFIED ON THE SCHEDULE ON OIL DISCHARGES NOT ADDRESSED BY A PREAUTHORIZATION PLAN.

The EPA Administrator's authority does not extend to OSC operational Decisions in the Coastal Zone

In addition, the EPA makes the statement in the preamble, "The Agency is clarifying that if the preauthorization plan is approved in advance for chemical or biological agent use under specified discharge circumstances, then the OSC may authorize the use of the agents on the Schedule for their intended purpose without the incident specific concurrences and consultations described in paragraphs (b) of this section unless otherwise directed by the Administrator in accordance with current concurrence authority." Since according to this rule the EPA will have already been involved in the preauthorization plan approval, why would the Administrator concurrence be necessary? As learned during DWH, the insertion of the EPA Administrator into the dispersant use process added a level of complexity and delays that the EPA personnel had a difficult time interpreting their EPA's intent at all levels. In addition, these actions taken were in direct conflict with the CWA and EO 12777 intent to give the OSC in the coastal zone this authority to direct response actions and dispersant use authority as provided by the RRT. EPA's interpretation of the law and codified by this new regulation provides EPA with "veto" authority at the RRT level and is in direct conflict with CWA and EO 12777 in the coastal zone. EPA should explain in detail where this authority to "veto" or disapprove dispersant use in the coastal zone after the agent has been approved by the EPA and preauthorization has been given to the OSC by the RRT is derived. It was obvious that the unprecedented use of the Administrator's authority to limit dispersant use during DWH was neither based on scientific study/facts nor approved by the resource trustees, RRT and the OSC (after misguided pressure). **EPA should give a full explanation of why this authority is needed and how this would benefit the natural resource trustees at the regional and national level and to the public in light of the lessons learned during DWH. In addition, the EPA should explain how this authority will not the conflict with the OSC's responsibility to direct the response in a timely and effective manner as provided for in CWA and EO 12777, especially when using dispersants**. In a preauthorization plan, dispersant use should not be limited by an Administrator but based on the operational conditions as determined by the OSC in consultation with the resource trustees and the affected States.

Commenter Name: Edward B. Overton, Ph.D.
Commenter Affiliation: public citizen
Document Control Number: EPA-HQ-OPA-2006-0090-0546-A1
Comment Excerpt Number: 1

Comment Excerpt:

When oil discharges occur in the open sea, there are basically limited options for human assisted mitigation of environmental impacts. These options include: collection with removal (i.e., skimming); collection with burning (i.e., in-situ burning); chemically treating the oil to allow dispersion; and the choice not using any of these response actions. In my opinion, any guidelines associated with the decision to use any of the response options should be left to the OSC in consultation with his/her support teams, the responsible party(s), and the oil spill response contractors. I believe that rules which require rather than suggest will be unduly restrictive in time-sensitive response situations, and this can potentially lead to increased environmental damage from the forcing of a "no response option" to be used. Oil spills are often dynamic events, and no strict set of rules, which "require" rather than "suggest" (or "recommend"), will fit all response situations (one size does not fit all). The goal is always to minimize damage rather than be restrictive in the use of response options. Certainly, the pros and cons of using any the three response options should be carefully considered, as well as the characteristics of any chemical treating agents in terms of their potential effectiveness and unwanted toxic impacts. However, in virtually all modern chemical dispersants, the oil itself is the primary carrier of toxic chemicals, and the act of dispersion will allow these toxic petro chemicals to be spread into the water column. Fortunately, this dispersion also causes dilution, which can offset the toxic impacts of the act of using dispersants.

Commenter Name: Frank Paskewich
Commenter Affiliation: Clean Gulf Associates (CGA)
Document Control Number: EPA-HQ-OPA-2006-0090-0586-A1
Comment Excerpt Number: 1

Comment Excerpt:

Degrades the Operational and Planning Authority of the On Scene Coordinator (OSC)

DRAFT

This rule, as written, will undermine the flexibility of the OSC to use dispersants as a viable spill response option. The OSC must make time critical decisions on the best and most effective spill response method to use in a particular situation, with dispersants serving as one of those options to consider. Through a Net Environmental Benefit Analysis (NEBA), the OSC is in the best position to evaluate, judge and weigh all spill response options against the possible environmental impacts. To assist the OSC, Regional Response Teams are routinely consulted to help evaluate the tradeoffs with each response method. The RRT/OSC relationship, as envisioned in the current National Contingency Plan (NCP), has withstood the test of time through a number of significant spills since its inception. The NCP also calls for the NRT to be consulted whenever there is insufficient policy guidance (§ CFR

300.115(k)). We feel the current regulations require no modification and that all decision - making regarding the

use of dispersants follow the deliberative process called for in the NCP.

Commenter Name: Frank Paskewich
Commenter Affiliation: Clean Gulf Associates (CGA)
Document Control Number: EPA-HQ-OPA-2006-0090-0586-A1
Comment Excerpt Number: 2

Comment Excerpt:

• (Preamble page 3389) –The preamble asserts that the EPA Administrator already has the authority for, and is

likely to have a more direct role in chemical or biological use decisions in situations like a spill of national significance. We believe the interpretation that the EPA administrator has unilateral authority for approving or

disapproving dispersants is in direct conflict with the current NCP process and could remove key decision - making

authority from the OSC who is evaluating all response options through a NEBA type approach. Essentially, this interpretation could result in the bypassing of the OSC, RRT and NRT in the deliberation process regarding the application of dispersants even where already pre-authorized.

Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1
Comment Excerpt Number: 139

Comment Excerpt:

The Proposed Rule adversely constrains the ability of the OSC to make the necessary operational decisions to ensure for an expeditious, efficient, and effective response to mitigate the impacts of a spill to the greatest extent possible.

Commenter Name: Roberta Highland
Commenter Affiliation: Kachemak Bay Conservation Society (KBCS)
Document Control Number: EPA-HQ-OPA-2006-0090-0340-A1
Comment Excerpt Number: 7

Comment Excerpt:

The authority to use a dispersant should be science based. The chain of authorization should include all stakeholders and not be superseded by higher authority in the EPA. The approval process needs to follow the agreed upon progressions developed in the preplanning processes.

Commenter Name: Mayor Mary Wythe
Commenter Affiliation: City of Homer, Alaska
Document Control Number: EPA-HQ-OPA-2006-0090-0364-A1
Comment Excerpt Number: 7

Comment Excerpt:

The authority to use a dispersant should be science based. The chain of authorization should include all stakeholders and not be superseded by higher authority in the EPA. The approval process needs to follow the agreed upon progressions developed in the preplanning processes.

Commenter Name: John Temperilli
Commenter Affiliation: public citizen
Document Control Number: EPA-HQ-OPA-2006-0090-0569-A1

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Comment Excerpt Number: 4

Comment Excerpt:

It hampers/weakens/limits the long-standing role of the FOSC in operational decision- making

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OSCS SHOULD NOT MAKE RESPONSE DECISIONS

Commenter Name: Diane and Joy
Commenter Affiliation: Lawrence Anthony Earth Organization (LAEO)
Document Control Number: EPA-HQ-OPA-2006-0090-0524-A1
Comment Excerpt Number: 13

Comment Excerpt:

We strongly recommend that the EPA cease putting the final chemical-decision responsibilities in the hands of OSCs and people who are not scientists, untrained and/or unqualified to make such decisions when they do not

have access to all data required to make such decisions. OSCs, who are often in the middle of a high - pressure,

emergency response when having to make these vitally important decisions, should only do so with reliable and best available decision-making tools. The buck should stop with Science and Technology Committees with adequate multi-agency representation with centralized database kept under NCP EPA Management.

DRAFT

Comment Excerpt Number: 15

Comment Excerpt:

As currently worded, the EPA is not held accountable for the decisions made regarding what chemical agents to use during a spill emergency on US navigable waters. This is designated as solely the responsibility of the US Coast

Guard On - Scene Coordinator housed in the Department of Homeland Security. The EPA is merely *listing*

information without regard for *appropriateness* or for making any science - based recommendations. In real life,

the buck doesn't stop anywhere, but appears to rest with potentially unqualified decision - makers (OSCs) who are

advised by other agencies, but who are unable to judge the accuracy of such consultation. Some of this may be due

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to peer - reviewed science and information having no central depository and summations.

IV.2.A.II. NCP REQUIREMENTS FOR COORDINATION

OPPOSE

Commenter Name: M. Swanson, A. Bauer, T. Miller, et al.
Commenter Affiliation: Prince William Sound Regional Citizens
Document Control Number: EPA-HQ-OPA-2006-0090-0266-A1
Comment Excerpt Number: 18

Comment Excerpt:

However, we are concerned that the proposed rule as written gives the OSC broad discretion to override preauthorization and make exceptions to virtually all components of the proposed rule. While the OSC will presumably have a strong background in pollution response and incident management, this person may not have the scientific or technical background to make decisions that override Subpart J product listings and regional preauthorization planning. The value of preauthorization planning is the fact that subject matter experts and natural resource trustees have a clear role in developing these plans and policies. Similar rigor should be applied to case-by-case decision-making.

The proposed rule as written empowers the OSC to use real-time data to inform decision-making. PWSRCAC supports this idea of science-based decision-making, but cautions that the OSC may not have sufficient independent expertise to interpret and apply such data. Natural resource trustees with local knowledge must have an active role in response decisions regarding chemical or biological agents. The Area Committee (AC) and Subarea Committees (unique to Alaska), State and Federal Trustee Agencies, Tribal entities, and Scientific Support Coordinator (SSC) all play important advisory roles to inform the OSC about scientific issues related to the use of oil spill treating agents.

PWSRCAC recommends that EPA revise the rule to create clear accountability for the OSC to consult with subject matter experts and trustee agencies. It should also clarify where consultation vs. concurrence is required to override preauthorization plans or make independent decisions about oil spill treating agents.

IV.2.A.III. PRIORITY COUNTERMEASURES SCHEME

SUPPORT

MECHANICAL RECOVERY SHOULD BE PRIORITY

Commenter Name: M. Swanson, A. Bauer, T. Miller, et al.
Commenter Affiliation: Prince William Sound Regional Citizens

ED_001324_00007556-00024

Document Control Number: EPA-HQ-OPA-2006-0090-0266-A1
Comment Excerpt Number: 2

Comment Excerpt:

PWSRCAC appreciates the Historical Background provided by EPA in the Statutory Authority section of the proposed rule, because it affirms the longstanding preference for mechanical recovery as a primary oil spill response tool, with dispersants as an alternative only "if other control measures are judged to be inadequate or infeasible." This is an important concept that still applies today, as mechanically containing and recovering spilled oil is always preferred over other spill treatment options because mechanical recovery is the only option that removes oil from the environment.

Comment Excerpt Number: 4

Comment Excerpt:

The National Contingency Plan (NCP) clearly establishes mechanical recovery as the primary and preferred oil spill removal method, and decisions to treat an oil spill with chemicals must be made in a cautious and deliberate manner.

Commenter Name: Marilyn Heiman, Director, U.S. Arctic Program
Commenter Affiliation: The Pew Charitable Trusts (Pew)
Document Control Number: EPA-HQ-OPA-2006-0090-0449-A1
Comment Excerpt Number: 2

Comment Excerpt:

DRAFT

Mechanical oil spill response should be the primary tool used to respond to spills in United States waters because mechanical oil spill response equipment removes oil from the water. Where mechanical oil spill response is infeasible or ineffective (e.g., in Arctic ice-infested waters above 30% ice concentration), in situ burning should be considered to remove oil from the water. Chemical dispersant use should be a last resort, because applying dispersants to an oil spill does not result in physical recovery of oil from the environment. If chemical dispersants are approved for use, the least toxic, most effective products should be used. The chemical dispersant use should only be considered if EPA has demonstrated through sound science and testing that dispersant application is nontoxic and not harmful to marine or subsistence resources, is acceptable to local residents, and is proven to result in a net environmental benefit.

Comment Excerpt Number: 19

Comment Excerpt:

Pew recommends EPA's rule require that chemical dispersants do not impede or hinder the efficacy of mechanical or in situ burning oil removal methods.

Commenter Name: Marianne Engelman Lado
Commenter Affiliation: Earthjustice
Document Control Number: EPA-HQ-OPA-2006-0090-0522-A1
Comment Excerpt Number: 2

Comment Excerpt:

The Proposed Rule's emphasis on preauthorization raises significant concerns. While advanced planning is critical

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to ensure that the federal on-scene coordinator ("OSC") and natural resource trustees have sufficient information to make the best decision under the prevailing circumstances, spill contingency planning efforts should emphasize the critical role of mechanical mitigation measures rather than chemical and biological responses. As the National Academy of Sciences has made clear, dispersants do not remove oil from the environment but, instead, "transfer oil from the water surface into the water column."[3] Chemical and biological responses may simply not be effective in some situations, and in others they may worsen the impacts on the environment under the particular conditions presented, including temperature, migration patterns, proximity to sensitive populations, type of oil, method of application, or the particular product available for use.

Footnote:

[3] Nat'l Research Council, Oil Spill Dispersants: Efficacy and Effects 193 (2005), available at http://www.nap.edu/catalog/11283/oil-spill-dispersants-efficacy-and-effects ("NRC Report").

Commenter Name: Dawn Winalski, Charlotte Brower
Commenter Affiliation: North Slope Borough (Borough or NSB)
Document Control Number: EPA-HQ-OPA-2006-0090-0582-A1
Comment Excerpt Number: 2

Comment Excerpt:

Oil removal should be given the highest priority over dispersant application in Arctic waters because dispersants distribute oil in the water column and do not remove oil from the water column, thereby leaving it in the marine environment, potentially contaminating subsistence resources that our people rely on for food and cultural existence. Many questions remain about whether dispersants will actually be effective in the cold water temperature and the low salinity of Arctic waters.

DRAFT

Comment Excerpt Number: 5

Comment Excerpt:

40 CFR § 300.910, Authorization for Agent Use

Oil removal should be given the highest priority over dispersant application in Arctic waters because dispersants distribute oil in the water column and do not remove oil, thereby leaving it in the marine environment, potentially contaminating subsistence resources that our people rely on for food and cultural existence. Mechanical oil spill response methods should continue to be used as the primary oil removal method. Alternatively, in-situ burning techniques may be effective in removing oil when mechanical oil spill response methods are rendered less efficient in the presence of ice.

The NSB is concerned that dispersant application can work at cross-purposes with oil removal by mechanical and in-situ burning methods by distributing oil through the water column and making it more difficult to recover or bum. Simply put, dispersant use hinders oil removal where it is applied. There is insufficient peer reviewed scientific information to show that dispersant use is less toxic than allowing oil to persist in the environment when it cannot be removed by mechanical recovery equipment or in-situ burning techniques. Therefore, the NSB wants to participate in any decision made to approve dispersant use in Arctic waters, or in waters that include migration routes for bowhead whales, birds and other migratory species that eventually end up in the Arctic Ocean that our people rely upon for subsistence.

Commenter Name: Catherine Kilduff

Commenter Affiliation: Center for Biological Diversity, Pacific Environment and Sunfrider Foundation
Document Control Number: EPA-HQ-OPA-2006-0090-0600-A1
Comment Excerpt Number: 1

Comment Excerpt:

Given the unanswered questions about the long-term impacts of dispersants on human health and the environment, we urge that removal of oil be the primary response tool and dispersants be used only in the most desperate situations, where removal is impossible. In regions where dispersants have not been well-tested, such as Alaska, use of chemical dispersants should not be preauthorized unless and until they can first be proven safe and effective.

Comment Excerpt Number: 3

Comment Excerpt:

2. Serious Effects on Wildlife and Ramifications for Human Health Justify Extreme Caution in Dispersant Use.

The best option for the environment to clean up an oil spill is removing the oil, which dispersants cannot do. Mechanical recovery of oil should remain the primary oil spill response tool in order to limit exposure of humans and wildlife to oil. Many of the benefits typically associated with dispersants were challenged in a 2005 National Research Council study, which concluded that little to no evidence exists for the assertions that dispersants reduce the impact of oil on shorelines and reduce the impact to birds and mammals on the water surface.[5] In fact, a dispersed oil spill increases concentration of dissolved compounds in the water column, potentially increasing threats to organisms, including humans, on or in the water.[6] The 2005 study also found that older tests that displayed enhanced biodegradation of chemical dispersants applied to oil were flawed due to unrealistic conditions.[7] Given that the benefits and costs of using dispersants in any given situation may be unquantifiable, it is important that use be precautionary and with necessary safeguards.

What information we do have indicates that dispersants may do more harm than good. Dispersants and dispersed oil have been shown to have significant negative impacts on many forms of marine life, including plankton, fish, corals, and birds. Dispersants release toxic breakdown products from oil that, alone or in combination with oil droplets and dispersant chemicals, can make dispersed oil more harmful to marine life than untreated oil.[8] Several research teams have shown that oil dispersed by a common dispersant, Corexit 9500A, is more toxic than either spilled oil or dispersant alone.[9] Deepwater corals, for example, showed more severe health decline in response to dispersant alone and oil-dispersant mixtures than in response to oil alone.[10]

Species can be affected by dispersants through a number of pathways. For example, many whales feed by skimming plankton, small fish, and squid from the surface. This feeding mechanism puts them at risk of ingesting dispersants and dispersed oil, as well as food contaminated with these chemicals. In addition, whales must surface to breathe, and in doing so can breathe in fumes from or ingest dispersants and dispersed oil.

Birds diving into the water to feed may be exposed through direct contact with dispersants and dispersed oil as well as through contaminated prey. Studies have found that dispersed oil damages the insulating properties of seabird feathers more than untreated oil, making the birds more susceptible to hypothermia and death.[11] Dispersants and dispersed oil have also been shown to have toxic effects on bird eggs that are similar or worse than from untreated oil. Birds exposed to dispersed oil that return to their nests risk contaminating their eggs, which can lead to the death of those eggs.[12]

In addition to whales, other marine mammals may be exposed to dispersants and dispersed oil as they swim and feed in the water column. While the effects of such exposure are not well known for marine mammals, studies have shown that dispersants create a toxic environment for fish by releasing harmful oil breakdown products into

the water. Dispersed oil has been shown to be toxic to fish at all life stages, from eggs to larval fish to adults, according to numerous laboratory studies that have tested a variety of species.[13]

Dispersants' negative impacts are not limited to wildlife, but also affect human health, according to at least two studies performed after the Deepwater Horizon oil spill. First, Li et al. (2014) showed that dispersants used caused acute injury to human airway epithelial cells, mice lungs and the gills of zebrafish and blue crabs.[14] Lungs and gills are constantly exposed to the environment through inhalation or the passage of water, so are particularly prone to exposure to dispersants and oil in the event of a spill. The potential for injury may exist long after the spill response is over; dioctyl sodium sulfo succinate ("DOSS"), a component of the dispersant used, has been documented in the Gulf of Mexico 64 days after application ceased.[15] Second, Kim et al. (2012) examined in laboratory the potential effects on human intestinal microbiota of exposure to oil and/or dispersants and found that when comparing the toxicity of Deepwater Horizon crude oil alone, Corexit 9500 alone, and dispersant-oil mixtures, the human intestinal microbiota was affected more by dispersed oil than by either oil or dispersant alone, which were found not to be highly toxic.[16] This study was designed to simulate consuming seafood contaminated by oil and/or dispersants, which was a threat after the Deepwater Horizon oil spill.

In sum, EPA's Product Schedule – in which the EPA must identify the quantities of dispersants that may safely be used[17] – operates as an important mechanism to safeguard public health and the environment.

Footnotes:

[5] National Research Council, (2005). Understanding Oil Spill Dispersants: Efficacy and Effects, http://www.nap.edu/openbook/030909562X/html/138.html.

[6] *Id.* at 49.

[7] *Id.*

[8] *See, e.g.,* V Jung, SW, OY Kwon, CK Joo, J-H Kang, M Kim, WJ Shim, Y-O Kim (2012). Stronger impact of dispersant plus crude oil on natural plankton assemblages in short-term marine mesocosms, Journal of Hazardous Materials, Volumes 217–218, Pages 338-349, ISSN 0304-3894, 10.1016/j.jhazmat.2012.03.034; Zuijdgeest A, M Huettel (2012). Dispersants as Used in Response to the MC252-Spill Lead to Higher Mobility of Polycyclic Aromatic Hydrocarbons in Oil-Contaminated Gulf of Mexico Sand. PLoS ONE 7(11): e50549. doi:10.1371/journal.pone.0050549.

[9] Zhang, Y.Q., et al., (2013). Chemical dispersant potentiates crude oil impacts on growth, reproduction, and gene expression in Caenorhabditis elegans, *Archives of Technology*, 87: 371-82; Rico-Martinez, R., Snell, T.W., Shearer, T. L., (2013). Synergistic toxicity of Macondo crude oil and dispersant Corexit 9500A (R) to the Brachionus plicatilis species complex (Rotifera), *Environmental* Pollution, 173: 5-10; Goodbody-Gringly, g. et al., (2013). Toxicity of Deepwater Horizon Source Oil and the Chemical Dispersant, Corexit (R) 9500, to Coral Larvae, *PLOS ONE*, 8: 1.

[10] Danielle M. DeLeo, Dannise V. Ruiz-Ramos, Iliana B. Baums, Erik E. Cordes, (2015). Response of deep-water corals to oil and chemical dispersant exposure, Deep-Sea Research II, http://dx.doi.org/10.1016/j.dsr2.2015.02.028.

[11] Jenssen, B.M., (1994). Review Article: Effects of Oil Pollution, Chemically Treated Oil, and Cleaning on the Thermal Balance of Birds, *Environmental Pollution*, 86: 207-15.

[12] Albers, P.H., (1979). Effects of Corexit 9527 on the Hatchability of Mallard Eggs, *Bull. Environm. Contam. Toxicol.*, 23: 661-68.

[13] Khan, R.A. and J.F. Payne, (2005). Influence of a Crude Oil Dispersant, Corexit 9527, and Dispersed Oil on Capelin (*Mallotus villosus*), Atlantic Cod (*Gadus morhua*), Longhorn Sculpin (*Myoxocephalus octodecemspinosus*) and Cunner (*Tautogolabrus adspersus*), *Bull. Environm. Contam. Toxicol.* 75: 50-56; Anderson, B.S. *et al.,* (2009).

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Preliminary investigation of the effects of dispersed Prudhoe Bay Crude Oil on developing topsmelt embryos, *Atherinops affinis, Environmental Pollution*, 157: 1058-61.

[14] Li, F. J., Duggal, R. N., Oliva, O. M., Karki, S., Surolia, R., Wang, Z., ... & Antony, V. B. (2014). Heme Oxygenase-1 Protects Corexit 9500A-Induced Respiratory Epithelial Injury across Species. *PloS one*, 10(4), e0122275-e0122275.

[15] Kujawinski EB, Kido Soule MC, Valentine DL, Boysen AK, Longnecker K, Redmond MC. (2011). Fate of dispersants associated with the deepwater horizon oil spill. *Environ Sci Technol*; 45: 1298–1306. doi: 10.1021/es103838p.

[16] Kim, J. N., Kim, B. S., Kim, S. J., & Cerniglia, C. E. (2012). Effects of crude oil, dispersant, and oildispersant mixtures on human fecal microbiota in an in vitro culture system. *MBio*, 3(5), e00376-12.

[17] 33 U.S.C. § 1321(d)(2)(G).

Commenter Name: William Smith
Commenter Affiliation:
Document Control Number: EPA-HQ-OPA-2006-0090-0034
Comment Excerpt Number: 1

Comment Excerpt:

Upon review it does seem all to obvious that there is definite intent on following a poor plan. The primary concern should be to simply remove the oil from the environment as fully and completely as possible. This is presuming absolute failure in preventing a spill to begin with of course. By insisting on leaving the oil in the water there is an assurance in that the hazardous aspects along with all the associated long term affects persist. These affects would included but not limited too:

An increased size and intensity of the observed zone of hypoxia off the Louisiana coast. Such described use of biological agents, dispersants and chemical agents only ensure that added Biological Oxygen Demand (BOD) is added to an already critical situation. I do realize that oil spills are not typically listed but obviously oil does biologically degrade over time often decades in fact and since many of the other sources are not only absolutely necessary but also impossible to forgo. We simply cannot do without agriculture nor municipal waste for starters.

Next of course comes the ecological damage which is directly linked to the fisheries in the Gulf. Oil does have a well known toxicity to marine life in general. By keeping the oil in the water there is only an insurance that more marine life will be exposed. The real plan of remediation must be to limit these exposures. It does take an extended period of time for oil to digest even with biological agents. Chemical agents typically would only be yet another chemical with added toxicity to marine life as well. The liberal use of dispersants is similar to other chemical treatments to an oil spill and in many ways it not only does nothing to remove the oil from the environment but makes the spill much more widespread as well as making it an impossibility to clean up at any point in the future. There are also numerous studies that show that the liberal use of dispersants actually increase the toxicity and recovery time for marine life as well. There is then the human health concerns since people live work eat in the areas affected there will/are extended exposures through various vectors leading to adverse health effects such as cancer. Cancer being the more highly identifiable disease. Increased prolonged exposure does indeed lead to a higher incidence of disease associated with exposure to oil in the environment even without direct contact. The liberal use of dispersants, chemical agents, and biological agents ill increase the probability of widespread chronic exposures.

It is entirely possible to deal with similar situations as the Deep Water Horizon spill back in 2010 without the widespread use of dispersants and everyone involved does realize that they should have been prepared at the very least if not actually required in fact. Unfortunately the being ill-prepared did open the door for emergency action.

Actions which by there very nature not only ensured that the spill could not actually every be cleaned up but also saved the effort in even trying to do so. My fear is that it seems at least by the equipment being made available at the oil industry trade shows for quicker and more effective injection into the plume of a blown-out well-head . The other efforts made such as operation "top kill" should have been prepared for a full decade before the spill as well as before any deep water leases were allowed to be made if not only for the sake of public health. Instead all of the top five oil producers in the region had the same emergency contingency plans with only slightly different colored covers and were remarkably similar to the plans for the artic drilling activities.

In short the federal government should demand that the oil be removed from the water or at the very least be giving such actions the highest priority.

Commenter Name: Rep. Frank Lucas (?)/Joanne Gross
Commenter Affiliation: Sierra Club
Document Control Number: EPA-HQ-OPA-2006-0090-0078
Comment Excerpt Number: 3

Comment Excerpt:

Research following the BP Gulf Oil spill showed that dispersants used to disperse oil in the gulf led to more toxicity, not less. I understand that the changes being considered now will actually include MORE dispersants. The EPA needs emphasize mitigation and containment not dispersants. The EPA should consider the research on it merits and be independent of the oil and gas industry and their concerns about cost overruns. Adding dispersants to the plumes as what happened the BP gulf spill increased the damage to the water and thus the people who live there. Oil companies need to prove they can contain any BP gulf-type of situation.

DRAF

Commenter Name: R. Durr
Commenter Affiliation:
Document Control Number: EPA-HQ-OPA-2006-0090-0201
Comment Excerpt Number: 1

Comment Excerpt:

Oil should be removed by physical means, and if chemicals are considered necessary to remove the oil, those chemicals should not be harmful to the environment, and in addition, those chemicals mixed with oil should not be any more harmful than the oil itself. In order to know that the chemicals will not cause more damage, proposed chemicals should be rigorously tested by independent and trustworthy scientists. The testing should take into account the environment in which the chemicals could be used, and it should be determined that using the chemicals will not adversely affect plants and animals in that environment. An oil spill is a toxic event. Let's be sure we are not adding insult to injury by deliberately spilling toxic chemicals.

Commenter Name: Mrs. Judith Keeling
Commenter Affiliation:
Document Control Number: EPA-HQ-OPA-2006-0090-0107
Comment Excerpt Number: 2

Comment Excerpt:

3) The EPA needs to move away from dispersants and focus more on mitigation. Researchers after the BP-Gulf oil

spill showed that dispersants made damage to wildlife and ocean life worse not better. I would prefer using bacteria to chemical, which means more research needs to be done.

Commenter Name: Riki Ott, PhD
Commenter Affiliation: ALERT Project, a project of Earth Island Institute
Document Control Number: EPA-HQ-OPA-2006-0090-0520-A1
Comment Excerpt Number: 3

Comment Excerpt:

Third, we find a trend towards increased use of in-situ burning, dispersants, other chemical and biological agents, and other mitigating devices and substances rather than a focus on containment and removal of oil as the primary line of defense in spill planning and response. This also is a sea change in system thinking. While EPA has attempted to curb use of some of the most dangerous and hazardous substances, we still find too much margin for error and abuse in the proposed rules. In particular, we are alarmed by the proposed definition of "sinking agents" as it will allow use of agents and substances that act to increase formation of oily plumes within a water body and/or sedimentation and deposition of oil to the bottom of a water body – while still maintaining the illusion that sinking agents are prohibited.

We cannot support rules that allow products to sink or submerge oil or facilitate such action. We cannot support rules that allow use of dangerous products or substances, which pretend to mitigate the threat of oil, but in reality do more harm than good. We want proof – proof before use – that the product will not harm people and the environment; proof through real-time monitoring while the product is being used that it is working as intended; and proof through long-term monitoring in ecosystem time (at least 10 years) that the product significantly benefitted the ecosystem, especially the organisms at the base of the food web that support aquatic life such as bacteria, plankton, and forage fish. And finally, we cannot support rules that allow use of dangerous products that harm our health and our children's health or the health of our workers, that diminish our quality of life, or that shorten our lives in the name of a human health risk tradeoff,[5] as a consequence of allegedly mitigating harm from the oil.

Footnotes:

[5] Coastal Response Research Center (CRRC), Research Planning Incorporated, and the National Oceanic and Atmospheric Administration, The Future of Dispersant Use in Oil Spill Response Initiative, March 2012, on p. 36. https://crrc.unh.edu/sites/crrc.unh.edu/files/media/docs/Workshops/dispersant_future_11/Dispersant_Initiative_FINALREPORT.pdf

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OPPOSE

PROPOSED RULE LIMITS DISPERSANT USE OPTION

Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1
Comment Excerpt Number: 10

Comment Excerpt:

The Proposed Rule indicates that the Agency "does not state or imply" that one response option is endorsed over another which is a practice shared by industry. However, the preponderance of additional requirements for dispersant use will likely have the unintended consequence of prohibiting, or delaying the approval of, dispersant use in a timely manner regardless of whether they may be the best, or only, response option. Further, the language contained in the preamble suggests that the Agency considers dispersants as a last priority, rather than giving them equal consideration with all other appropriate response options. Additionally, API and NOIA are concerned that the Proposed Rule may cause chemical manufacturers to either discontinue the production of effective, commercially-available products or discontinue research development of the next generation of dispersants.

Comment Excerpt Number: 14

Comment Excerpt:

All oil spill response options have their place in the response toolkit because of the extreme variability of spill conditions. Dispersants become a critical response tool for larger spills far from shore; spills more distant from stockpiles of recovery and containment equipment; when weather and ocean conditions preclude the use of other options; or when weather conditions are predicted to become more severe because they can be rapidly applied by aircraft or subsea (at a high encounter rate) when wind and wave conditions prevent other vessel-based recovery options.

The Proposed Rule focuses on the potential risks of dispersants without recognizing the benefits and core purpose of dispersants, which is to rapidly dilute the spilled oil and enhance removal of the oil from the environment through microbial degradation, resulting in reduced VOCs and shoreline impacts. Ultimately, the purpose of dispersants is to reduce the overall toxicity and persistence of oil in the environment.

DRAFT

Commenter Name: Paul A. Schuler
Commenter Affiliation: Oil Spill Response Limited (OSRL)
Document Control Number: EPA-HQ-OPA-2006-0090-0399-A1
Comment Excerpt Number: 6

Comment Excerpt:

TOOLBOX APPROACH:
To meet global industry preparedness and response requirements, OSRL (and all industry funded OSROs) maintains a capability to employ ALL known and accepted methods of response. OSRL's capability was developed through extensive study and investment in stockpiles of air mobile equipment and materials, technical expertise and experience, knowledge of logistics and crisis management, and response support systems. The methods or strategies actually employed in an incident are based on a large number of environmental, operational, weather, logistical, and effectiveness factors associated with each specific incident aligned to each specific response method and capability. This "Toolbox" approach requires immediately available, accessible, and

in - depth capabilities for conventional containment, mechanical recovery, shoreline clean - up, in - situ burning,

and dispersants stockpiles and systems for surface and aerial application, and subsea dispersant injection, intervention and containment systems. OSRL believes that the proposed changes to Subpart J, discourages the use of dispersants and thereby makes the efficacy of investing in and maintaining stockpiles and delivery systems

untenable. Should OSROs determine that dispersants will NOT be authorized for use even in appropriate circumstances, this important capability will disappear and potentially result in greater harm to the environment in the event of an oil spill.

Comment Excerpt Number: 8

Comment Excerpt:

The current US system is a model for the rest of the world and is particularly held up in the Caribbean and Latin America as an effective way to make good and speedy decisions about response methods. Again, if there is not a

reasonable expectation of timely and appropriate dispersant use decision - making process, which the proposed

Subpart J changes, then OSRO's will see dispersants as a viable option to invest in.

Commenter Name: John Temperilli
Commenter Affiliation: public citizen
Document Control Number: EPA-HQ-OPA-2006-0090-0569-A1
Comment Excerpt Number: 2

Comment Excerpt:

Members of EPA Administrator Jackson's team attempting to arbitrarily limit or change the use of dispersants during the Deepwater spill response appear to be key members of the current effort from EPA headquarters to once again limit the use of dispersants as a viable tool in the response option toolbox.

It severely restricts/eliminates an important response option from the toolbox

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Commenter Name: David McBride
Commenter Affiliation: Anadarko Petroleum Corporation (Anadarko)
Document Control Number: EPA-HQ-OPA-2006-0090-0572-A1
Comment Excerpt Number: 2

Comment Excerpt:

Limiting the availability of proven response tools will significantly increase RP exposure and liability. If EPA removes a proven and viable response tool such as the use of dispersants to mitigate the spilled oil, then EPA is imposing additional risk and liability on industry by potentially allowing spilled oil to contaminate sensitive shoreline habitat that could have been prevented if all response tools were made available. As history has shown, the costs resulting from contaminated shorelines could be billions of dollars. Anadarko strongly supports the continued use of dispersants, and requests EPA to keep dispersants as one of the response tools for an oil spill.

PRIORITIZATION STATEMENT SHOULD BE REMOVED

Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1

ED_001324_00007556-00033

Comment Excerpt Number: 16

Comment Excerpt:

Dispersants have proven to be an effective way to respond to an oil spill, most notably in those situations that prohibit, or otherwise limit, the effectiveness of other response measures. We submit that all response options should be contemplated based on their individual, or combined, ability to respond to discharged oil, either on or below the water's surface, in a manner that causes the lowest negative effect on the environment and promotes the most rapid recovery of the affected ecosystem.

Comment Excerpt Number: 31

Comment Excerpt:

EPA should not establish a policy or rule that mechanical recovery is always the priority choice of countermeasures to use in a response. In the preamble for this section (column 1, 80 Fed. Reg. 3387), the Agency makes the following statement:

"During the DWH response, a priority countermeasures scheme was established to first use mechanical recovery via skimming/booming or in-situ burning followed by subsea dispersant and lastly surface dispersant use."

This may have been the conceptual prioritization from the perspective of EPA, but in reality dispersants played a much larger role and it was the responsibility of the UC to determine the best use of response assets on a daily basis to account for weather conditions, VOC suppression, oil slick locations, response equipment availability, etc. Every spill is different and specific references to a single spill event can indirectly and inappropriately be perceived as a recommended practice and should be avoided. In any spill scenario, all response tools must be used to their maximum effect. The Agency's unprecedented use of "Directives" during the DWH incident severely limited the use of dispersants and circumvented the NEBA decision-making process allowing significantly more oil reaching the water's surface and, subsequently, the shoreline. This resulted in additional environmental impacts with no documented benefits to the marine ecosystem.

The Agency should reconsider this statement and prioritization as it puts unneeded complexity into the response decision-making process and inappropriately prioritizes mechanical recovery over other response options. The effectiveness of mechanical recovery can be limited in large, offshore spills as a result of typical environmental conditions, such as wave action/height or wind conditions as well as the extensive surface area that must be covered. Further, the Agency's artificial prioritization of this technique over other viable response options is contrary to the NEBA concept to determine the best blend of response options (with no pre-determined or pre-existing bias) to achieve the best overall protection and recovery for the ecosystem.

IV.2.A.IV. ADVANCED PLANNING RELATIVE TO ACP (INCLUDING NEBA/CERA)

SUPPORT

Commenter Name: Sarah Brace
Commenter Affiliation: Pacific States/British Columbia Oil Spill Task Force (Task Force)
Document Control Number: EPA-HQ-OPA-2006-0090-0514-A1
Comment Excerpt Number: 7

Comment Excerpt:

The Task Force members support EPA's pursuit of:

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Supporting timely decision-making; if dispersant use is to be seen as an effective realistic option, the decision-making process must be swift. There is substantial planning, training and preparation work that goes into viable dispersant use – beyond just having the dispersants on-hand.

OPPOSE

Commenter Name: Riki Ott, PhD
Commenter Affiliation: ALERT Project, a project of Earth Island Institute
Document Control Number: EPA-HQ-OPA-2006-0090-0520-A1
Comment Excerpt Number: 16

Comment Excerpt:

As for mitigating ecological impacts in general, this was couched as a subjective "environmental trade-off" of short-term harm to the sea life in the upper water column to reduce harm to the seashore and to birds and mammals on the sea surface. This logic is flawed. As observed by Louisiana shrimper Clint Guidry in his May 24, 2010, testimony to Agency and congressional representatives, "The Gulf is the Mother and the estuaries are the nurseries. If the Mother dies, there will be no children to incubate." [19] In hindsight, dispersant applications in major oil spills have never prevented oil from coming ashore,[20] and the oil that comes ashore has dispersant mixed with it.[21] The effect of dispersant and oil-dispersant combined on the waterproof and thermal properties of fur and feathers remains untested,[22] despite there being a long-standing recommendation of the National Research Council to do so[23] – perhaps because the answer is blatantly obvious.[24]

Footnotes:

[19] Guidry, Clint, 2010, Testimony, Galliano, Louisiana, May 24, 2010, provided by Mr. Guidry.

[20] French, John, 2013, How do oil dispersants work as oil spill response counter measures?, presentation at the 6th annual Northwestern Tribal Water Rights Conference hosted by the Center for Water Advocacy, Anchorage, Alaska, October 2013.

[21] Kirby, James "Rip" III, "Findings of Persistency of Polycyclic Aromatic Hydrocarbons in Residual Tar Product Sourced from Crude Oil Released during the Deepwater Horizon MC252 Spill of National Significance," supported by the Surfrider Foundation, April 14, 2012, http://surfrider.org/images/uploads/publications/Corexit_Connections.pdf
Koska, Joel, et al., 2011, Hydrocarbon-degrading bacteria and the bacterial community response in Gulf of Mexico beach sands impacted by the [BP] Deepwater Horizon oil spill, Appl. Environ. Microbiol. November 2011, 77(22):7962-7974, doi: 10.1128/AEM.05402-11.

[22] Committee on Understanding Oil Spill Dispersants: Efficacy and Effects (National Research Council of the National Academies), Oil Spill Dispersants: Efficacy and Effects, The National Academies Press, Washington, DC, 2006.

[23] Committee on Effectiveness of Oil Dispersants (National Research Council, Marine Board, Commission on Engineering and Technical Systems), Using Oil Spill Dispersants on the Sea, National Academy Press: Washington, DC, 1989.

[24] For example, dispersant impacts could reasonably be anticipated to strip natural oils off fur and feathers, destroying water-resiliency and thermal insulation properties and be ingested during grooming or preening. Further, dispersants could strip the natural oily mucus layer off fish and smooth-skinned marine mammals.

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Commenter Name: Travis G
Commenter Affiliation:
Document Control Number: EPA-HQ-OPA-2006-0090-0122
Comment Excerpt Number: 1

Comment Excerpt:

Please do not remove one of the most vital tools in toolbox with regards to dispersant and the industry's ability to combat crude oil spills at sea. In 2010 when the Macondo well blew out in the Gulf of Mexico, crude oil began spilling into the gulf. Crude, as a natural substance is consumable by natural processes that take place in the ocean all of time. In large volumes however, the natural processes have trouble consuming so much crude and the substance is able to travel throughout the water column and get dangerously near to sensitive environmental areas and places with flourishing wildlife. Dispersant delivered mainly by air is the most effective tool in the industry's toolbox that allows the cleanup to take place as quickly, efficiently, and as safely as possible. During the Macondo incident in 2010, dispersant was the reason that the crude oil gushing out of the ocean's floor was able to stay contained to a large area around the well in the open ocean a opposed to washing ashore onto sensitive environmental areas and beaches stretching from South Texas to the panhandle of Florida. Without dispersants, crude oil would likely have covered many areas and likely would have killed countless numbers of birds, fish and other wildlife not to mention its effects on humans and other habitants that live in shallow areas and close to shorelines. When reviewing your regulatory policy, please consider this valuable tool and please allow it to remain a viable option with regards to cleaning up spills. Dispersant is a safe product with a proven track record. While there are no perfect options when it comes to cleaning up after a disaster, we would be much better off managing the operation far off shore and in the open ocean as opposed to potentially destroying fragile habitats and shorelines where most fish and wildlife reside. Without dispersant, containing disasters will be more costly and difficult if not impossible and we will result in greater environmental impacts in the event of a spill. Thank you for the opportunity to comment.

PROPOSED RULE LACKS NEBA PERSPECTIVE

Commenter Name: Philip B Smith
Commenter Affiliation: Shell Offshore Inc. (Shell)
Document Control Number: EPA-HQ-OPA-2006-0090-0391-A1
Comment Excerpt Number: 3

Comment Excerpt:

Proposed revisions conflict with best practices and established policies aiming to minimize impacts from oil spills

The use of dispersants in response to an oil spill should be seen as an aid to the process of natural dispersion, dilution and biodegradation and not viewed as a release of a harmful chemical on its own. Dispersants should be treated similar to firefighting foam, as a means to reduce the potential impact of a more harmful circumstance. This balance has been and will continue to be managed through the Net Environmental Benefit Analysis (NEBA), a process encapsulated within the oil spill preparedness and response framework, which compares response techniques and results in a selection of response options that ensures maximum environmental protection and fastest ecosystem recovery.

In the United States, the NEBA process is used through every stage of oil spill preparedness and response- before a spill, during a spill, and after a spill. Before a spill, the formal NEBA process is conducted during the planning phase

at the Area and Regional Response Team levels with input from state and Federal participants to determine the benefits and limitations associated with each response technology within their individual areas of responsibility. This Consensus Ecological Risk Assessment (CERA) process was developed by the U.S. Coast Guard in the mid-1990s and provides a structured, scientific method to evaluate the likely environmental actions and make an assessment of the required trade-oils associated with them, considering possible impacts to sensitive resources and the environment. Over the years, regulators have conducted numerous NEBA/CERA workshops which led to the establishment of dispersant preapproval zones and an expedited checklist for decision-making. This was a direct result of decades of experience and consistent confirmation that NEBA is the most appropriate way to manage offshore dispersant use and the realization that any related decisions should be made as quickly as possible to minimize environmental damage to sensitive and economically significant nearshore resources.

During a spill, government decision-makers use RRT checklists and conduct a rapid NEBA to compare and rank the strengths and weaknesses of different response options given conditions specific to the incident. Lessons learned following a spill are incorporated into future policies and plans.

Regrettably, this proposed rule greatly lacks a NEBA perspective. It incorrectly focuses on intrinsic, hazard-based criteria for substance listing and ignores the risk-based trade-off decision process responders must consider during an oil spill response. It does not recognize that dispersants are only applied when regulators and response decision-makers deem them necessary to prevent more significant and harmful ecologic and economic consequences.

The significant additional limitations to dispersants resulting from the proposed regulation could result in higher (and preventable) environmental and economic damage than the current version of the regulation. Shell recommends the establishment of NCP Product Schedule listing and use criteria that are more reflective of the NEBA process than those presented in the proposed rule which simply focus on toxicity testing and creation of "stop" field thresholds based on specific organism impacts. The proposal favors protecting pelagic and benthic species at the expense of other more sensitive resources. Of particular concern, the proposed rule would put critical habitats, such as the ocean's surface and near-surface zones, as well as sensitive shorelines and nearshore areas, at greater risk to environmental damage.

In the context of NEBA (and its predecessor, the Consensus Ecological Risk Assessment, or CERA), scientists understand and accept that marine organisms may experience localized, transient toxic effects from exposure to dispersed oil, but these local effects are offset by the benefit of dispersant use in preventing oil from drifting ashore and causing severe and long-term harm to more sensitive coastal resources. While knowledge of the potential for toxic effects to marine organisms is useful for conducting a NEBA, it should not be the sole indicator that dictates the use of dispersants. All resources at risk must be considered in the response option decision-making process, with emphasis on coordinating a response that will promote the most rapid overall recovery of the affected ecosystem.

Commenter Name: Greg DeMarco
Commenter Affiliation: Exxon Mobil Corporation (ExxonMobil)
Document Control Number: EPA-HQ-OPA-2006-0090-0402-A1
Comment Excerpt Number: 1

Comment Excerpt:

We believe that in the event of a spill, a robust response is required. This includes ensuring the availability of the most appropriate tools for the job and the timeliness of response activities. As a result, it is imperative that all of the spill response tools that may be brought to bear be available for deployment and implementation within an overall framework of a Net Environmental Benefit Analysis (NEBA).[1] It is our belief that severely limiting use of

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dispersants by establishing arbitrary thresholds for listing, adding burdensome controls over an already effective preauthorization process, and requiring activities during a response that do not contribute directly to the operational, decision-making activities, such as additional dispersant monitoring or water sampling, may result in a less effective response, especially from a NEBA perspective.

For example, anything that delays the decision to appropriately deploy dispersants can lead to long lasting negative effects as highlighted by the following excerpt from a Good Practice Guide recently published jointly by the International Association of Oil and Gas Producers (IOGP) and IPIECA:

Floating oil that drifts close to shore over sea-grasses or comes ashore in particularly sensitive coastal habitats such as mudflats or wetlands can cause severe and long-lasting damage to these habitats and to the populations and shoreline communities of birds, mammals and other species. It can take years to decades for some of these shoreline communities to recover from oiling. Dispersant use can prevent this damage from happening. 2

Footnote:

[1] See Baker, J.M., Net Environmental Benefit Analysis for Oil Spill Response, IOSC Proceedings, 1995, pp. 611·614. http://ioscproceedings.org/doi/pdf/10.7901/2169-3358-1995-1-611

[2] From: Dispersants: Surface Application, Good Practice Guidelines for Incident Management and Emergency Response Personnel, IOGP Report 532, 2015

Further information on the much slower recovery potential for sensitive shorelines versus open waters is provided in:

Impacts of oil spills on marine ecology. IPIECA·IOGP Good Practice Guide Series, Oil Spill Response Joint Industry Project (OSR-JIP). IOGP Report 525, 2015;
Impacts of oil spills on shorelines. IPIECA-IOGP Good Practice Guide Series, Oil Spill Response Joint Industry Project (OSR.JIP). IOGP Report 534, 2015 http://oilspillresponseproject.org/completed-products

Comment Excerpt Number: 5

Comment Excerpt:

There is little within the proposed rule changes that relate spill response choices to the concept of NEBA. In practical reality, during an emergency response, NEBA-based considerations must be taken into account before any decision to curtail specific operations is made. [8] These should take into account the circumstances of the spill, the practicalities of spill response options, scientific understanding of the relative impacts of oil and clean-up options, and a value judgment of the relative importance of the social, economic and environmental resources at risk. Consensus-based decisions require balanced and informed discussions based on the best scientific data and an understanding of the pros and cons of all response options.[9] The reason dispersants are an important tool for response to certain types of offshore oil spills is that other options may have significantly limited effectiveness under a variety of conditions. Without oil spill response experience, a reader of the proposed Rule could conclude that there is little need for dispersants to be used since other response options may effectively manage any spill. Because of the challenges of implementing other response options, a decision not to have dispersants available to responders is a decision that could result in oil stranding on shorelines where it may persist for an extended time. This is in contrast to oil that is effectively dispersed offshore where it will biodegrade rapidly so that the majority of the oil will persist for a much shorter period of time. Reducing the persistence of the oil in the environment is critical to reducing the overall impacts.[10] This is not to say that water column organisms are less intrinsically important than surface or shoreline species but using NEBA can and does provide a critical framework for deciding what is best for the overall ecosystem. Important considerations to understand in assessing this tradeoff include: [11]

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- Impacts to the water column are mitigated by dilution, that is potentially toxic levels of dispersed oil are limited in duration and physical coverage/extent and effected populations (e.g. plankton) tend to be ones that recover quickly.
- Oil effectively dispersed in the water column will persist for weeks because of biodegradation while oil stranded in near shore and shoreline areas can persist for years releasing soluble oil components to the near shore areas.
- Near shore and shoreline areas are the nursery grounds for many species, even those that live offshore as adults. So protecting the near shore areas also protects organisms that live as adults offshore.
- The bio density of near shore areas (swamps and marshes) is far greater than the bio density in pelagic waters offshore.
- Dispersants also protect surface dwelling organisms offshore, i.e., marine mammals, birds, and turtles.
- Slicks on the water surface are far more likely to impact fish eggs and larva that tend to float at or near the water surface also supporting removal of oil from the surface with dispersants.
- In certain geographies, slicks can impact mangroves and loss of mangroves can have decades-long impacts and impact the near shore water column by allowing shoreline erosion that increases sediments and potentially affecting corals and other species.

[Footnotes:]

[8] (a) IPIECA-OGP Oil Spill Response Joint Industry Project, Oil spill risk assessment and response planning for offshore Installations, 2013 http://oilspillresponseproject.org/sites/default/files/uploads/JIP%206%2Q-%200il%20spill%20risk%20assessment.pdf
(b) API Net Environmental Benefit Analysis for effective oil spill preparedness and response. 2013. www.api.org/-/media/Files/EHS/Clean_Water/Oil_SpillPrevention/NEBA/NEBA-Net-Environmentai-Benefit-Analysis-July-2013.pdf

[9] (a) IPIECA-OGP Oil Spill Response Joint Industry Project, on spill risk assessment and response planning for offshore installations, 2013 http://oilspillresponseproject.org/sites/default/files/uploads/JIP%206%2Q-%200il%20spill%20risk%20assessment.pdf
(b) API Net Environmental Benefit Analysis for effective oil spill preparedness and response. 2013. www.api.org/-/media/Files/EHS/CleanWater/Oil_Spill_Prevention/NEBA/NEBA-Net-Environmentai-Benefit-Analysis-July-2013.pdf

[10] Hazen, et at., Deep-Sea Oil Plume Enriches Indigenous Oil-Degrading Bacteria, Science, 330 (2010), pp. 204-208.

[11] (a) French McCay, D . and Graham, E. Quantifying Tradeoffs - Net Environmental Benefits of Dispersant Use. International Oil Spill Conference Proceedings: May 2014, Vol. 2014, No.1, pp. 762-775.
(b) McManus, M.A., Woodson, C.B. Plankton Distribution and Ocean Dispersal. The Journal of Experimental Biology, 215 (2012), pp. 1008-1016.
(c) DeMicco et al., Net Environmental Benefit Analysis (NEBA) of Dispersed Oil on Nearshore Tropical Ecosystems: TROPICS - The 25., Year Research Visit, International Oil Spill Conference Proceedings, May 2011, Vol. 2011-282.
(d) Varela et al., The Effect of the "Prestige" Oil Spill on the Plankton of the N-NW Spanish Coast. Marine Pollution Bulletin 53 (2006)., pp. 272·296.
(e) Addassi, at al., Establishment of Dispersant Use Zones in the State of California: A Consensus Approach for Marine Waters 3-200 Nautical Miles from Shore. International Oil Spill Conference Proceedings: May 2005, Vol. 2015, No. 1, pp. 187-191.

ED_001324_00007556-00039

Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1
Comment Excerpt Number: 1

Comment Excerpt:

API, NOIA, and our respective members recognize the important mission of the EPA in protecting human health and the environment and share in this mission. More than most industries, the oil and natural gas industry understands the nature of risk and places at the center of its concern comprehensive planning for and effective management of risks in order to safeguard human well-being and protect environmental resources. To this end, woven into every operational endeavor are release prevention measures, preparedness methods and plans for rapid, effective response should an incident resulting in a release occur. Developed alongside regulatory agencies, operators submit to and follow a distinct set of response principles which protect shared values. The framework by which these principles are employed and tradeoffs are made in order to protect these shared values is called Net Environmental Benefit Analysis (NEBA). NEBA is a process used by the response community for making the best choices to minimize impacts of oil releases on people and the environment. NEBA aids in protecting people and the environment, and is the matrix through which every decision is made in a response event. In the offshore context, oil dispersing agents are a primary tool in the NEBA process and the response toolkit, as they are a principal tool used for protecting human health and defending environmentally sensitive areas. When a release occurs, judgment and response speed are critical. In an offshore setting, dispersants are essential in creating a safe environment and are a key ingredient in marshaling an effective, swift response.

DRAFT

Comment Excerpt Number: 12

Comment Excerpt:

A Net Environmental Benefit Analysis Process Ensures Response Choices that Minimize the Impacts of Oil Spills on People and the Environment

Any changes to the rule must take into account the Net Environmental Benefit Analysis (NEBA)[2] process. When a spill occurs, the OSC must make time-critical choices about which response options to implement immediately and effectively to manage the potential impacts of the spill. The NEBA process helps the OSC select choices that minimize the impacts of the spill on people and the environment. NEBA is a consensus-based planning tool that is used to bring natural resource trustees, regulators and stakeholders together to address resource-management decision-making needs for an oil spill response. It provides a structured, scientific method to evaluate the likely net reduction, or possible increase, in environmental and socio-economic impacts resulting from the implementation candidate response options as compared to the natural recovery or "do nothing" alternative. An assessment of the trade-offs associated with each option is then conducted taking into consideration the potential impacts to sensitive environmental resources and local community values. The NEBA process determines which response option or combination of options can best reduce the overall impact of spilled oil to common values and promote the fastest overall ecosystem recovery. Of particular note, the NEBA process considers the potential effects to a wide range of concerns, ranging from likely environmental effects (i.e., deep marine to terrestrial, etc.) to possible economic consequences. When initially considering the potential outcomes, no individual area receives a greater priority over another. Instead, all are weighed from an

equal footing and only after evaluating all the likely effects is a determination made regarding the response option that offers that greatest environmental benefit. In so doing, decision-makers ensure that an unbiased process is used, with input from relevant stakeholders, to determine the best course of action. This process has been adopted all over the world to identify response methods that will yield the greatest benefit with the least impact.[3]

The NEBA process can be used in both oil spill preparedness planning and response. In the United States, a formal NEBA process is conducted during the planning phase at the Area Committee and Regional Response Team (RRT) levels with input from state and Federal participants to determine the benefits and limitations from using each response technology within their individual areas of responsibility. In most offshore regions of the U.S., this is accomplished in the form of the Consensus-Based Ecological Risk Assessments (CERA) process (NEBA equivalent) used by the U.S. Coast Guard (USCG)[4] and supported by the National Oceanic and Atmospheric Administration (NOAA), EPA, other Federal and state agencies, and academia. More than twenty workshops were held in various locations around the continental U.S., Caribbean, and Alaska from 1995 to 2011 to compare the benefits and risks of various response options when considering resource trade-off decisions. All of the workshops resulted in final publications (available from USCG) that were delivered to the Area Committees and RRTs to assist with response planning. One example of how this CERA/NEBA process was used to inform dispersant use decision-making is summarized in several papers authored by regulators in the state of California.[5] The applicability of the CERA/NEBA process as a tool for facilitating dispersant decisionmaking during spill response and planning was also evaluated by NOAA and published in a 2008 paper.[6]

In 2014, the practice of incorporating a NEBA review during Source Control drills in the Gulf of Mexico was implemented by RRT VI during several large scale spill response exercises,[7] which has fostered good cooperation between the agencies to focus on the goal of minimizing shoreline community and ecosystem impacts by selecting response options that can maximize the effective treatment of oil offshore. NEBA discussions during both of these recent spill drills resulted in the concurrence of the RRT to authorize dispersants (both aerially and subsea) to treat the offshore oil slick.

Government decision-makers and/or the Responsible Party can conduct a rapid NEBA during actual spill responses to compare and rank the strengths and weaknesses of different response options for the incident-specific conditions. Lessons learned following a spill are incorporated into future policies and plans. Ecological recovery studies of the 1996 Sea Empress spill in the UK demonstrate the benefit of dispersant application along the coastline to prevent persistent oil from stranding in shoreline habits.[8] A more recent publication examined the recovery rates for a tropical ecosystem during a controlled study of dispersed versus untreated shoreline oil slicks and concluded that better recovery occurred in the areas where dispersant was used.[9]

Regrettably, the Proposed Rule lacks a NEBA perspective. It incorrectly focuses on intrinsic, hazardbased criteria for substance listing and ignores the more appropriate risk-based trade-off decision process responders must consider during an oil spill response. It does not recognize that dispersants are only applied when regulators and response decision-makers deem them necessary to prevent more significant and harmful consequences. The Proposed Rule favors protecting pelagic and benthic species while putting critical habitats, such as the ocean's surface and near-surface zones, as well as sensitive shorelines, at greater risk to environmental damage. Modeling results presented at the 2005 International Oil Spill Conference concluded that:

> "...the results of the modeling support the contention that there are more opportunities to save wildlife, shorelines, and sensitive habitats along the shore with dispersant use than

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there are risks of impacting water column biota. If the areas that would be impacted by surface oil are those where wildlife are concentrated, as they typically are near shore, and the water column impacts resulting from dispersant use would be offshore where water column biota are lower in abundance, the trade-off is much more heavily weighted toward dispersant use before oil comes near the shoreline. In fact, for medium or smaller spills, or even larger spills where sensitive species and life stages are not present, the impact of dispersant use on water column biota could be negligible."[10]

For oil spills where dispersant use is contemplated, a typical NEBA will predict the potential impacts to aquatic organisms from an increased exposure to dispersed oil droplets. Dispersant use is typically restricted to water depths greater than 10 to 20 meters so that dilution will minimize exposure or impacts to the benthic community. Studies have shown the dispersed oil concentrations are rapidly diluted within the large volume of receiving water from a high of a few hundred parts per million to a few parts per million within a few hours. Consequently, exposure to the toxic effects of the dispersed oil will be of short duration and limited to those aquatic organisms that inhabit near surface waters. The NEBA will also estimate the reduction of impacts to waterfowl, shoreline ecosystems and coastal communities resulting from the reduction in, or elimination of, the quantity of floating oil. The trade-offs of a short term increase in exposure of selected aquatic organisms to dispersed oil versus an increase in oil impacting coastal environments and communities must be evaluated and take into account local community values to determine if dispersant use is warranted.

Given the challenges of implementing other response options, a decision not to have dispersants available to responders could result in oil stranding on shorelines where it may persist for an extended time. Effectively dispersed oil will biodegrade rapidly so that the majority of the oil will persist for a much shorter period of time. Reducing the persistence of the oil in the environment is critical to reducing the overall impacts.[11] This is not to say that water column organisms are less intrinsically important than surface or shoreline species but using NEBA can and does provide a critical framework for deciding what is best for the overall ecosystem. Important considerations to understand in assessing this tradeoff include.[12]

- The impacts to the water column are mitigated by dilution – that is the potentially toxic levels of dispersed oil are limited in duration and physical coverage/extent and effected populations (e.g., plankton) tend to be ones that recover quickly.
- Oil effectively dispersed in the water column will generally biodegrade after a few days or weeks while oil stranded in near shore and shoreline areas can persist for years.
- Near shore and shoreline areas are the nursery grounds for many species, even those that live offshore as adults, so protecting the near shore areas also protects organism that live as adults offshore.
- The bio density of near shore areas (swamps and marshes) is far greater than the bio density in pelagic waters offshore.
- Dispersants also protect surface dwelling organisms offshore, i.e., marine mammals, birds, and turtles, through removal of floating oil.
- Slicks on the water surface are far more likely to impact fish eggs and larva that tend to float at or near the water surface than quickly removing oil from the surface with dispersants.
- In certain geographies, slicks can impact mangroves and other shoreline vegetation that can subsequently die off and result in shoreline erosion that increases sediments in the near shore water column and

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potentially affects corals and other species.

The Agency should consider the NEBA process and how and why dispersants are used before making changes to the Subpart J Regulations.

[Footnotes:]

[2] NEBA is similar to the Consensus Ecological Risk Assessment (CERA) process developed by the U.S. Coast Guard in the mid-1990s.

[3] See, Incident management system for the oil and gas industry: good practice guidelines for incident management and emergency response personnel, IPIECA, August 2014, http://www.ipieca.org/publication/incident-management-system-oil-and-gas-industrygood-practice-guidelines-incident-manage.

[4] Aurand, D., Walko, L., & Pond, R. (2000). Developing consensus ecological risk assessments: Environmental protection in oil spill response planning. Washington, D.C.: U.S. Coast Guard.

[5] Addassi, Y. N., & Faurot-Daniels, E. (2005). California oil spill dispersant plan-Achievement through cooperation. Proceedings of the 2005 International Oil Spill Conference, 2005(1), 433-437. doi:10.7901/2169-3358-2005-1-433; Addassi, Y. N., Sowby, M.,

[6] Mearns, A., & Evans, M. (2008). Evaluating the consensus ecological risk assessment workshop as a tool for facilitating decision making during spill response and planning. Proceedings of the 2008 International Oil Spill Conference Proceedings, 2008(1), 739-741. doi:10.7901/2169-3358-2008-1-739

[7] Freeport McMoran Source Control drill (April 30-May 1, 2014) and BP Source Control drill (Nov 5-6, 2014)

[8] Lunel, T., Rusin, J., Bailey, N., Halliwell, C., & Davies, L. (1997). The net environmental benefit of a successful dispersant operation at the Sea Empress incident. Proceedings of the 1997 International Oil Spill Conference, 1997(1), 185-194. doi:10.7901/2169-3358-1997-1-185

[9] Baca, B., Rosch, E., DeMicco, E. D., & Schuler, P. A. (2014). TROPICS: 30-year follow-up and analysis of mangroves, invertebrates, and hydrocarbons. Proceedings of the 2014 International Oil Spill Conference, 2014(1), 1734-1748. doi:10.7901/2169-3358-2014.1.1734

[10] French McCay, et al., Modeling Fates and Impacts of Hypothetical Oil Spills in Delaware, Florida, Texas, California, and Alaska Waters, Varying Response Options Including Use of Dispersants. International Oil Spill Conference Proceedings: May 2005, Vol. 2005, No. 1 pp. 735-740. Also available at http://ioscproceedings.org/doi/pdf/10.7901/2169-3358-2005-1-735.

[11] Hazen, et al., Deep-Sea Oil Plume Enriches Indigenous Oil-Degrading Bacteria, Science, 330 (2010), pp. 204-208.

[12] (a) French McCay, D., and Graham, E. Quantifying Tradeoffs – Net Environmental Benefits of Dispersant Use. International Oil Spill Conference Proceedings: May 2014, Vol. 2014, No. 1, pp. 762-775.
(b) McManus, M.A., Woodson, C.B. Plankton Distribution and Ocean Dispersal. The Journal of Experimental Biology, 215 (2012), pp. 1008-1016.
(c) DeMicco et al., Net Environmental Benefit Analysis (NEBA) of Dispersed Oil on Nearshore Tropical Ecosystems: TROPICS – The 25th Year Research Visit, International Oil Spill Conference Proceedings, May 2011, Vol. 2011-282.
(d) Varela et al., The Effect of the "Prestige" Oil Spill on the Plankton of the N-NW Spanish Coast. Marine Pollution Bulletin 53 (2006), pp. 272-296.
(e) Addassi, et al., Establishment of Dispersant Use Zones in the State of California: A Consensus Approach for Marine Waters 3-200 Nautical Miles from Shore. International Oil Spill Conference Proceedings: May 2005, Vol. 2015, No. 1, pp. 187-191.

Commenter Name: Richard E. Dodge, Ph.D.
Commenter Affiliation: public citizen
Document Control Number: EPA-HQ-OPA-2006-0090-0423-A1

Comment Excerpt Number: 1

Comment Excerpt:

I am one of the original researchers for the Tropical Oil Pollution Investigations in Coastal Systems (TROPICS, 1983-1994) Field Study in Panama that laid the foundational for the concept of Net Environmental Benefit Analysis (NEBA) as it relates to the use or non-use of dispersants to combat oil spills. As the author of several peer reviewed scientific papers on the subject, and as Dean of the Nova Southeastern University Oceanographic Center and National Coral Reef Institute, which currently is conducting research on the relative effects of dispersed and non-dispersed crude oil on coral, I am keenly interested in preserving the marine environment for future generations.

From my research, and from those that followed at the TROPICS field site in 2002-2012, it was clear that the overall disturbance to the TROPICS study ecosystem was greater in the Non-dispersed crude oil site. Meanwhile, over the years, the overall recovery of the TROPICS study ecosystem was significantly higher in the Dispersed Crude oil site.

I am a committed proponent of the use of NEBA in guiding decisions to use or not to use dispersants to combat oil spills. In this construct, the toxicity of dispersants is but one of several factors in the decision equation. In my opinion, the emphasis on dispersant toxicity is currently misplaced and does nothing but further promote fear and misunderstanding of the science of oil spill response. THE FOCUS ON DISPERSANT USE SHOULD BE ON THE NEBA PROCESS. Within the NEBA process, the various tradeoffs, including relative toxicity, effects, etc., of the various approaches under consideration can be evaluated.

When the future of our precious environment is at risk from an oil spill it is exceedingly difficult to guarantee that appropriate and proper actions will always be taken. In this regard, our environmental trustees have awesome responsibilities. In my opinion, the best way to ensure that we do our best thing to protect and preserve the environment, is to focus on NEBA as a decision-making process. The focus on any one factor, such as dispersant toxicity, to the exclusion of what produces the best result for the protection and recovery of the environment on a macro scale, is the wrong path to take. I believe the proposed changes to Subpart J take us down that wrong path that will in some cases negatively impact our ability to respond to oil spills and protect the marine environment.

DRAFT

Commenter Name: Anonymous
Commenter Affiliation: Unknown
Document Control Number: EPA-HQ-OPA-2006-0090-0435
Comment Excerpt Number: 1

Comment Excerpt:

This document does not recognize the absolute goal of oil-spill response by reducing damages from a net environmental benefit analysis (NEBA) perspective. The amendment only focuses on the debit side of the NEBA and a more effective discussion would gauge efficacy and toxicity of dispersants but also how to determine the credit side of NEBA. I recognize that trade offs are mentioned but much more is needed.

Commenter Name: John Temperilli
Commenter Affiliation: public citizen
Document Control Number: EPA-HQ-OPA-2006-0090-0569-A1
Comment Excerpt Number: 7

Comment Excerpt:

It lacks an overall NEBA perspective of fully engaging environmental benefit tradeoff assessment to make a decision regarding use or non-use.

Commenter Name: Unsigned
Commenter Affiliation: Marine Well Containment Company (MWCC)
Document Control Number: EPA-HQ-OPA-2006-0090-0571-A1
Comment Excerpt Number: 5

Comment Excerpt:

Response Coordination
Dispersants are applied when response decision-makers consider it required/beneficial to the overall response. The Net Environment Benefit Analysis (NEBA) process provides a structured framework for collaboration from which response decision-makers can consider response scenario specifics and the trade-offs associated with environmental actions. MWCC maintains that new rules should not discourage, nor impede the FOSC's ability to make an informed, timely decision through the NEBA process.

Commenter Name: David McBride
Commenter Affiliation: Anadarko Petroleum Corporation (Anadarko)
Document Control Number: EPA-HQ-OPA-2006-0090-0572-A1
Comment Excerpt Number: 3

Comment Excerpt:

DRAFT

Removes Net Environmental Benefit Analysis (NEBA) or environmental tradeoffs/ risk analysis for use of dispersants as well as use of incident specific data or science. Anadarko believes that prior to the use of dispersants, a proper incident specific NEBA process working with Federal, State, local and private industry scientists should be conducted to determine the best response efforts to minimize impact to the environment. To conduct a proper NEBA, Anadarko requests EPA to share all field and test data that influenced their decision to redefine toxicity effects caused by dispersants. API provides excellent references to studies showing the benefits of using dispersants which contradicts the Proposed Rule. Anadarko strongly believes that every response tool, technology and expertise needs to be utilized to during a spill response.

Commenter Name: Greg Pollock
Commenter Affiliation: Texas General Land Office
Document Control Number: EPA-HQ-OPA-2006-0090-0481-A1
Comment Excerpt Number: 2

Comment Excerpt:

Overall Net Environmental Benefit
The TGLO represents the State's interests when oil spills threaten the jurisdictional waters of the state. We actively participate utilizing the National Incident Management System (NIMS), Incident Command System (ICS), as authorized and directed by Homeland Security Presidential Directive 5 (HSPD5). This system has served well in creating a coordinated response where the unified command makes time sensitive choices to minimize the affects of an ongoing or potential oil spill. The system utilizes the best available science to balance the environmental tradeoffs to achieve the optimum net environmental benefit.

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In the following sections the TGLO would like to respond to specifics within the proposed rule that we feel inhibit our ability to respond to an oil spill utilizing best available science in order to achieve an optimum net environmental benefit.

GENERAL

Commenter Name: Riki Ott, PhD
Commenter Affiliation: ALERT Project, a project of Earth Island Institute
Document Control Number: EPA-HQ-OPA-2006-0090-0520-A1
Comment Excerpt Number: 20

Comment Excerpt:

We also believe that subsea dispersant use is undesired. We find no scientific evidence to support the claim that subsea dispersant use provides a net environmental gain or mitigates oil impacts to the benthic community. In 2012, scientists convened to evaluate dispersant use during the BP DWH disaster. As part of a lengthy report, scientists conceded that toxicity tests focused on 2 or 3 species were of limited value as predictors for ecosystem impacts.[74] Subsequent toxicity tests on rotifers using chemically-dispersed oil found the oil-dispersant combined was lethal to half of the early life stages of rotifers, a finding called "ecologically significant" by the authors.[75] Also, oil eating bacteria are concentrated in the upper zones of the ocean[76] and biodegradation is a kinetic process in that it occurs faster in warmer water. Biodegradation at depth in cold water is non-existent or extremely limited. Basically, we know next to nothing about dispersant impacts on deep-sea ecology, but we find it reasonable to assume that dispersants will have the same devastating short- and long-term impacts, noted above, in the deep sea that they have had in other ocean zones more accessible to scientists.

Footnotes:

[74] NOAA et al., 2012, Dispersant Initiative Report.
[75] Rico-Martinez, 2013. http://www.sciencedirect.com/science/article/pii/S0269749112004344
[76] Fingas, 2014 Dispersant Review.

Commenter Name: Diane and Joy
Commenter Affiliation: Lawrence Anthony Earth Organization (LAEO)
Document Control Number: EPA-HQ-OPA-2006-0090-0524-A1
Comment Excerpt Number: 4

Comment Excerpt:

The NCP should be viewed as an **integrated system** with inter-related tools. It should not leave critical adjudications of what response method is **appropriate** for use on a given spill in the hands of unqualified decision-makers operating in high-stress emergency conditions. Looking at a response method in a single view without regard to how these chemical and biological agents work within an integrated system is problematic as well as dangerous.

Commenter Name: Yvonne Addassi
Commenter Affiliation: California Department of Fish and Wildlife, Office of Spill Prevention and Response (CDFW-OSPR)

ED_001324_00007556-00046

Document Control Number: EPA-HQ-OPA-2006-0090-0508-A1
Comment Excerpt Number: 4

Comment Excerpt:

Issue: Pg. 3384, Col. 2, "Many coastal ACPs include some type of preauthorization zones for dispersants, while most … RCPs address other product categories."

Level of Support: Clarify

Comment:

For RRT IX, all elements of coastal ACPs that have "statewide" utility (e.g., use of all ARTs) have been moved into the RRT IX RCP. ACPs only provide general ART policy overviews, then link to the RCP for all statewide ART plans (dispersants, bioremediants, other OSCAs, in-situ burning).

Commenter Name: James D. "Buddy" Caldwell
Commenter Affiliation: State of Louisiana
Document Control Number: EPA-HQ-OPA-2006-0090-0580-A1
Comment Excerpt Number: 1

Comment Excerpt:

During the BP spill, the NCP requirements for chemical dispersants like Corexit left much to be desired, and the EPA approved of the deployment of more than 1.8 million gallons of dispersants in the Gulf of Mexico. The application of dispersants concealed the scope of the damage and had unanticipated ecological impacts to our coastal waters and natural resources, as well as health impacts on response workers and our citizens. Furthermore, the State and local on-scene coordinators had little input in the oil spill remediation protocols. I strongly urge the EPA to adopt new regulations that prioritize reducing risks to people and the environment by ensuring that, to the extent possible, the products authorized for use will actually work to clean up the affected area and not cause further harm during oil spill response. The new rule should also establish general listing, testing and monitoring requirements for all authorized chemical agents to ensure that the general public and the state trustees are able to understand the potential impacts of oil spill response operations.

Commenter Name: Philip B Smith
Commenter Affiliation: Shell Offshore Inc. (Shell)
Document Control Number: EPA-HQ-OPA-2006-0090-0391-A1
Comment Excerpt Number: 17

Comment Excerpt:

Shell agrees with the sentiment expressed by the Agency in the preamble related to the importance of preauthorization and expedited decision making, but would emphasize that they are not only "critical elements of contingency planning activities" but also critical elements of response decision making.

Commenter Name: Unsigned
Commenter Affiliation: Spill Control Association of America (SCAA)
Document Control Number: EPA-HQ-OPA-2006-0090-0483-A1
Comment Excerpt Number: 1

ED_001324_00007556-00047

Comment Excerpt:

The role and decision-making process of dispersant use, under the prudent and careful discretion of the designated Federal On-Scene Commander (FOSC), is a critically important tool in an overall response strategy. The response to, and subsequent clean-up of any oil spill is not an exacting science, and is invariably influenced by a multitude of factors and "trade-off" decisions. SCAA supports continued research and education on the net environmental benefit of dispersants use, while at the same time cautions against a potentially biased position that promotes wide scale restriction or prohibition of their use.

Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1
Comment Excerpt Number: 9

Comment Excerpt:

Of more relevance is the use of toxicity results to assist in a NEBA-based discussion of the relative merit of using a particular dispersant in favor of another. Similarly, the attempt to link lab test results to decisions relating to pre-authorization and use is misplaced since laboratory tests are useful in understanding differences between products, not their real world performance.

Commenter Name: Emily Hague
Commenter Affiliation: American Petroleum Institute (API) and National Ocean Industries Association (NOIA)
Document Control Number: EPA-HQ-OPA-2006-0090-0611-A1
Comment Excerpt Number: 19

DRAFT

Comment Excerpt:

In the context of NEBA (and its forebear, the Consensus Ecological Risk Assessment, or CERA), scientists understand and accept that marine organisms may experience localized, transient toxic effects from exposure to dispersed oil, but these local effects are offset by the benefit of dispersant use in preventing or minimizing oil drifting ashore and causing severe and long-term harm to more sensitive coastal resources and communities. While knowledge of the potential for toxic effects to marine organisms is useful for conducting a NEBA, it cannot be the sole indicator that dictates the use of dispersants. All resources-at-risk as well as coastal communities must be considered in the response option decision-making process, with the emphasis on coordinating a response that will result in the least overall impacts while promoting the most rapid overall recovery of the affected ecosystem.

Commenter Name: Richard A. Charter
Commenter Affiliation: The Ocean Foundation
Document Control Number: EPA-HQ-OPA-2006-0090-0306-A1
Comment Excerpt Number: 11

Comment Excerpt:

The Current Draft of the Proposed Changes to Subpart J Should Be Updated to Include Full Consideration of Each of the Following Items:

In responding to any given incident, a timely decision about dispersant application by a multi-agency panel of decision makers working in conjunction with the on-scene coordinator, and based on the best available

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information about species in the path of the spill, seasonal considerations, weather, wind, currents, and other factors should not categorically preclude an informed decision not to proceed with dispersant application after carefully weighing all factors in play during a specific incident. State-of-the-art radars, satellite tracking of seasurface current drogues, and other real-time spill trajectory modeling tools will inevitably have a role in assessing the degree and scope of comparative risk to various biological resources and critical habitats within and adjoining sensitive locations. The application of dispersants should only be undertaken in extreme situations and needs to be respected as a response strategy of last resort, after a full accounting of the downside risks that such action presents. A much higher burden of proof of compelling need and a higher demonstrable net environmental benefit than that applied in recent events must be in place before aerial dispersion, subsea injection, or other deployment of chemicals suspected of having toxic or ecologically-damaging properties is allowed.

Comment Excerpt Number: 18

Comment Excerpt:

Subpart J Amendments Must Better Consider the Timing and Context of Dispersant Decisions:

Outside of U.S. waters, in countries where dispersant use is often subject to a strong policy bias related to resulting elevated toxicity to submerged habitats, there is usually a requirement for a judgment to be made - and argued to the relevant authority - that there is a net environmental benefit of applying dispersant. This decision must often be made quickly during an actual spill incident response due to the short window of time available before the slick spreads exponentially or before natural weathering increases the viscosity of most oils to an untreatable stage. Resource managers will likely be called upon to make carefully considered recommendations about whether, where, or how much dispersant should be applied to floating oil products and these critical decisions must necessarily be based upon a combination of seasonal, meteorological, and geographic real-time and site-specific considerations. These considerations include what fish species or life-stages of aquatic organisms in the water column will likely experience increased oil exposure and toxicity by sinking the hydrocarbon product and breaking it into more bio-available particles through the use of dispersant. Particulate oil droplets resulting from surface or subsea dispersant application tend to resemble planktonic forms of food to many marine species, thereby creating the potential for a greater uptake of toxic oil components by some animals that live in the water column. To the degree that archival documentation of baseline conditions is completed well in advance of a spill and indicates anticipated seasonal distribution of probable spill target species - including birds, fish, shellfish, and crabs and each species' larval stages or offspring - more informed response decisions can be made by resource managers. These baseline datasets can help to avoid or mitigate the inadvertent amplification of spill impacts to certain parts of the food chain by dispersants and their byproducts. In addition, the full extent of damage to public trust resources can thus be better documented using a strong baseline data analysis, helping to ensure just compensation to damaged parties by the spiller. In making decisions about dispersant use, success rates for all response methodologies that have been documented during precursor incidents should also be considered.

Commenter Name: Delice Calcote
Commenter Affiliation: Alaska Inter-Tribal Council
Document Control Number: EPA-HQ-OPA-2006-0090-0581-A1
Comment Excerpt Number: 11

Comment Excerpt:

The Current Draft of the Proposed Changes to Subpart J Should Be Updated to Include Full Consideration of Each of the Following Items:

In responding to any given incident, a timely decision about toxic dispersant application by a multi-agency panel of decision makers that includes the Tribal Government representative(s) working in conjunction with the on-scene coordinator, and based on the best available information about species in the path of the spill, seasonal considerations, weather, wind, currents, and other factors should not categorically preclude an informed decision not to proceed with toxic dispersant application after carefully weighing all factors in play during a specific incident. State-of-the-art radars, satellite tracking of sea-surface current drogues, and other real-time spill trajectory modeling tools will inevitably have a role in assessing the degree and scope of comparative risk to various biological resources and critical habitats within and adjoining sensitive, vital and critical habitat locations. The application of dispersants should only be undertaken in extreme situations and needs to be respected as a response strategy of last resort, after a full accounting of the downside risks that such action presents. A much higher burden of proof of compelling need and a higher demonstrable net environmental benefit than that applied in recent events must be in place before aerial dispersion, subsea injection, or other deployment of chemicals suspected of having toxic or ecologically-damaging properties is allowed.

Comment Excerpt Number: 18

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Subpart J Amendments Must Better Consider the Timing and Context of Dispersant Decisions:

Outside of U.S. waters, in countries where dispersant use is often subject to a strong policy bias related to resulting elevated toxicity to submerged habitats, there is usually a requirement for a judgment to be made - and argued to the relevant authority - that there is a net environmental benefit of applying dispersant. This decision must often be made quickly during an actual spill incident response due to the short window of time available before the slick spreads exponentially or before natural weathering increases the viscosity of most oils to an untreatable stage. Resource managers will likely be called upon to make carefully considered recommendations about whether, where, or how much dispersant should be applied to floating oil products and these critical decisions must necessarily be based upon a combination of seasonal, meteorological, and geographic real-time and site-specific considerations. These considerations include what fish species or life-stages of aquatic organisms in the water column will likely experience increased oil exposure and toxicity by sinking the hydrocarbon product and breaking it into more bio-available particles through the use of dispersant. Particulate oil droplets resulting from surface or subsea dispersant application tend to resemble planktonic forms of food to many marine species, thereby creating the potential for a greater uptake of toxic oil components by some animals that live in the water column. To the degree that archival documentation of baseline conditions is completed well in advance of a spill and indicates anticipated seasonal distribution of probable spill target species - including birds, fish, shellfish, and crabs and each species' larval stages or offspring - more informed response decisions can be made by resource managers. These baseline datasets can help to avoid or mitigate the inadvertent amplification of spill impacts to certain parts of the food chain by dispersants and their byproducts. In addition, the full extent of damage to public trust resources can thus be better documented using a strong baseline data analysis, helping to ensure just compensation to damaged parties by the spiller. In making decisions about dispersant use, success rates for all response methodologies that have been documented during precursor incidents should also be considered.

Commenter Name: Riki Ott, PhD
Commenter Affiliation: ALERT Project, a project of Earth Island Institute
Document Control Number: EPA-HQ-OPA-2006-0090-0520-A1
Comment Excerpt Number: 77

Comment Excerpt:

Recommendations: Require worst-case scenario planning for spills in freshwater, including evacuation, housing, and alternative drinking water supplies; do not allow oil to be transported without a viable oil spill contingency plan.

DRAFT

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To: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Mon 5/16/2016 7:31:03 PM
Subject: Oil Budget Calculator - NOAA DWH - Page 26 - Multi Spectral Scanning to Estimate Slick Coverage at the Water Surface
OilBudgetCalc_Full_HQ-Print_111110.pdf

Page 26-27:

Ocean Imaging, using a multi-spectral scanner to estimate slick coverage at the water surface directly over the spill site, observed the oil appearance both during dispersant operations and no dispersant operations. Figure 11 shows a time period from May 10 through May 12. The individual images represent relative thickness measurements of surface oil at specific times. The larger the red area, the more thick oil is present. Surface conditions were reasonably similar during this time period. Subsurface injection began at 0430 hrs on May 10 and continued with an average injection rate of 8 gallons per minute. If the dispersant was as highly effective as suggested by certain experts, then more than half of the released oil should have been chemically dispersed. The May 10th A.M. image may be too early to show these results and May 10th P.M. seems to show a drop in surface oil. However, May 11th and May 12th show similar surface expressions although the latter should be displaying more oil. Therefore, these observations provide inconclusive results.

The R/V Brooks McCall field study (Appendix 7) gave some droplet size distribution information but not with sufficient clarity to separate the amount of oil chemically dispersed from the amount of oil naturally dispersed. Analysis was ongoing at the time of preparation of this report and may yet provide useful guidance on this matter.

Given the limited nature of the field data, the best that could be done was to estimate effectiveness using the experience and knowledge of dispersant experts. Unfortunately, reaching consensus among the experts was not possible.

Oil Budget Calculator

Deepwater Horizon

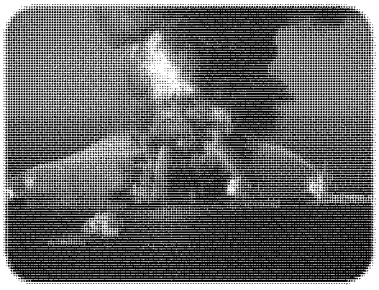
TECHNICAL DOCUMENTATION

November 2010

A Report by:

The Federal Interagency Solutions Group,
Oil Budget Calculator Science and Engineering Team

Oil Budget Calculator
Deepwater Horizon



TECHNICAL DOCUMENTATION

A Report to the National Incident Command

November 2010

This document is the product of several individuals who were consulted on particular aspects of the Oil Budget Calculator, provided field data, suggested formulas, analysis methods, and/or reviewed the algorithms used in the calculator.

LEADS:

Lehr, Bill	National Oceanic and Atmospheric Administration (NOAA)
Bristol, Sky	U.S. Geological Survey (USGS)
Possolo, Antonio	National Institute of Standards and Technology (NIST)

MAJOR CONTRIBUTORS OR REVIEWERS: (See Appendix 9 for short biographies)

Expert	Affiliation	Major contribution
Allen, Alan	[redacted]	In-situ burning
Boufadel, Michel	[redacted]	Review
Coolbaugh, Tom	[redacted]	Review
Daling, Per	[redacted]	Field data
Fingas, Merv	[redacted]	Emulsion
French McCay, Debbie	[redacted]	Review
Goodman, Ron	[redacted]	Review
Jones, Robert	[redacted]	Evaporation
Khelifa, Ali	[redacted]	Dispersion
Lambert, Pat	[redacted]	Review
Lee, Ken	[redacted]	Field data
Leifer, Ira	[redacted]	Hydrates
Mearns, Alan	[redacted]	Biodegradation
Overton, Ed	[redacted]	Dissolution
Payne, James	[redacted]	Review

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Many others contributed directly or indirectly to the Calculator development but were not necessarily involved in the preparation of this document. Some are listed below:

Expert	Affiliation	Major contribution
Beegle-Krause, C.J.	[redacted]	Subsurface oil
Farr, Jim	[redacted]	Oil chemistry
Galt, Jerry	[redacted]	Review
Hammond, Steve	[redacted]	Interface
Lacheras, Juan	[redacted]	Natural dispersion
Mabile, Nere	[redacted]	In-situ burning
Miller, Mark	[redacted]	Initial summary
Svekovsky, Jan	[redacted]	Remote sensing
Yapa, Pooji	[redacted]	Subsurface oil

The Coastal Response Research Center (CRRC), a partnership between the National Oceanic and Atmospheric Administration and the University of New Hampshire, provided logistical support with document preparation and the peer-review process. Particular thanks to Nancy Kinner, Zachary Magdol and Kathy Mandsager.

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EXECUTIVE SUMMARY

An oil budget (ICS Form 209) is normally prepared as part of the Incident Action Plan for ordinary oil spills. The Deepwater Horizon spill was anything but ordinary, and a special tool had to be developed to construct a workable oil budget useful to the unified command in making its response decisions. This report describes that tool.

The National Incident Command (NIC) assembled several interagency expert scientific teams to estimate the volume of BP Deepwater Horizon oil that has been released from the well and the short-term fate of that oil. The expertise of government scientists serving on these teams was complemented by non-governmental and governmental specialists providing data, offering suggestions, and reviewing the calculations and conclusions.

The Flow Rate Technical Group (FRTG) and the Department of Energy (DOE) developed estimates of the flow rate and of the total volume of oil released. A second interagency team, led by the U. S. Geological Survey (USGS) from the Department of the Interior, and the National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) from the Department of Commerce, developed a tool called the Oil Budget Calculator to determine what happened to the oil.

The Oil Budget Calculator was designed to assist the Situation Unit of the Incident Command System (ICS). Therefore, its sole purpose was to inform and advise the response, and it should not be used to assess environmental damage or any other purpose.

The Calculator became operational on June 22, 2010 but continues to undergo modification and refinement, not only best to characterize what happened to the oil in this case, but also to assist in the response to future, similar spills. The numbers in this report may change as new information becomes available. The calculator assumed as an input the estimated 4.9 million barrels of oil discharged in total from the well from April 20 until July 14, 2010, provided by FRTG/DOE, and used both direct and indirect measurements and the best scientific estimates available to determine what has happened to the oil.

This report discusses the methods used to estimate the portions of that volume that were recovered directly from the well head, dispersed either chemically or naturally, evaporated or dissolved, burned or skimmed, and the portion left over ("other" oil) that may still be amenable to response actions. The latest results, by and large, are consistent with early results, produced by an early version of the Calculator and announced in a NOAA press release of

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August 4, 2010: the early estimate of the percentage of "other" (or, "residual") oil was 26%; the current version of the Calculator estimates it at 23%, and qualifies this estimate with the belief that, with high confidence, the true percentage should be between 11% (best-case scenario) and 30% (worst-case scenario).

The report also describes the methods used to qualify such estimates with uncertainty assessments. Processes such as direct capture and burning, that were directly measured on-scene, have the smallest uncertainty. Processes such as dispersion that have to be estimated based upon limited data, theoretical considerations and expert knowledge from past incidents, have the greatest uncertainty. The emphasis was on getting a conservative answer so as not to underestimate cleanup requirements. In terms of response, this translates into using conservative estimates for cleanup efficiency, particularly with regard to skimmer efficiency and dispersant success.

The Calculator does not track the final fate of the spilled oil. Instead it estimates oil that may be amenable to response decisions as opposed to oil that is not (e.g. dissolved or evaporated oil). No attempt was made to estimate the amount of dispersed oil that reached the sediments; nor was degradation rate of any of the oil components evaluated quantitatively. The focus was on estimating the fraction of the spilled oil that might still be amenable to response actions, so that informed decisions could be made.

The Oil Budget Calculator is believed to be sufficiently accurate to meet the needs of the Deepwater Horizon spill response. Thus, while it may have underestimated dispersed oil, it predicted sufficient amounts of subsurface oil as to encourage a large-scale water-sampling program. Suggestions are provided at the end of the report that would allow improved budgets in future large-scale incidents.

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LIST OF ACRONYMS

ASA	Applied Science Associates
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
BOP	Blowout Preventer
DOE	Department of Energy
DOI	Department of the Interior
DOR	Dispersant to Oil Ratio
DWH	Deepwater Horizon
FRTG	Flow Rate Technical Group
ICS	Incident Command System
ITOPF	International Tanker Owners Pollution Federation Limited
LISST	Laser In Situ Scattering and Transmissometry
MNS	Mackay-Nadeau-Steelman Laboratory Test
NIC	National Incident Command
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOAA/ERD	NOAA's Emergency Response Division
NRC	National Research Council
ORR	Oil Recovery Rate
PAH	Polycyclic Aromatic Hydrocarbon
RE	Recovery Efficiency
ROV	Remotely Operated Vehicle
SMART	Special Monitoring of Applied Response Technologies
TE	Throughput Efficiency
USCG	United States Coast Guard
USGPA	United States Gallon per Acre
USGS	United States Geological Survey
WHOI	Woods Hole Oceanographic Institute

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1. INTRODUCTION

The Oil Budget Calculator grew out of a need to provide status of the spilled oil to the National Incident Command. Excel spreadsheets were first created to record volumes of skimmed oily water, of oil burned, and of dispersant applied. Later, the number of barrels that were directly captured was also recorded. However, there was no accounting for the fate of the remaining oil, and as the model became increasingly complex, the spreadsheets became difficult to interpret. Therefore, the U.S. Geological Survey (USGS), the U. S. Coast Guard, the National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) developed the Calculator, using data and supplementary expertise provided by non-government experts. The Calculator became operational, as a response tool, on June 22, 2010. However, it continues to undergo modification and refinement.

This document discusses the technical understanding that was captured in the model implemented in the Calculator — a simplified model that has evolved over time since it was first applied to produce results announced by NOAA on August 4, 2010 —, presents an assessment of the oil fate at the time of the well having been capped for good, and gives recommendations for future research. The aforementioned early results (published in a NOAA press release) included the estimate of 26% as the percentage of residual or "other" oil. The latest results presented in this report update this estimate to 23%, and assert that, with high confidence, the true percentage should be between 11% (best-case scenario) and 30% (worst-case scenario).

Because this matter has drawn the attention of scholars and other interested parties outside the oil spill science community, additional background material is included. However, in the end, this report is still only the technical documentation of a tool used for response, and it is neither a comprehensive review of the relevant technical literature, nor a research contribution intended for publication in a professional journal. Interested readers seeking more background on oil spill science are referred to Lehr (2001), NRC (2003), or Reed et al. (1999). Appendices describe the statistical approach used to qualify the Calculator's estimates with uncertainty assessments, the Calculator itself, the raw data used in the Calculator, and supporting findings of laboratory and field studies.

It is important to remember that the Deepwater Horizon incident was an emergency, not an experiment. In spill emergencies, decision makers need immediate information that

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sometimes requires estimates of unknown quantities without as much data as a scientific study normally would demand. Some of the processes governing the fate of the oil are poorly understood and knowledge about them mostly consists of the personal experience of skilled spill responders. In developing the Calculator, the team handled these poorly understood phenomena by constructing a simplified model that the participating experts could reach a consensus on, or by choosing compromise values (for rate or other constants, for example) if a consensus could not be reached.

The usefulness and accuracy of the Oil Budget Calculator needs to be assessed in light of its purpose, further discussed below. The answers that the Calculator provides to the response team only need to be accurate to the extent that they correctly inform cleanup decisions and do not lead to errors in response actions. Accuracy beyond that level, while desirable from a scientific viewpoint, is superfluous for the purpose for which the tool was designed. Hence, potentially large errors (e.g., in estimates of volumes of dispersed oil) likely would be inconsequential unless they would have led to misdirected response activities: we are not aware of instances of such misdirection in this case.

The reader is cautioned that the numerical values stated in this report are estimates based on the information available at the time that the estimates were produced, and are based on the simplified understanding that the time constraints of the response allowed: therefore, not only are they tentative, but most likely will change as new information becomes available. For this reason, the final mass balance calculation of the Deepwater Horizon Spill lies somewhere in the future, to be produced only after all the appropriate and necessary studies will have been completed.

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2. PURPOSE AND BRIEF DESCRIPTION OF THE OIL BUDGET CALCULATOR

Once spilled into the marine environment and moved from the source, the oil interacts with the environment in a number of processes collectively called weathering. Figure 1 shows some short-term processes that acted on this spilled oil. These processes change both the composition and properties of the oil, and can result in the amount of oil in the water environment being continually reduced. Other longer-term processes such as biodegradation, photo-oxidation, and sedimentation may have an impact on the environment but are less amenable to response decisions.

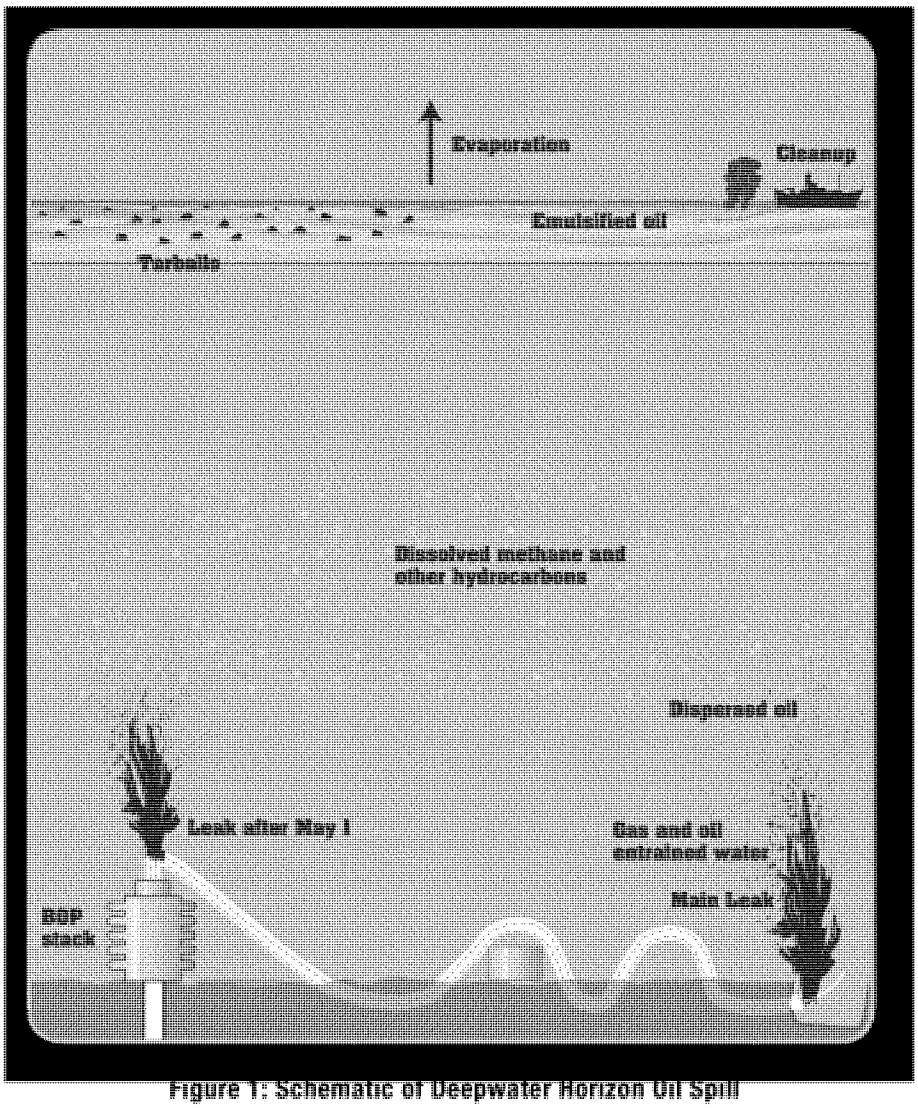

Figure 1: Schematic of Deepwater Horizon Oil Spill

The Oil Budget Calculator was designed to assist the Situation Unit of the Incident Command System (ICS). ICS was developed to provide federal, state, and local governments, as well as private and not-for-profit entities, with a consistent framework for the preparation for, response to, and recovery from any incident or event, regardless of the size, nature, duration, location, scope, or complexity. The ICS Form 209 provides the mass balance information that the unified command needs to assess the size of the threat and make informed response decisions. Preparing the mass balance tables for an ICS 209 form is usually a straightforward process. Vessel tanks are sounded, reports from the field estimate oil amount recovered or beached, and standard fate and behavior models, perhaps coupled with trained observer overflights, provide the remaining numbers for the tables. Such was not the case for the recent Deepwater Horizon Spill. Instead, the most sophisticated technology, involving expertise and apparatus never before used on oil spills, was necessary to construct even the most rudimentary mass balance table. The Oil Budget Calculator was a combined effort of several federal agencies, leading academics in the field of spill science, and practical response experts with years of actual spill experience. Its results are a product of field measurement, scientific analysis and practical cleanup expertise. The emphasis was on getting a conservative answer. In terms of response, this translates into using conservative estimates for cleanup efficiency, particularly with regard to skimmer efficiency and dispersant success.

The application of the tool defined its design requirements:

- Calculator must be operable by response personnel, not specialized staff, and use easily accessible input data.
- Calculator must generate output that provides information similar to the standard ICS 209 form along with some estimate of the confidence of the answers generated.
- Calculator must be able to deal with incomplete, uncertain, or missing data and still provide the best estimate available to the unified command.
- The Calculator should be conservative in its answers (i.e., it should err on overestimating oil that is still available to cleanup activities as opposed to oil that is outside of response capabilities).

It is important to understand what the Calculator is not designed to accomplish:

- The Calculator is not a spill research tool, although new research has been a product of its development. Simplifications were made to make it accessible to response personnel.
- The Calculator is not a damage assessment tool and is not applicable to determining environmental impact of the spilled oil. Other methods are required for this task.

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- The Calculator does not track the final fate of the spilled oil. Instead it estimates oil that may be amenable to response decisions as opposed to oil that is not (e.g. dissolved or evaporated oil).

The logical structure of the algorithm that drives the Calculator is straightforward. Mass is conserved as processes act upon the spilled oil. The chronological order that is assumed for the unfolding of these processes is based on observations from other spills and our understanding of the corresponding science. Oil that comes from the well either is directly captured or not. The portion that is not captured there, in turn either is dispersed naturally or chemically in the jet zone at the leakage points, or rises to the surface. Some of the dispersed oil dissolves into the water column. Some of the oil that floats to the sea surface either dissolves on the way up or quickly evaporates. Oil that remains on the surface can be burned or skimmed. Some of the surface oil disperses naturally or chemically into the water column. After all these processes, there will be some oil left. A brief description of the governing equations (listed in full in Appendix 1) is given below.

(1) *Subtract off direct recovery from the total amount escaping from the reservoir.* While this oil does not enter the Gulf waters, it was important to record this amount for the Unified Command since logistical assignments depend upon it. If $V_R(t)$ is the oil volume discharged on day t and $V_{DT}(t)$ is the amount of oil directly recovered, then the effective discharge, $V_{RE}(t)$, is given by

$$V_{RE}(t) = V_R(t) - V_{DT}(t) \tag{1}$$

(2) *Determine the lower water column chemical dispersion amount.* The amount of oil that is dispersed as a result of the injection of dispersants is calculated. To guarantee that mass balance is maintained, this amount cannot exceed the effective discharge. Some of the oil that is dispersed as small droplets will have a portion of the hydrocarbons dissolve into the surrounding water. Subtracting this gives $V_{DC}(t)$, the net chemically dispersed oil:

$$V_{DC}(t) = (1 - k_7)\min(90k_2V_{CB}(t), V_{RE}(t)) \tag{2}$$

Here, $V_{CB}(t)$ is the volume of dispersing chemicals injected into the subsurface jet. The rate constants k_2 and k_7 are defined in Appendix 1 along with the other rate constants.

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They are treated as random variables whose probability distributions describe our incomplete knowledge about their values, which is a consequence of our uncertainty about the exact attributes of the physical process the equations attempt to model.

(3) *Determine natural dispersion from the leaking jet.* From oil that is not chemically dispersed, compute the fraction that is naturally dispersed. Again, subtract oil that dissolves from the droplets.

$$V_{DN}(t) = (1 - k_7)\max(0, k_1(V_{RE}(t) - V_{DC}(t)/(1 - k_7))) \tag{3}$$

(4) *Calculate the dispersed oil near the bottom.* Add the amount that is chemically dispersed and naturally dispersed near the bottom. This oil is not available for evaporation, nor is the oil that dissolved near the bottom.

$$V_{DB}(t) = V_{DC}(t) + V_{DN}(t) \tag{4}$$

(5) *Compute skimmed oil as a fraction of oily water recovered.* Not all the liquid recovered by mechanical recovery, V_{OW}, is oil. The rate constant k_6 specifies that fraction. $V_{NW}(t) = k_6 V_{OW}(t)$ defines the net skimmed oil. Oil at all stages of weathering is skimmed. The model makes the assumption that the majority of the skimmed oil is 'older' oil. Hence, this oil is assumed to have already lost all oil that might evaporate.

(6) *Determine oil that evaporates or dissolves.* Compute oil that evaporates from surface oil during its first day on the surface or dissolves. Add evaporation from the second day on the surface plus oil that dissolves from dispersed oil. Let $Z = V_{RE}(t) - V_{DB}(t)/(1 - k_7)$ be the oil that makes it to the surface on day t. The oil that rose to the surface on day t-1 and is still left (neglecting natural surface dispersion and skimming) is $W(t-1) = (1 - k_4)Z(t-1) - V_{BU}(t-1)$. Since evaporation and dissolution are combined, dissolution from the bottom is added to V_E, the net evaporated or dissolved, where

$$V_E(t) = k_4 Z(t) + k_5 W(t-1) + \frac{k_7}{1 - k_7} V_{DB}(t) \tag{5}$$

Here V_{BU} is the volume of oil that is burned in-situ. The model uses reported values for daily volumes burned as one of its inputs. Since the burns involve oil that will have reached the

surface at any prior point in time, occasionally the total volume burned on a particular day may exceed the amount of oil surfacing on that day.

(7) *Determine natural surface dispersion.* Surface dispersion, V_{NS}, is a competitive process with emulsification and the potential for dispersion decreases as the oil weathers on the surface. Disperse the surface oil that is available for surface dispersion, after subtracting evaporation and burning:

$$V_{NS}(t) = k_8 \max(0, W(t)) \tag{6}$$

(8) *Determine chemically dispersed oil near the surface.* Compute volume of chemically dispersed oil from surfactants sprayed on the surface slicks, $V_{DS}(t)$. Check that it does not exceed oil volume on the surface, based upon $V_S(t-1)$, which is the total volume of surface oil remaining from the day before.

$$V_{DS}(t) = \min(20k_3 V_{CS}(t), V_S(t-1)) \tag{7}$$

Here, $V_{CS}(t)$ is the volume of dispersants used on day t. The remainder is then added to the "Other" oil category. For the purpose of the Calculator, this "Other" oil is treated as if it is all on the surface, when in fact some of it is not.

Appendix 1 lists all the equations used in the current version of the calculator, and explains how the uncertainty assessments for the estimates were produced. The corresponding results are described in Appendix 2, and are summarized in Figures 12 and 13.

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3. PREVIOUS EXPERIENCE THE IXTOC SPILL

The Deepwater Horizon incident is not the first large oil spill in the Gulf of Mexico. In June of 1979, the Ixtoc I exploratory well in the Bay of Campeche blew out, releasing oil for 290 days. It was the largest spill in history, at that time, totaling approximately 3.5 million barrels. The well was in much shallower water (165 ft) than the Deepwater Horizon.

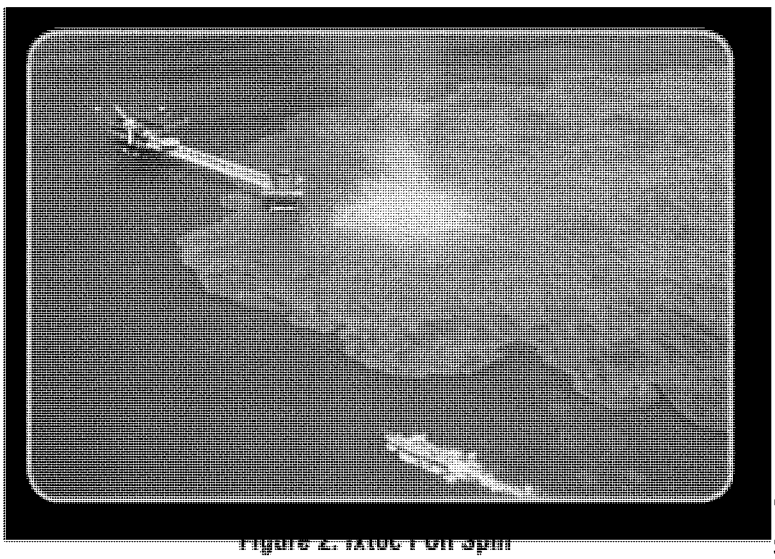

Figure 2. Ixtoc I Oil Spill

In many ways, the present Deepwater Horizon spill and response is similar to Ixtoc incident. For example, in both cases the oil released at the well was saturated with gas and formed an emulsion on the surface. In terms of the response, various devices were employed at the Ixtoc and Deepwater Horizon but were unsuccessful at stopping the flow of oil from the well. Again in both situations, eventually a relief well was employed to stem the flow. As for countermeasures, literature states mechanical recovery removed about 4-5% of the oil from the water surface during Ixtoc, which appears similar to the Deepwater Horizon incident. Large-scale dispersant operations were undertaken on oil on the water surface. In both events there was an impact on the fishing industry from the outright ban or local restrictions on fishing.

As much as the two incidents were similar, there are key differences. It is not the objective of this report to directly compare the two spills. However, as it relates to the subsequent discussion of the Oil Budget Calculator it is important to mention some pertinent detail.

Based on a limited literature review, the obvious difference is the depth of the oil release point where the Ixtoc I release point was approximately 165 ft (51m) below the water surface and the Deepwater Horizon release point was approximately 5000 ft. (1500m) below the water surface. Second, dispersants were used on the surface oil slick at the Ixtoc I but no subsurface application is noted (Jernelov and Linden, 1981). The loss to evaporation to the atmosphere of the Ixtoc I oil was reported as 50%. It is postulated that the circumstance of the Ixtoc I incident facilitated a larger mass of the oil reaching the water surface enabling greater overall mass loss to evaporation into the atmosphere in comparison to the conditions at the Deepwater Horizon incident.

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There appears to be some differences in the physical and chemical properties of the two oils. Literature (Jernelov and Linden, 1981, Linton and Koons, 1983) noted the Ixtoc oil was a light type with an API gravity of 32, heavier than the Deepwater Horizon oil. Detailed chemical analysis of the Ixtoc I well head oil was not available in the literature reviewed preparing for the Oil Budget Calculator report. The literature did report that the Ixtoc I oil formed a "chocolate mousse" emulsion on the water surface within kilometers of the wellhead (Overton, 1981). Empirical evidence shows that the Ixtoc I and Deepwater Horizon Macondo oils differed; this will have some bearing on the mass balance determination of the oil spills.

Finally, literature on the Ixtoc I oil spill reported that the change in the chemical properties of the spill oil along with the heavy sediment load in the water column caused a good fraction of the oil to settle on the bottom of the Gulf of Mexico. News reports published in September 2010 indicated that this might also be true for this spill. However, ongoing sampling programs have not confirmed the claim of extensive oil being present on the bottom of the Gulf from Deepwater Horizon.

Jernelov and Linden (1981) constructed the following mass balance table for the Ixtoc I oil spill which has been included here for the convenience of the readers. It should be noted the table prepared by Jenelov and Linden reports values based on information available at the time. Readers are referred to the literature for further details on the assumptions used and contradictory opinions.

Table 1: Mass Balance for Ixtoc 1

	Percent	M Tons
Burned at well site	**1**	
Mechanically removed	**5**	
Degraded biologically, photo, chemically	**12**	
Landed on Mexican beaches	**6**	
Landed on Texas beaches	**<1**	
Sank to bottom	**25**	
TOTAL	**100**	**476,000**

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4. LEAK RATE AND SUBSURFACE OIL BEHAVIOR

Oil was initially leaking from two major sources several hundred meters apart. After severing the riser in early June, oil only leaked from the single location at the blowout preventer (BOP). The leak rate varied both in the short-term and in the longer-term. The latter was due mainly to the drop in reservoir pressure. Figure 3 shows the estimated flow rate, based upon studies done by various teams of experts employing a variety of methods. Details on the measurements of the Flow Rate Technical Group (FRTG) Plume Team using image correlation velocimetry are available in the Plume Calculation Team Report (2010). At the time of this document preparation (August and September 2010), the report by the joint effort of the FRTG and Department of Energy (DOE) was still in draft form. The source estimates by FRTG/DOE were considered to be accurate to within ten percent. This uncertainty level is adopted by the Calculator, with three release rates (FRTG/DOE estimate minus ten percent, FRTG/DOE estimate, and FRTG/DOE estimate plus ten percent).

The leak was a combination of gas and oil. In fact, a key parameter in estimating flow was the average ratio of these two. The actual value seemed to vary over the time period of the spill. Increasing gas increased the velocity of the plume but decreased the mass flow. Analysis of available short movies of the riser flow showed the existence of periods when the flow oscillates from pure gas to seemingly pure oil. The DOE/FRTG consensus generally accepted an average value of 44% oil percentage by volume for the exiting flow, based upon measurements of Woods Hole Oceanographic Institute (WHOI, 2010).

The Deepwater Horizon spill was unique not only for its size but also its location at a mile beneath the water surface. In general, when oil and gas are released from a deep-water location, they are expected to break into bubbles or droplets of various sizes. These sizes can vary widely. In field trials off Norway (Chen and Yapa, 2003), they were generally between 1 mm and 10 mm. Leifer (2010) has suggested, however, that the gas bubbles for the Deepwater Horizon spill were smaller than the North Sea experiments.

The larger droplets have a relatively stronger buoyancy force to friction force than the smaller droplets (this ratio increases with diameter) and therefore move faster towards the surface than smaller droplets. If the simple form of Stokes' law is assumed (not valid for larger droplets), droplet rise/fall velocity, v_{rise}, is a function of the water viscosity, υ_w, relative density difference, $\Delta\rho$, and characteristic droplet size, d. The value of c_{stoke} varies, depending upon several factors. Figure 4 shows the rise velocity for this oil, according to Yapa et al. (2010).

$$v_{rise} = c_{stoke}\Delta\rho\frac{d^2}{\upsilon_w} \tag{8}$$

All the droplets are subject to cross currents that will move them laterally while moving upwards. For this reason the larger droplets and the smaller droplets may not come to the surface at the same location, but quite a distance apart. If there are droplets of very fine scale, it may take weeks or even months for them to come to the surface (Galt, 2010). Galt concluded that even for the large droplets, the rise time was several hours, an answer consistent with Yapa (2010) estimates. Galt also concluded that droplets in the 100 to 200 micron diameter range would take such a long time to surface from a depth of one mile that they were effectively dispersed. This is considerably larger than the common maximum diameter size limit for dispersed oil droplets of around 60-80 microns (Lehr, 2001; NRC 2005). Spaulding et al. (2000) estimated that the rise time for 200 micron droplets with specific gravity of 0.81, less dense than this oil, would have a rise time from this depth on the order of a week.

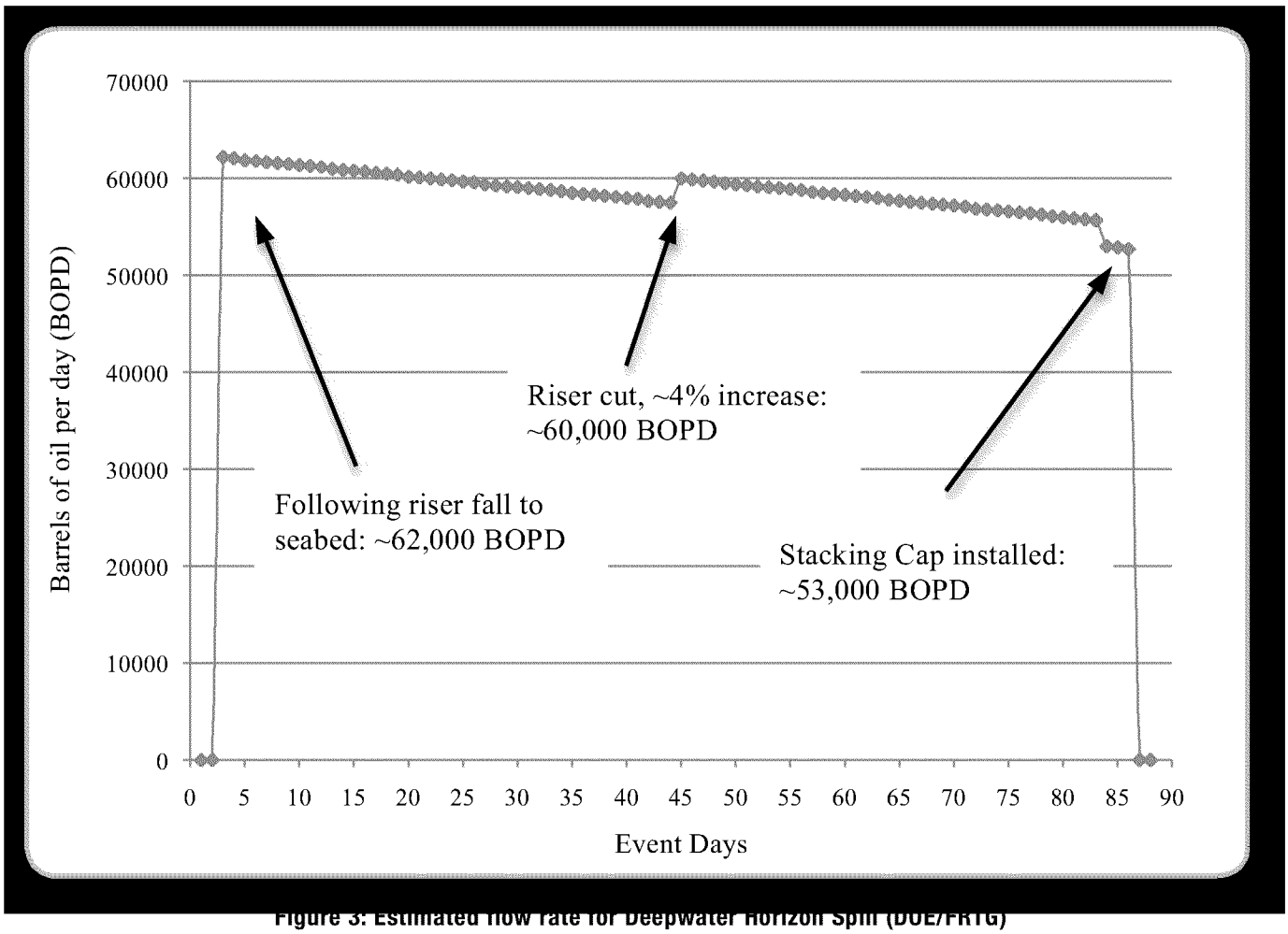

Figure 3: Estimated flow rate for Deepwater Horizon Spill (DOE/FRTG)

However, the large surface slicks showed that a good percentage of the released oil did make it to the surface. The remote sensing effort of the NASA ER/2 equipped with Airborne

Visible InfraRed Imaging Spectrometer (AVIRIS) surveyed about 30% of the core area of the surface spill on May 17, 2010. Extrapolating the examined area to the whole slick, Clark et al (2010) estimated that a minimum of floating oil of between 66,000 and 120,000 bbl. Limitations of the instruments do not allow measurement of very thick oil. The report suggested that if adjustments were made for this limitation, the surface oil could be as much as 500,000 bbl. According to the DOE-FRTG estimates, approximately 1.6 million bbl had been released from the well-head by that time. This suggests that somewhat less than a third of the oil had reached and remained on the surface if the report's hypothesis is correct. Since sub-surface recovery and dispersant applications were limited preceding this date, this estimate is not inconsistent with the later estimated values of remaining oil produced by the Oil Budget Calculator.

The plume also contained gas of many bubble sizes. For this incident, a large amount gas bubbles dissolved and may never have made it to the surface. Gas bubbles move faster than oil bubbles if they are the same size. Because of this, gases can separate from the main plume and start going in a slightly different direction (Chen and Yapa, 2004). Gases when released in deep-water, also have the potential to be converted into hydrates. Methane has a level of hydrate dissociation generally around 550 m of water depth as shown in Figure 5. This is not a fixed value. It depends on parameters like water temperature and gas type (Spaulding et al, 2000). Natural gas can get converted to hydrates at a much higher level. Therefore, gases can get converted into hydrates as they travel up. Hydrates are still buoyant with specific gravities of around 0.92 to 0.96. As hydrates travel towards the water surface they can get reconverted back into gas when they reach the lower pressure in the shallower regions (Leifer, 2010). Where the oil to gas ratio is sufficiently high, rather than an oily bubble, the aggregate is better described as a droplet with internal bubble. He concludes this effect could be very significant. For a primarily gas bubble (i.e., very low oil to gas ratio), in contrast, the effect of surface flow around the bubble pushing surface materials towards the downstream hemisphere could minimize any oil effect. This blowout occurred at far greater pressure than has been studied in the Deep Spill study (Johansen et al. 2000), or the lab (Masutani and Adams (2000), at depths where hydrate formation is far more rapid (Rehder et al. 2009). The oil budget calculator does not keep track of the gas bubbles, hydrates or dissolved gases.

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5. DISSOLUTION

Unlike a typical spill, oil from the Deepwater Horizon spill entered the marine environment 5000 feet below the surface of the Gulf, and started weathering before it reached the air-water surface. Because of the nature of the material flowing from the riser, which was a miscible mixture of oil and natural gas, significant dispersion of the liquid oil occurred near the wellhead. Some of the oil droplets were so small, less than a 100 microns in diameter, that the turbulent diffusivity of the water was enough to overcome the oil's natural buoyancy, and caused the micro droplets to be dispersed at depth by ocean currents. Larger droplets floated to the surface, however the speed of the transit was determined by the size of the drops. Larger accumulations of droplets of oil rose fairly quickly while smaller droplets rose slowly and were dispersed further from the spill site by currents in the water column.

The important point about this movement of oil from the wellhead is that oil in tiny droplets is exposed to weathering processes both at depth as well as on its transit to the surface, and once on the surface, weathering continues. Another important point is that much of the oil moved through the marine environment as tiny drops, and these drops were continually exposed to uncontaminated Gulf water in their transit. This means that the dissolution of compounds from the tiny oil droplets was not controlled by equilibrium factors, and this resulted in an almost continuous molecular extraction from the oil droplets by the water column. The results of this continuous extraction are that even sparingly soluble compounds were extracted from the droplets and dissolution was a much more important factor in the weathering of Deepwater Horizon spilled oil than it is in more common surface oil spills.

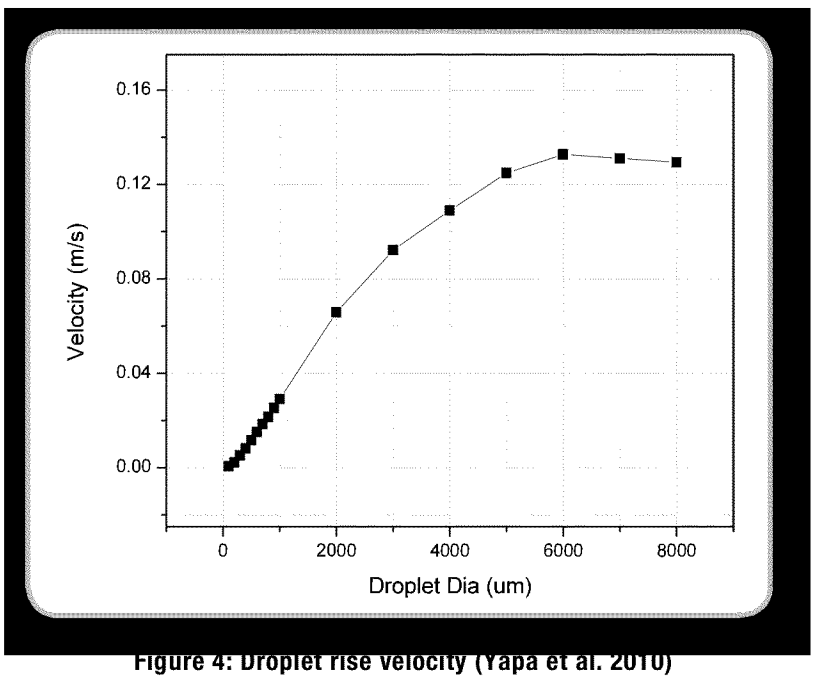

Figure 4: Droplet rise velocity (Yapa et al. 2010)

The proverb that oil and water do not mix is usually scientifically accurate when it relates to molecular dissolution of oil into the surrounding water from a surface spill. For the normal surface type spill, dissolution is less important for estimating the mass balance of the slick (NRC 2003). However, as described above, because of the nature and depth of the release, dissolution of oil into the water column was a significant weathering factor.

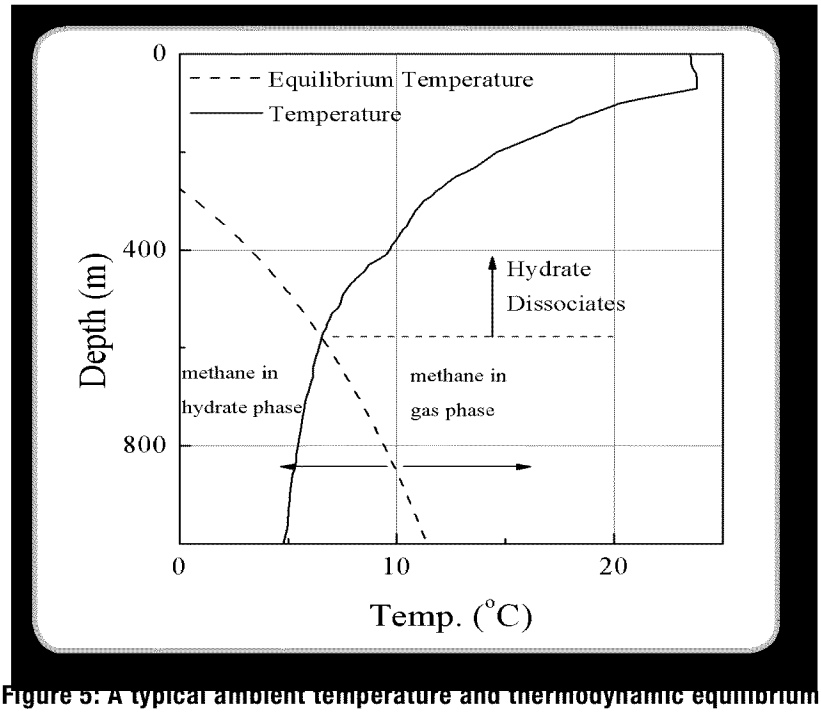

Figure 5: A typical ambient temperature and thermodynamic equilibrium curve for Methane (Chen and Yapa 2004)

The dissolution process is a very complex series of interactions between hydrocarbon molecules that are non-polar and surrounding water molecules that are polar. In general, polar molecules dissolve in polar solvents, seawater in this case, and non-polar molecules dissolve in non-polar solvents, the oil in this case. However, because of their molecular shapes, sizes, and chemical bonds, some non-polar compounds are slightly soluble in polar solvents. Such is the case when considering oil solubility in seawater. As a general rule, small mono-aromatic compounds, such as benzene and the alkyl benzenes, have significant seawater solubility compared to equivalently sized saturated compounds. This solubility extends to larger aromatic compounds, such as naphthalene and its alkyl homologues, and may also slightly extend to three-ringed aromatic compounds such as the phenanthrenes and the dibenzothiophenes. As a rule of thumb, saturate compounds are the least water soluble of the components of oil, probably because they have no significant interactions with solvent water molecules and do have significant interactions with similar non-polar compounds in the oil. The conclusions are consistent with experimental results obtained at SINTEF (Melbye at al. 1999) which showed that a component needs to have a water solubility of a

minimum 0.3 -1 mg/L in seawater (Figure 6) in order to have any significant potential to dissolve out from an oil droplet when rising to the surface. This means that n-alkanes up to maximum n-C8-9 may have a potential to dissolve but larger alkanes have very limited solubility potentials. However, the mono-aromatic benzene compounds (the BTEX's), C0-C3 Napthalenes, and the C0-C1-alkylated 3-rings PAH can be stripped out of oil droplets because of their water solubilities. The bottom line is that when tiny droplets of oil transit the water column to the surface, many of the low molecular weight one, two and maybe three-ringed aromatic compounds can be dissolved into the water column. This dissolution can affect both the toxicity and physical properties of surface oil from deepwater releases.

Few models or studies exist for oil dissolution at spills, mostly in dated work and older generation spill models. Mackay and Shiu (1975) measured the aqueous solubility of fresh and weathered crude oil. Payne et al. (1984) reported that studies of Prudhoe Bay crude found that truly dissolved components were almost exclusively alkyl-substituted lower weight mono-aromatic hydrocarbons with very little n-alkane dissolution. The dissolution rate depends directly upon surface area, which was proportionally larger per volume spilled for this spill incident compared to a normal surface spill by factors of 100 to 1000. Mackay and Leinonen (1977) concluded that, for droplets less than 100 microns in diameter, dissolution is very rapid for any component that will dissolve at all. Any remaining material in the droplet will consist of relatively insoluble saturate hydrocarbons, i.e. hydrocarbons with a carbon number greater than about 8, and larger multi-ringed aromatic PAHs. While the droplets that made it to the surface were larger than 100 microns, the extended time that it took for them to reach the surface suggests that dissolution of even marginally soluble compounds occurred.

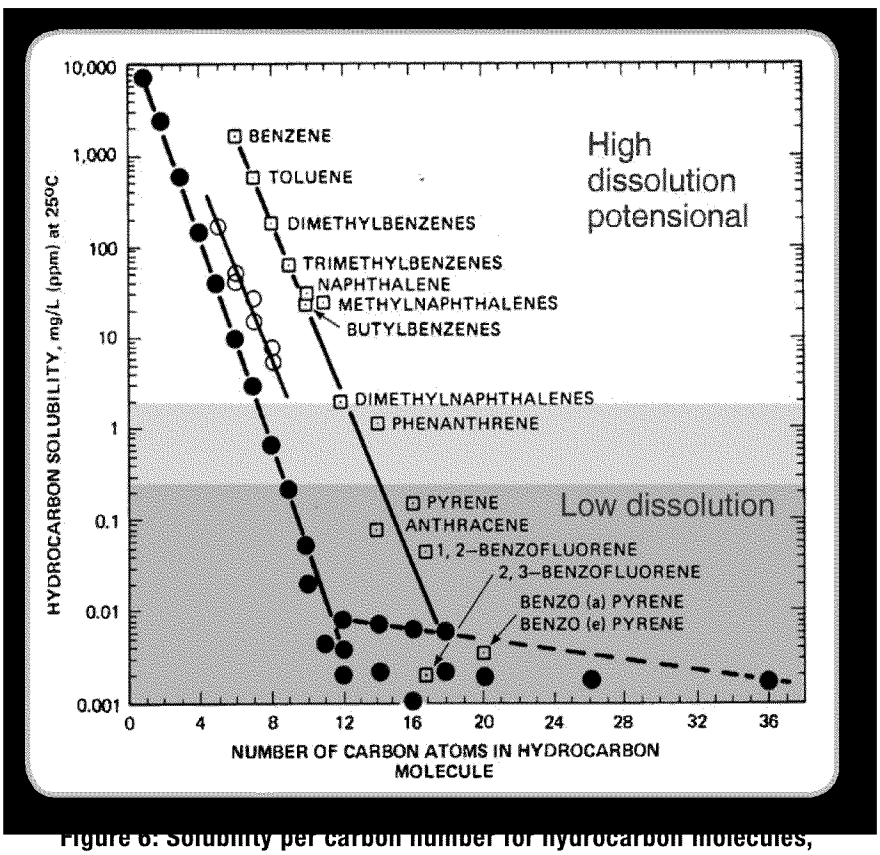

Figure 6: Solubility per carbon number for hydrocarbon molecules, (Modified from McAuliffe, 1987 IOSC - proc. Pp 275-288)

It should be pointed out that initial chemical analysis of some samples collected below the Gulf's surface indicates that significant dissolution did occur. One and two ringed aromatic compounds, and some of the three ringed sulfur heterocyclic aromatic compounds, appear to have been dissolved during transit from the wellhead. These compounds have carbon numbers above 10, and there is some evidence that normal alkanes were also slightly affected by the long transit that occurred as oil drops moved through the water column.

Based upon the chemistry of the oil and the above discussions, it was estimated that any oil exposed to conditions that could lead to dissolution would lose between 5-10% of its volume this way. Since many of these same molecules would evaporate, this process was included in the evaporative losses estimate for any oil that made it to the surface. However, dissolution is subtracted from oil dispersed near the bottom that never reaches the air-water interface. These estimates may change as further studies underway at SINTEF and elsewhere provide additional information. At a minimum, it may be possible to separate dissolved fraction from evaporative fraction. If, on final review, we find that water samples with oil droplets were collected just below the water surface, then by using GC-MS, it is possible to look at the changes in ratios between the more semi-volatile aromatics (e.g. 2-3 rings PAH's and their alkyl homologues) versus the corresponding n-alkanes with same boiling Points (similar vapor pressure, but with far less solubility). In that way, it would be possible to say more specifically how much of the depletion of the components in the range of C10 -C17 is due to dissolution, and how much is due to evaporation. Such information would be useful for impact assessment but, for the purpose of response, would be of limited value. The Oil Budget Calculator groups dissolution and evaporation.

6. EVAPORATION

Laboratory and field studies of oil weathering under wide ranging conditions and for a wide range of crude oils demonstrate that surface slicks quickly lose volatile components to evaporation. As the more volatile compounds are lost, the rate of evaporation slows. Evaporation is often the most significant loss mechanism from surface slicks during the first week following a spill. Generally, after a week at sea, evaporation is no longer a significant loss mechanism for surface oil. For light crude oils, such as this oil, the great majority of the evaporative loss occurs within a couple days of its exposure to the air.

Empirical methods were used to estimate the evaporation rate during this spill. Samples of weathered oil collected from the sea surface were analyzed using GC/MS. Laboratory weathering of the source oil provided an independent assessment of evaporative behavior. Estimations of evaporation rates were not based on model predictions; rather models were used in analyzing data from field measurements.

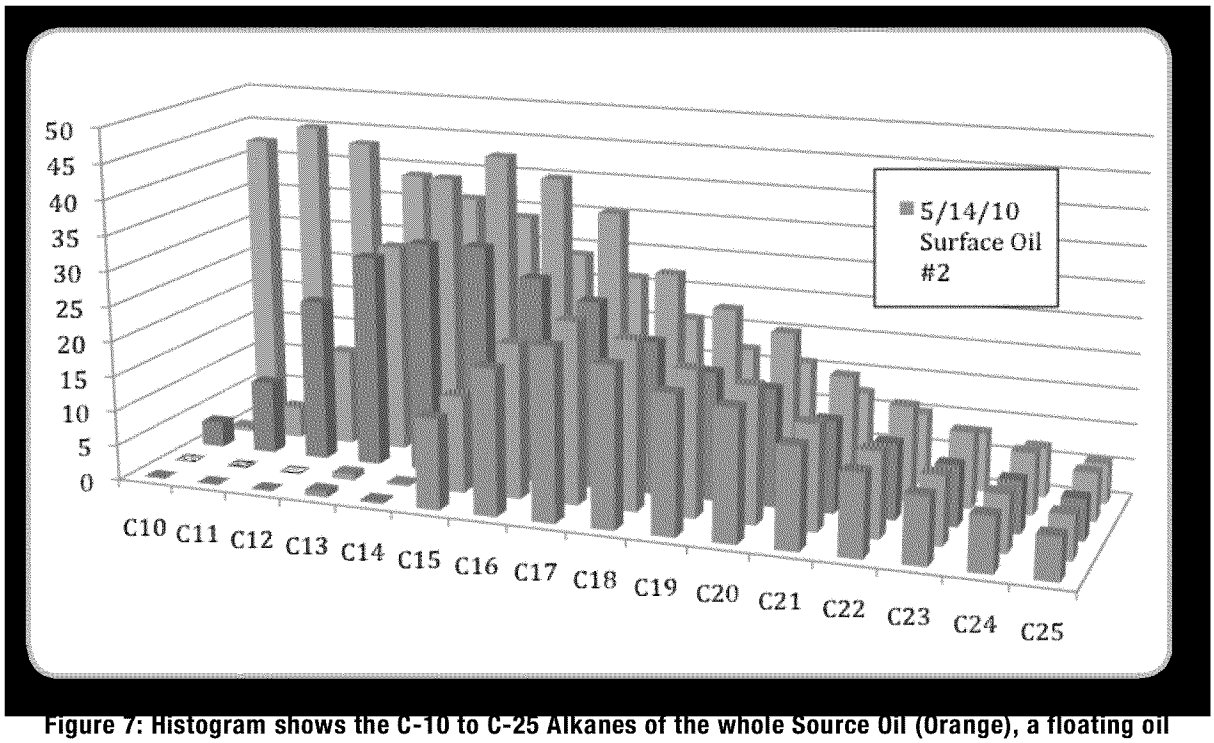

Figure 7: Histogram shows the C-10 to C-25 Alkanes of the whole Source Oil (Orange), a floating oil sample immediately adjacent to the source (red), and two floating oil samples at a relatively highly weathered oil further away from the source (green, purple). The highly weathered samples show that virtually all the alkanes below C-15 have been stripped from the original source oil. (Blue bar graph is sample from dispersant efficiency testing).

Evaporation changes not only the volume of a surface oil slick, but changes the chemical composition of the oil as well. Because smaller chemical compounds are preferentially lost during evaporation, it affects the relative abundance of individual chemical compounds within the oil. These changes can be observed by comparing the composition of unweathered oil to that which has weathered on the surface. Other loss processes, such as dissolution, can also change the composition of the oil. While dissolution is usually not a dominant loss mechanism for surface spills it might be significant for releases in deep water. Without the appropriate samples, it was not practical to try to resolve the relative importance of dissolution and evaporation, so these two losses are grouped. Oil that never reached the sea surface is not susceptible to evaporative loss, so the measured estimates of fraction evaporated only applies to the oil that surfaced.

Pseudo-component models (Payne et al. 1984; Kirstein et al. 1984) were used to process measured data. These models approximate the oil as an ideal mixture of a relatively small number of components, each component representing a range of individual chemical compounds with similar vapor pressures. Each component is characterized by a mole fraction and a vapor pressure. The rate, per unit area, at which a component evaporates from the surface slick is proportional to the wind speed, the mole fraction of that component within the oil (which varies with time), and the vapor pressure of that component (which varies with the temperature of the oil, assumed to be the same as the water temperature). The rate equations for the components are solved simultaneously. The total evaporation rate is set equal to the sum of the rates of the individual components. This method has been adapted for an oil-weathering model, ADIOS2™, developed by NOAA (Jones 1997), the Type A model developed by ASA (French et al., 1996) and the OWM model developed by SINTEF (Reed, Singsaas et al. 2001).

NOAA's Emergency Response Division (NOAA/ERD) measured the composition of several oils (Figure 7). For the purpose of this discussion on evaporation, in Figure 7 we focus on the oil from the reservoir (Source oil, orange) and the two weathered oils (green and purple) collected from the sea surface on, or around, 16 May. It is not known how long the weathered samples were on the sea surface before being collected. GC/MS analysis was used to measure the relative abundance concentrations of chemical compounds that make up the oil. The weathered oil samples exhibited an expected depletion of the more volatile compounds. The pseudo-component evaporation model used in ADIOS2 (Jones 1997) was initialized with oil-composition data provided by BP in conjunction with oil-composition data measured by NOAA/ERD. The ratio of components measured in the more weathered oil samples was compared to those predicted by the model. The extent of evaporative loss was based on the correlation between the measured and modeled ratios. These two weathered oil samples exhibit an average mass loss of 36%. Since the age of these samples is not known, this provides a lower bound on the possible evaporative loss of the surface oil.

SINTEF analyzed three samples of floating oil collected on June 4th and 5th for fraction evaporated (Leirvik, Daling et al. 2010). They analyzed the samples by GC/MS and related the fraction evaporated to the depletion of alkanes in the C14 to C16 range. They correlated the degree of evaporation with the depletion of these peaks using past results. Their measured data indicated a mass loss to evaporation of 44%, 47%, and 50%. They estimate that the time at sea for these three samples was 1-2 days, 2-3 days, and 4-5 days, respectively.

Laboratory measurements performed by S.L. Ross Environmental Research Ltd. (S.L. Ross Environmental Research Ltd., 2010) on unweathered Deepwater Horizon oil were consistent with measurements of the above-mentioned surface oil samples. They artificially weathered a 2cm thick slick of Deepwater Horizon oil in a wind tunnel for 2 weeks. They measured that approximately 35% had evaporated after 2 days, and 45% after 2 weeks. Their measurements exhibit a cumulative evaporation, which is essentially a logarithmic function of time with the majority of the evaporation occurring in the first few days.

Camili et al. (Camili, Reddy et al. 2010) from Woods Hole Oceanographic Institute measured the composition of oil collected from the top 30 m of the water column. They made no attempt to quantify the fractional loss but did attribute the loss of the more volatile compounds to evaporation. Their measurements can be viewed as an additional observation suggesting substantial evaporative loss.

As mentioned above, dissolution also affects oil composition and so losses to dissolution must be considered as contributing to the measured values. Measurements reported here constitute lower bounds to the possible combined losses to evaporation and dissolution of oil that reached the surface. Loss fractions range from 36% to 50% and are self-consistent. The authors of this report believe that these data provide a close lower bound to the fraction of surface oil lost to the combination of evaporation and dissolution.

The oil budget calculator based the evaporation/dissolution estimates on the compositional change observed in samples of surface oil. It approximates the evaporation/dissolution process as occurring over 2 days; the majority of the loss occurring in the first day. To simplify data entry, requirements to enter variable wind speeds were eliminated. Cumulative evaporation is sensitive to oil composition and temperature but is relatively insensitive to wind speed. The original approximation was 37% lost during the first day (potentially as high as 44% and as low as 33%) with a second day loss of 4% (potentially as high as 6% and as low as 0%). Hence the range of total evaporation of the oil that surfaced was between 37% and 50%. Currently, there is no plan to revise these values.

7. WEATHERING ESTIMATION BY EMULSIFICATION

An alternative approach to calculating mass loss has been suggested by Fingas (2010) that uses the fact that the surfacing oil formed emulsions. One important factor to the formation of emulsions is that oils often must weather to a certain percentage before a certain type of emulsion occurs. This is because the asphaltenes and resins must be at a sufficient content to stabilize the oil and also the viscosity must be high enough to retain water droplets long enough for asphaltene/resins stabilization to take place.

Oils from similar oil fields have a tendency to form similar emulsions with similar weathering tendencies. Gulf oils that formed stable emulsions had weathering percentages of 37.7, 26.2, 16.4, 25.5, 22.6, 24, and 35.2%. These average 26.8%. If the Deepwater Horizon oil shows similar tendencies, the weathering that took place near the release of the Deepwater Horizon was about 16 to 38% with the likelihood that it was near 27%. However, experimental studies by SL Ross Ltd. (see pp. 3 in Appendix 8) and studies at SINTEF showed that an evaporative loss of at least 40-45 wt %, (representing a 200 - 250C+ residue) is needed for this crude oil to start form a significant and stable emulsion. Some additional evaporation would occur as the surface oil moved away from the area, transported by winds and surface currents. Observations of large amounts of emulsified oil indicate that such emulsified oil, at least, had already weathered sufficiently to emulsify.

8. NATURAL DISPERSION

While the oil released in this spill was buoyant, not all of the oil rose to the surface. Small droplets of oil stayed suspended in the water column just as small dust particles will stay suspended in the atmosphere due to the underlying fluid turbulence. Such droplets will eventually be assimilated through dissolution and biodegradation. They also may become attached to suspended sediment in the water.

Some limited data exists on dispersed oil from the results of RV Brook McCall Survey LISST (Laser In Situ Scattering and Transmissometry) measurements performed by the Bedford Institute of Oceanography (see Appendix 7). It lends support to the hypothesis that much of the oil released was dispersed into the water column. However, since the samples were subsurface, they may be preferentially sampling the droplet distribution with the larger droplets having risen to the surface. Payne's study reported plumes of oil droplets at depths greater than 2 km. away from the source with larger droplets on the top of the plume and smaller below. This would be consistent with a large amount of dispersion and weak buoyancy. One should be careful about over-interpretation of particle size distribution data that were collected for this specific purpose during the Gulf of Mexico oil spill emergency response operations. Under this emergency response effort, rapid, less than perfect actions had to be taken to support the requirement for immediate action to monitor the fate and transport of the oil.

The NOAA oil fate and behavior model, ADIOS2, uses the dispersion formulas developed by Delvigne and Sweeney (1988). These formulas estimate the distribution of droplets sizes based upon the dissipation energy rate e. For most surface spills, the turbulent energy comes from breaking waves. Li and Garret (1998) estimate that typical dissipation rates in breaking waves range from 0.1 to 10 $m^2/\sec^3$. Others have reported different values. For example, measurements in a wave tank gave values of 0.01 to 0.1 $m^2/\sec^3$ at the surface (Wickley-Olsen et al., 2007). Field measurements showed lower values varying between about 0.1 and 1 m^2/sec^3 (Gemmrich and Farmer, 2004, Gemmrich, 2010). Additional information on the value of ε can be found in Kaku et al. (2006).

ADIOS2 suggests that if this spill occurred at the surface under average conditions, only a few percent of the oil would disperse because the oil would emulsify. If emulsification is prevented, natural dispersion could be as much as 30%.

However, it is not breaking waves but the turbulence at the leak that formed these oil

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droplets. In this case, a new method had to be developed to estimate dispersion rate. ADIOS2, following standard guidelines (NRC 2003), assumes that droplets must be smaller than 70 microns in diameter to be considered permanently dispersed. While appropriate for surface spills, it is probably too restrictive for spills happening a mile deep. The Calculator uses 100 microns as a cutoff. Based upon the earlier discussion of surfacing time, this was also too restrictive but was consistent with the conservative approach used to calculate oil fate.

Following DS, $Q(\delta)$, the entrained droplet mass density for droplets of diameter δ is given by the equation

$$Q(\delta) = C\varepsilon^{0.57}\delta^{0.7} \tag{9}$$

where C is a constant that depends upon the properties of the oil slick.

For a surface spill, ADIOS2 would expect that the dispersed oil would be

$$M_{disp(bw)} = \int_0^{70\mu} Q_{bw}(\delta)d(\delta) = C\varepsilon_{bw}^{0.57}\frac{(70\mu)^{1.7}}{1.7} \tag{10}$$

where the *bw* subscript indicates that this applies to dispersion caused by breaking waves.

If we apply this method to the subsurface leaking pipe (subscript lp) then the same equation would be

$$M_{disp(lp)} = \int_0^{100\mu} Q_{lp}(\delta)d(\delta) = C\varepsilon_{lp}^{0.57}\frac{(100\mu)^{1.7}}{1.7} \tag{11}$$

and the ratio, *R*, between the two would be

$$R = \frac{M_{disp(lp)}}{M_{disp(bw)}} = 1.8\left(\frac{\varepsilon_{lp}}{\varepsilon_{bw}}\right)^{0.57} \tag{12}$$

Thus the estimate of the increase in natural dispersion becomes a problem of estimating ε_{lp} and ε_{bw} . Lasheras (2010) has suggested that, to first approximation (Friehe et al. 1972; Gibson, 1963), the maximum theoretical dissipation rate of turbulent kinetic energy can be estimated by

$$\varepsilon_{lp} \approx U_{lp}^3 / D_{lp} \approx 7m^2 / \sec^3 \tag{13}$$

where U_{lp} is the exit velocity of the flow jet and D_{lp} is the pipe diameter. He points out that experiments by Martinez –Bazan et al (1999) show that, for distances less than 15 pipe diameters from the orifice, the dissipation rate is much smaller, perhaps as little as 0.02 $m^2/\sec^3$. If we take a mid-range value from the Li and Garret suggested bounds for breaking wave dissipation rates compared to the theoretical maximum for ε_{lp} we get virtually all of the oil naturally dispersing. This obviously does not match observation. If, instead, we use the experimental results of Martinez-Bazan et al., we get approximately 20% subsurface natural dispersion. This more conservative value was used by the Oil Budget Calculator with an assumed maximum of 30% and a minimum of 10%. The minimum value is considered to be the lowest credible estimate consistent with Camilli et al. (2010) and the maximum the largest estimate consistent with the AVIRIS and LISST results.

Lasheras also pointed out that the characteristic size D_{char} of droplets small enough not to be broken by the turbulent shear forces can be estimated by a simple function of the oil-water surface tension:

$$D_{char} = \frac{\left(\frac{1.5\sigma_{o-w}}{\rho_{oil}}\right)^{3/5}}{\varepsilon^{2/5}} \approx 10mm \qquad (14)$$

This matches the North Sea experiments discussed earlier. While the Oil Budget Calculator conservatively assumes that oil that is not dispersed near the bottom would come to the surface, this is not the case. For example, marine snow present in Gulf waters would scavenge some of the oil droplets on their journey to the surface. The extent of this affect for this spill is uncertain at this time.

Oil droplet size distribution is greatly affected by viscosity and surface tension. Since some of the lighter ends are lost through dissolution on the oil journey to the surface and since the surface oil emulsifies, the viscosity of the surface oil was quite high compared to the oil at the leaking riser. The seas were usually relatively calm, although there were periods of high winds. The original Budget Calculator assumption was that the surface oil would have negligible natural dispersion. This was consistent with the standard to conservatively estimate any reduction in surface oil through either natural or cleanup actions, although certain experts disagreed with this assumption. They pointed out that much of the initial surface oil was not on the surface after storm events. Also, the studies by SINTEF indicate that the weakly emulsified oil is dispersible with enough energy input. Therefore the Calculator was modified to include 5 % natural dispersion of surface oil, based upon ADIOS2 model results. Low value was no dispersion and high value was 10%. As in other dispersion estimations, there was not a uniform consensus by the experts on this revised estimate.

9. CHEMICAL DISPERSION

A typical commercial dispersant is a mixture of three types of chemicals; solvents, additives and surfactants. The surfactants are the active ingredient and contain both hydrophobic and hydrophilic groups. This allows them, when coating the oil surface, to reduce its surface tension by as much as a factor of 20 or more, reducing mean droplet size in droplet formation caused by turbulent shearing (Li and Garrett, 1998). Caneveri et al. (1989) measured declines in oil-water interfacial tensions from 18 mN/m without dispersant to 0.1 mN/m with dispersant. More recently Khelifa and So (2009) used a spinning drop instrument to measure declines of oil-brine interfacial tension for three different oils. Declines from 18.3 mN/m without dispersant to 6.5 10^{-4} mN/m with Corexit 9500 at 1:20 dispersant to oil ratio (DOR) were measured. The same study showed that corresponding droplet size decreases from about 220 mm to 25 mm when the DOR increases from 1:500 to 1:10. (DOR is often expressed with the 1: omitted. Therefore, a DOR of 20 and a DOR of 1:20 refer to the same ratio).

Clayton et al. (1993) noted that successful dispersion of oil in actual dispersant applications only occurs if five requirements are met.

(1) The dispersant must reach the oil surface
(2) The dispersant must penetrate the oil surface
(3) The surfactant must orient at the oil-water interface
(4) The surface tension must be reduced
(5) Sufficient mixing energy must be applied

A total of 43,884 barrels of dispersant were used at the DWH incident:

- 18,379 barrels of dispersant were used by sub-sea addition to the discharging oil and gas stream.
  - Initially this was at 12 gallons/minute, later reduced to 7 gallons per minute.
  - The EPA imposed maximum sub-sea use of 15,000 gallons/day (357 bbl/day), equivalent to 10.4 gallons/min

- 25,505 barrels of dispersant were applied to oil on the sea surface (see Figure 8).

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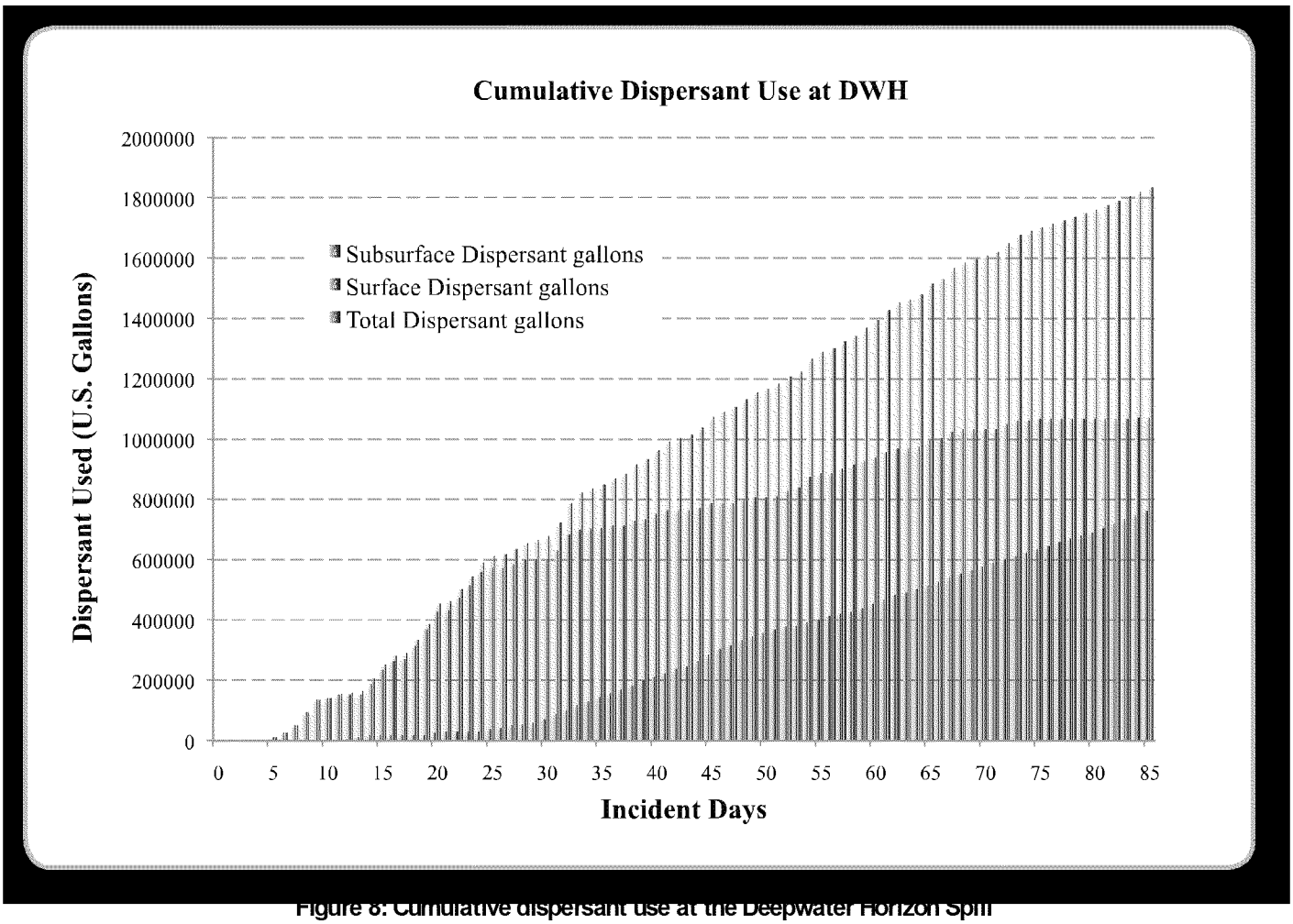

Figure 8: Cumulative dispersant use at the Deepwater Horizon Spill

Estimating effectiveness of these dispersant operations was the most difficult challenge in constructing the Budget Calculator, given the present state of oil response technology. As Lewis (2010) points out, the effectiveness of dispersant use at real oil spill incidents cannot be determined by measuring the dispersed-oil-in-water concentration in the water column with sufficient resolution in time or space to produce an accurate mass balance. Nor are there currently commercially available remote sensing techniques capable of measuring oil layer thickness with sufficient accuracy and with sufficient resolution to enable the volume of an oil slick to be determined at any point in time, or how the volume changes with time.

Some surface dispersant applications employed the SMART (2006) protocols. SMART (Special Monitoring of Applied Response Technologies) is a Federal cooperatively designed and regionally approved monitoring program for dispersant operations and *in situ* burning. However, SMART provides mostly qualitative, not quantitative, estimates of dispersant effectives. SMART teams could at best say that there was some dispersion caused by the dispersant applications.

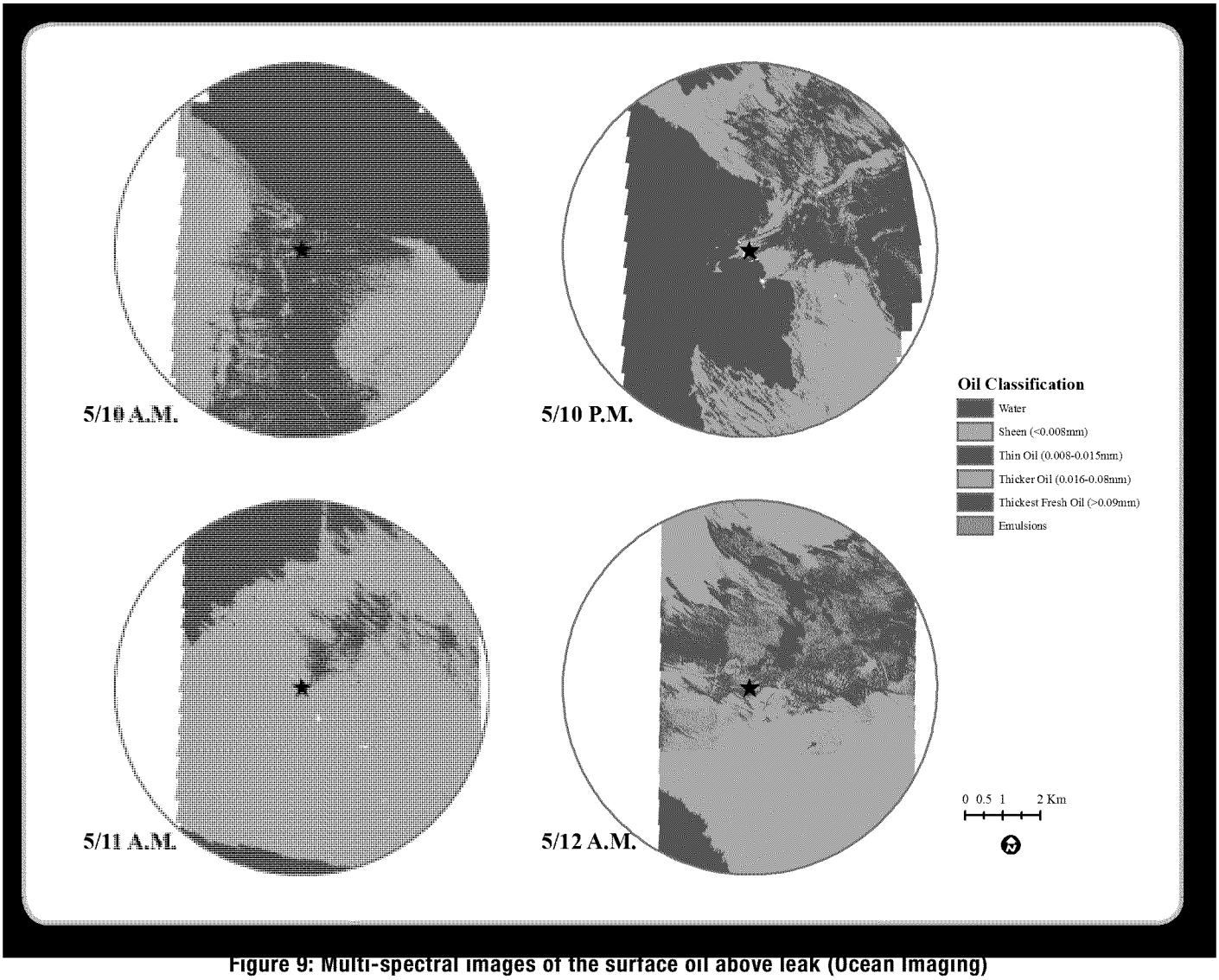

Figure 9: Multi-spectral images of the surface oil above leak (Ocean Imaging)

Ocean Imaging, using a multi-spectral scanner to estimate slick coverage at the water surface directly over the spill site, observed the oil appearance both during dispersant operations and no dispersant operations. Figure 11 shows a time period from May 10 through May 12. The individual images represent relative thickness measurements of surface oil at specific times. The larger the red area, the more thick oil is present. Surface conditions were reasonably similar during this time period. Subsurface injection began at 0430 hrs on May 10 and continued with an average injection rate of 8 gallons per minute. If the dispersant was as highly effective as suggested by certain experts, then more than half of the released oil should have been chemically dispersed. The May 10th A.M. image may be too early to show these results and May 10th P.M. seems to show a drop in surface oil. However, May 11th and May 12th show similar surface expressions although the latter should be displaying more oil. Therefore, these observations provide inconclusive results.

The R/V Brooks McCall field study (Appendix 7) gave some droplet size distribution information but not with sufficient clarity to separate the amount of oil chemically dispersed from the amount of oil naturally dispersed. Analysis was ongoing at the time of preparation of this report and may yet provide useful guidance on this matter.

Given the limited nature of the field data, the best that could be done was to estimate effectiveness using the experience and knowledge of dispersant experts. Unfortunately, reaching consensus among the experts was not possible.

9A. CHEMICAL DISPERSION: SURFACE APPLICATION

Surface application of dispersant for this spill was extensive. At over 25 thousand bbls, were it a spill by itself, it would be one of the larger spills in U.S. waters. Dispersants were normally applied by aircraft at a dosage of 5 gallons/acre (USGPA) (5000 liter/sq. km). The dosage (DOR) needed to disperse surface emulsions depends highly on the weathering degree (e.g., water content, viscosity) of the emulsion. In Figure 10, controlled laboratory testing shows (and is further discussed in Appendix 6, Figure 4.3) that for the low weathered dark brown (pos. 4) emulsions (i.e., the type of emulsions that the aerial applications was focused on), a very low "absolute" dosage of 1:250 is sufficient in order to disperse the dark emulsion effectively under high mixing energy (breaking waves). This means that an aerial application with typically 5 USGPA is sufficient dosage in order to disperse such dark-brown emulsion with thicknesses around 1 mm as long as the application is efficient and high mixing energy is available. SMART samples similarly show significantdispersed oil in the surrounding water after surface operations in 3 out of 19 samples (see Table 2). When the emulsion become more weathered (i.e. light brown-orange-reddish in color), with a typical water content of >50%, and a significantly higher viscosity, the emulsion was still dispersible under high mixing energy, but a more "traditional" dosage of 1:50 - 1:25 was needed in order to disperse the emulsion effectively using COREXIT 9500. It is probable that some sprayed dispersant missed the oil or was deposited on oil layers that are thinner (such as sheen) or much thicker (emulsified oil) than the nominal 0.1 mm thick oil layer that most dispersant spray systems are designed to treat. Also, the most heavily weathered state of the emulsified oil would impede dispersant success.

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Alternative View 1: We believe the Oil Budget Calculator overestimates the effectiveness of chemical dispersants because:

- The WHOI survey and the Ocean Imaging pictures do not support it
- The surface oil was emulsified and there was insufficient mixing in the subsurface injection.

Alternate View 2: We believe that the Oil Budget Calculator underestimates the effectiveness of chemical dispersants because:

- Lab studies show that both the fresh and emulsified oil are dispersible
- There was sufficient energy both subsurface and at the surface to disperse the oil.

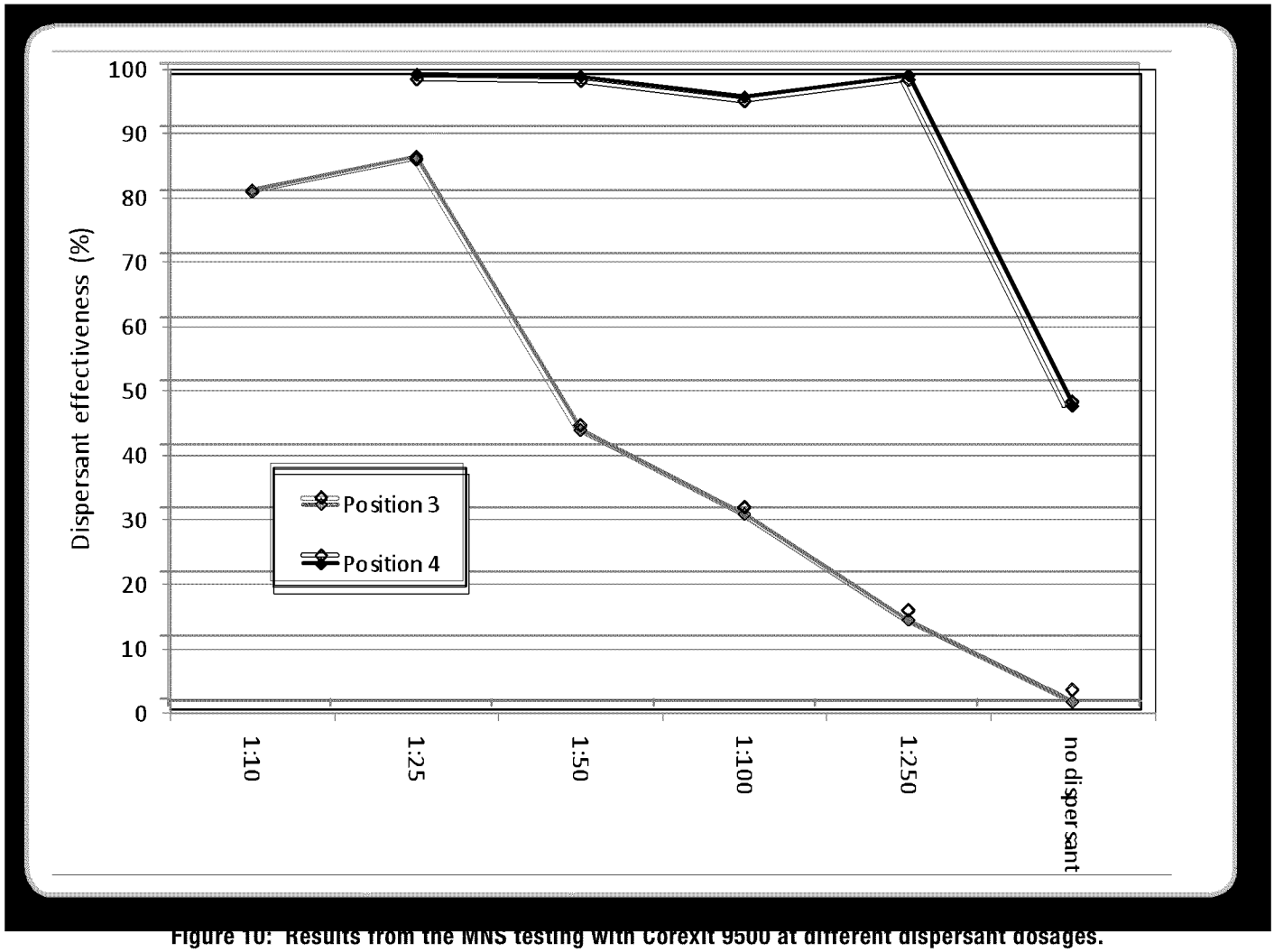

Figure 10: Results from the MNS testing with Corexit 9500 at different dispersant dosages. Position 3 Light brown / reddish emulsion: Viscosity 7200 cP, water content 50%; Position 4: Dark Brown emulsion: Viscosity 1250 cP, water content 33 %.

For the reasons stated in the subsurface dispersant application estimation, it was difficult to assess the efficacy of this effort, with a wide variation in the opinions of the experts. As in the case of subsea dispersant operations a compromise value is used in the new version of the Oil Budget Calculator in lieu of a consensus number. The expected DOR is 1:10 with a low value of 1:5 and a high value of 1:20

Table 2: USCG Surface Water Dispersant Study Sample Results.

USCG ID#	[redacted]
USCG-062	
USCG-063	
NSF-036-10-GB-064	
NSF-036-10-GB-065	
NSF-036-10-GB-067	
NSF-036-10-GB-068	
NSF-036-10-GB-070	
NSF-036-10-GB-071	
NSF-036-10-GB-072	
NSF-036-10-GB-073	
NSF-036-10-GB-075	
NSF-036-10-GB-076	
NSF-036-10-GB-077	
NSF-036-10-GB-078	
NSF-036-10-GB-079	
NSF-036-10-GB-080	
NSF-036-10-GB-082	
NSF-036-10-GB-083	
NSF-036-10-GB-084	
NSF-036-10-GB-085	
NSF-036-10-GB-086	
NSF-036-10-GB-087	
NSF-036-10-GB-088	
NSF-036-10-GB-089	
NSF-036-10-GB-090	
NSF-036-10-GB-091	
NSF-036-10-GB-092	

9B. CHEMICAL DISPERSION: SUBSURFACE APPLICATION

Measurement of subsurface operation was, at best, highly indirect. The most directly applicable was a published study by Camilli et al. (2010), who reported results from a subsurface hydrocarbon survey using an autonomous underwater vehicles and a ship-cabled sampler. Using BTEX results as an indicator of oil concentration, they concluded that an observed plume of oil at approximately 1100 m. depth represented about 6-7% of the oil leaking from the wellhead. The plume location was consistent with the expected location of subsurface dispersed oil based upon the Clarkson well blowout model (Latimer and Zheng, 2003).

Most of the experts believed that the conditions subsurface were good for dispersant operations. It is likely that all five of the conditions listed by Clayton et al (1993) were generally met. However, the addition of dispersant at 7 to 12 gallons / minute through a narrow diameter wand held by a ROV into the flow of escaping oil and gas would probably not have added dispersant to all of the oil; some oil would have escaped into the water column untreated with any dispersant. Without carrying out some experimentation, it is not possible to say what proportion of the escaping oil would and would not have been treated with dispersant. Also, using the estimated flow rate shown on Figure 3 and the data available on the daily rate of dispersant applications, the dosage of chemical dispersant (DOR) for subsurface application varies from 1:1200 to 1:92; 19% of the time (13 days) the DOR was less than 1:250, 34% of the time (23 days) it was between 1:150 and 1:250 and 43 % of the time (29 days) it was between 1:150 and 1:100. Yet, laboratory studies show that COREXIT 9500 is effective on this type of oil and there was more than sufficient turbulent energy.

The Oil Budget Calculator originally used a very conservative estimate for subsurface dispersant operations. The ITOPF Technical Information Paper for "The use of Chemical Dispersants to Treat Oil Spills" (http://www.itopf.com) recommends for planning purposes the use of 1 part dispersant for 20 parts oil as the dosage rate. They point out that spraying equipment is often preconfigured to achieve this. Some laboratory studies also support this number (Fingas et al. 1995; Khelifa and So, 2009).

Some experts were concerned that the entrained gas would reduce the effectiveness of the dispersant application by preventing contact between oil and surfactant. They also thought that the time of contact might be insufficient to achieve optimum effect. Their concerns are captured in the choice for minimum effectiveness. However, other experts believe that a 1:20 effectiveness ratio greatly underestimated that actual amount of oil dispersed. They point to successful applications in the North Sea, producing a larger ratio of dispersed oil to surfactant applied. Ratios as large as DOR 1:100 were suggested. One of the experts was concerned about hydrate interference with dispersant application.

Failing to achieve common agreement of the experts, the new calculator uses a compromise estimate of a DOR of 1:40 with a low estimate of 1:20 and high estimate of 1:90.

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10. BURNING

Burning *in-situ* was extensively used during the Deepwater Horizon Spill. Environmental conditions, location of the incident and the nature of the oil made this possible. Oil was gathered into areas enclosed with special booms and set afire.

For ignition to occur with most oils, the oil film must generally be greater than 2 to 3 mm. Ignition will depend upon the water content of the oil, emulsions of 20 to 25 % or more typically being very difficult to ignite. Since free-floating oil slicks are typically on the order of a tenth of a mm or less, most oil spills need to be contained in special fire-resistant booms. High winds and waves (typically in excess of 1 m short-period, wind waves) may prevent burn operations because of the difficulty of preventing entrainment and splash over within the fire boom, and, because of the difficulty of achieving an initial ignition. Most relatively fresh crude oils (even emulsions of 15% to 20% water) may burn with a "thickness-reduction" or "regression" rate of approximately 0.05 mm/sec, slightly more than a tenth of an inch per minute (ASTM, 2003). This represents an oil elimination rate of approximately 0.07 gpm/sq.ft. Higher water contents of approximately 25% to 40%, though very difficult to ignite, may burn at rates of approximately 0.05 gpm/sq.ft. During the burning of oil or emulsions on water, part of the oil is turned into smoke. The actual percentage depends upon the size of the burn and other factors, but usually is in the range of only 5% to 15% of the original volume of oil burned. With typically less than 5 % of the original volume remaining as burn residue, the controlled elimination of spilled oil through combustion is recognized as a highly efficient response option. The burn rates used during the Deepwater Horizon incident range from 0.07 gpm/sq.ft (representing lightly emulsified oils) to 0.05 gpm/sq.ft for burns that may have involved more highly emulsified oils. These oil elimination rates are in line with ASTM standards, and most burns were carried out on emulsions with relatively low water content and along convergence lines where unstable emulsions and wind-herded films had accumulated as dark brown to black oil layers. Daily estimates of the volume of oil burned were recorded as minimum and maximum values reflecting these oil elimination rates. The results were calculated throughout the Deepwater Horizon incident using surface and aerial observations that included the size and duration of each burn. Nearly all burns involved 500-ft-long booms towed in a U-configuration, while attempting to maintain a "gap ratio" (i.e., swath-to-boom-length ratio) of ~ 0.3. A single fire boom could therefore hold 500 to 1000 bbl of oil in its apex, the downstream area only ~1/3 of the way toward the leading ends of the boom. A single burn could often eliminate its contents within an hour or less. Field crews concluded that some surface slicks must have been in the range of 2.5 mm to 5 mm to achieve some of the larger burns. This represents a very thick oil emulsion layer.

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Figure 11 illustrates the minimum and maximum daily oil elimination rates based upon the burn rates described above. It should be noted that the percentage of burned oil reported by the Calculator applies to all the oil released by the well. If one computes burning share based only upon the volume of available surface oil, the fraction burned is much larger, representing a significant portion of the surface oil. The Oil Budget Calculator uses the range of reported burn values depicted in Figure 11 in its calculations. The uncertainty range for the amount of burned oil is small compared to the other processes discussed in this report.

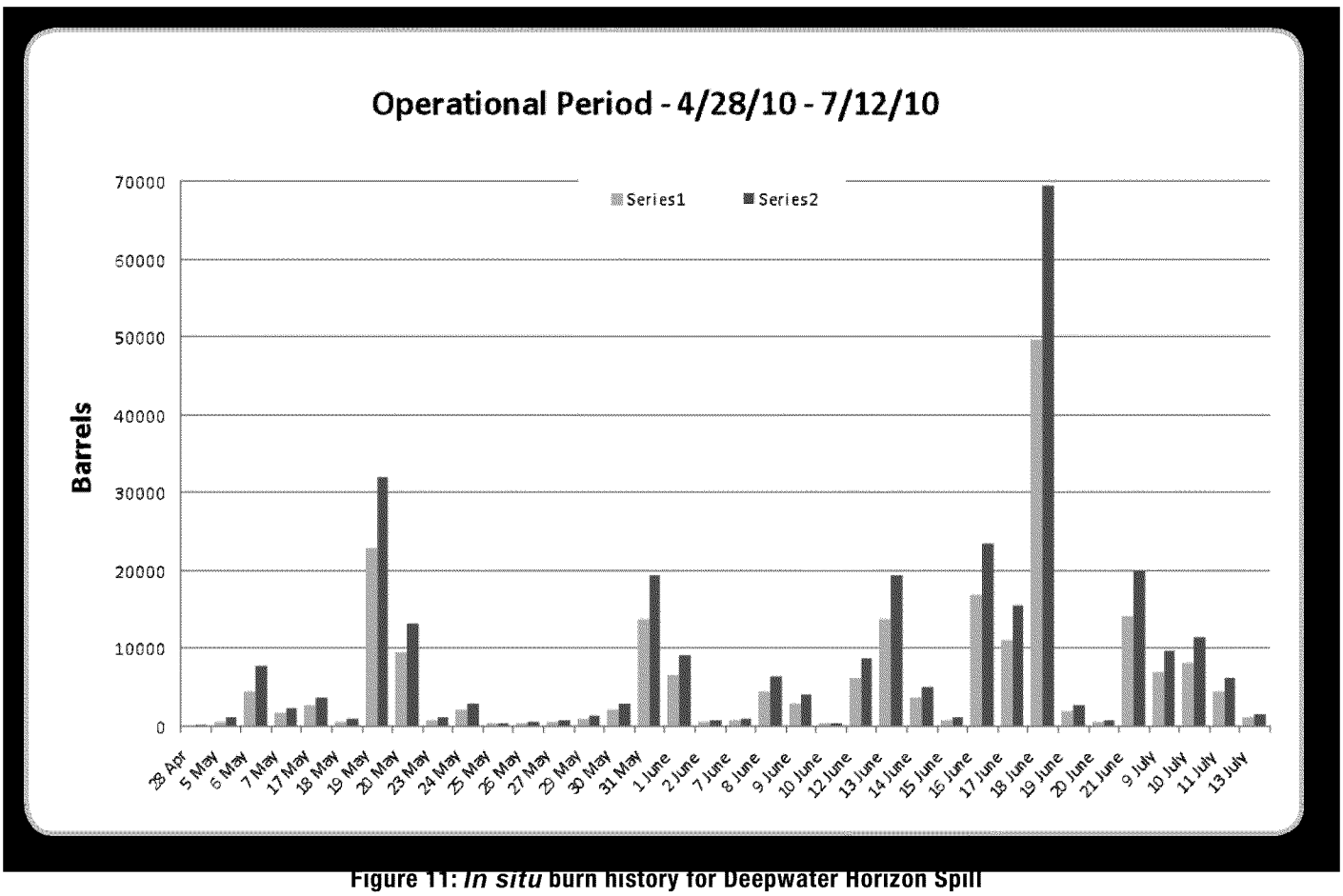

Figure 11: *In situ* burn history for Deepwater Horizon Spill

11. MECHANICAL RECOVERY

Skimmers were the most commonly used mechanical devices use to remove oil from the Gulf water surface. These skimmers varied greatly in size, application, and capacity, as well as in recovery efficiency and water pickup (Schulze, 1993; Schwartze, 1979). In the particular case of the Gulf oil spill the major issue was the amount of water recovered with the skimmed oil. Rather than estimate oil-water ratios, simple measurements of the barge oil would seem the rational way to determine this amount. However, to date, no such measurements are available. Therefore it was necessary to estimate skimmer performance based upon sea conditions, nature of the oil, and past experience.

A skimmer's performance is affected by a number of factors including the thickness of the oil being recovered, the extent of weathering and emulsification of the oil, the presence of debris, and weather conditions at the time of recovery operations. A skimmer's overall performance is usually determined by a combination of its recovery rate and the percentage of oil recovered. The maximum amount of oil that a skimmer could recover is called the 'Nameplate Recovery Rate' and is typically provided by the manufacturer of a skimmer (Fingas, 2010; Meyer et al, 2009). A similar definition is the 'Effective Daily Recovery Capacity', which is the amount that a skimmer could recover in daylight hours under ideal conditions. The recovery rate is the volume of oil recovered under specific conditions. It is measured as volume per unit of time and is usually given as a range. If a skimmer takes in a lot of water, it is detrimental to the overall efficiency of an oil spill recovery operation.

Skimmer performance is chiefly the product of three parameters. The Oil Recovery Rate (ORR) is the quantitative rate in volume per unit time, usually m^3/hour and is corrected for water recovery. The throughput efficiency (TE) is applicable only to advancing skimmers. The throughput efficiency is the percentage of oil presented to a skimmer versus that recovered, in percent. The recovery efficiency (RE) is the percent of oil recovered out of the total oil and water recovered. For the Gulf recovery effort, the RE is the most important factor. We know the total liquids recovered, but we do not know exactly how much oil was in this liquid and therefore must estimate the actual oil recovered. Past studies show that the average RE of the skimmers in wave conditions is 33%.

The measured water content of skimmed emulsions varied. An estimate of the actual recovered oil would be a product of the average RE times the oil content of the emulsion. The Calculator assumes that 20% of the skimmed liquid was oil, with a range between 10% and 40%. These are conservative estimates in line with the philosophy behind the Calculator. They are also considered temporary numbers, pending any measurement results.

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12. OTHER OIL

The Oil Budget Calculator does not quantify the amount of oil volume that becomes tar balls, forms surface slicks, sinks due too sedimentation, remains in the surf zone or impacts the shore and is subsequently cleaned up. These are instead grouped together as 'other oil'.

The amount of oil listed as 'other' is quite large. Obviously, there are no longer large surface slicks in the Gulf of Mexico. So where is this oil? Some obviously did impact the coastline, particularly the Louisiana coastline. Cleanup operations recorded the volume of oil debris that was recovered during shoreline cleanup. However, no estimates were made of the percentage of oil in this debris so it is not possible to give a reliable estimate of this amount. Based upon past spills, the oil content of collected debris mass is only a few percent. Some of the oil may have aggregated with sediment in the water column and settled to the sea bottom. The Oil Budget Calculator does not estimate sedimentation.

Much of this oil probably formed tarballs or millimeter scale oil droplets since the conditions of this spill were conducive to such tarball/droplet formation (turbulent subsurface release, large use of dispersant on weak emulsions, etc). The larger tarballs are very persistent in the marine environment and can travel hundreds of miles, sometimes re-concentrating in convergence zones far from the original spill site. Some limited efforts were made to collect and quantify the larger tar ball mass density in the nearshore areas but the available data was insufficiento make a global estimate. Thsmaller oil droplets behave in some respects almost as dispersed oil and are similarly subject to biodegradation, dissolution, and sedimentation.

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13. LONGER-TERM PROCESSES

While not tracked by the Oil Budget Calculator, there are other processes that work to break down the spilled oil. Two important ones for the Gulf of Mexico are photo-oxidation and biodegradation.

The combination of hydrocarbons with oxygen is called oxidation. The newly formed oxidized compounds may affect the oil slick by increasing dissolution, dispersion or emulsification. While trace metals in the oil may influence the oxidation process, ultraviolet light significantly increases oxidation. Virtually all of the molecules that evaporate from the slick undergo photochemical oxidation in hours or days. Also, beached oil will show the effects of exposure to sunlight. Even floating oil can show chemical changes due to this process. Overton (1981) exposed IXTOC I crude oil to sunlight and discovered the formation of tarry flakes, showing the involvement of photolysis. Observers at the *Mega Borg* spill in the Gulf of Mexico noticed the formation of crusts on floating tarmats and tar balls, with the hypothesis that this was due to photo-oxidation.

Hydrocarbons, including those found in oil slicks, are a food source for many microorganisms. The rate of such biodegradation depends upon the availability of nitrogen- and phosphorus-containing nutrients in the water, as well as the surface exposure of the oil to the organisms. Swannel and Daniel (1999) suggest that dispersant use on a slick may speed up biodegradation by promoting the growth of indigenous, hydrocarbon-degrading bacteria as well as increasing the surface area of the oil available for microbial colonization.

Bacteria capable of degrading various groups of petroleum hydrocarbons have been found in all oceans and in deep as well as shallow water. Research on biodegradation has occurred with many types of oils and fuels, at temperatures ranging from -1C (polar) to over 30 C (hot, tropical), and at natural oil seeps. Tools for documenting biodegradation rates include microbial taxonomy and abundance, nutrient uptake, oxygen utilization and mass loss.

The Deepwater Horizon blowout resulted in petroleum hydrocarbon contamination on sand beaches and marshes, at the sea surface, in the warm (30-35C) upper water column adjacent to dispersant operations, and in cold (4.5 to 5C) water at 1100 to 1300 m deep. Available results to date have been reported from surveys conducted in May and June, 2010, and focused on indicators of biodegradation in the contaminated deepwater layers (Camilli et al., 2010 and Hazen et al, 2010).

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Camilli et al (2010) reported presence of sub-surface volatile hydrocarbons and also only slight reductions of oxygen at depth and suggested biodegradation rates were low potentially resulting in many months of hydrocarbon persistence. Hazen et al (2010) reported that the dispersed hydrocarbons in deep water originating from the Deepwater Horizon blowout source stimulated deep-sea indigenous γ-proteobacteria that are closely related to known petroleum-degraders. Hydrocarbon-degrading genes coincided with the concentration of various oil contaminants, namely alkanes. Changes in hydrocarbon composition with distance from the source and incubation experiments with environmental isolates demonstrated faster than expected hydrocarbon biodegradation rates at 5°C. The half-life degradation rates ranged from about 2 to 6 days, depending on the alkane. Based on these results, Hazen et al (2010) concluded that the potential exists for intrinsic bioremediation of the petroleum hydrocarbons in the deep-water column without substantial oxygen drawdown.

Other studies unrelated to this incident have reported a wide range of hydrocarbon degradation rates depending on all the variables indicated above. The Hazen et al (2010) rates are not inconsistent with those published by Venosa and Holder (2007) for cold water using dispersed Alaska North slope crude oil.

Past biodegradation research has focused on marine waters of moderate to warm temperatures, including oil-contaminated sediment interstitial waters of beaches and marshes as well as dispersed/dissolved hydrocarbons. Going back into history, Walker and Colwell (1977) measured the loss of mass South Louisiana crude oil during replicated in situ incubation field experiments in a North Carolina estuary at 30C. The mean mass of 365 mg of oil was reduced to 235 mg in one week (35% reduction), 178.5 mg in 2 weeks 51.1 percent reduction) , 11.2 mg in 3 weeks (97.0 per cent reduction and and 8.8 mg in 4 weeks (97.6 per cent), yielding a half life of about 2 weeks (14 days). Bacteria counts reached maximum in 3 weeks then stared to decline. Presumably, the initial loss of mass was due to evaporation of more volatile components whereas the later stages were the result of biodegradation. These simple rate results fall somewhere between the predictions of Camilli et al (2010) and Hazen et al (2010).

Since the 1970's, there has been a considerable amount of field, mesocosm, and laboratory work done. The rates resulting from these studies also range widely depending on oil types, oil weathering, dispersion effectiveness, dispersant composition, nutrient loadings, and especially which target petroleum compounds or groups of compounds each research team analyzed. The National Research Council (NRC, 2005) reviewed much of the work done on biodegradation of dispersed oil concluding that most of the work has not been consistently

standardized sufficient to confidently extrapolate from the laboratory to the field. Further, there is a paucity of work on degradation of higher molecular weight polycyclic aromatic hydrocarbons, the most toxic compounds. Field studies in contaminated marshes and beach sediments, have demonstrated a wide range of biodegradation rates; oil biodegraded almost completely within a few weeks at some locations while it persisted for tens of years at other locations (Reddy et al., 2002; Short et al, 2004). Boufadel et al., (2010) noted low oxygen and nutrient concentration that might have prevented effective biodegradation of the Exxon Valdez oil spill. The study of Li and Boufadel (2010) highlighted that understanding beach hydraulics is a critical step in predicting the fate of oil within beaches. Therefore, we would expect this oil to undergo biodegradation at different rates in different compartments of the Gulf ecosystem

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14. ASSESSMENT AND FUTURE PLANS

While pure scientific research can be done on oil spills, most oil spill science is applied science. Tools such as the Oil Budget Calculator are only useful if they provide information that will assist response decisions. Conversely, they need only be as accurate as the precision needed for these decisions. Improved accuracy beyond those levels may be important in the academic sense but not in the response area. Figures 12 and 13, below, show the output from the model, given the revisions described in this document. They vary somewhat from earlier calculations but probably not significantly according to the above criteria.

The estimates of the Calculator were admittedly rough for the reasons discussed in this report. However, the estimates were probably sufficient to meet the needs of the Response. Ultimately, of course, that judgment will be made by the NIC. The experience in developing the Calculator points to areas of needed future research and planning:

(1) **Protocols for surface and subsurface sampling:** While oil samples were collected for impact assessment, few samples were properly collected and categorized for response. For example, samples often came from skimming barges, where oil in different states of degradation was blended together. Future response plans should specify methods for gathering proper representative samples.

(2) **Dispersed oil droplet size:** A major improvement in estimating dispersant efficiency would be possible if practical operational tools and methods existed to characterize droplet size distribution of subsurface oil.

(3) **Basic Models for Longer-term processes:** While longer-term processes such as biodegradation often happen outside the time frames of the response, understanding and being able to predict such longer-term changes may be useful in making response decisions.

(4) **Estimation of collected shoreline oil:** For a complete mass balance, procedures should be implemented that estimate the fraction that is oil or oiled debris gathered from shoreline cleanup.

(5) **Expanded modeling capabilities:** Many of the team members that assisted with the Oil Budget Calculator are also part of a working group of spill experts developing the specifications for the next generation of oil spill model. These specifications need to be translated into real code.

(6) **Revised interface:** A better interface is necessary to more properly display the intrinsic uncertainty in the Calculator.

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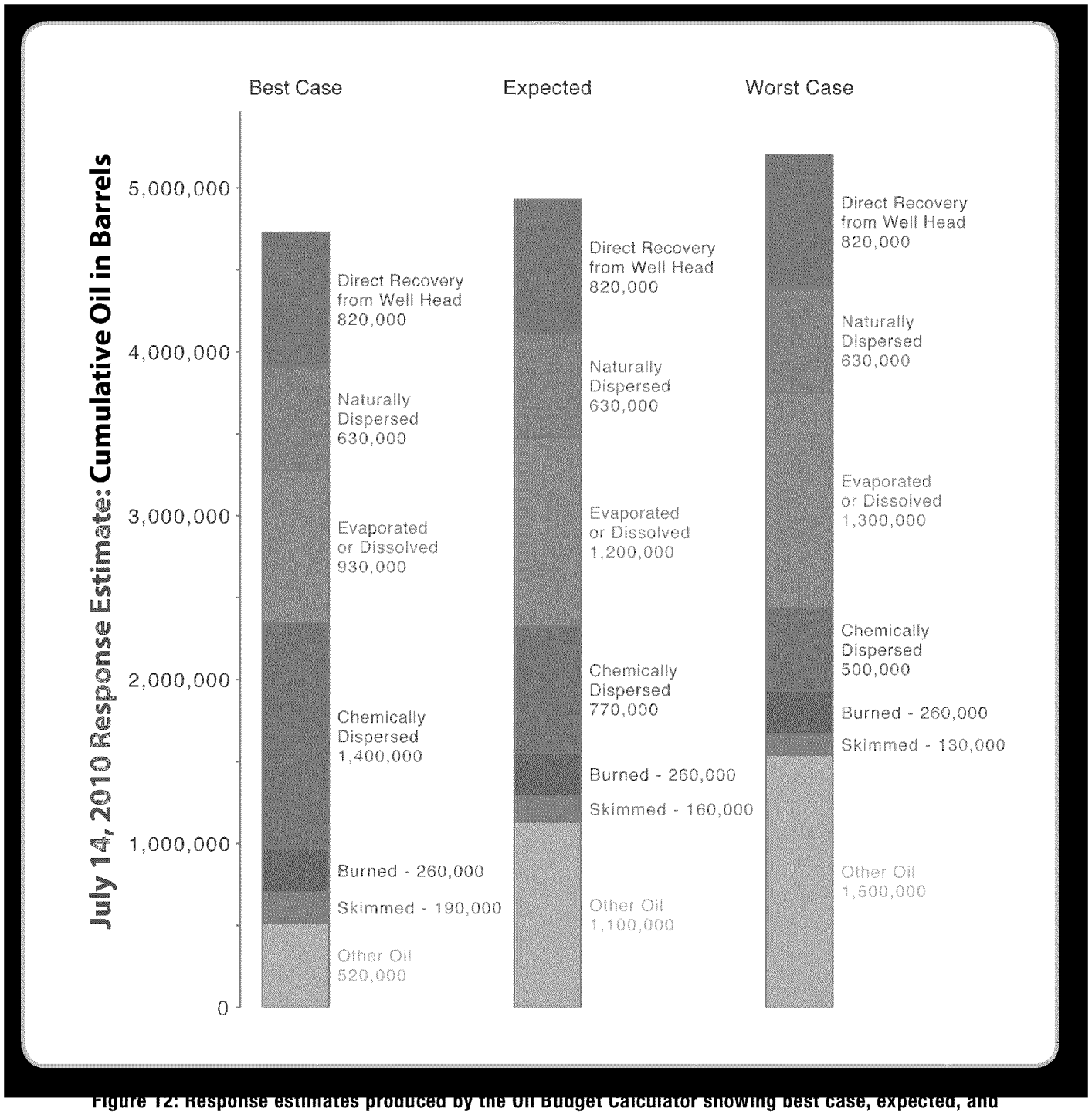

Figure 12: Response estimates produced by the Oil Budget Calculator showing best case, expected, and worst case volumes of the seven different portions that the calculator tracks individually, of the cumulative volume of oil discharged through July 14, 2010. These estimates served solely as a guide for the national response to the Deepwater Horizon MC252 Gulf Incident. The best and worst cases are defined in Appendix 1: they are the combinations of values of the seven variables depicted in each stack that correspond to the lower and upper endpoints of a 95% confidence interval for the volume of Other Oil .

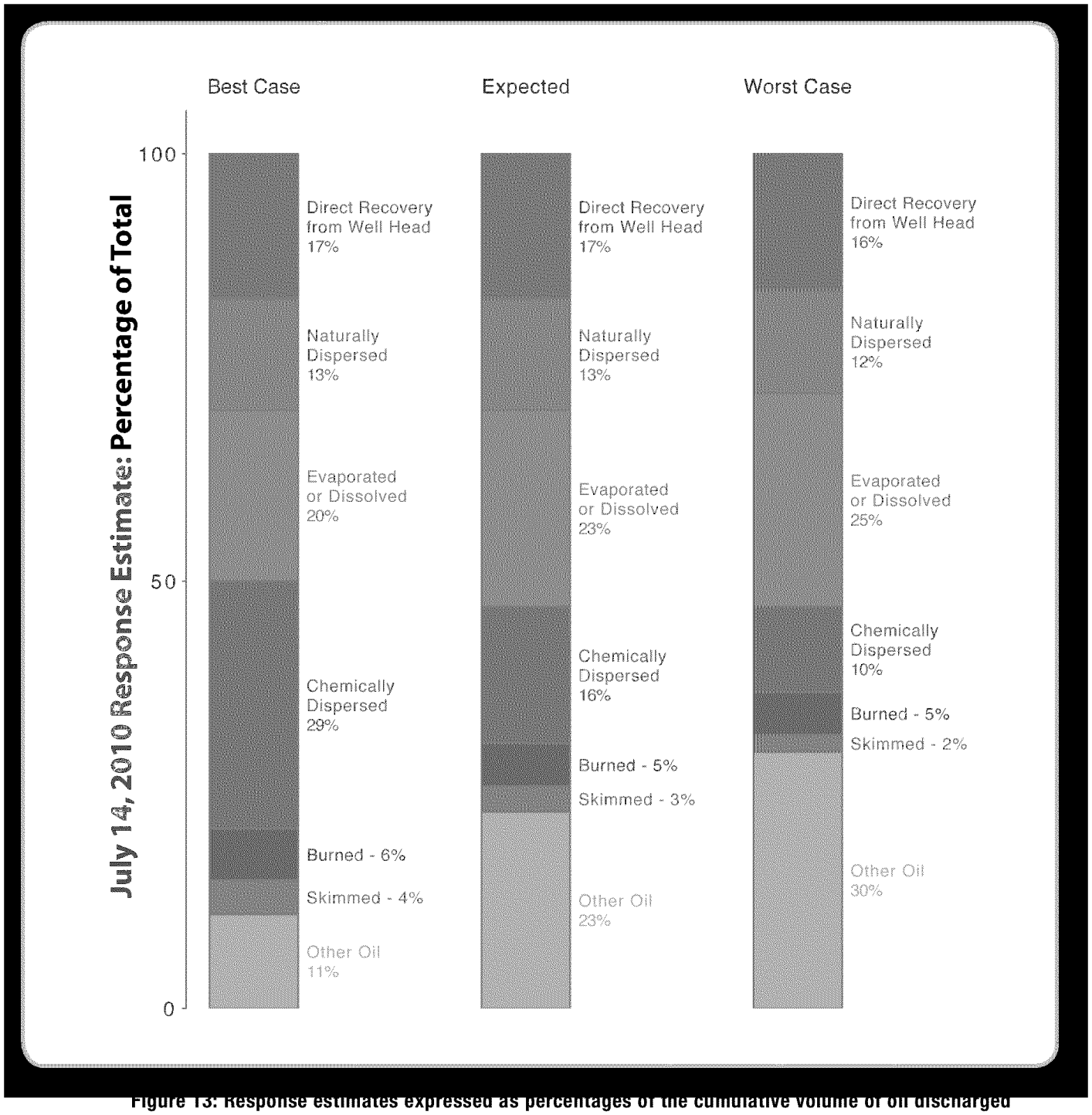

Figure 13: Response estimates expressed as percentages of the cumulative volume of oil discharged through July 14, 2010, in the best, expected, and worst cases. These estimates served solely as a guide for the national response to the Deepwater Horizon MC252 Gulf Incident.

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Appendix 1

A1 Uncertainty Assessment of Mass Balance Estimates

A1.1 Introduction

We have developed and applied statistical methods to gauge the uncertainty associated with the estimates of the volumes of the principal fractions of the oil spilled from the Deepwater (Macondo) well that the Oil Budget Calculator tracks individually, in addition to the volume of oil that has been recovered via the Riser Insert Tube Tool (RITT) or via the Top Hat: (i) oil that has been naturally or chemically dispersed; (ii) oil that has evaporated or dissolved; (iii) oil in skimmed oily seawater; (iv) oil that has been burned; and (v) residual (or, other) oil that remains either on or below the sea surface, in other forms.

The uncertainty associated with the volume of each of these fractions includes contributions from the uncertainty of the eight rate constants in the mass balance equations that describe where the spilled oil will have gone.

Figure A1.1 on page A1.7 shows the result of the uncertainty analysis for the volume of residual oil, depicted as an uncertainty envelope, throughout the 86-day period from April 20 (explosion and fire on Deepwater Horizon platform) to July 14, 2010 (last day with discharge from the well). The lower bound of this envelope corresponds to a best-case scenario, and the upper bound to a worst-case scenario. Section A1.8 describes the methods used to characterize these scenarios quantitatively, and Appendix 2 shows the corresponding results.

A1.2 Input and Output Quantities

The quantities that we are primarily interested in, and whose values we track, are referred to as *output quantities*; and the quantities that these depend on (which are measured directly or indirectly, or that we have other prior knowledge of), are referred to as *input quantities*.

For example, the volume $V_{DC}(t)$ of oil that was dispersed on day t by underwater application of a volume $V_{CB}(t)$ of a chemical dispersant can be modeled as $V_{DC}(t) = (1 - k_7) \min\ 90k_2V_{CB}(t), V_R(t) - V_{DT}(t)$, where $V_R(t)$ denotes the volume of oil discharged from the well, of which $V_{DT}(t)$ will have been recovered via RITT/TopHat, and k_2 and k_7 denotes *rate constants*.

In this example, $V_{DC}(t)$ plays the role of output quantity, and $V_{CB}(t)$, $V_R(t)$, $V_{DT}(t)$, k_2, and k_7 play the role of input quantities. Of the latter, only $V_{CB}(t)$ and $V_{DT}(t)$ were measured directly; $V_R(t)$ was estimated by other teams in the Flow Rate Technical Group equation A1.1 on page A1.2; k_2 and k_7 are the results of assessments supplied by subject-matter experts.

The *mass balance equations* A1.1 on page A1.2– A1.16 on page A1.2 express relations between all the relevant quantities, and involve what we have been calling input and output quantities, as well as other quantities that we call intermediate quantities because they are used in the calculations but are not of primary interest for the purposes of the Oil Budget Calculator.

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$$V_{RE}(t) = V_R(t) - V_{DT}(t) \tag{A1.1}$$

$$X(t) = 90V_{CB}(t) \tag{A1.2}$$

$$V_{DC}(t) = (1 - k_7)\min\ k_2X(t), V_{RE}(t) \tag{A1.3}$$

$$Y(t) = V_{RE}(t) - \frac{V_{DC}(t)}{1 - k_7} \tag{A1.4}$$

$$V_{DN}(t) = (1 - k_7)\max\ 0, k_1Y(t) \tag{A1.5}$$

$$V_{DB}(t) = V_{DC}(t) + V_{DN}(t) \tag{A1.6}$$

$$V_{NW}(t) = k_6V_{OW}(t) \tag{A1.7}$$

$$Z(t) = V_{RE}(t) - \frac{V_{DB}(t)}{1 - k_7} \tag{A1.8}$$

$$W(t) = \max\ 0, (1 - k_4)Z(t) - V_{BU}(t) \tag{A1.9}$$

$$V_E(t) = k_4Z(t) + k_5W(t - 1) + \frac{k_7}{1 - k_7}V_{DB}(t) \tag{A1.10}$$

$$V_{NS}(t) = \max\ 0, k_8W(t) \tag{A1.11}$$

$$V_{DS}(t) = \min\ 20k_3V_{CS}(t), V_S(t - 1) \tag{A1.12}$$

$$V_D(t) = V_{DB}(t) + V_{DS}(t) + V_{NS}(t) \tag{A1.13}$$

$$V_{SD}(t) = V_{RE}(t) - V_E(t) + V_{NW}(t) + V_{BU}(t) + V_D(t) \tag{A1.14}$$

$$V_S(t) = V_{SD}(1) + \cdots + V_{SD}(t) \tag{A1.15}$$

$$V_C(t) = V_{DS}(t) + V_{DC}(t) \tag{A1.16}$$

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The input, intermediate, and output quantities are listed in Table A1.1 on page A1.4. Typically, all of these quantities vary from day to day, and this dependence will be indicated explicitly when necessary, as in $V_R(t)$, for the volume of oil discharged on day number t (day 1 being April 20, 2010).

All volumes are assumed to be expressed in barrels of oil (bbl), with 1bbl = 42 U.S. (liquid) gallons ≈ 159L. The policy of the National Institute of Standards and Technology (NIST) is to use the International System of Units (metric units) in all publications. In this document, however, the units used traditionally in the oil industry are also used.

All of the output quantities have cumulative counterparts, except $V_S(t)$, which, by definition, already includes contributions from oil released on day t as well as residues of oil that will have been released on prior days but have not yet been recovered, evaporated or dissolved, burned, or dispersed (which in practice means dispersion into droplets of less than 70μm to 100μm in diameter). $V_{SD}(t)$ is the contribution to the residual oil originating from oil spilled on day number t, and $V_S(t)$ is the corresponding cumulative sum (from day number 1 through day number t), as defined in equation A1.15 on page A1.2.

A1.3 Uncertainty

The *Guide to the expression of uncertainty in measurement* (GUM) [Joint Committee for Guides in Metrology, 2008a], and its companion *International vocabulary of metrology* (VIM) [Joint Committee for Guides in Metrology, 2008c], are international standards that codify the meaning of "uncertainty" in the context of measurement science, and provide the technical basis whereon it may be gauged quantitatively, and interpreted in practice.

The VIM defines *measurement uncertainty* as a "non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used." *Measurand* is the "quantity intended to be measured." In our case, the volumes of the different fractions of the spilled oil, aforementioned, that the Oil Budget Calculator tracks separately, all are measurands.

Here, and in many other studies, the measurands are not accessible for direct measurement, and the corresponding measured values, or estimates of their values, are obtained by applying *measurement functions* [Joint Committee for Guides in Metrology, 2008c, 2.49] to values of other quantities that are either measured directly, or themselves are functions of yet other quantities that will have been measured directly, or about which there exists some prior information. In our case, these measurement functions are the mass balance equations.

The uncertainty analysis we describe in Section A1.7 on page A1.11, serves to propagate the measurement uncertainty associated with the input quantities to the output quantities of interest. Since the methods used to model the uncertainty of the input quantities are probabilistic, and the methods used to propagate their uncertainties to the output quantities are statistical, the end-product of such analysis typically is an interval that, with some specified probability (typically 95 %) includes the true, albeit unknown value, of the output quantity.

For example, we will conclude that the volume of residual oil on day number 86 (July 14,

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INPUT QUANTITIES	
V_{BU}	Oil volume burned
V_{CB}	Dispersant volume sprayed, subsurface
V_{CS}	Dispersant volume sprayed, surface
V_{DT}	Oil volume recovered via RITT/TopHat
V_{OW}	Oily water volume recovered
V_R	Oil volume discharged
INTERMEDIATE QUANTITIES	
V_D	Oil volume dispersed, total
V_{DB}	Oil volume dispersed, subsurface
V_{DC}	Oil volume dispersed chemically, subsurface
V_{DS}	Oil volume dispersed chemically, surface
V_{RE}	Oil volume effectively discharged
V_{SD}	Oil volume contributed to residual, daily
W	Auxiliary variable
X	Auxiliary variable
Y	Auxiliary variable
Z	Auxiliary variable
OUTPUT QUANTITIES	
V_{DN}	Oil volume dispersed naturally, subsurface
V_{NS}	Oil volume dispersed naturally, surface
V_C	Oil volume dispersed chemically
V_E	Oil volume evaporated or dissolved
V_{NW}	Oil volume skimmed
V_S	Oil volume residual (or, other oil)

Table A1.1: Input, intermediate, and output quantities.

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2010), will have been between 0.53 and 1.5 million barrels (Mbbl) of oil, with 95% probability (Appendix 2). This means that one is prepared to bet at odds of 19:1 in favor of the true value of such volume indeed lying in this interval. Noting that 1bbl = 42U.S. (liquid) gallons ≈ 159L, that interval may equivalently be stated as 22×10^6 U.S. gallons to 63×10^6 U.S. gallons, or as 84×10^6 L to 240×10^6 L.

All the quantities in play here are affected by uncertainty. In the example above, it is not only the rate constants k_2 and k_7 that have associated uncertainty re?ecting the imperfect knowledge that experts have about their values. The values of $V_{CB}(t)$, $V_R(t)$, and $V_{DT}(t)$ all include some measurement error that we express as uncertainty about their true values.

However, the only quantities whose associated measurement uncertainty has been characterized are $V_R(t)$ (oil volume discharged) and V_{BU} (oil volume burned), and the rate constants $k_1, \ldots, k_8$. The subject-matter experts believe that these indeed are the major sources of uncertainty, and that the contributions made by measurement error affecting V_{DT}, V_{CB}, V_{CS}, and V_{OW} (all de?ned in Table A1.1 on page A1.4) are minor by comparison.

The mass balance equations that, among other outputs, produce an estimate of residual oil V_S, describe a simpli?ed model for the partition of the oil among the several fractions that we track, shortly after release, and re?ect a particular understanding of the physical and chemical processes that drive that partition.

Other models that could conceivably be entertained, or other choices that could be made about the values of the rate constants, which some oil spill experts might regard as equally reasonable, most likely would produce estimates for V_S different from those this model produces, even when applied to the same data. The corresponding dispersion of values of such alternative estimates would re?ect model uncertainty. Although our uncertainty analysis does not re?ect this, it is widely recognized that, in many studies, model uncertainty contributes substantially to the overall uncertainty.

A1.4 Approach

The uncertainties associated with the volume of oil discharged and with the rate constants in the mass balance equations are modeled probabilistically and then propagated to the output quantities using the Monte Carlo simulation method that, in one form or another, has been in use for many years in many different disciplines [Metropolis and Ulam, 1949], and that has been codi?ed for use in measurement science in the form of an international standard [Joint Committee for Guides in Metrology, 2008b].

The probabilistic models used for this purpose serve to describe the imperfect or incomplete knowledge about the values of a quantity. For example, in Section A1.5 on page A1.7, we model the uncertainty about the volume discharged on day t as $(1 + Q)V_R(t)$, where Q denotes a Gaussian (or "normal") random variable with mean 0 and standard deviation 0.05. This is one way of saying that, with high con?dence (95 %), the actual volume is within 10 % (= 2 × 0.05) of the value estimated for the volume discharged. The same can be said in other ways, too: for example, by modeling Q as a random variable with a uniform (or rectangular) distribution

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between - 0.1 and +0.1.

The same limitation applies to all the models we shall employ to model uncertainty with. Even though we believe that they are reasonable for the situations at hand, ultimately they all reflect arbitrary choices, because the science regulating these matters is not yet sufficiently developed to identify a single model as necessarily better or more adequate than all the others. In Section A1.9 on page A1.14 we will assess the sensitivity of our conclusions to this, and to other modeling assumptions.

As noted already in Section A1.3 on page A1.3, and except for V_R, V_{BU}, and for the rate constants, the uncertainty associated with the input quantities (V_{DT}, V_{CB}, V_{CS}, and V_{OW}) has not been quantified. We proceed on the assumption that the measurement uncertainty of these input quantities is negligible by comparison with the uncertainty components attributable to the imperfect knowledge of the "true" values of the volume discharged and of the rate constants. Also as noted towards the end of Section A1.3 on page A1.3, model uncertainty is not captured either, even though we cannot claim that it is negligible.

The Monte Carlo simulation method that we have used to propagate uncertainty from input to output quantities comprises two steps: first, the generation of multiple scenarios defined by combinations of conceivable values of all the input quantities; second, the summarization of the values of the output quantities corresponding to these scenarios. The results reported in Appendix 2 are based on 100 000 scenarios.

More precisely: for each scenario, we drew (or simulated) values from the probability distributions that model the uncertainty associated with the volume discharged, with the volume burned, and with the rate constants, and then used these simulated values in the calculations that produce time series of daily values of the output quantities. The values simulated for the rate constants vary from scenario to scenario, not from day to day.

Consider $V_S(t)$, the volume of residual oil on day t, for example. Its counterparts that correspond to m simulated scenarios are denoted $V_{1,S}(t), \ldots, V_{m,S}(t)$, and we refer to them as *replicates* of $V_S(t)$.

These m replicates may be summarized in a histogram, or by their average and standard deviation, or, as we do in Figure A1.1 on page A1.7, by means of an interval, ranging from $V_{S,L}(t)$ to $V_{S,U}(t)$, that brackets a specified proportion of them, say 95 %, which we then regard as a 95 % confidence interval for the "true" value of $V_S(t)$, and interpret as explained in Section A1.3 on page A1.3. This is the so-called *percentile method* of constructing bootstrap confidence intervals [Efron and Tibshirani, 1993, §13.3].

The lower and upper envelopes depicted in Figure A1.1 on page A1.7 were obtained by joining with red lines the points corresponding to $V_{S,L}(1)$, $V_{S,L}(2)$, ... (for the lower envelope), and to $V_{S,U}(1)$, $V_{S,U}(2)$, ... (for the upper envelope).

In addition to these envelopes, we also compute the average of the simulated values of $V_S(t)$, over all m scenarios, for each day t. Owing to the non-linear way in which some of the participating quantities (rate constants or input variables) enter in the mass balance equations, and given that the probability distributions of some of the rate constants are markedly asymmetrical,

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with one tail much longer than the other, those averages need not coincide with the values that one obtains by solving the mass balance equations using the expected values of the rate constants, and the measured or estimated (but otherwise undisturbed) values of the input quantities.

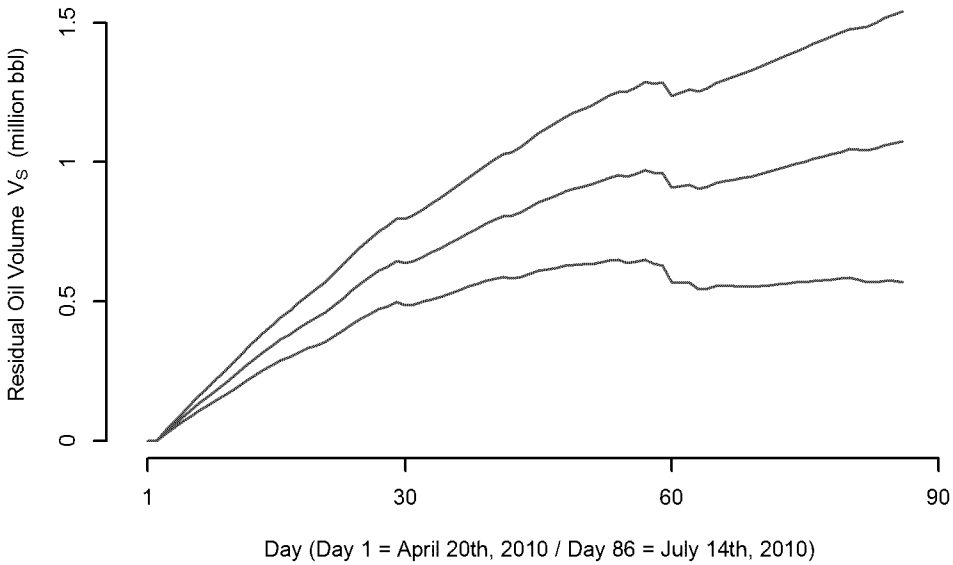

Figure A1.1: Volume of residual oil (V_S), and approximate 95 % con?dence band. The daily increments $V_{SD}(1), \ldots, V_{SD}(t)$ that $V_S(t)$ is the cumulative sum of, occasionally are negative, which explains the behavior of the curves around day 61 (June 18, 2010), when a large volume of oil was burned on the surface, indeed far more than the residual increment for that day. Since there was no additional discharge after day 86 (July 14, 2010), the curves ?atten beyond this date (not shown).

A1.5 Volume Discharged V_R and Volume Burned V_{BU}

The time series $V_R(1), V_R(2), \ldots$ of volume of oil discharged daily from the well, depicted in Figure A1.2 on page A1.8, is taken as an input to the mass balance calculations ($V_R(t)$ denotes the volume discharged on day t, with day 1 being April 20th, 2010): in fact, these daily volumes re?ect consensus estimates produced by the Flow Rate Technical Group (an explanation of how these estimates were derived will be published separately from this report).

The 10 % relative uncertainty that has been associated with the volume discharged is interpreted as follows: the simulated time series $V_R(1), V_R(2), \ldots$ of the daily discharge is modeled as the product

$$V_R(t) = (1 + Q)V_R(t), \text{ for } t = 1, 2, \ldots, \tag{A1.17}$$

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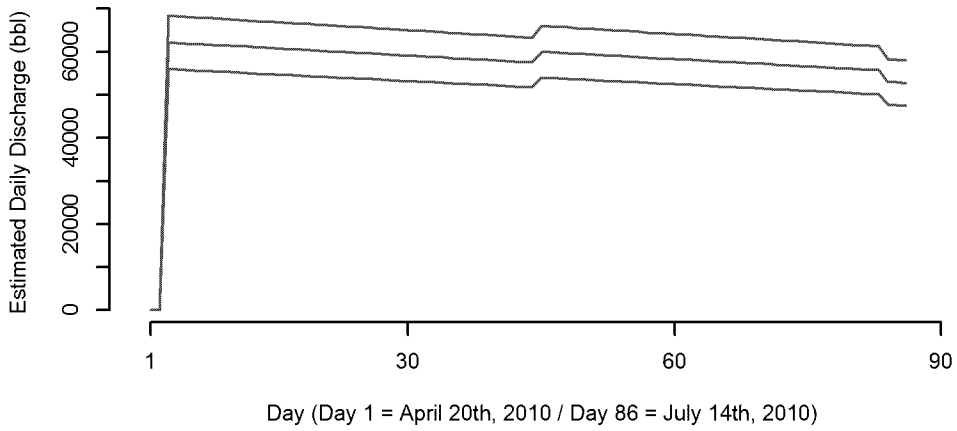

Figure A1.2: Daily volume of oil discharged from the Deepwater (Macondo) well. The best estimate is represented by the blue line, while the red envelope defines a range of ±10% around the best estimate. Since there was no additional discharge after day 86 (July 14, 2010), the curves drop to zero beyond this date (not shown).

where $V_R(t)$ denotes the nominal discharge on day t, and Q is a Gaussian random variable with mean 0 and standard deviation 0.05.

In these circumstances, and with high probability (95 %), the actual discharge should be within 10 % (= 2 × 0.05) of the nominal discharge; however, the model entertains a small chance (5 %) that it could deviate by more than ±10% from nominal.

Whatever deviation from nominal is selected for one particular scenario, it is assumed to apply to all the days of that scenario. For example, if we were 3 % too low in one scenario (meaning that $Q = -0.03$), then we would be 3 % too low in every day of that scenario; and if, in another scenario, we were 7 % too high ($Q = 0.07$), then we would be 7 % too high in every day of this scenario.

Over a two and half-month period, about 400 controlled burns of oil on the surface were conducted, which eliminated about 5 % of the oil that was discharged from the well. For the several burns that typically occurred each day, estimates of the minimum and maximum volume burned were provided.

We model the uncertainty associated with the total volume burned on a particular day as uniformly distributed between the given minimum and maximum. The corresponding standard deviation equals the difference between the maximum and the minimum divided by $\sqrt{12}$. The relative standard deviation equals the standard deviation divided by the average of the minimum and the maximum.

For the purpose of generating stochastic scenarios, these daily relative standard deviations were summarized by their geometric average, which turned out equal to 9.65 %. Similarly to how we

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treat the volume discharged, we have modeled the uncertainty associated with the daily volume of oil burned $V_{BU}(t)$ as described in equation A1.18, where the $\{B(t)\}$ denote independent Gaussian random variables with mean 0 and standard deviation 0.0965.

$$V_{BU}(t) = \quad 1 + B(t) \;\; V_{BU}(t), \text{ for } t = 1, 2, \ldots. \tag{A1.18}$$

Note that, differently from how we modeled the uncertainty of the volume discharged, here we perturb the estimates of the daily volumes of oil burned, independently from day to day.

A1.6 Probability Models for Rate Constants

The mass balance equations listed above include *rate constants* $k_1, \ldots, k_8$. Subject-matter experts have described their state of knowledge about the values of these constants by regarding them as outcomes of random variables, and by providing location and spread information about the corresponding probability distributions, listed in Table A1.2. This is a standard statistical device to express uncertainty assessments, and should not be interpreted as suggesting that these rate constants are intrinsically random, according to any of the common meanings of randomness.

RATE CONSTANT	DEFINITION	$_{0.025}$	μ	$_{0.975}$
k_1	Natural dispersion (subsurface)	0.10	0.20	0.30
k_2	Chemical dispersion (subsurface)	2/9	4/9	1.00
k_3	Chemical dispersion (surface)	0.05	0.10	0.20
k_4	1st day evaporation	0.33	0.37	0.44
k_5	2nd day evaporation	0.00	0.04	0.06
k_6	Net oil fraction in skimmed oil	0.10	0.20	0.40
k_7	Dissolution of dispersed oil	0.05	0.075	0.10
k_8	Natural dispersion (surface)	0.00	0.05	0.10

Table A1.2: Rate Constants. Expected values (μ) and 2.5th ($_{0.025}$) and 97.5th ($_{0.975}$) percentiles of the probability distributions that model the associated uncertainties.

We have interpreted the information in Table A1.2 as follows: the probability is approximately 95 % that the true value of a rate constant lies in the interval from $_{0.025}$ to $_{0.975}$, and has expected value μ. In addition, we also assume that the possible values for the rate constants are non-negative, and also that they are no larger than 1, except possibly for k_2 and k_3.

Once the probability model described below was fitted to the information in Table A1.2, these assumptions were satisfied (with probability just about equal to 1) for all but k_5 and k_8. Indeed, as modeled, both k_5 and k_8 could be negative with probability about 2.5 %: for this reason, their distributions were truncated at 0.

For k_2, k_3, k_4, and k_6, it so happens that the distance from the expected value (μ) to the 97.5th percentile ($_{0.975}$) is greater than or equal to the distance from the expected value (μ) to the

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2.5th percentile ($_{0.025}$): that is, their probability distributions have the right tail longer than the left tail (in other words, they are skewed to the right). For k_5 the opposite happens, and its distribution is skewed to the left. The distributions for k_1, k_7, and k_8 are approximately symmetrical.

Many different probability models are available that describe right skewness, and a few can describe skewness either to the left or to the right, and still involve no more than three adjustable parameters, which is the number of pieces of information listed for each rate constant in Table A1.2 on page A1.9.

One of these, which includes the normal distribution as a special case, is the skew normal distribution described by Azzalini [1985], and implemented by Azzalini [2010] in package sn for the R environment for statistical programming and graphics [R Development Core Team, 2010].

Another model that we have considered, given that the rate constants have values essentially between 0 and 1, was the beta distribution. Since the skew normal distribution managed to reproduce the information available about the rate constants much more accurately than the beta distribution, we have used the skew normal distribution as a model for all of the rate constants.

The adjustable parameters of the skew normal distribution are the location , the scale , and a shape parameter that controls skewness. The values we selected for these parameters that reproduce the entries in Table A1.2 on page A1.9 are listed in Table A1.3 on page A1.11. We obtained them by taking the following steps (Figure A1.3 depicts the resulting probability densities):

(a) If $_{0.975}$ and $_{0.025}$ denote the 97.5th and 2.5th percentiles of a skew normal distribution, the ratio ($_{0.975}$ - μ)/(μ - $_{0.025}$) (which depends neither on μ nor on) is an effective proxy for the distribution's skewness. Since the shape parameter is a monotonically increasing function of the skewness of the skew normal distribution, we built an interpolating spline [Venables and Ripley, 2002] → such that ≈ → ($_{0.975}$ - μ)/(μ - $_{0.025}$) with negligibly small error for values of over a suitably wide range.

(b) For each rate constant, first we estimated using the function → just described, by applying it to the values in Table A1.2, and then found values of and that minimize

$$_{0.025} - F^{-1}_{,,}(0.025)^2 + {}_{0.975} - F^{-1}_{,,}(0.975)^2 + \mu - + \frac{\overline{2}}{\sqrt{(1+{}^2)}}{}^2,$$

where $F^{-1}_{,,}$ denotes the inverse of the cumulative probability distribution function of the skew normal distribution with location , scale , and shape . The idea here is to choose values for the adjustable parameters that best reproduce the mean and percentiles given for each rate constant. The last term in the foregoing expression is determined by the fact that the expected value of a skew normal distribution with location , scale , and shape , is + $\overline{2}/\sqrt{(1+{}^2)}$.

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RATE CONSTANT			
k_1	0.200	0.0500	0.00
k_2	0.191	0.356	760
k_3	0.0470	0.0681	176
k_4	0.332	0.0483	8.44
k_5	0.0612	0.0272	- 167
k_6	0.0940	0.136	176
k_7	0.075	0.0128	0.00
k_8	0.0500	0.0255	0.00

Table A1.3: Parameters of Probability Distributions for Rate Constants. Values of the location , scale , and shape of the skew normal distributions used to represent the information available about the values of the rate constants.

A1.7 Uncertainty Analysis

The uncertainty analysis is based on statistics of multiple scenarios, generated by Monte Carlo simulation, as outlined in Section A1.4 on page A1.5. Each scenario is de?ned by a value of the random variable Q introduced in equation A1.17 on page A1.7, by values of the random variables $\{B(t)\}$ in equation A1.18 on page A1.9, and by a set of values of the rate constants obtained by sampling the probability distributions?tted as described in Section A1.6 on page A1.9. The scenario proper consists of the time series of values of the output variables that correspond to the simulated values of Q and of the rate constants.

The fact that the same sampled value of each rate constant is used for every day of each scenario effectively induces statistical dependencies between the quantities that are functions of the rate constants. The uncertainty analysis does take these dependencies into account.

More precisely, we have taken the following steps:

(a) We selected a value for m, the number of scenarios (m = 100 000 for the results in Appendix 2).

(b) For $i = 1, \ldots, m$:

(b1) We drew a sample of size one from the probability distribution of Q, and used it to generate a replicate of the time series of the values of oil volume discharged, by application of equation A1.17 on page A1.7.

(b2) We drew a sample of size one from the probability distribution of each of the random variables $\{B(t)\}$, and used them to generate a replicate of the time series of the values of oil volume burned, by application of equation A1.18 on page A1.9.

(b3) We drew a sample of size one from the probability distribution?tted to each rate constant.

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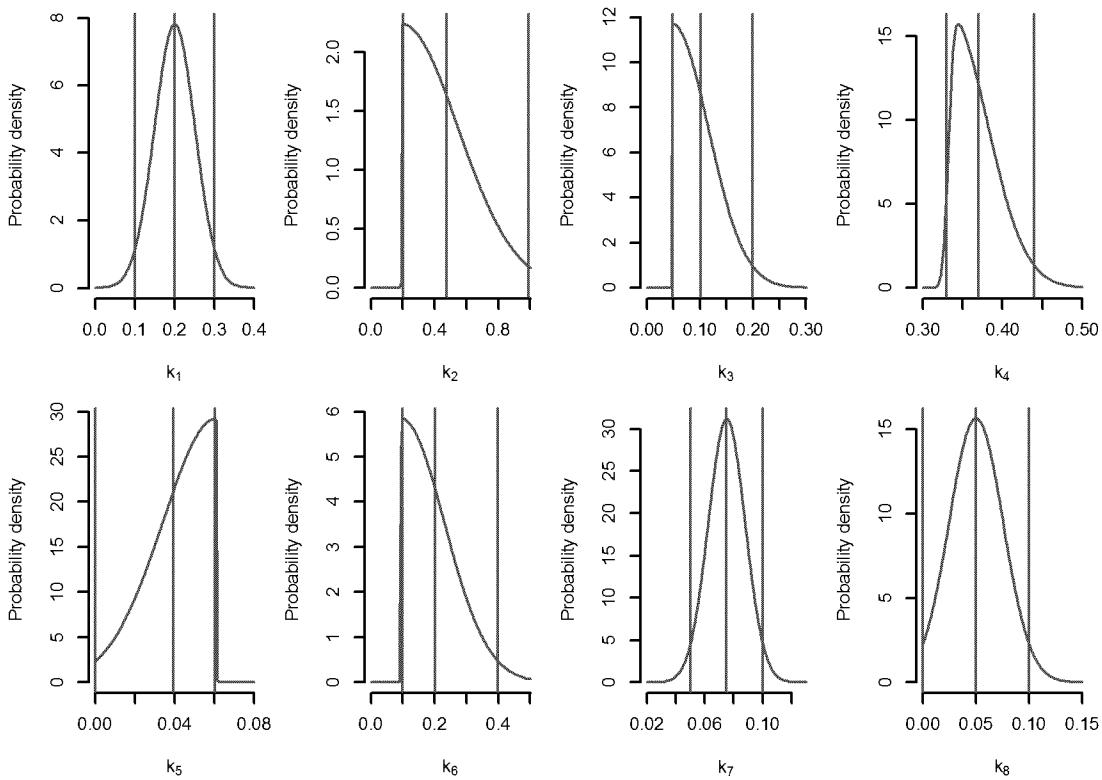

Figure A1.3: Skew normal probability densities for the rate constants. The vertical red lines mark the locations of the 2.5th percentile $_{0.025}$, the expected value μ, and the 97.5th percentile $_{0.975}$, which reproduce the values specified by the subject-matter experts, listed in Table A1.2 on page A1.9.

(b4) Using the time series obtained in step b1 on page A1.11, the values for the rate constants obtained in step b3 on page A1.11, and the values of the input quantities, we used the mass balance equations (equations A1.1 on page A1.2– A1.16 on page A1.2), to compute the time series of daily values of the output quantities, and of their cumulative sums (where applicable).

(c) Step b on page A1.11 produced m simulated values of each output quantity on each day, whose 2.5th and 97.5th percentiles define the lower and upper 95 % probability envelopes for the value of the output quantity.

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A1.8 Best-Case and Worst-Case Scenarios

For any particular day t, the corresponding points on the lower and upper bounds (red envelope) for $V_S(t)$, depicted in Figure A1.1 on page A1.7 and whose ordinates are $V_{S,L}$ and $V_{S,U}(t)$, bracket the true volume of residual oil on that day, with 95 % probability.

Given their fairly extreme nature, we take these endpoints to represent best-case and worst-case scenarios, even though there are scenarios that are better than that best, and worse than this worst because the interval from $V_{S,L}(t)$ to $V_{S,U}(t)$ encompasses only the middlemost 95 % of the m simulated replicates $V_{1,S}(t), \ldots, V_{m,S}(t)$ that will have been generated for $V_S(t)$.

This approximate, practical characterization of what the "best" and "worst" situations may be is motivated by the desire to focus the management of the crisis on scenarios that, although fairly extreme, still are "buffered" by non-negligible tail probabilities that lend them statistical credence, rather than on speculatively extreme cases.

Now, given $V_{S,L}(t)$ for day t, we wish to find the combinations of values of all the other variables that correspond to this best-case scenario, and that also satisfy the mass balance equations. Similarly for $V_{S,U}(t)$, and for the worst-case scenario.

It is not immediately obvious what these combinations of values should be because $V_{S,L}(t)$ does not necessarily correspond to the case where all the rate constants, and the variables Q and $\{B(t)\}$, simultaneously have their "best" values. This is so for two reasons: first, these variables are assumed to vary independently of one another from scenario to scenario (an assumption that is discussed and probed in Section A1.9 on page A1.14); second, such "best" values may yield a far more extreme, and practically irrelevant, value for the volume of residual oil, than what we have defined $V_{S,L}(t)$ to be.

Since the volume of residual oil depends on the values of several other quantities, and does so in the complicated way that the mass balance equations describe precisely, we will write $V_S(t) = h(V_R(t), \ldots, V_{NW}(t))$ to denote this dependence summarily, omitting reference to Q, to the $\{B(t)\}$, and to the rate constants. The function h subsumes all the mathematical manipulations that these quantities undergo finally to produce $V_S(t)$.

Our goal is to find the most likely values of $V_R(t), \ldots, V_{NW}(t)$ that, once processed through h, yield $V_{S,L}(t)$ as the volume of residual oil left on day number t, and that satisfy the mass balance equations. (Recall that $V_{S,L}(t)$ denotes the 2.5th percentile of the set of m simulated values of the volume of residual oil, as defined in Step c on page A1.12.) And then to do similarly for $V_{S,U}(t)$, the 97.5th percentile.

Taken together, those most likely values will then define the best-case scenario. (And similarly the worst-case scenario.) Since this amounts to "inverting" the function h, our goal can be fairly described as *scenario inversion*. The problem, of course, is that h is not invertible in the strict sense of mathematics because there are many combinations of values of $V_R(t), \ldots, V_{NW}(t)$ that yield the same value of $V_S(t)$.

To perform a satisfactory scenario inversion that yields the best-case scenario, we start from the realization that such scenario will correspond to some combination of values of $V_R(t), \ldots, V_{NW}(t)$ that, once processed through h, produces a value for $V_S(t)$ that is close to $V_{S,L}(t)$.

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To find such combinations of values of the arguments of the function h, we selected a suitably small positive value , and searched through the set of simulated values of $V_R(t), \ldots, V_{NW}(t)$ for those that satisfy $|h(V_{i,R}(t), \ldots, V_{i,NW}(t)) - V_{S,L}(t)| <$. Let S_L denote the resulting subset of combinations of values of $V_R(t), \ldots, V_{NW}(t)$.

Since S_L comprises many such combinations, the problem remains of selecting one that is representative of the best-case scenario. We did this by finding, for each output variable of interest that the volume of residual oil is a function of, its average over those of its values that are present in S_L.

We also verified that these averages indeed are representative of the values they subsume, by inspecting their locations in histograms of these values. This process was repeated, using a comparably defined set S_U for the worst-case scenario. These best-case and worst-case scenarios for July 14, 2010 (day t = 86) are characterized quantitatively, and depicted graphically, in Appendix 2.

A1.9 Sensitivity Analysis

As described in Section A1.7 on page A1.11, the uncertainty analysis is based on simulated scenarios, and each of these scenarios is defined by a time series of simulated values of discharged oil, by a time series of volumes of burned oil, and by a set of simulated values of the rate constants.

These simulations are based on particular models (probability distributions) for all the participating quantities: although reasonable, other models could also reasonably be entertained. For example, we mentioned already, in Section A1.4 on page A1.5, that the variable Q that appears in equation A1.17 on page A1.7, and which we assumed had a particular Gaussian distribution, conceivably might also have been modeled as having a particular uniform distribution instead. The same applies to the variables $\{B(t)\}$ relating to the volume of oil burned.

One assumption that we have made but that we have not yet discussed is that the random variables modeling the rate constants are stochastically independent. Although this represents an approximation suggested by the subject-matter experts, it is not only possible but indeed likely that some of them should be interrelated.

For example, it is reasonable to expect that the rates of evaporation, k_4 and k_5, on the first and second days after discharge of a fresh batch of oil into the sea should vary together over time, because they may be driven by common factors. Similarly, k_2 and k_3, the rate constants that describe the effectiveness of chemical dispersion under and on the sea surface, may be interrelated for similar reasons.

To ascertain the sensitivity of our results to our modeling assumptions, we have focused on the volumes of residual oil V_S, and performed an alternative uncertainty analysis assuming that the correlation coefficient between k_2 and k_3, and between k_4 and k_5, was $\sqrt{0.5}$, rather than 0. This assumption about the correlations means that the potential variability in k_2 over time would "explain" about 50% of the corresponding variability in k_3 (and similarly for k_4 and k_5).

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To impose correlations between these two pairs of rate constants, we used a Gaussian copula [Nelsen, 2006, Possolo, 2010], which is a standard technique for this purpose. This creates a multivariate probability distribution with the correlations specified ($\sqrt{0.5}$ between k_2 and k_3 and also between k_4 and k_5, and 0 between all the other possible pairs), and such that the individual rate constants, when taken each one by itself, still has the same skew normal distribution that was fitted as described in Section A1.6 on page A1.9.

We have also studied the sensitivity of the results to the assumptions we made about the random variable Q, introduced in equation A1.17 on page A1.7, and about the random variables $\{B(t)\}$ introduced in equation A1.18 on page A1.9. The former drives the variability between simulated scenarios, of the time series of volume of oil discharged from the well. The latter models the measurement uncertainty associated with the volume of oil that has been burned. Originally we assumed that Q has a Gaussian distribution with mean 0 and standard deviation 0.05. For the sensitivity analysis we have assumed instead that Q is uniformly distributed between -0.1 and $+0.1$. Similarly for the $\{B(t)\}$.

The results of this sensitivity analysis, depicted in Figure A1.4 on page A1.16, show that the presence of such statistical dependence as we have entertained for selected pairs of rate constants, possibly in conjunction with a different model for Q and for the $\{B(t)\}$, widens the uncertainty envelope for the time series of values of V_S. However, it changes the upper bound hardly at all, and depresses the lower confidence envelope, thus suggesting that the assumptions we made originally are the more conservative ones among the alternatives we have considered.

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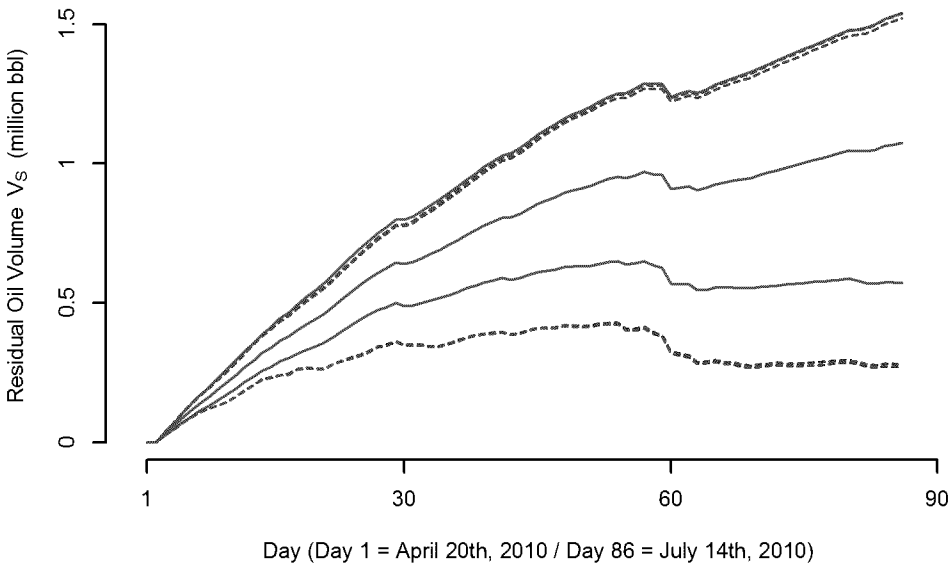

Figure A1.4: Sensitivity Analysis. Volume of residual oil (V_S) and variants of the approximate 95 % con?dence band, corresponding to assuming that k_2 and k_3, as well as k_4 and k_5, are correlated (dashed, green line), or that, in addition to this, the random variable Q and the random variables $\{B(t)\}$, introduced in equation A1.17 on page A1.7 and in equation A1.18 on page A1.9, respectively, are uniformly distributed, rather than Gaussian (dotted, brown line). These alternatives mostly reduce the lower con?dence envelope, thus suggesting that the assumptions we made originally are the more conservative ones among the alternatives we have considered. Since there was no additional discharge after day 86 (July 14, 2010), the curves ?atten beyond this date (not shown).

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Appendix 2

A2 Oil Budget Calculator Web-based Tool

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Background

One of the most visible aspects of the Oil Budget Calculator is the technological application that was created as a response tool for personnel with National Incident Command (NIC). The first iteration of an oil budget calculator was built in a Microsoft Excel spreadsheet by U.S. Coast Guard (USCG) staff with the National Response Center. This tool captured simple daily variables from the response effort (e.g., amount of oil skimmed from the surface) and instantiated basic formulas for a best- and worst-case scenario based on calculations used in previous spill events. The USCG requested help from the Interagency Solutions Group established from NIC for help with the spreadsheet tool in terms of reporting and characterizing the results along with help from a science team in the underlying calculations and assumptions.

To address this need, the Interagency Solutions Group consulted a U.S. Geological Survey (USGS) computer science team on the tool itself and National Oceanic and Atmospheric Administration (NOAA) scientific support personnel to engage a team of oil fate and behavior scientists. After discussing the basic requirements for the final tool needed by NIC staff, in particular the need for ease of access without new software requirements, the USGS team opted for the creation of a Web-based application. This section of the report discusses the engineering of the Web-based system and its relationship to the scientific model developed by partners in NOAA and the National Institute of Standards and Technology.

Requirements for the Calculator

Initial requirements for the purpose and use of the calculator were received in phone conversation with NIC staff on June 17, 2010 (National Incident Command Personnel, 2010). Further requirements and requests for features in the application continued to evolve through the course of the project as NIC staff, scientific support personnel, and others began using reports from the tool in response activities. All technical requirements, features, and associated tasks for the tool were captured in an online project management system used by the USGS team as a way to document the evolution of the application and a record for any future activities.

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A high-level discussion of requirements is summarized below:

- The tool needed to be easily accessible by NIC staff and NOAA scientific support personnel providing input to response activities, not requiring any additional desktop software or a major learning period.
- The tool needed to be secure so that only authorized personnel could access the system, and specific NIC staff needed the ability to specify who could perform specific functions in the system.
- Only certain personnel could be authorized to enter data into the Daily Values Database, and all data needed to be logged so that individual entries could be tracked to the user who entered them and when they were entered.
- Only certain personnel could be authorized to access daily and summary reports from the system, and those accesses needed to be logged.
- Only certain personnel involved with scientific support could be authorized to change the underlying calculations and assumptions used to calculate the oil budget.
- The tool needed to include the ability to view the daily and cumulative total figures and associated charts for any day in the incident.
- The tool needed to provide a print feature so that authorized report users could output a daily executive summary used by response and communications personnel.
- The tool needed a feature to output all daily values entered into the system in a spreadsheet table so that the figures could be shared and viewed independently.

In total, 98 separate features or improvements were captured and tracked in the project management application used for the work during the course of the engineering and development effort.

Scenarios

The oil budget calculation needed to incorporate the concept of scenarios to include at least a theoretical best and worst case scenario in terms of the amount of oil being discharged and the relative effectiveness of response activities. A third scenario used mean values to provide a probable case, or at least a baseline set of numbers predicated on the best available knowledge of oil fate and behavior. The requirement to essentially bound the problem and effectiveness of the response played a critical role in the design of the application and reports.

During the period when the well was still discharging oil, the Oil Budget Calculator used a simplistic approach to calculating and presenting scenarios that used only the difference in flow rate estimates as the variable between scenarios. After continued examination of the tool with the statistical experts working on the oil budget model, the final iteration of the calculator (version 2.0) included a more rigorous presentation of the scientific uncertainty in the theoretical best- and worst-case scenarios. This version of the tool

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incorporated the upper and lower bounds of uncertainty for the effectiveness of individual response activities in addition to the uncertainty bounds for the flow rate.

Components of the Calculator

The tool consisted of the following basic elements:

- Daily Variables – daily variables entered by USCG staff with the NIC
- Global Variables – global flow rate values based on government estimates and formulas stored as variables to produce cumulative totals from the oil budget calculating model
- Modeling Application technological application to pass daily variables to a scientific model that encapsulated assumptions and statistical calculations to produce daily oil budget figures
- Reporting Application executive summary reporting component that presented daily oil budget numbers and charts

These components were brought together as a Web-based tool within a Java application framework called Grails (Grails Community, 2010) and several existing infrastructural elements already in place within the USGS network and able to be tuned toward the application. Front-end Web services were provided on an Apache Web server platform (Apache Project, 2010). Database elements were stored within a PostgreSQL (PostgreSQL, 2010) environment using Hibernate (JBoss Community, 2010) for data object and relational mapping and persistence. Authentication services were provided by a USGS framework founded on a technology called Java Open Single Sign-On (JOSSO Community, 2010). The Oil Budget Calculator model was written in the R scientific programming language (R Project, 2010) using a dedicated virtual machine set up as an "R Application Server." All application components were configured to run on servers using the Red Hat (Red Hat, 2010) version of the Linux operating system.

Daily Variables

A simple database table managed through the Web application housed variables of the response effort entered by NIC personnel. In some cases, the values were direct measurements, and in others the values were the results of established standard measurement protocols used by the USCG for incident response (National Incident Command Personnel, 2010).

- Oil Collected via RITT/Top Hat (barrels) – Values for the amount of oil recovered by the vessels Helix Producer, Discoverer Enterprise and the Q4000 and reported by British Petroleum.
- Oil Burned (barrels) Total oil burned using standard rates from the American Society for Testing and Materials (American Society for Testing and Materials, 2006).
- Oily Water Collected (barrels) – Total of estimated measurements from multiple collection methods and contractors.

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- Subsurface Dispersants Used (gallons) Direct report from dispersant operations.
- Surface Dispersants Used (gallons) Direct report from dispersant operations.

Later in the response effort, once inland recovery of oil reached a point where total numbers could be captured, a value of tons of oily debris was added to the daily variables database as a reporting value. This figure was not used in the oil budget calculation but was included in the reporting tool. Based on the requirement to have an output of daily variables in a spreadsheet format, a feature was added to export all daily values as an Excel spreadsheet file.

Global Variables

The Oil Budget Calculator went through three distinct iterations based on the best government estimates of flow/discharge rate from the leaking well. All values were provided to the Oil Budget Calculator team from the Deepwater Horizon Flow Rate Technical Group and were refined over time as more and better information became available. The need to include multiple scenarios resulted in flow estimates of high, low, and mean being stored in the global variables portion of the database and used in the calculations.

The global variables data also contained several formulas stored as a simple formula language and used in the final calculations of cumulative totals on the output from the oil budget model. Global variables were considered the domain of the oil fate and behavior science team building the model and were only editable by application administrators.

Modeling Application

The initial iteration of the Oil Budget Calculator employed a very simple model based directly on the individual calculations provided in an interim report. These formulas were stored in the application as global variables and acted directly on daily variables, triggered whenever daily variables were modified in any way. Initial reports from this method shared amongst the development and science teams prior to production release of the application indicated a need for an increased level of statistical sophistication in the model.

Following engagement of personnel from the National Institute of Standards and Technology (NIST), the oil budget calculations were refactored into a statistical model and codified using the R scientific programming language (R Project, 2010). The development team engineered an application server environment to house and run the R processing engine, receive values from the application maintaining daily variables, trigger the model to run calculations, and ingest calculated output variables from the model back into the final database.

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Reporting Application

The reporting toolset was built within the same Grails application framework (Grails Community, 2010). The executive summary report presented two to three scenarios over the course of the application. Initially, the application presented only a high flow scenario, based on the government's maximum discharge estimate, and a low flow scenario, based on the government's minimum discharge estimate. Personnel from NIC later requested the addition of a scenario based on mean discharge as a single value report that could be used in certain planning and communication processes. For each scenario, the reporting tool provided a table of the calculator output of daily and cumulative totals.

The report also included charting generated using the JFreeChart Java library (JFree.org, 2010). The Oil Budget pie chart provided a response estimate representation of the total amount of oil released over time for the actual government estimates of discharge as well as a higher flow and lower flow estimate from the ±10% uncertainty factor, the relative amounts of oil recovered or dispersed by both natural and response methods, and the total remaining oil calculated by the oil budget model. A stylized stacked bar chart was used in place of the pie chart in earlier iterations of the tool.

The reporting application included a feature to select any day in the incident and view the full report for the day, showing cumulative totals at that point. The reports could be viewed online via a Web browser and exported in Adobe Acrobat (PDF) format. Charts could also be viewed individually as image files for incorporation into alternate presentations.

Evolution of the Oil Budget Calculator

The Oil Budget Calculator online tool went through several distinct iterations recorded as versions of the tool throughout its lifecycle. The iterations of the tool used for the incident response activity were recorded as 1.x versions through the final version 1.3.1. This first generation of the tool was used for the public release of information about the Oil Budget Calculator (NOAA, 2010).

Based on input from the science team responsible for the final Oil Budget Calculator report to National Incident Command and a significant reworking of the scientific model, a second generation (version 2.0) of the tool was prepared. The major difference between the two generations of the tool was the calculation and characterization of scientific uncertainty for the variable elements in each of three scenarios. Version 1.x of the tool used only a variable discharge rate based on the ±10% uncertainty in the official government estimates of discharge produced by the Deepwater Horizon MC252 Flow Rate Technical Group - 62,200 bbl on April 22, 2010 to 52,700 bbl on July 14, 2010 (Lehr and others, 2010) – to produce reports for three scenarios (official government estimates, high flow scenario, and low flow scenario). Version 2 of the tool used calculations of scientific uncertainty for individual elements of the report to produce

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expected, best case, and worst case scenarios as discussed in Appendix 1 of the Oil Budget Calculator report.

Version 2 of the online tool was not used in the actual response effort. Rather it was prepared as the next generation of the tool and presented to National Incident Command as an improvement on the calculations based on increased information and knowledge about the Deepwater Horizon incident provided by the science team. It was meant to help inform future development of the response tool for other incidents.

The following sections present report elements from the two generations of the online tool captured for July 14, 2010 the last day in the incident where reported values for skimming and burning oil were recorded.

Oil Budget Calculator – Version 2.0

Table A2.1 comes directly from version 2.0 of the online tool using the calculations described in Appendix 1 of the report. The colors next to the individual calculated values correspond to colors in the charts that are part of the generated oil budget report. Two of the charts showing cumulative total oil and percentage of total are provided in the body of the report for the same day, July 14, shown in the table.

Table A2.1. Oil Budget Calculator cumulative totals for the official estimated discharge rate and expected scenario (62,200 bbl on April 22, 2010 to 52,700 bbl on July 14, 2010) through July 14, 2010 (from version 2.0 of the Oil Budget Calculator)

Calculated Values	Cumulative	July 14
Discharged	4,900,000	53,000
Recovered via RITT and Top Hat	820,000	13,000
Dispersed Naturally	640,000	5,200
Evaporated or Dissolved	1,200,000	9,500
Available for Recovery	2,300,000	25,000
Chemically Dispersed	770,000	13,000
Burned	260,000	1,100
Skimmed	160,000	5,200
Other Oil	1,100,000	6,000
Recorded Values		
Dispersant Used	43,695	327
Inland Recovery (Cumulative)	0 tons	

*** All unlabeled values in barrels; rounded to 2 significant digits**

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Oil Budget Calculator – Version 1.x

Table A2.2 and figure A2.1 show the cumulative oil budget from the version of the online tool used in the response effort. The response tool used a numbered versioning scheme of 1.x, ending with 1.3.1. This version of the tool and the table and figure included here provide background documentation on the evolution of the tool. The previous section on version 2.0 represents a significant improvement in the Oil Budget Calculator based on the substance of this report.

Table A2.2. Oil Budget Calculator cumulative totals for the official estimated discharge rate (62,200 bbl on April 22, 2010 to 52,700 bbl on July 14, 2010) through July 14, 2010 (from version 1.3.1 of the Oil Budget Calculator)

Calculated Values	Cumulative	July 14
Discharged	4,928,100	52,700
Recovered via RITT and Top Hat	817,739	12,843
Dispersed Naturally	763,948	6,924
Evaporated or Dissolved	1,242,668	11,168
Available for Recovery	2,103,745	21,765
Chemically Dispersed	418,075	5,237
Burned	263,900	1,100
Skimmed	156,694	5,110
Remaining	1,265,075	10,318
Recorded Values		
Dispersant Used	43,695	327
Inland Recovery (Cumulative)	0 tons	

*** All unlabeled values in barrels.**

Table A2.2 comes directly from the online tool. The colors next to the individual calculated values correspond to colors in the charts that were part of the generated oil budget report. Significant refinements occurred between the version of the tool used during the response the new version presented in the final report. Most notably for the table of values:

- The term Remaining was changed to Other Oil to help alleviate an impression that the other calculated values in the report might not remain in the environment at all.
- Numeric figures were rounded to two significant digits to better represent the level of scientific uncertainty inherent in the calculations.

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Figure A2.1. Cumulative percentage of oil from the calculator for natural processes and response activities using the official estimated discharge rate (62,200 bbl on April 22, 2010 to 52,700 bbl on July 14, 2010) through July 14, 2010 (from version 1.3.1 of the Oil Budget Calculator)

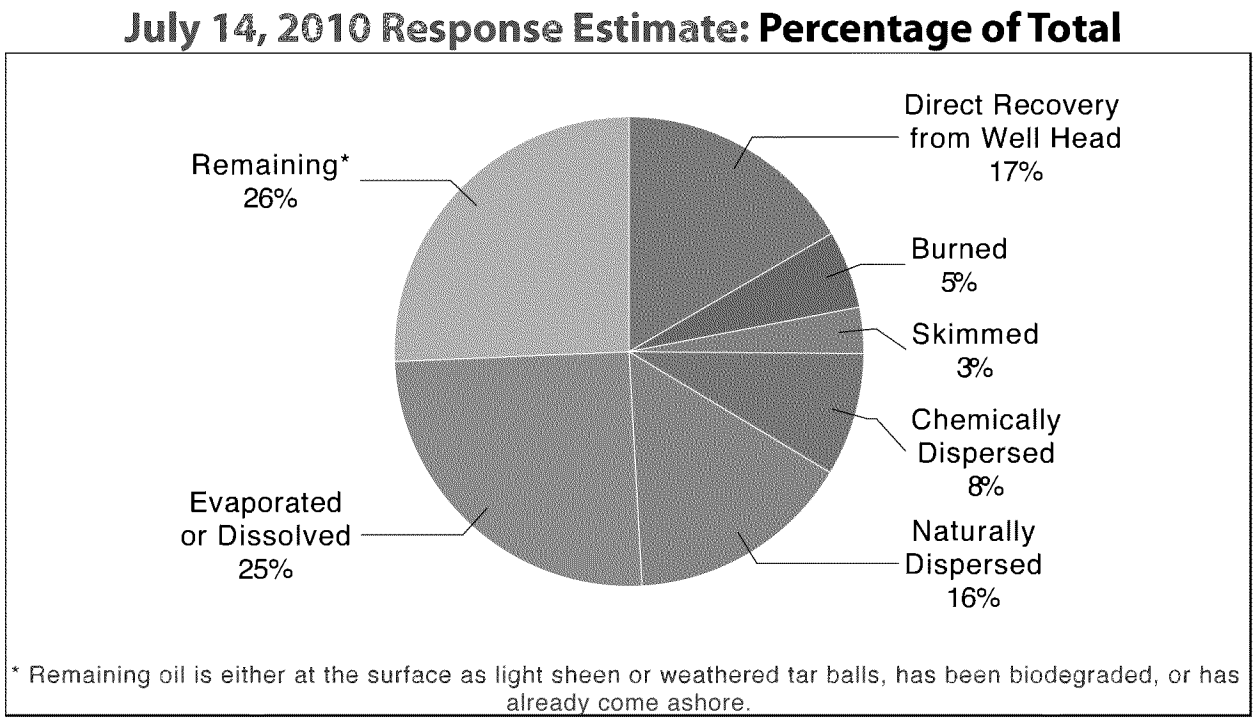

Figure A2.1 comes directly from the online tool. Significant refinements occurred between the charts included in the version of the tool used during the response and the new version presented in the final report. Most notably, the single pie chart that presented only one possible scenario at a time in three separate images was replaced with a bar chart that presented best case, expected, and worst case scenarios in one graphic to help show the scientific uncertainty inherent in the model. These charts are included in the body of the report.

Application Security and Logging

Authentication for the application was provided using an existing framework in the USGS based on JOSSO technology (JOSSO Community, 2010) and a directory service of user accounts. Users were placed into one of three roles within the application:

- Report Readers Access to view and print reports for any day in the incident
- Data Entry Personnel – Access to view and print reports and to enter and maintain daily variables
- Administrators Each of the above rights plus access to enter and maintain global variables

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All accesses to the online application were logged via the authentication system. Changes to daily and global variables were logged separately and available for viewing within the application. Printed reports, generated as a PDF download, were stamped with a user ID and date in the footnote of every page.

All versions of the Web application and R statistical model were tracked as they were deployed onto the technological framework using a versioning system called Subversion (Apache.org, 2010). Subversion logs and underlying Web site access logs are stored in a secure data storage framework and available as necessary.

Future of the Oil Budget Calculator Web Application

The overall utility of the online application proved a valuable tool for the response and communication efforts as reported by NIC and NOAA staff involved directly in response activities. The first generation of the tool was still in use for the Deepwater Horizon incident at the time of writing, and USCG staff indicated a desire to continue discussions about either ongoing partnership with the USGS or technology transfer to a USCG facility.

Following the production of this report and major input by the oil fate and behavior science team, version 2.0 of the Oil Budget Calculator was prepared with modifications to the calculator model and major changes to the presentation of scientific uncertainty in the output reports. The scientific reasoning behind the calculations is discussed extensively in the report, and the new model is laid out within Appendix 2. The new model resulted in significant differences in the final cumulative totals and associated visualizations with a higher overall degree of confidence based on the extensive review of the model and input by the science team preparing the Oil Budget Calculator report.

The technological framework developed for the calculator, including the separation between data entry, model calculations, and reporting was created to be extensible and scalable to other incidents using variations on the model and to entirely different applications of similar concepts. Further discussions with NIC personnel will determine the eventual fate of the tool beyond the Deepwater Horizon incident.

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Appendix 3

A3 Data Input Used by Calculator

Date	Government Estimate of Discharge VRG bbls	Inland Recovery IR tons	Oil Burned VBU bbls	Oil Collected via RITT/TopHat VDT bbls	Oily Water Collected VOW bbls	Subsurface Dispersants VCBg gallons	Surface Dispersants VCSg gallons
04/20/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
04/21/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
04/22/2010	62200.00	0.00	0.00	0.00	0.00	0.00	1701.00
04/23/2010	62100.00	0.00	0.00	0.00	1630.00	0.00	0.00
04/24/2010	61900.00	0.00	0.00	0.00	155.00	0.00	0.00
04/25/2010	61800.00	0.00	0.00	0.00	0.00	0.00	9818.00
04/26/2010	61700.00	0.00	0.00	0.00	7832.00	0.00	14486.00
04/27/2010	61600.00	0.00	0.00	0.00	18557.00	0.00	27078.00
04/28/2010	61500.00	0.00	95.00	0.00	3306.00	0.00	42143.00
04/29/2010	61400.00	0.00	0.00	0.00	3245.00	0.00	40913.00
04/30/2010	61300.00	0.00	0.00	0.00	1427.00	2196.00	4900.00
05/01/2010	61200.00	0.00	0.00	0.00	992.00	0.00	11653.00
05/02/2010	61000.00	0.00	0.00	0.00	0.00	3399.00	0.00
05/03/2010	60900.00	0.00	0.00	0.00	0.00	5812.00	0.00
05/04/2010	60800.00	0.00	0.00	0.00	9996.00	7580.00	34273.00
05/05/2010	60700.00	0.00	880.00	0.00	0.00	0.00	49575.00
05/06/2010	60600.00	0.00	6155.00	0.00	21452.00	0.00	28770.00
05/07/2010	60500.00	0.00	2010.00	0.00	13788.00	0.00	7270.00
05/08/2010	60400.00	0.00	0.00	0.00	26189.00	0.00	41690.00
05/09/2010	60200.00	0.00	0.00	0.00	33865.00	0.00	55932.00
05/10/2010	60100.00	0.00	0.00	0.00	8957.00	9460.00	56220.00
05/11/2010	60000.00	0.00	0.00	0.00	0.00	2100.00	7940.00
05/12/2010	59900.00	0.00	0.00	0.00	0.00	0.00	39710.00
05/13/2010	59800.00	0.00	0.00	0.00	0.00	0.00	41620.00
05/14/2010	59700.00	0.00	0.00	0.00	0.00	0.00	44031.00
05/15/2010	59600.00	0.00	0.00	500.00	0.00	7222.00	14208.00
05/16/2010	59400.00	0.00	0.00	900.00	6987.00	6300.00	670.00
05/17/2010	59300.00	0.00	3175.00	1030.00	23873.00	7980.00	13213.00
05/18/2010	59200.00	0.00	785.00	1200.00	13903.00	3450.00	12386.00
05/19/2010	59100.00	0.00	27350.00	3000.00	11849.00	4879.00	3352.00
05/20/2010	59000.00	0.00	11150.00	2200.00	13600.00	14151.00	1.00
05/21/2010	58900.00	0.00	0.00	2175.00	13126.00	14400.00	29892.00
05/22/2010	58800.00	0.00	0.00	1361.00	12025.00	14130.00	52946.00
05/23/2010	58700.00	0.00	950.00	1120.00	14108.00	14738.00	18104.00
05/24/2010	58500.00	0.00	2450.00	0.00	4135.00	14494.00	630.00
05/25/2010	58400.00	0.00	350.00	6078.00	3943.00	12925.00	200.00
05/26/2010	58300.00	0.00	450.00	2596.00	7681.00	11529.00	7752.00
05/27/2010	58200.00	0.00	700.00	0.00	9936.00	14347.00	1029.00
05/28/2010	58100.00	0.00	0.00	0.00	10110.00	13670.00	18445.00
05/29/2010	58000.00	0.00	1200.00	0.00	27319.00	14588.00	2900.00
05/30/2010	57900.00	0.00	2550.00	0.00	10471.00	13073.00	17631.00
05/31/2010	57700.00	0.00	16550.00	0.00	11845.00	13936.00	11686.00
06/01/2010	57600.00	0.00	7900.00	0.00	11719.00	12201.00	0.00
06/02/2010	57500.00	0.00	700.00	0.00	18241.00	8073.00	3375.00

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Date	Government Estimate of Discharge VRG bbls	Inland Recovery IR tons	Oil Burned VBU bbls	Oil Collected via RITT/TopHat VDT bbls	Oily Water Collected VOW bbls	Subsurface Dispersants VCBg gallons	Surface Dispersants VCSg gallons
06/03/2010	60000.00	0.00	0.00	0.00	4833.00	17753.00	6200.00
06/04/2010	59900.00	0.00	0.00	6087.00	8912.00	20655.00	13701.00
06/05/2010	59800.00	0.00	0.00	10496.00	8568.00	20306.00	125.00
06/06/2010	59700.00	0.00	0.00	11119.00	3123.00	13937.00	0.00
06/07/2010	59500.00	0.00	850.00	14842.00	11754.00	14732.00	10744.00
06/08/2010	59400.00	0.00	5450.00	15006.00	5350.00	13763.00	8324.00
06/09/2010	59300.00	0.00	3500.00	15816.00	12802.00	12112.00	2100.00
06/10/2010	59200.00	0.00	350.00	15402.00	9658.00	10163.00	5872.00
06/11/2010	59100.00	0.00	0.00	15554.00	18510.00	8447.00	14305.00
06/12/2010	59000.00	0.00	7550.00	15039.00	14459.00	4852.00	10356.00
06/13/2010	58900.00	0.00	16600.00	15208.00	12383.00	9916.00	36012.00
06/14/2010	58800.00	0.00	4300.00	15421.00	6083.00	9800.00	10741.00
06/15/2010	58600.00	0.00	1000.00	10448.00	11891.00	11726.00	2768.00
06/16/2010	58500.00	0.00	20150.00	18227.00	16995.00	8777.00	13593.00
06/17/2010	58400.00	0.00	13300.00	25295.00	9185.00	5763.00	12423.00
06/18/2010	58300.00	0.00	59550.00	24552.00	16436.00	9148.00	15711.00
06/19/2010	58200.00	0.00	2300.00	21041.00	12713.00	16911.00	8510.00
06/20/2010	58100.00	0.00	600.00	23291.00	11335.00	14070.00	19576.00
06/21/2010	58000.00	0.00	17050.00	25836.00	25583.00	14233.00	11217.00
06/22/2010	57800.00	0.00	0.00	27097.00	8828.00	9793.00	2008.00
06/23/2010	57700.00	0.00	0.00	16866.00	4660.00	9891.00	5099.00
06/24/2010	57600.00	0.00	0.00	23735.00	9875.00	12871.00	21088.00
06/25/2010	57500.00	0.00	0.00	24548.00	14530.00	12540.00	4633.00
06/26/2010	57400.00	0.00	0.00	22758.00	17462.00	12654.00	23022.00
06/27/2010	57300.00	0.00	0.00	24455.00	18641.00	11558.00	6626.00
06/28/2010	57200.00	0.00	0.00	23400.00	0.00	13174.00	0.00
06/29/2010	57100.00	0.00	0.00	25223.00	50.00	11560.00	324.00
06/30/2010	56900.00	0.00	0.00	23079.00	290.00	13609.00	0.00
07/01/2010	56800.00	0.00	0.00	25154.00	284.00	10558.00	17852.00
07/02/2010	56700.00	0.00	0.00	25291.00	74.00	11065.00	14210.00
07/03/2010	56600.00	0.00	0.00	25198.00	1966.00	11698.00	432.00
07/04/2010	56500.00	0.00	0.00	24960.00	854.00	10429.00	3079.00
07/05/2010	56400.00	0.00	0.00	24982.00	7417.00	11688.00	803.00
07/06/2010	56300.00	0.00	0.00	24761.00	218.00	11655.00	473.00
07/07/2010	56100.00	0.00	0.00	24578.00	156.00	11770.00	1245.00
07/08/2010	56000.00	0.00	0.00	24379.00	26.00	11512.00	0.00
07/09/2010	55900.00	0.00	8300.00	24792.00	12140.00	10748.00	0.00
07/10/2010	55800.00	0.00	9850.00	15199.00	25924.00	13210.00	0.00
07/11/2010	55700.00	0.00	5300.00	8235.00	18296.00	15420.00	0.00
07/12/2010	53000.00	0.00	0.00	8302.00	9397.00	14038.00	0.00
07/13/2010	52900.00	0.00	1400.00	17064.00	9998.00	13997.00	999.00
07/14/2010	52700.00	0.00	1100.00	12843.00	25551.00	13746.00	0.00
07/15/2010	0.00	0.00	350.00	9307.00	10793.00	8391.00	0.00
07/16/2010	0.00	0.00	1100.00	0.00	14135.00	0.00	0.00
07/17/2010	0.00	0.00	0.00	0.00	7601.00	0.00	0.00
07/18/2010	0.00	0.00	0.00	0.00	5122.00	0.00	0.00
07/19/2010	0.00	0.00	100.00	0.00	3113.00	0.00	200.00

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Date	Government Estimate of Discharge VRG bbls	Inland Recovery IR tons	Oil Burned VBU bbls	Oil Collected via RITT/TopHat VDT bbls	Oily Water Collected VOW bbls	Subsurface Dispersants VCBg gallons	Surface Dispersants VCSg gallons
07/20/2010	0.00	0.00	0.00	0.00	930.00	0.00	0.00
07/21/2010	0.00	0.00	0.00	0.00	56.00	0.00	0.00
07/22/2010	0.00	0.00	0.00	0.00	142.00	0.00	0.00
07/23/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/24/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/25/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/26/2010	0.00	0.00	0.00	0.00	1.00	0.00	0.00
07/27/2010	0.00	0.00	0.00	0.00	226.00	0.00	0.00
07/28/2010	0.00	0.00	0.00	0.00	390.00	0.00	0.00
07/29/2010	0.00	0.00	0.00	0.00	264.00	0.00	0.00
07/30/2010	0.00	0.00	0.00	0.00	35.00	0.00	0.00
07/31/2010	0.00	0.00	0.00	0.00	79.00	0.00	0.00
08/01/2010	0.00	0.00	0.00	0.00	105.00	0.00	0.00
08/02/2010	0.00	0.00	0.00	0.00	51.00	0.00	0.00
08/03/2010	0.00	0.00	0.00	0.00	15.00	0.00	0.00
08/04/2010	0.00	0.00	0.00	0.00	11.00	0.00	0.00
08/05/2010	0.00	0.00	0.00	0.00	2.00	0.00	0.00
08/06/2010	0.00	0.00	0.00	0.00	98.00	0.00	0.00
08/07/2010	0.00	0.00	0.00	0.00	2.00	0.00	0.00
08/08/2010	0.00	0.00	0.00	0.00	179.00	0.00	0.00
08/09/2010	0.00	0.00	0.00	0.00	2.00	0.00	0.00
08/10/2010	0.00	41693.00	0.00	0.00	170.00	0.00	0.00
08/11/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/12/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/13/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/14/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/15/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/16/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/17/2010	0.00	4222.00	0.00	0.00	0.00	0.00	0.00
08/18/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/20/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/22/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/23/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/24/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/25/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/26/2010	0.00	2424.00	0.00	0.00	0.00	0.00	0.00
08/27/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/28/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/29/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/30/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/31/2010	0.00	2134.00	0.00	0.00	0.00	0.00	0.00
09/01/2010	0.00	126.00	0.00	0.00	0.00	0.00	0.00
09/02/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/03/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/04/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Date	Government Estimate of Discharge VRG bbls	Inland Recovery IR tons	Oil Burned VBU bbls	Oil Collected via RITT/TopHat VDT bbls	Oily Water Collected VOW bbls	Subsurface Dispersants VCBg gallons	Surface Dispersants VCSg gallons
09/05/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/06/2010	0.00	427.00	0.00	0.00	0.00	0.00	0.00
09/07/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/08/2010	0.00	429.00	0.00	0.00	0.00	0.00	0.00
09/09/2010	0.00	405.00	0.00	0.00	0.00	0.00	0.00
09/10/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/11/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/12/2010	0.00	562.00	0.00	0.00	0.00	0.00	0.00
09/13/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/14/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/15/2010	0.00	493.00	0.00	0.00	0.00	0.00	0.00

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Appendix 4

A4 ICS 209 Form (Oil Budget Component)

1. Incident Name	2. Operational Period (Date / Time) From: To: Time of Report	ICS 209-CG OIL/HAZMAT ATTACHMENT

3. HAZMAT/Oil Spill Status (Estimated, in gallons)			
Common Name(s):			
UN Number:	■ Secured	■ Unsecured	
CAS Number:	Remaining Potential (bbl):		
	Rate of Spillage (bbl/hr):		
	Adjustments To Previous Operational Period	Since Last Report	Total
Volume Spilled/Released			
Mass Balance - HAZMAT/Oil Budget			
Recovered HAZMAT/Oil			
Evaporation/Airborne			
Natural Dispersion			
Chemical Dispersion			
Burned			
Floating, Contained			
Floating, Uncontained			
Onshore			
Total HAZMAT/Oil accounted for:	N/A	N/A	
Comments:			

4. HAZMAT/Oil Waste Management (Estimated, Since Last Report)			
	Recovered	Disposed	Stored
HAZMAT/Oil (bbl)			
Oily Liquids (bbl)			
Liquids (bbl)			
Oily Solids (tons)			
Solids (tons)			
Comments:			

5. HAZMAT/Oil Shoreline Impacts (Estimated in miles)			
Degree of Impact	Affected	Cleaned	To Be Cleaned
Light			
Medium			
Heavy			
Total			
Comments:			

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Appendix 5

A5 Oil Properties

Table A5.1: Macondo reservoir fluid composition, based upon Pencor data provided by BP.

Gas-Liquid Ratio 2.89 scf/stb	Vapor Gravity	0.807	(Air = 1.00)
	API Gravity	35.2	°API at 60 °F (Water Free)
	Water Content	0.02	weight %

Component (Symbol / Name)		Atmospheric Liquid (mole %)	Atmospheric Liquid (weight %)
N_2	Nitrogen	0.000	0.000
CO_2	Carbon Dioxide	0.000	0.000
H_2S	Hydrogen Sulfide	0.000	0.000
C1	Methane	0.003	0.000
C2	Ethane	0.148	0.021
C3	Propane	0.456	0.097
iC4	i-Butane	0.263	0.073
nC4	n-Butane	0.958	0.268
iC5	i-Pentane	0.943	0.327
nC5	n-Pentane	1.536	0.533
C6	Hexanes	3.977	1.648
C7	Heptanes	8.318	3.747
C8	Octanes	11.541	5.960
C9	Nonanes	9.103	5.250
C10	Decanes	7.837	5.048
C11	Undecanes	5.965	4.215
C12	Dodecanes	4.982	3.855
C13	Tridecanes	4.754	4.000
C14	Tetradecanes	4.254	3.886
C15	Pentadecanes	3.563	3.528
C16	Hexadecanes	3.455	3.688
C17	Heptadecanes	2.755	3.139
C18	Octadecanes	2.685	3.240
C19	Nonadecanes	2.274	2.874
C20	Eicosanes	1.963	2.594

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C21	Heneicosanes	1.599	2.237
C22	Docosanes	1.421	2.083
C23	Triacosanes	1.281	1.959
C24	Tetracosanes	1.149	1.827
C25	Pentacosanes	0.938	1.555
C26	Hexacosanes	0.850	1.467
C27	Heptacosanes	0.892	1.603
C28	Octacosanes	0.791	1.474
C29	Nonacosanes	0.704	1.361
C30	Triacontanes	0.642	1.283
C31	Hentriacontanes	0.607	1.255
C32	Dotriacontanes	0.543	1.159
C33	Tritriacontanes	0.470	1.035
C34	Tetratriacontanes	0.458	1.039
C35	Pentatriacontanes	0.379	0.885
C36	Hexatriacontanes	0.346	0.832
C37	Heptatriacontanes	0.333	0.823
C38	Octatriacontanes	0.316	0.802
C39	Nonatriacontanes	0.273	0.712
C40	Tetracontanes	0.268	0.717
C41	Hentetracontanes	0.195	0.534
C42	Dotetracontanes	0.217	0.610
C43	Tritetracontanes	0.194	0.557
C44	Tetratetracontanes	0.186	0.548
C45	Pentatetracontanes	0.169	0.508
C46	Hexatetracontanes	0.146	0.450
C47	Heptatetracontanes	0.160	0.503
C48	Octactetracontanes	0.135	0.434
C49	Nonatetracontanes	0.123	0.402
C50+	Pentacontanes Plus	2.482	11.355
Total		100.000	100.000
Calculated Mole Weight		208.03	
Measured Mole Weight		208.03	

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Table A5.2: Analysis by Louisiana State University of fresh oil samples compared to reference oil.

Source Oil, Pre-spill **Sample Weight:** 310 mg **Final Extracted Volume:** 30 mL		**LSU ID#: Lab Ref Oil** **South Louisiana Crude** **Sample Weight:** 500 mg **Final Extracted Volume:** 20 mL	
Alkane Analyte:	**Concentration (ng/mg)**	**Alkane Analyte:**	**Concentration (ng/mg)**
nC-10 Decane	2600	nC-10 Decane	2600
nC-11 Undecane	2600	nC-11 Undecane	2700
nC-12 Dodecane	2600	nC-12 Dodecane	2600
nC-13 Tridecane	2500	nC-13 Tridecane	2600
nC-14 Tetradecane	2400	nC-14 Tetradecane	2300
nC-15 Pentadecane	2000	nC-15 Pentadecane	2200
nC-16 Hexadecane	1800	nC-16 Hexadecane	2000
nC-17 Heptadecane	1700	nC-17 Heptadecane	1900
Pristane	960	Pristane	970
nC-18 Octadecane	1500	nC-18 Octadecane	1700
Phytane	770	Phytane	910
nC-19 Nonadecane	1300	nC-19 Nonadecane	1500
nC-20 Eicosane	1300	nC-20 Eicosane	1400
nC-21 Heneicosane	1100	nC-21 Heneicosane	1300
nC-22 Docosane	1000	nC-22 Docosane	1200
nC-23 Tricosane	940	nC-23 Tricosane	1100
nC-24 Tetracosane	890	nC-24 Tetracosane	1000
nC-25 Pentacosane	600	nC-25 Pentacosane	620
nC-26 Hexacosane	510	nC-26 Hexacosane	510
nC-27 Heptacosane	350	nC-27 Heptacosane	360
nC-28 Octacosane	300	nC-28 Octacosane	310
nC-29 Nonacosane	250	nC-29 Nonacosane	260
nC-30 Triacontane	230	nC-30 Triacontane	230
nC-31 Hentriacontane	150	nC-31 Hentriacontane	190
nC-32 Dotriacontane	120	nC-32 Dotriacontane	150
nC-33 Tritriacontane	100	nC-33 Tritriacontane	110
nC-34 Tetratriacontane	90	nC-34 Tetratriacontane	110
nC-35 Pentatriacontane	92	nC-35 Pentatriacontane	110
Total Alkanes	***30752***	***Total Alkanes***	***32940***
LSU ID#: 2010133-02 **Source Oil** **Sample Weight:** 310 mg		**LSU ID#: Lab Ref Oil** **South Louisiana Crude** **Sample Weight:** 500 mg	

Final Extracted Volume: 30 mL		Final Extracted Volume: 20 mL	
Aromatic Analyte:	**Concentration (ng/mg)**	**Aromatic Analyte:**	**Concentration (ng/mg)**
Naphthalene	750	Naphthalene	710
C1-Naphthalenes	1600	C1-Naphthalenes	1300
C2-Naphthalenes	2000	C2-Naphthalenes	1500
C3-Naphthalenes	1400	C3-Naphthalenes	1100
C4-Naphthalenes	690	C4-Naphthalenes	590
Fluorene	130	Fluorene	100
C1-Fluorenes	340	C1-Fluorenes	270
C2-Fluorenes	390	C2-Fluorenes	270
C3- Fluorenes	300	C3- Fluorenes	240
Dibenzothiophene	53	Dibenzothiophene	56
C1-Dibenzothiophenes	170	C1-Dibenzothiophenes	210
C2-Dibenzothiophenes	220	C2-Dibenzothiophenes	280
C3- Dibenzothiophenes	160	C3- Dibenzothiophenes	240
Phenanthrene	290	Phenanthrene	200
C1-Phenanthrenes	680	C1-Phenanthrenes	360
C2-Phenanthrenes	660	C2-Phenanthrenes	340
C3-Phenanthrenes	400	C3-Phenanthrenes	200
C4-Phenanthrenes	200	C4-Phenanthrenes	84
Anthracene	6.1	Anthracene	6.2
Fluoranthene	4.2	Fluoranthene	4.5
Pyrene	8.9	Pyrene	7.1
C1- Pyrenes	68	C1- Pyrenes	43
C2- Pyrenes	84	C2- Pyrenes	31
C3- Pyrenes	96	C3- Pyrenes	31
C4- Pyrenes	54	C4- Pyrenes	20
Naphthobenzothiophene	11	Naphthobenzothiophene	7.8
C-1 Naphthobenzothiophenes	48	C-1 Naphthobenzothiophenes	30
C-2 Naphthobenzothiophenes	37	C-2 Naphthobenzothiophenes	30
C-3 Naphthobenzothiophenes	22	C-3 Naphthobenzothiophenes	25
Benzo (a) Anthracene	5.5	Benzo (a) Anthracene	5.4
Chrysene	36	Chrysene	14
C1- Chrysenes	100	C1- Chrysenes	28
C2- Chrysenes	100	C2- Chrysenes	27
C3- Chrysenes	54	C3- Chrysenes	18
C4- Chrysenes	19	C4- Chrysenes	5.6
Benzo (b) Fluoranthene	2.3	Benzo (b) Fluoranthene	1.7

Benzo (k) Fluoranthene	1.8	Benzo (k) Fluoranthene	1.5
Benzo (e) Pyrene	6.6	Benzo (e) Pyrene	2.9
Benzo (a) Pyrene	1.0	Benzo (a) Pyrene	1.0
Perylene	0.92	Perylene	0.89
Indeno (1,2,3 - cd) Pyrene	0.20	Indeno (1,2,3 - cd) Pyrene	0.22
Dibenzo (a,h) anthracene	1.3	Dibenzo (a,h) anthracene	0.92
Benzo (g,h,i) perylene	1.2	Benzo (g,h,i) perylene	1.1
Total Aromatics	***11203***	***Total Aromatics***	***8394***

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SINTEF REPORT

SINTEF

SINTEF Materials and Chemistry

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TITLE

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CLIENT(S)

BP

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ABSTRACT

A study using the MNS and IFP dispersibility tests has been performed at SINTEF on three emulsions from the DWH spill.

Difference in effectiveness of different dispersant products: The products Corexit 9500, Corexit 9527 and OSR 52 were tested on two emulsions with different degrees of weatering (Viscosities of 2700 and 7200mPas). Corexit 9500 show good efficiency for both emulsions, Corexit 9527 showed reduced effectiveness for the heavily weatered emulsion, while OSR 52 showed reduced dispersibility for both tested emulsions

Dispersant dosage: Tests were performed on two emulsions with a range of dispersant dosages. Results show that a relatively high dosage (DER = 1:25 or higher) was required to obtain good dispersant efficiency for the heavily weathered emulsion. For less weathered emulsions a lower dosage was sufficient..

-Aerial application of dispersants at a low dosage (5USGPA) can be recommended for moderately weathered emulsion (dark brown colour)

-Boat application is recommended for highly weathered emulsions (light brown/orange). A high dosage should be used (25USGPA), and reapplication should be considered if necessary.

Mixing energy requirements: Results from tests with different energy input were compared to assess the requirement for mixing energy on the sea surface to disperse the emulsions. Results show that as long as mixing energy is sufficiently high (i.e. breaking waves) even the most weathered sample showed good dispersibility (given sufficient dosage of dispersants). At low sea states artificial mixing energy may be a recommended option 0.5-1 hour after dispersant application.

Viscosity Limit for use of dispersants: Testing indicate reduced dispersibility for emulsions with viscosity >9000 mPas, and poor dispersibility >25000mPas. These limits are valid for DER=1:25.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1		
GROUP 2		
SELECTED BY AUTHOR		

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1 Background

A sampling campaign were conducted in the vicinity of the DWH release point cruise in the period June 2-5. Three samples were taken of weathered DWH-oil and the physical properties of the samples have been characterised. The sampled emulsions had a span in weathering time estimated to 1 to 5 days on the sea surface. The span in weathering gives the emulsions very different physical properties. Sampling and physical characterisation of the emulsions are described in the cruise report (Leirvik,*et.al.*2010).

As the physical properties change the dispersibility of the emulsions will change. From an operational point of view this would mean that different dispersant application strategies may be needed for emulsions at different stages of weathering.

A dispersibiltiy study has been performed at SINTEF on the sampled emulsions. The following operational aspects have been studied:

- Dosage of dispersant at different stages of emulsion weathering.
- Effectiveness of three dispersant products at different stages of emulsion weathering
- Mixing energy required to efficiently disperse the DWH emulsions.
- Viscosity Limit for the dispersibility of DWH emulsions.

The IFP and MNS dispersibility tests are described in Chapter 2. Sampling positions and the physical properties of the emulsions are summarised in Chapter 3. Results from the dispersibility testing are given in Chapter 4. Conclusions and operational recommendations are given in Chapter 5.

2 Experiemental Setup

There are several different tests for evaluating the effectiveness of chemical dispersants. Energy input will differ in different tests, and the obtained effectiveness will be representative for different wave energies. Most tests in this study is performed using the medium-to-high energy MNS test (representing breaking wave conditions). The MNS test is described in chapter 2.1. To assess the energy requirement for dispersing emulsions at different stages of weathering. Tests have also been performed with the low energy IFP test. The IFP test is described in chapter 2.2 .

2.1 The MNS Test

The MNS test (Mackay-Nadeau-Szeto, Mackay and Szeto, 1980) is estimated to correspond to a medium to high sea-state condition with breaking waves. The energy input in this system, applied by streaming air across the oil/water surface, produces a circular wave motion. The sample of the oily water is taken under dynamic conditions after a mixing period of 5 min. The test apparatus is shown in Figure 2.1.

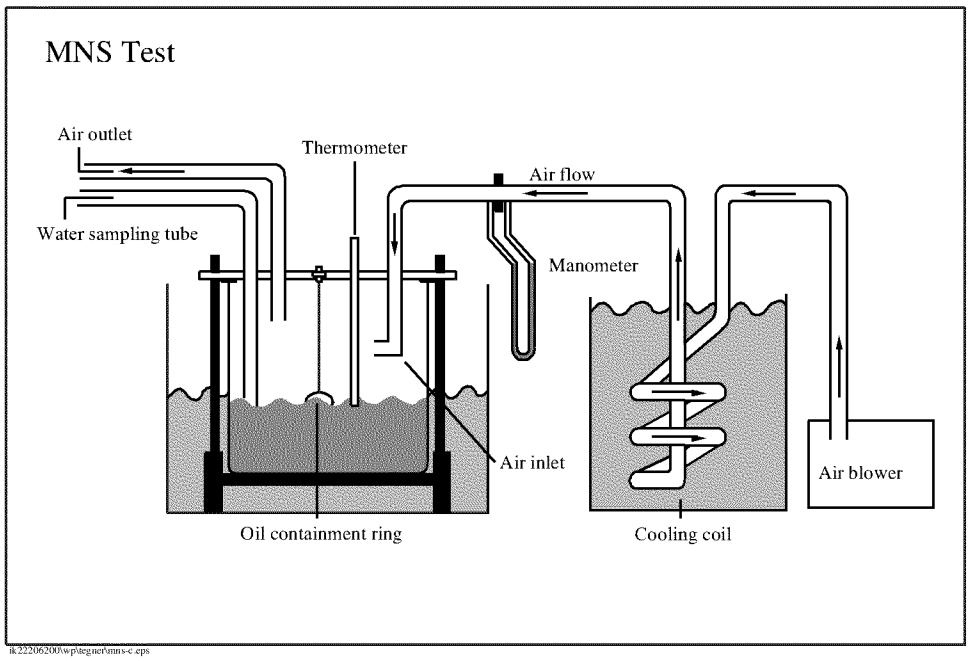

Figure 2.1 MNS test apparatus.

When the test results in the MNS test shows an effectiveness > 70 – 80%, the emulsion is considered to be easily (good) dispersible. In the range down to 5% effectiveness, the emulsion is still dispersible, however, the dispersion process may need some more time. Effectiveness < 5% means that the emulsions is poorly dispersible when using dispersant. These laboratory-derived dispersibility borders have been established based on correlations to field studies (Daling and Strøm, 1999).

2.2 The IFP Test

The IFP Test (Institute Francais du Petrole test, Bocard *et al*, 1984) is a low energy test estimated to represent low wave energies (2 - 5 m/s wind speed). A ring beating up and down in the test vessel at a given frequency, gives energy input to the seawater column. The water column is continuously diluted, which gives a more realistic approach to field conditions compared to other tests. The test apparatus is shown in Figure 2.2.

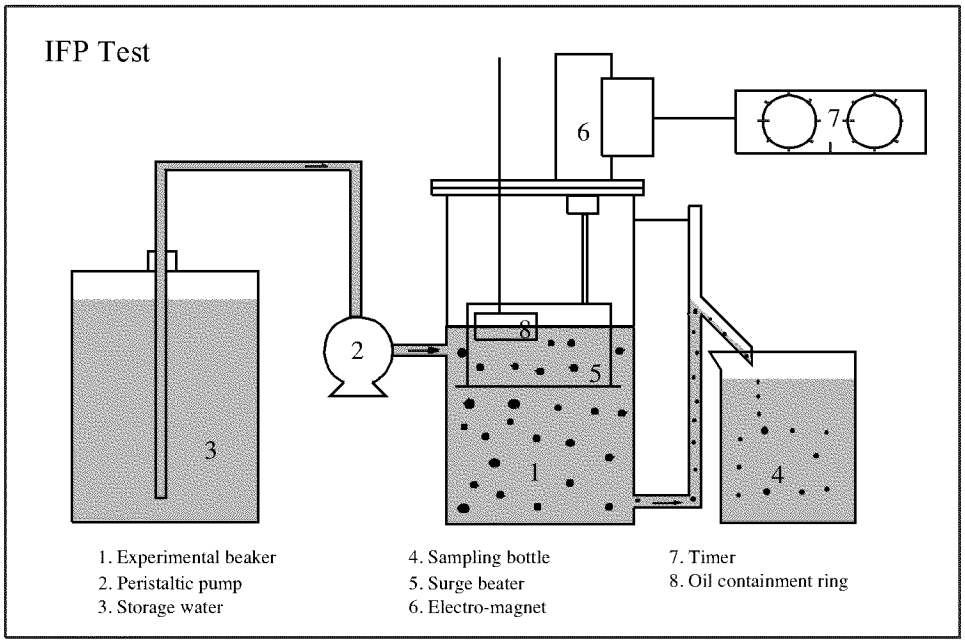

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Figure 2.2 IFP test apparatus.

When the test results in the IFP test shows an effectiveness ~ 50%, the emulsion is considered to be easily (good) dispersible- even at low sea conditions. If the effectiveness is below 40 -50% effectiveness, the emulsion may still be dispersible. During a response operation under calm conditions in the field, additional mixing energy may be required. This extra turbulence can be supplied by e.g. propel-washing from vessels or by using high delivery FI-FI monitors 1-2 hours after a dispersant application in order to fulfil the dispersion process.

3 Sampling and Physical Characterisation of the Test Emulsions

The physico-chemical properties of the sampled emulsions were characterised both on site, and in analysis at SINTEF laboratories. The results from the measurements are summarised in Table 3.1. The sampling positions are shown in Figure 3.1, and the samples are described in brief below. Sampling and analysis is described in detail in the cruise report (Leirvik *et.al.*,2010).

Table 3.1 Summary of physical and chemical properties of the sampled emulsion

	Position 2	Position 3	Position 4
Evaporative loss (wt%)	47	50	44
Estimated time on sea surface (days)	1-1.5	4-5	2-3
Emulsion thickness (mm)	1.3	2.6-3.7	0.9-1.4
Water content (vol%)	67	50	33
Density (g/ml)	0.961	0.975	0.956
Viscosity (mPas)10 s^{-1} at 32°C	2770	7230	1250
Viscosity (mPas)10 s^{-1} at 27°C	3540	12500	2030
Viscosity (mPas)10 s^{-1} at 25°C		17900	
Viscosity (mPas)10 s^{-1} at 22°C		24700	
Viscosity (mPas)10 s^{-1} at 20°C		32300	

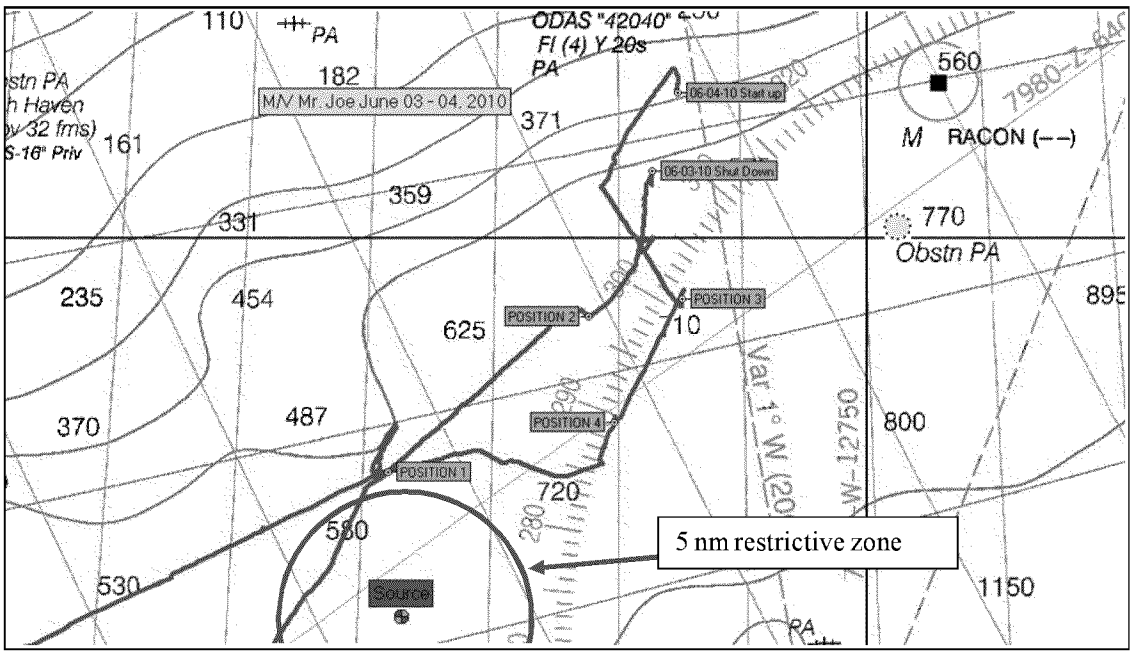

Figure 3.1 Sample positions compared to the DWH source

Position 2
Samples were taken 12 nm miles NE (downwind) from the DWH source. The slick was only 100–200 m long and 2–10 m wide, and the oil was readily spreading on the sea surface. The emulsion was light brown in color, indicating significant emulsification.

Figure 3.2 Emulsion in Position 2

Position 3
Samples were taken 17nm NE (downwind) from the DWH source. The slick was approximately 100 x 30 meters. The emulsion was light brown /orange /reddish in color and appeared more elastic and less prone to spreading on the sea surface, which indicates that this slick had been heavily weathered (evaporative loss, emulsification and photo-oxidation).

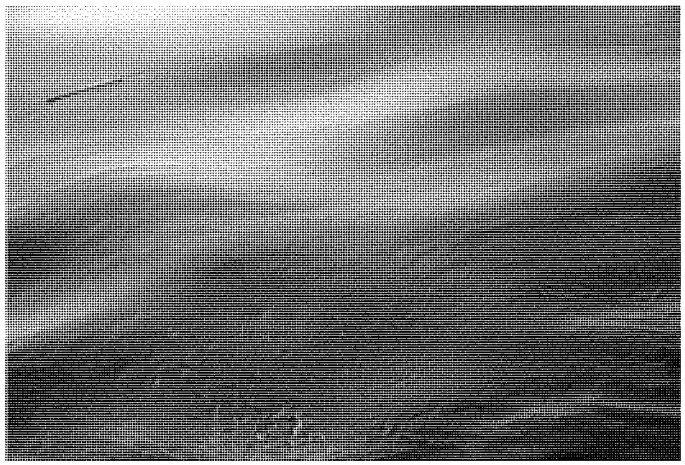

Figure 3.3 Emulsion in Position 3

Position 4
Samples were taken 10 nm miles NE (downwind) from the DWH source. The sampled slick was approximately 50 x 30 meters, and was part of a continuous belt of slicks aligned downwind from the DWH source. The emulsion was dark brown, and darker than the emulsions in Positions 2 and 3. This dark color indicates a lower degree of weathering than the emulsion in Positions 2 and 3.

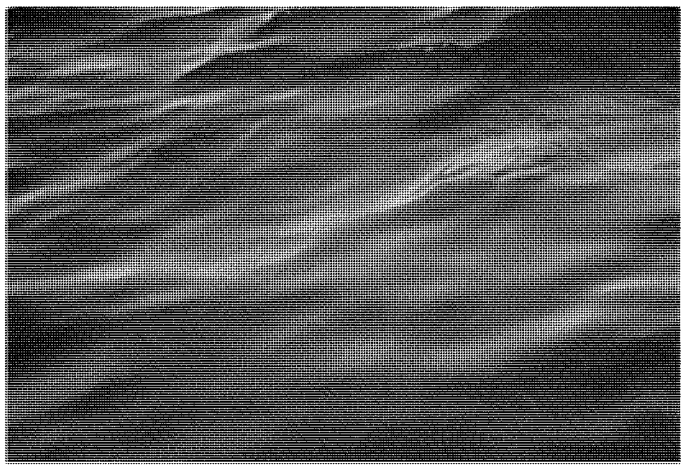

Figure 3.4 Emulsion in Position 4

4 Experimental Results

Laboratory tests have been performed to study different operational aspects. Comparative testing between different dispersant products is described in chapter 4.1. Results from testing with different dispersant dosages are shown in chapter 4.2. The requirement for energy is studied by testing with a low energy test representing sea states without breaking waves (IFP), and a Medium/high energy test (MNS) representing sea states with breaking waves. The results are shown in chapter 4.3. Viscosity limits for the dispersibility of DWH emulsions have been established by testing at increasing viscosities. This work is presented in Chapter 4.4.

4.1 Testing with Various Dispersants

Tests have been performed with different dispersant products for samples from position 2 and position 3. The three tested products were Corexit 9500, Corexit 9527 and OSR52. The comapartive tests were performed with a **dispersant/emulsion-ratio (DER)** of 1:25.

Table 4.1 Results from the MNS test with different dispersant products. DER=1:25 in all tests.

	Position 3 (7200 mPas)	Position 2 (2770 mPas)
Corexit 9500	86	91
Corexit 9527	55	90
OSR 52	71	62
blank	2	44

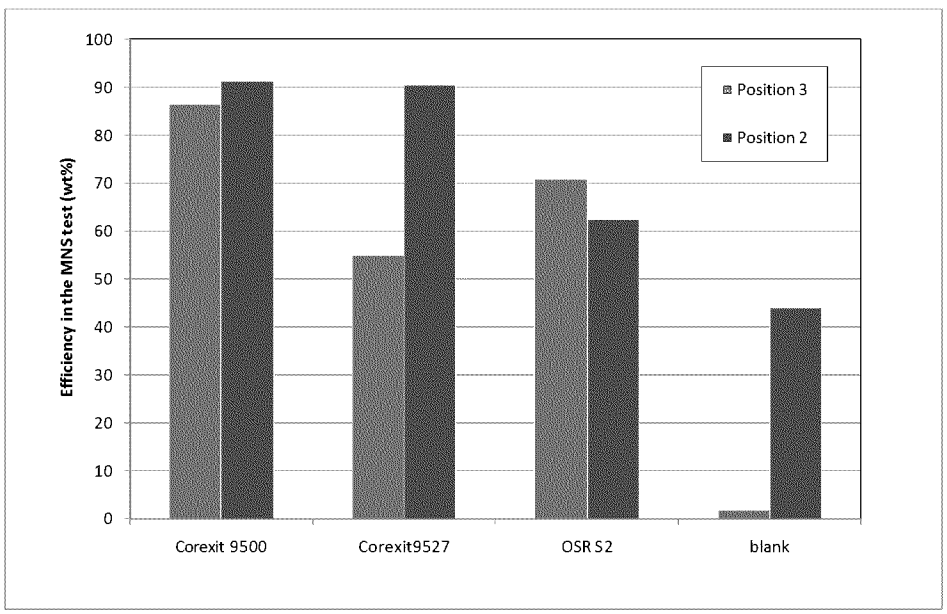

Figure 4.1 Results from the MNS test with different dispersant products. The dosage is 1:25 in all tests.

Reduced effectiveness in the MNS test is defined as <75% (Daling and Strøm,1999), while poor dispersibility is defined as <5%. The two Corexit products show good efficency for the moderatly weathered emulsion from position 2, while OSR 52 have a somehow reduced dispersibility. For the heavily weathered emulsion sampled in position 3, only Corexit 9500 show good dispersibility, while Corexit 9527 and OSR 52 showed reduced dispersibility.

4.2 Testing with Various Dispersant Emulsion Ratios (DER)

Tests have been performed to study the dispersant effectiveness as a function of dispersant dosage. The tests have been done on the emulsions from position 3 and position 4. The medium/high energy MNS test has been used in the study. Results are shown in Table 4.2 and in Figure 4.2.

Table 4.2 Results from the MNS test with Corexit 9500 at different dispersant dosages

DER	%Effectiveness in the MNS test	
	Position 3 (7200 mPas)	Position 4 (1250mPas)
1:10	81	
1:25	86	99
1:50	44	99
1:100	31	96
1:250	15	99
no dispersant	2	48

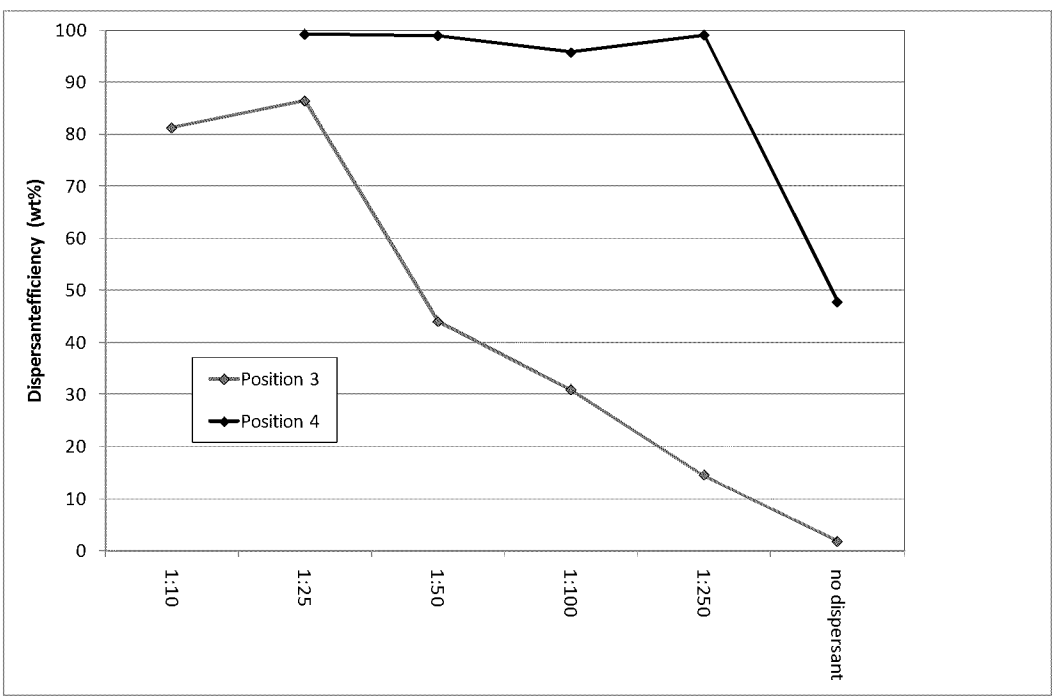

Figure 4.2 Results from the MNS testing with Corexit 9500 at different dispersant dosages.

Results show that at a dosage of 1:25 and higher, the dispersant efficiency is high for the highly weathered emulsion sampled in position 3. At lower dosages the efficiency will gradually decrease. Tests performed on the least weathered emulsion (position 4) show a good efficiency for all the tested dosages.

4.3 Testing with Different Energy Input

To study the effect of energy input on the dispersibility testing has been performed with both the MNS and IFP tests. The MNS is a high energy test representative to high sea states. The IFP test supply a relatively low energy input and is thought to be representative for low sea states without breaking waves. Results from testing with the two methods are shown in Table 4.3 and in Figure 4.3.

Table 4.3 Results from the MNS and IFP tests with samples from the different positions using Corexit 9500 and DER=25.

	Test effectiveness (wt%) w/ Corexit 9500 and DER=1:25	
	MNS	IFP
Position 4	99	46
Position 2	91	48
Position 3	86	34

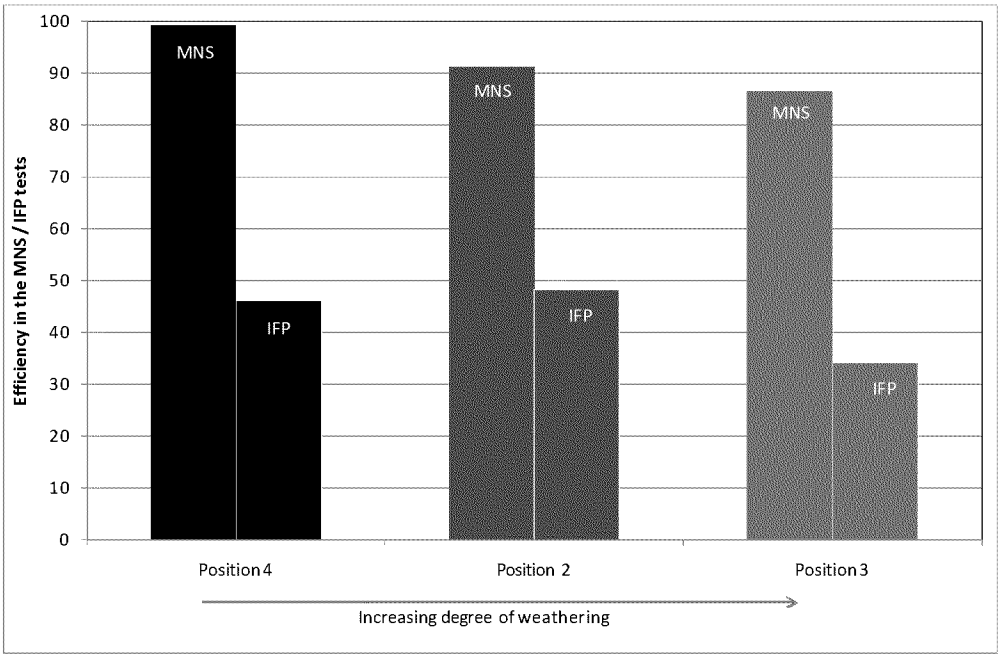

Figure 4.3 Results from the MNS and IFP tests with samples from the different postions using Corexit 9500 and DER=1:25.

Results show that whith a dosage of 1:25 of Corexit 9500 all the samples show a relative good dispersibility for the MNS test. This is in accordance to the conclusions for the tests performed with the Field Effectiveness Test onboard Mr.Joe (Leirvik,*et.al.*2010). For the low energy IFP samples from positions 2 and 4 show a slightly reduced dispersibility. The heavily weathered sample from position 3 show a significant reduction in dispersibility.

4.4 Chemical Dispersibility vs Viscosity

In systematic weathering studies performed over the past 20 years at SINTEF (Daling and Strøm,1999) an upper viscosity limit for an oils dispersibility is determined. The viscosity limit is strongly related to the specific oil that is investigated. In this study with a limited amount of emulsions even the most weathered emulsion had a good dispersibility (at32°C), a viscosity limit could not be established. Therefore additional testing where performed at lower temperatures to yield dispersibility data on higher viscosities. The results from all tests done with the MNS test is compared with the emulsion viscosities in Table 4.4.

Table 4.4 Results from the MNS test and the Viscosity of the emulsions. The table includes the additional tests performed at lower temperatures. Tests are performed with Corexit 9500 and DER=1:25.

Position	Temperature (°C)	Temperature (°F)	Viscosity at shear rate $10s^{-1}$(mPas)	MNS dispersant efficiency (wt%)
4	32	90	1250	99
2	32	90	3700	91
3	32	90	7230	86
3	28	82	12500	66
3	25	77	17000	44
3	22	72	24700	16
3	20	68	32300	0

The dispersant effectiveness from the MNS test is plotted against the emulsion viscosity in Figure 4.4.

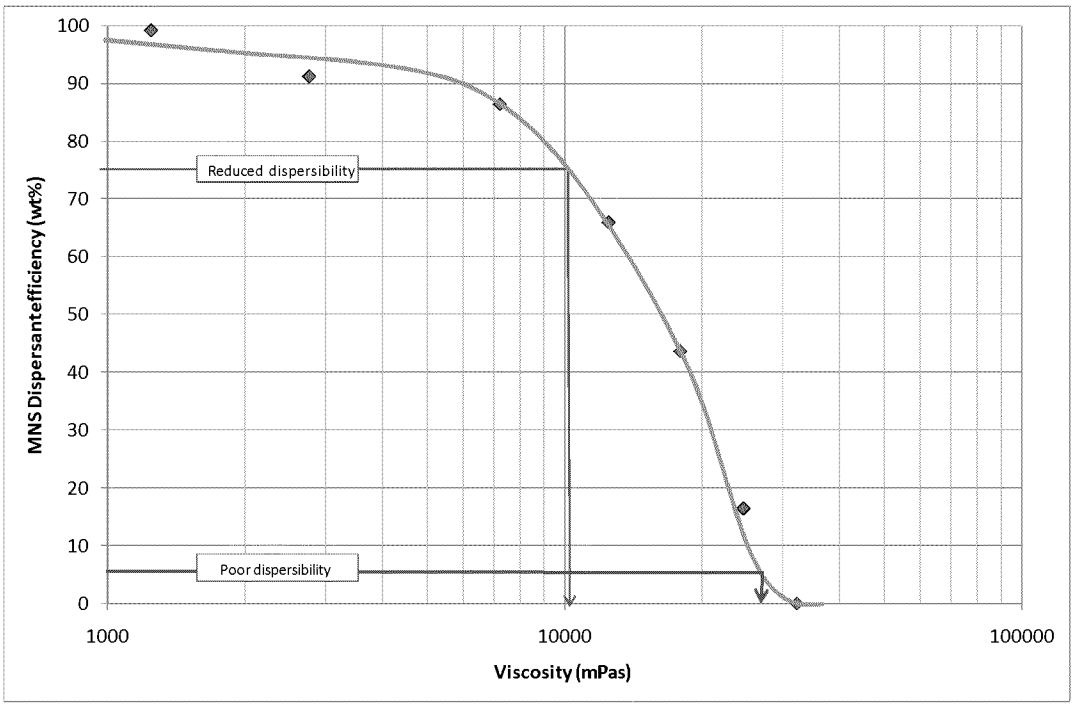

Figure 4.4 Dispersant efficiency in the MNS tests plotted against viscosity. Viscosity is reported at shear rate $10s^{-1}$.

As described in chapter 2.1, in the MNS test reduced dispersibility is defined as below 75%, while poor dispersibility is defined below 5%. Based on the curve drawn in Figure 4.4 reduced dispersibility will occur for viscosites above 10000mPas, while poor dispersibility can be expected for viscosities exceeding 25000 mPas. The drawn limits is based on studies using a dispersant/emulsion-ratio of 1:25.

The time it take for emulsions to reach the defined viscosity limits will depend on the wind speed and temperatures. The weatering time for the tested emulsions where estimated based on the evaporative loss of the samples in the cruise report (Leirvik,*et.al.*,2010). The estimated time on the sea surface for the emulsions is shown in Table 4.5.

Table 4.5 - Tentative time at sea based on evaporative loss and use of the SINTEF Oil Weathering Model.

	Evaporative loss (wt%)	Viscosity (mPas)	Tentative time at sea
Position 2	47%	3700	2-3 days
Position 3	50%	7200	4-5 days
Position 4	44%	1250	1-2 days

4.5 Visual Observations During Testing

The moderately weathered emulsions sampled in position 2 and 4, generally dispersed well. For the emuslion from position 4 small droplets were formed within the first minute of the test as shown in *Figure 4.5*

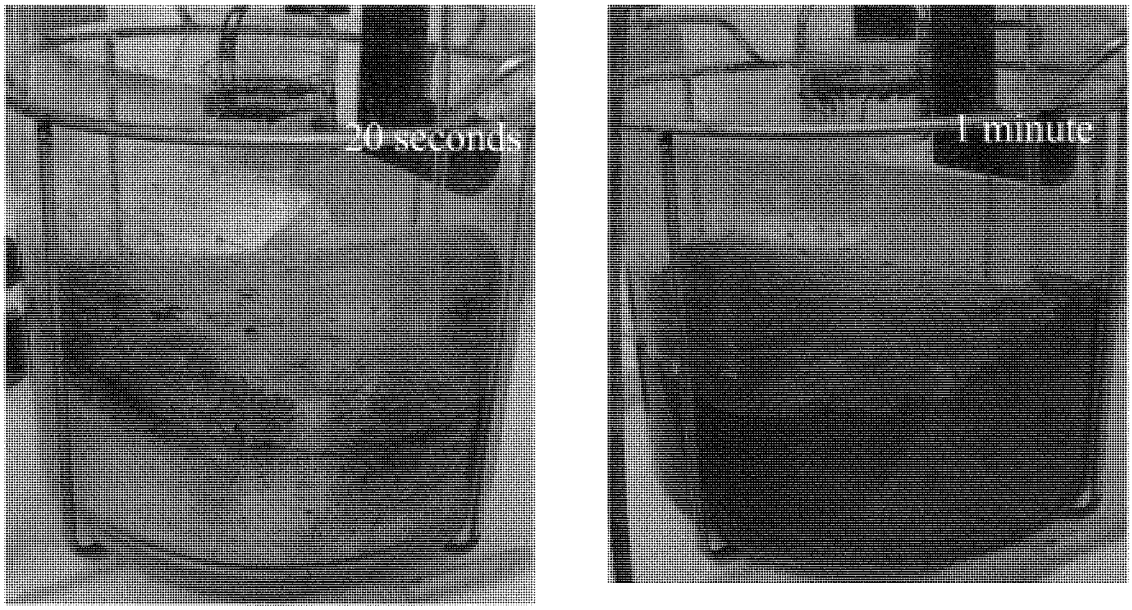

Figure 4.5 Gradual formation of small droplets with time in the MNS test. The image is from testing with Emulsion 4 and Corexit 9500 at DER=1:25

In tests performed with the heavily weathered emulsion from position 3, the formation of small droplets was slower. After five minutes (the test duration) a significant amount of small droplets were formed, but strings of emulsion were still present in the water. This is demonstrated in Figure 4.6.

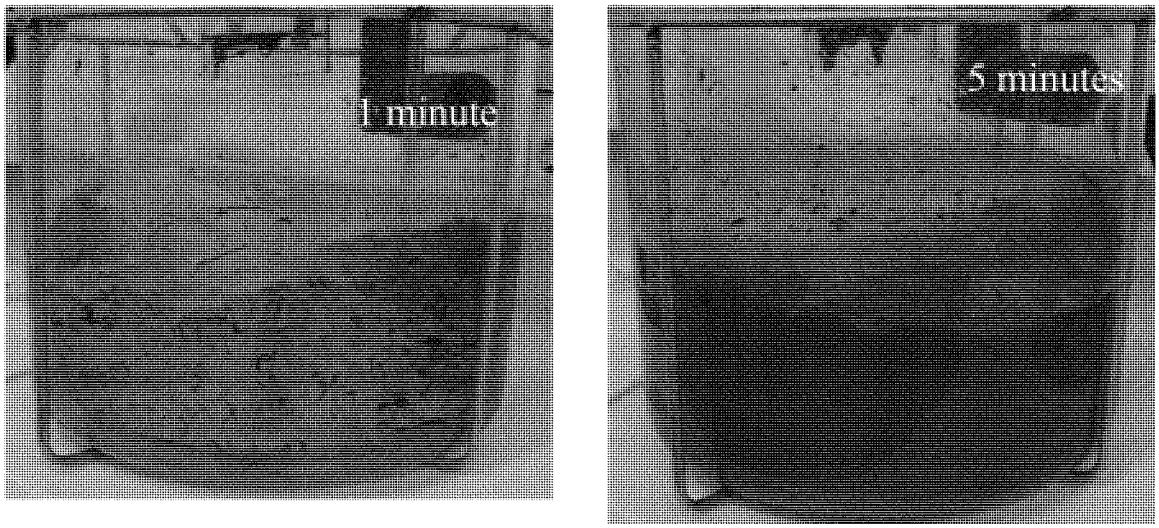

Figure 4.6 Gradual formation of small droplets with time in the MNS test. The image is from testing with Emulsion 3 and Corexit 9500 at DER=1:25

In the IFP test the same effects could be observed. For the less weathered emulsions (Position 2 and 4) small droplets were formed to make a cafe au lait coloured suspension. In the tests with the heavily weathered emulsion from position 3 the particles in suspension were non-spherical and larger in size. This is examplified in Figure 4.7.

Figure 4.7 Droplet formation in the IFP test with the emulsion from position 3. The test is performed with Corexit 9500 and DER=1:25.

Even though not all dispersed particles are within the optimal particle size range, the dispersant will contribute to breaking up the viscous emulsion and significantly reduce the lifetime of oil on the sea surface.

Emulsions were also tested without addition of dispersants. Images from the tests are shown in Figure 4.8. The natural dispersion in the tests with emulsions from position 2 and 4 were relatively high. The emulsion from position 2 even formed quite small droplets. The emulsion from position 3 did not spread on the surface of the test vessel, and few droplets formed at all.

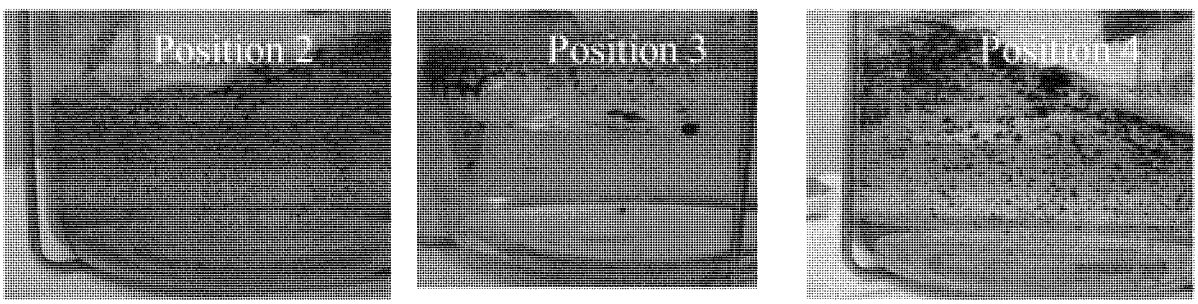

Figure 4.8 Droplet formation in the MNS tests without addition of dispersant in the different positions.

5 Conclusions and Operational Recommendations

5.1 Testing with different dispersant products

Tests have been performed with different dispersant products for one moderately weathered emulsion (position 2 / 2770mPas) and one heavily weathered emulsion (position 3 / 7250mPas). The three tested products were Corexit 9500, Corexit 9527 and OSR52. The comapartive tests were performed with a DER of 1:25.

The two Corexit products show good effectiveness for the moderatly weathered emulsion from position 2, while OSR 52 showed a somehow reduced dispersibility. For the heavily weathered emulsion sampled in position 3, only Corexit 9500 show good dispersibility, while Corexit 9527 and OSR 52 showed reduced dispersibility (<75% effectiveness in the MSN test).

5.2 Dispersant dosage requirement

A minimum DER is required to yield efficient dispersion of a slick. The required dosage usually increases as the oil weathers on the sea surface. As the physical properties of the emulsion change the thickness of the slick will also increase and the required dosage will increase accordingly. In dispersant application operations the dosage is often given in US Gallons Per Acre (USGPA). Dispersant/Emulsion-ratio at different dosages is given at differing slick thicknesses in Table 5.1.

Table 5.1 Dispersant/Emulsion-ratio at different dosage and slick thickness

	DER at varying Slick thickness		
USGPA	1 mm	2 mm	4mm
5	1:200	1:400	1:800
25	1:50	1:100	1:200
2x25	1:25	1:50	1:100

<u>Low/Moderately weathered emulsions (dark brown appearance)</u>

The results show good dispersibility in the MNS test for the least weathered emulsion (Position 4). The emulsion disperses even at DER as low as 1:250 in the MNS test. The slick sampled in position 4 had a thickness of ~1mm. To achieve a dispersant/emulsion-ratio of 1:250 for a slick of this thickness an application dosage of 5 USGPA is required (Table 5.1). This mean that the low dosage used in standard aerial application will be sufficient for emulsions at a such low degree of weathering.

Highly weathered emulsions (light brown/orange appearance)
The results show good dispersibility in the MNS test for the most weathered emulsion (Position 3) at DER of 1:25 and above. At ratios under 1:50 the efficiency in the MNS test were gradually decreasing. The highly weathered slick sampled in position 3 had a documented thickness of up to 4 mm. A dosage of 5 USGPA would correspond to a dispersant/emulsion-ratio of 1:800 for a slick with this thickness (Table 5.1). According to the test results, this is a too low dosage to disperse the emulsion. A dispersant/emulsion-ratio above 1:50 is recommended as the minimum dosage for heavily weathered emulsions such as the sample from position 3. According to Table 5.1 a minimum dosage of 25 USGPA is required to efficiently disperse heavily weathered emulsion similar to the tested emulsion from position 3.
The slick should be monitored after the dispersant treatment, and if emulsion is still on the surface a re-treatment of the slick should be considered in order to achieve sufficient dosage.

5.3 Sea state dependency

Tests were conducted with the high energy MNS test and with the low energy IFP test. The MNS is thought to be representative for energy at high/medium sea states with presence of breaking waves (typically >5m/s). The IFP test is representative to calmer sea states with no breaking waves. The comparative tests were carried out on all the sampled emulsions and with a dispersant/emulsion-rate of 1:25. At this dosage all emulsions dispersed readily in the MNS test. The dispersibility was slightly reduced in the IFP test for the moderately weathered emulsions from position 2 and 4, while dispersibility was significantly reduced for the heavily weathered sample from position 3. This means that the emulsions are dispersible given sufficient wave energy. In calm sea conditions, introduction of additional mixing-energy/turbulence 0.5-1 hour after dispersant treatment, could be a rational operational strategy. Such mixing energy could be supplied to the treated slick e.g. by prop-washing or by spraying the slick with the vessels FI-FI system.

5.4 Viscosity limit for use of dispersants

As an emulsion weather on the sea surface the physical properties will change, and the dispersibility will gradually decrease. The change in physical properties and thus the changes in dispersibility are highly dependent on the wind/wave conditions. In the systematic weathering studies performed in general at SINTEF, dispersant effectiveness is linked to the viscosity of the emulsion. The viscosity is predicted by use of the SINTEF Oil Weathering Model (Daling and Strøm,1999) and a time window for effective use of dispersants can be estimated. The weathering properties of the DWH oil are not studied and predictions of the change in physical properties can not be done. A defininite time window for use of dispersants can therefore not be established. In this study only the relationship between dispersibility and viscosity has been established.

The most weathered sample tested in this study had a viscosity of 7200 mPas after an estimated weathering time of 4-5 days on the sea surface under relative calm weather conditions. This emulsion still showed good dispersibility in the high energy MNS test at a dispersant/emulsion-ratio of 1:25. In lack of more viscous emulsions the emulsion from position 3 is tested at lower temperatures to gain higher viscosities. The tests indicate that at a dispersant/emulsion-ratio of 1:25 the dispersibility will be reduced at a viscosity of 10000 mPas. Poor dispersibility will occur as the emulsion reaches a viscosity of approximately 25000mPas.

6 References

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Appendix 7

A7 "Bench Top" LISST Particle Size Analysis

K. Lee, Z. Li and H. Niu – Centre for Offshore Oil, Gas and Energy Research, Fisheries and Oceans Canada

The standard operational procedure (SOP) for LISST-100X particle size analysis used in the Gulf of Mexico oil spill monitoring program (i.e., Deepwater Horizon Spill) was developed for the measurement of particle-size distributions under two scenarios. The first was bench top measurement of small particles, and the second was continuous in-situ monitoring with the instrument deployed over the side of the vessel at specific depths.

Laboratory ***"bench-top"*** measurements with the LISST-100X instrument on board the vessel were specifically targeted at measuring ***small particles*** (d < 70 μm) suspended in the water column. For this purpose, discrete samples were collected from both the surface (with bucket), and from different depths in the water column using CTD casts with a Niskin rosette sampler. On average, the total length of time between the recovery of sample and the bench-top LISST-100X analysis was more than half an hour including casting of rosette Niskin bottles, sub-sampling, and data acquisition by LISST-100X. Due to the buoyant nature of dispersed oil droplets in the water column, larger particles (Lunel, 1993; Lunel, 1995) would have risen at a speed that is beyond the limit of the time period for handling discrete seawater samples (Table 1).

TABLE 1 - Rise time of oil droplets

Diameter (μm)	Rise velocity (cm/min)	Time to rise 1 metre (min)
10	0.03	3330
20	0.132	760
30	0.294	340
40	0.522	190
50	0.84	120
70	1.62	62
80	2.10	48
100	3.30	30
150	7.20	14
200	13.20	8
300	29.40	3
400	52.2	2
500	81.6	1

The LISST-100X particle size analyzer (Type C) is an optical device that measures light intensity over a series of detector rings (numbered 1 through 32). After the acquisition of light intensity for the 32 discrete rings and eight other auxiliary parameters, the raw data are subsequently processed with the manufacturer provided inversion algorithm to automatically calculate volume concentrations (in μl/l) for particle size bin number 1 through 32 (corresponding with the detector ring numbers), along with output of 10 other parameters including laser transmission sensor power, laser reference sensor in calibrated

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units, pressure, temperature, computed optical transmission over path, and beam-attenuation, etc.

Under ideal conditions, the data acquired using the bench-top measurement SOP would have recorded discrete particle size volume concentrations over the first 20 size bins (bins 1-20 or 2.5 - 68.8 μm) only, and would have shown zero or close to zero readings for the large-sized bins (#21 – 32, or 68.8 to 500 μm). However, the recorded data do not always show the low readings expected. Instead, extremely high values over the last several bins were recorded. A number of conditions may exist that lead to high apparent values of large particles:

(1) Variation of the seawater temperature of the samples collected from different depths in the water column and the ambient air temperature. The water temperatures vary widely from close to freezing (4°C) at maximum depths to very warm water at the surface (30°C). Stratification of the water inside the small chamber may cause laser beam reflection and a false signal of the presence of larger particles (Mikkelsen et al., 2008; Styles, 2006). Corrective action was taken in late June, 2010 to overcome the effect of temperature variation by introducing a full-path mixing chamber.
(2) Slight miss-alignment of the LISST-100X (#1215 and #1174) that may impact the inner ring light intensity reading. This will subsequently propagate through inversion process to affect several numbers of upper-end particle size bins, but negligible impact on medium and small particle size data (communication with the manufacturer)
(3) The presence of actual particles larger than the upper limit of our targeted small particles (68.6 μm). This is not unexpected, for a number of reasons such as the retention of larger oil droplets within the counting cell of the instrument due to (a) the relatively short time between sample recovery and analysis for the samples that were collected from the surface or near the surface (0-50m depth), (b) the potential presence oil droplets with a density close to the seawater because of the dissolution of light components, and (c) potential coalescence of small particles into larger ones. Furthermore, large particles other than oil (e.g., biogenic material) may also exist.

Considering the high uncertainties involved in the analysis of large particles, analysis of "bench top" data and interpretation should be focused on the small sized particles ($d < 70$ μm) which have been recognized in the oil spill community as permanently dispersed oil droplets. We discourage over-interpretation of particle size distribution data that were collected for this specific purpose during the Gulf of Mexico oil spill emergency response operations. Under this emergency response effort, rapid, less than perfect actions had to be taken to support the requirement for immediate action to monitor the fate and transport of the oil following subsurface injection of dispersant.

Preliminary data analysis was performed with particle size bins 1 through 25, corresponding to particle size ranges of 2.5 to 157 μm (Table 2). Figures 1 and 2 display discrete particle size distribution of the surface samples for all stations, and Figures 3 and 4 the peak total particle concentrations in sub-surface samples. The peaks that were used are defined as the maximum small particle concentration at depth for each station. These particle size distribution histograms clearly demonstrate the presence of a large amount of

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very small particles (d < 10 μm), suggesting the presence of chemically dispersed oil droplets (Li et al., 2008; Li et al., 2009; Lunel, 1993; Lunel, 1995). The strong signal of the chemically dispersed oil particles is also indicated by the observed multimodal distribution profiles rather than a mono-modal size distribution that is often generated by natural dispersion (Li et al., 2009).

Figures 5 to 8 summarize the fraction of small particles (d < 68.8 μm) within the complete range of particle sizes (2.5 – 157 μm). These data clearly indicate that the vast majority of volume fractions of the measured particles are in the small particles range. However, exceptions do exist for a number of stations where large fractions of particles appear to fall in the range above 70 μm (e.g. the surface samples of stations 101-104 and subsurface samples of stations 101 and 102 of R/V Brooks McCall, surface samples of stations 60-80 and subsurface samples of stations 60-80 of R/V Ocean Veritas). This needs to be further investigated.

Figures 9-12 present the cumulative particle size distribution of all measured particles from all the surface stations and all the peak sub-surface stations. These graphs show that nearly 80-90% of the measured surface and subsurface particles are □ 70 μm (bin 1 to 21), and the median diameters of the measured particles of both surface and subsurface particles are nearly 20 to 30 μm. These size data are in good agreement with previous observations at sea (Lunel, 1993; Lunel, 1995).

Due to the restriction of time, more detailed data analysis and interpretation are certainly yet to be done. The association with field operational and oceanographic parameters needs to be further investigated. Nevertheless, the preliminary results and elementary data analysis suggest high effectiveness of chemical dispersants in oil dispersion from subsurface application. An estimation of the amount of oil dispersed based on the operational parameter, namely dispersant to oil ratio, in calculating the amount of chemically dispersed oil may not be the most accurate approach. A thorough inspection of all the field collected data, including discrete samples and continuous in-situ (over-the-side) vessel deployment data (to be addresses in future reports), and numerous other field sampling data should be synthesized and digested to provide a more scientifically sound estimation of dispersant effectiveness, the amount of oil naturally or chemically dispersed from the subsurface and surface dispersant application, and the oil mass balance on the whole. The possible impact of dispersant-containing oil in rising and after rising to the water-air interface should not be neglected. Effective chemical dispersion of oil after adding dispersant in calm sea proves still effective after prolonged standing time in static and flowing waters before increased wave energy becomes available (Lewis et al., 2010). Such a scenario may happen to the subsurface dispersant injection situation, in which an excellent mixture of oil and dispersant in situ at depth can facilitate continued dispersion of oil wherever turbulent mixing energy is encountered – regardless of whether it is at the surface or subsurface.

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Table 2: The lower, medium and upper limit of each size bin in microns for the LISST-100X particle counter

Size bin #	Lower	Medium	Upper
1	2.50	2.72	2.95
2	2.95	3.20	3.48
3	3.48	3.78	4.11
4	4.11	4.46	4.85
5	4.85	5.27	5.72
6	5.72	6.21	6.75
7	6.75	7.33	7.97
8	7.97	8.65	9.40
9	9.40	10.2	11.1
10	11.1	12.1	13.1
11	13.1	14.2	15.4
12	15.4	16.8	18.2
13	18.2	19.8	21.5
14	21.5	23.4	25.4
15	25.4	27.6	30.0
16	30.0	32.5	35.4
17	35.4	38.4	41.7
18	41.7	45.3	49.2
19	49.2	53.5	58.1
20	58.1	63.1	68.6
21	68.6	74.5	80.9
22	80.9	87.9	95.5
23	95.5	104	113
24	113	122	133
25	133	144	157

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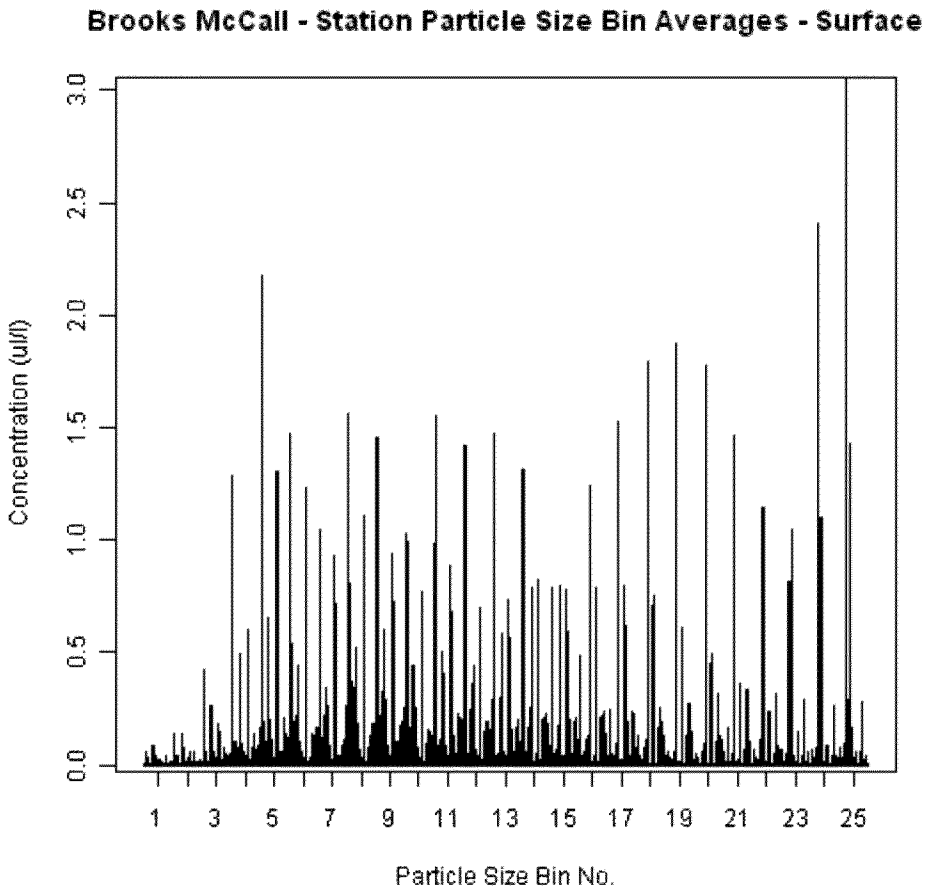

Figure 1: Particle-size distributions (see Table 1 for size range of corresponding Bin No.) for the surface samples of all stations of the R/V Brooks McCall.

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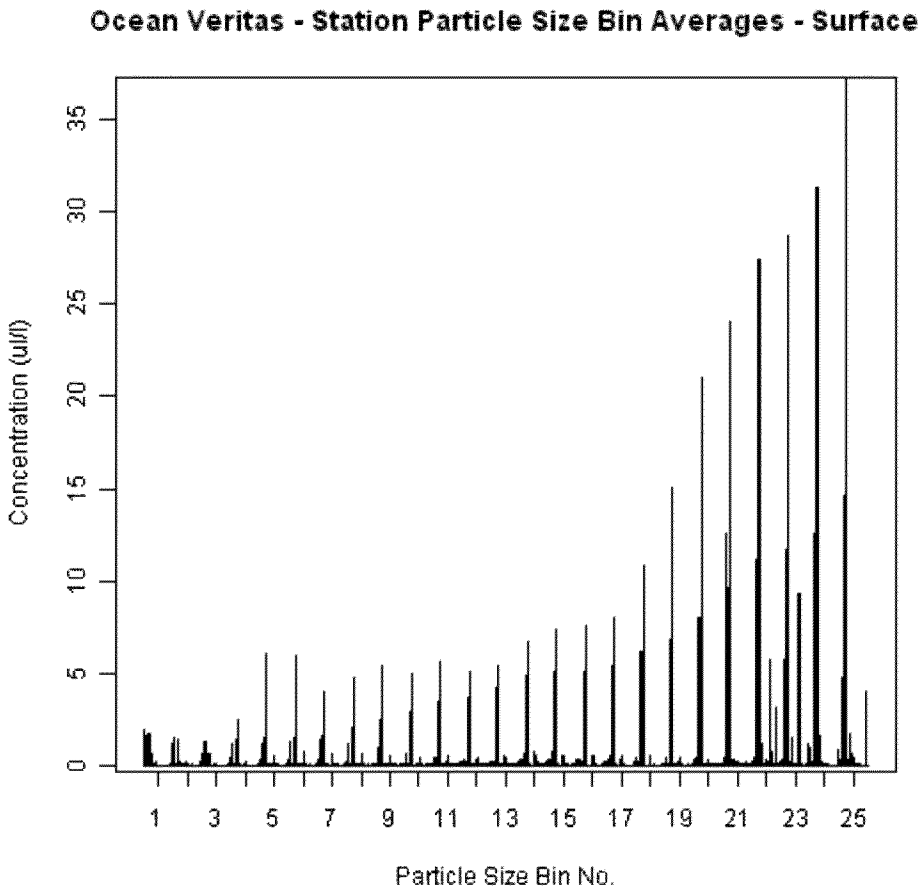

Figure 2: Particle-size distributions for the surface samples of all stations of the R/V Ocean Veritus.

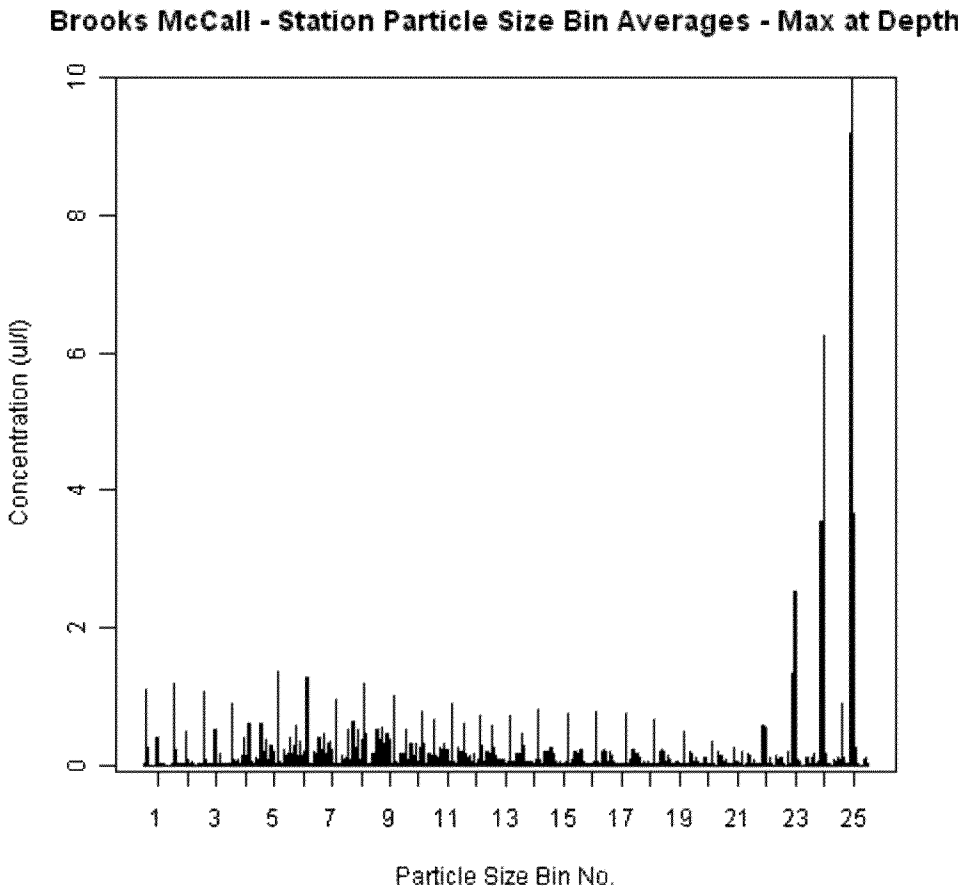

Figure 3: Particle-size distributions for the peak total concentration in sub-surface samples of all stations of the R/V Brooks McCall.

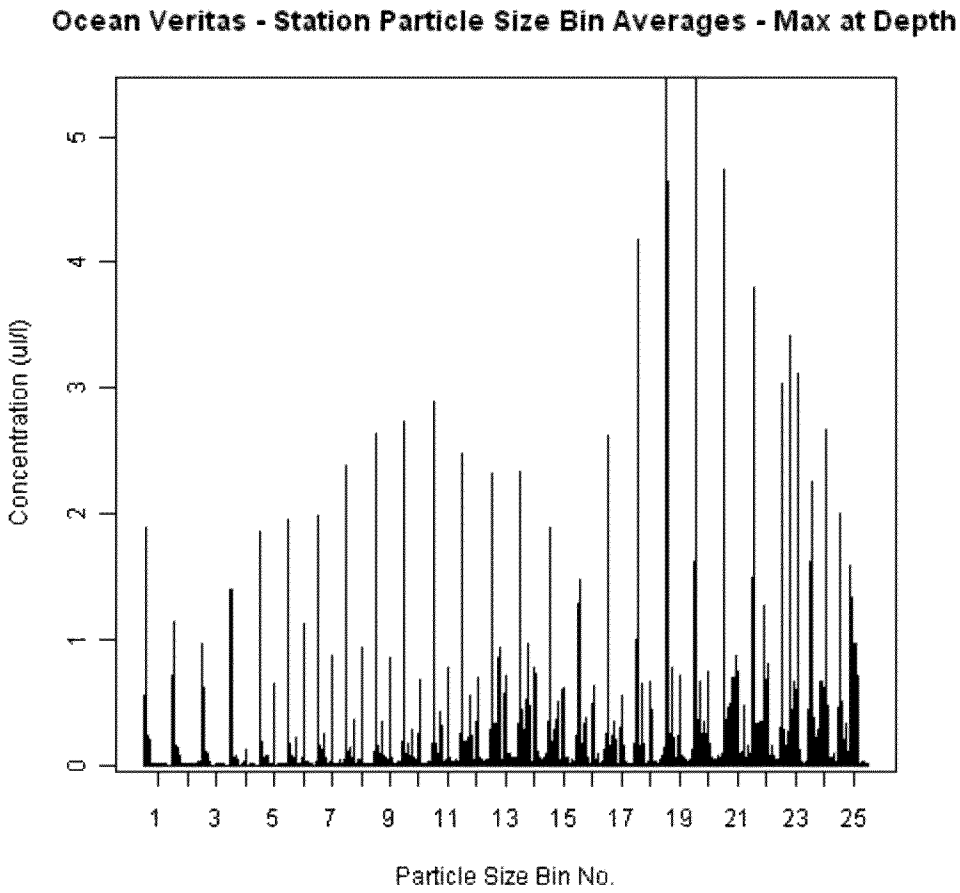

Figure 2: Particle-size distributions for the peak sub-surface samples of all stations of the R/V Ocean Veritus.

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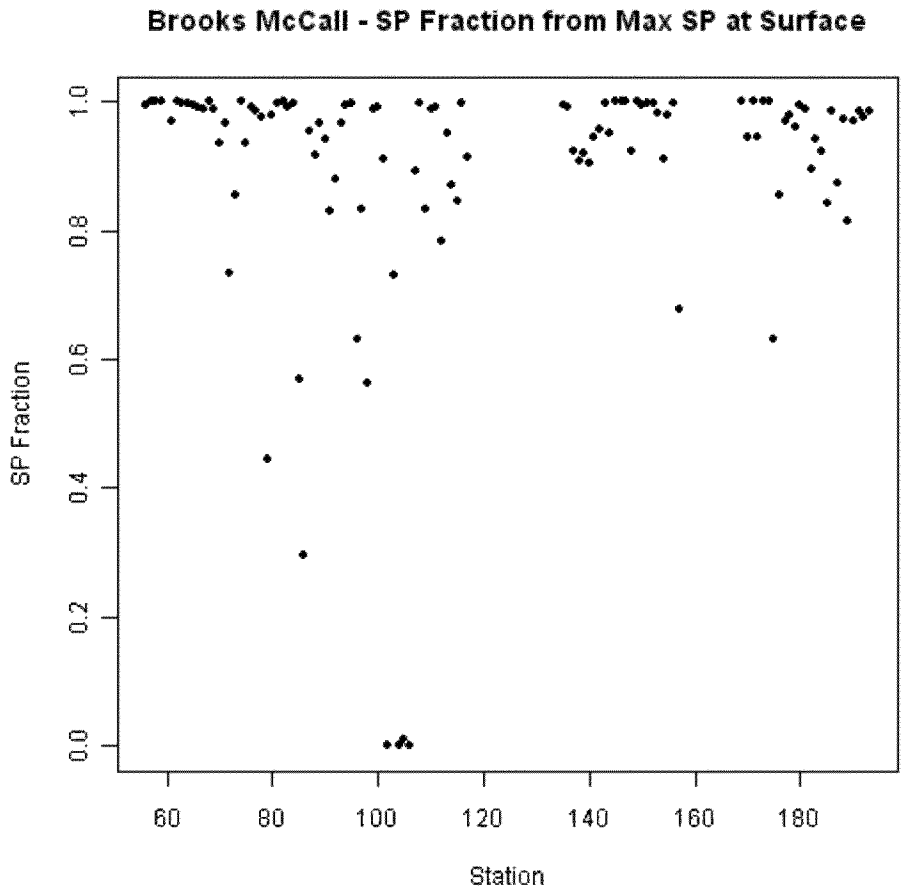

Figure 3: Small particle (d < 68.6 um) fraction of the total measured particles (2.5 – 157 um) for the surface samples of all stations of the R/V Brooks McCall.

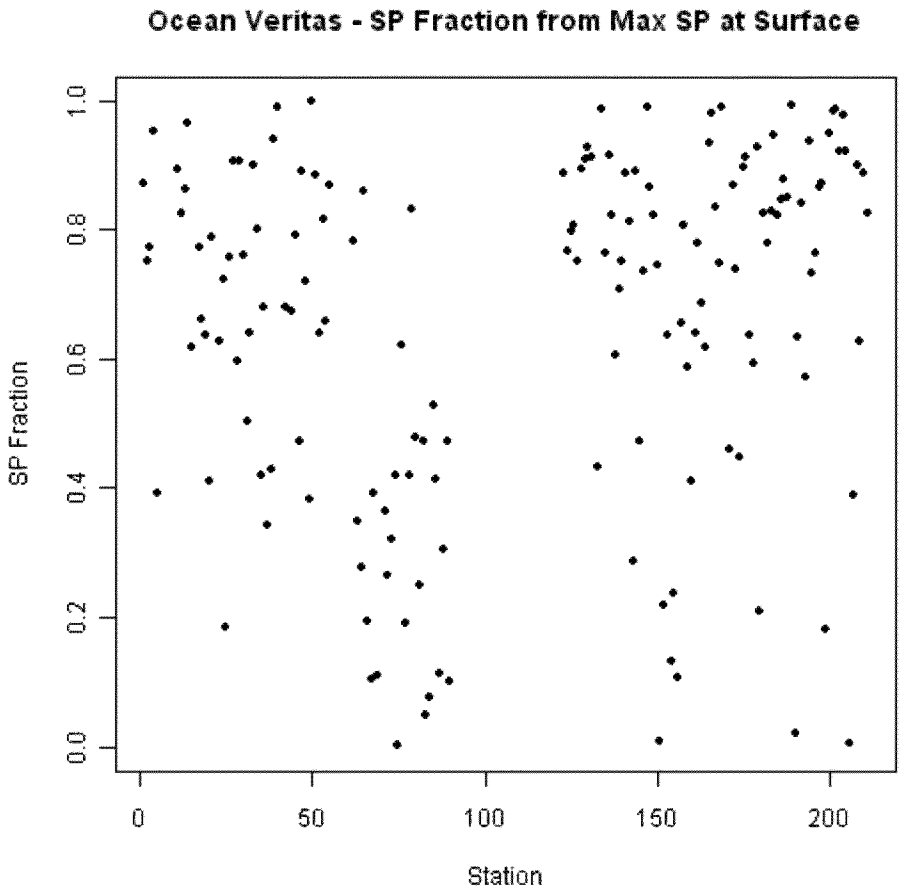

Figure 6: Small particle (d < 68.6 um) fraction of the total measured particles (2.5 – 157 um) for the surface samples of all stations of the R/V Ocean Veritas.

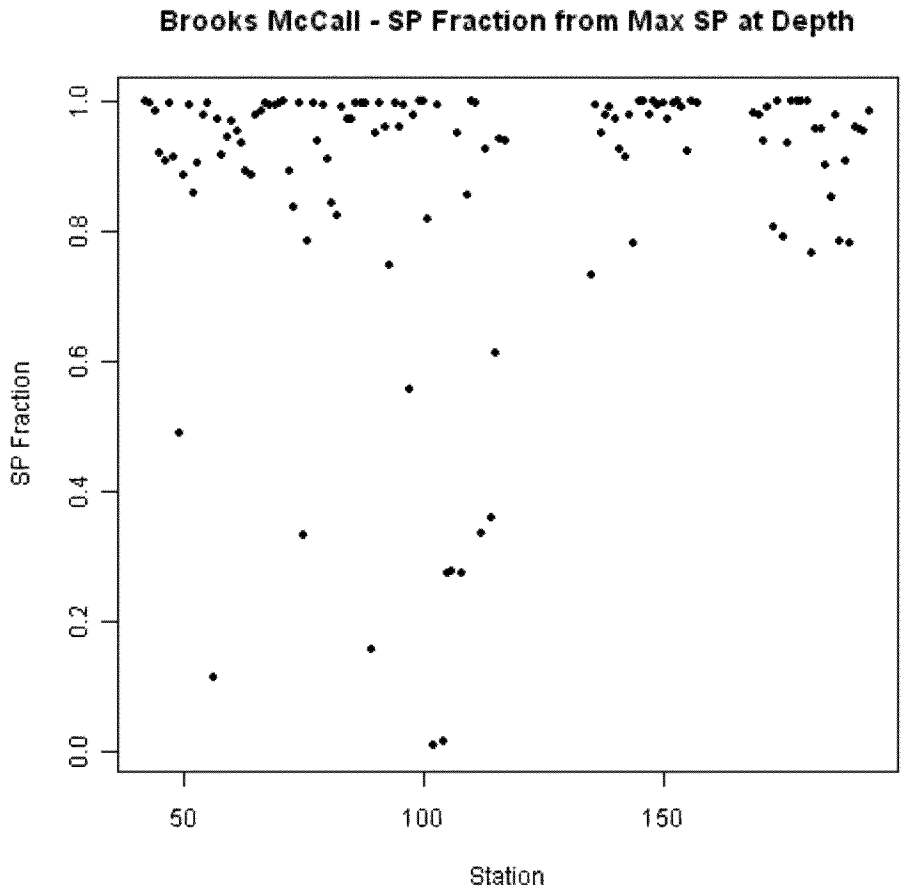

Figure 7: Small particle (d < 68.6 um) fraction of the total measured particles (2.5 – 157 um) for the peak sub-surface samples of all stations of the R/V Brooks McCall.

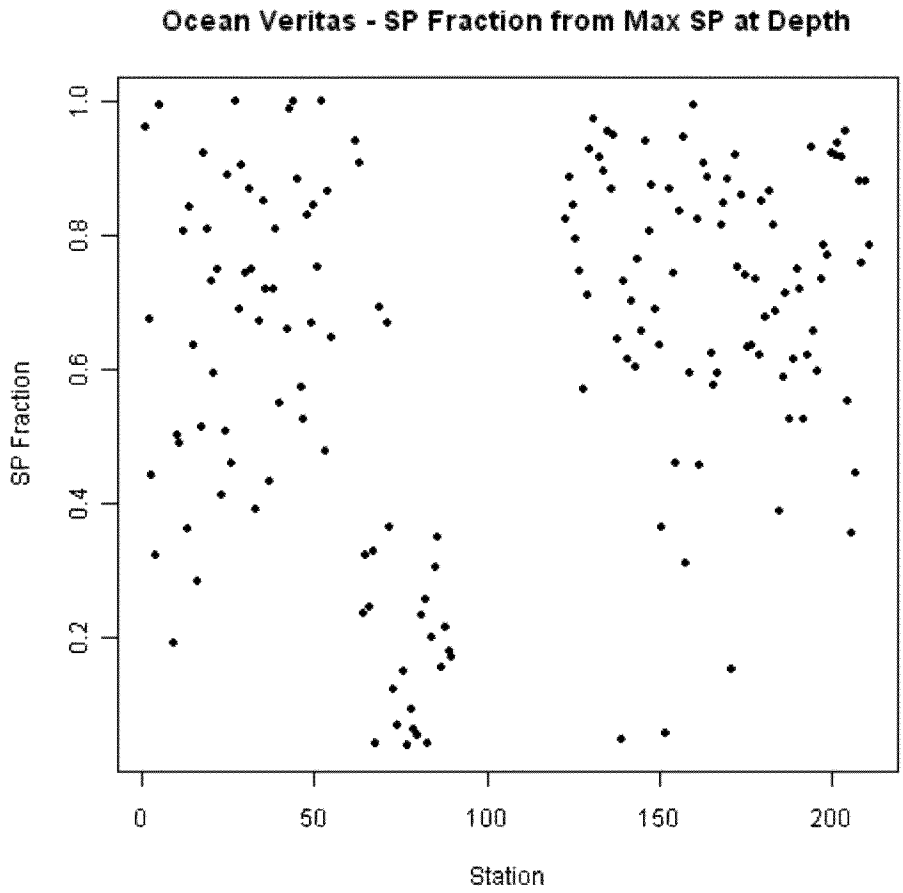

Figure 4: Small particle (d < 68.6 um) fraction of the total measured particles (2.5 – 157 um) for the peak sub-surface samples of all stations of the R/V Ocean Veritas.

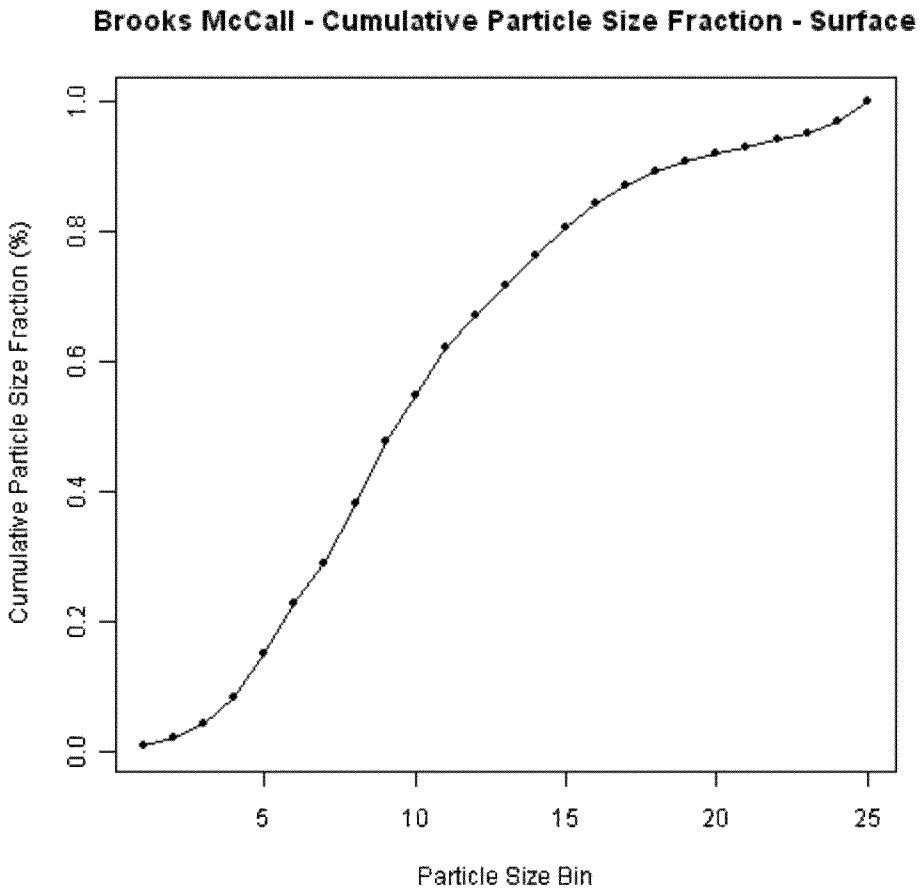

Figure 5: Cumulative particle-size distribution for all the surface samples of all stations of the R/V Brooks McCall.

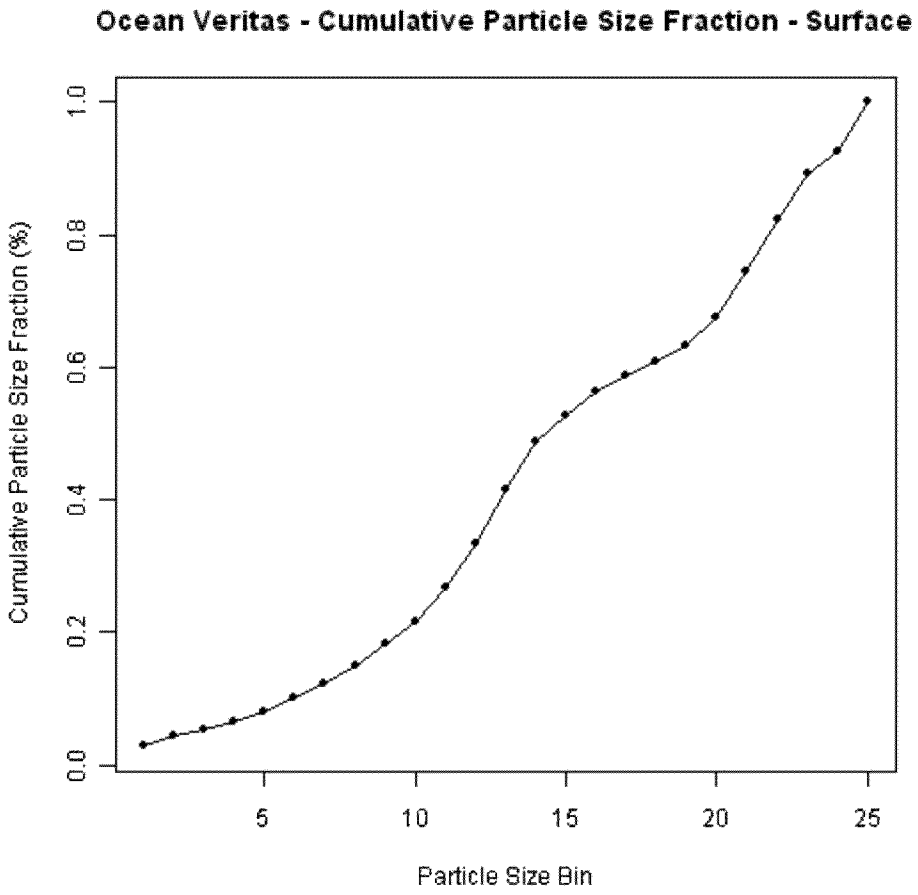

Figure 10: Cumulative particle-size distribution for all the surface samples of all stations of the R/V Ocean Veritas.

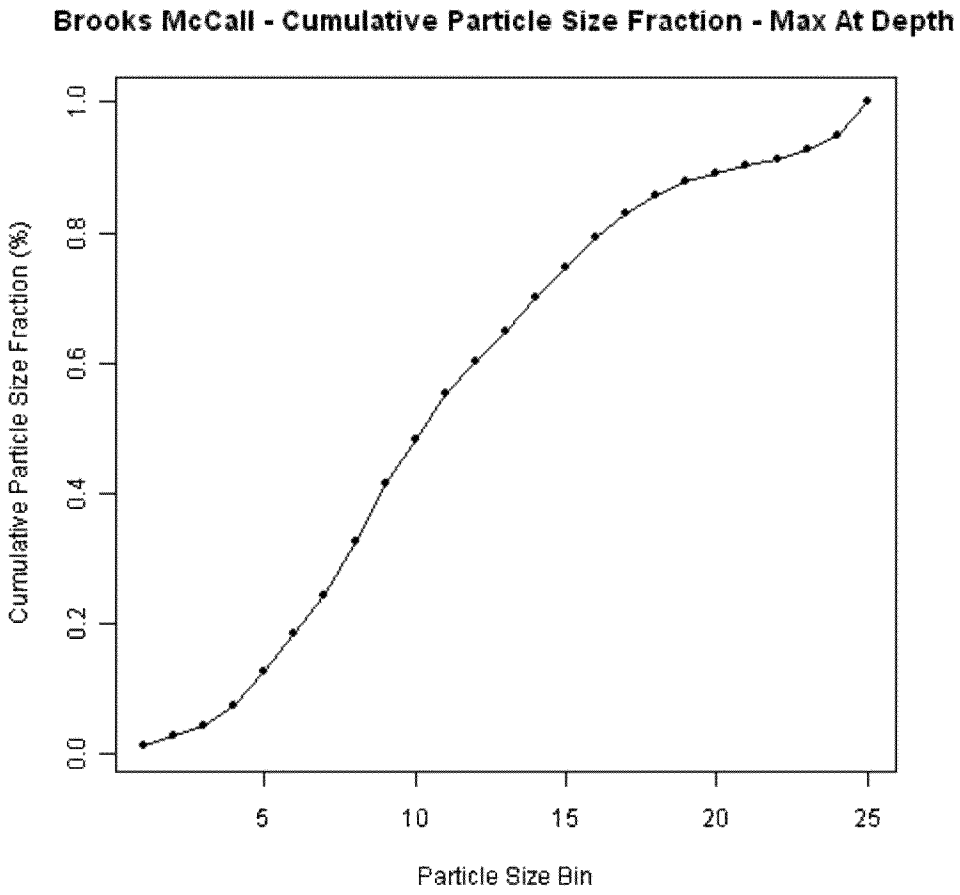

Figure 11: Cumulative particle-size distribution for all the peak sub-surface samples of all stations of the R/V Brooks McCall.

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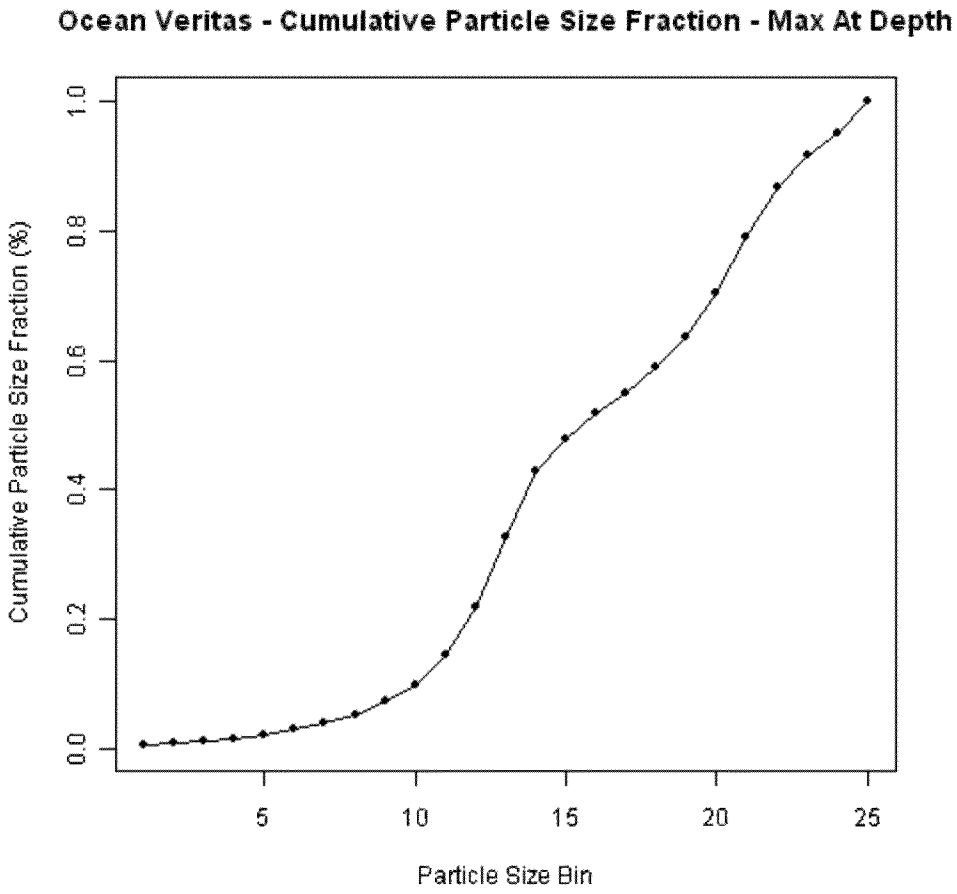

Figure 6: Cumulative particle-size distribution all the peak sub-surface samples of all stations of the R/V Ocean Veritas.

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Appendix 8

A8 Spill Related Properties of MC 252 Crude Oil Sample ENT-052210-178

For

BP

by

SL Ross Environmental Research Ltd.

July, 2010

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1. INTRODUCTION

When oil is spilled in the marine environment its physical and chemical properties will change over time through processes such as evaporation and emulsification. These changes will affect both the fate and behavior of the spill and the opportunities for using countermeasures effectively. For example, an oil may be relatively fluid and non-viscous when initially spilled, but may become viscous within a short time. It is important to know whether this will happen and how long it will take, defining the so-called Window of Opportunity for countermeasures.

The objective of this study was to conduct simulated oil spill weathering experiments on MC 252 ENT-052210-178 crude oil. The quantitative results of the tests (involving both fresh and weathered oil) can be used as input to most oil spill models that are used internationally to predict the fate and behavior of spills of specific oils.

2. PHYSICAL PROPERTY TESTS: METHODS AND RESULTS

The laboratory testing described here involved 2.7 L of the crude oil. The oil was subjected to the analyses outlined in Table 2-1. Test temperatures were chosen to cover the typical range of seasonal variation for the open water season in the target region. Temperature of 15°C and 35°C were chosen.

A discussion of the methodology of each of these tests is presented in Appendix A, along with an explanation of the effect that each oil property has on spill behavior.

The results of the weathering and analyses of the crude oil are presented separately in the following section. Complete test results can be found in Appendix B.

Table 2-1 Test Procedures for Spill-Related Analysis of MC 252 ENT-052210-178 Crude Oil

Property	*Test Temperature(s)*	*Equipment*	*Procedure*
Evaporation	Ambient	Wind TunnelASTM Distillation Apparatus	ASTM D86
Density	15° and 35°	Anton Paar Densitometer	ASTM D4052
Viscosity	15° and 35°	Brookfield DV III+ Digital Rheometer c/w Cone and Plate	Brookfield M/98-211
Interfacial Tension	Room Temperature	CSC DuNouy Ring Tensiometer	ASTM D971
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
Emulsification Tendency/Stability	15° and 35°	Rotating Flask Apparatus	(Mackay and Zagorski 1982; Hokstad and Daling 1993)

2.1 RESULTS

The results of the property analysis of MC 252 ENT-052210-178 are summarized in Table 2-2. The complete test results can be found in Appendix B. The two levels of evaporation noted in the table represent the amounts evaporated from a 2 cm-thick slick in the wind tunnel after two days and two weeks, respectively.

2.1.1 Evaporation

MC 252 ENT-052210-178 is a light crude with an API gravity of 37.2°. Approximately 35% of the oil evaporated after two days in the wind tunnel, and about 45% evaporated after two weeks of exposure.

Figure 2-1 is a predicted evaporation curve for a spill involving a 10-mm thick slick in a 5 knot wind at 25°C (77°F). Please note that the curve only applies at a water temperature of 25°C. If other temperatures (or slick thicknesses and wind speeds) are of interest, these curves can be generated using the equations in Appendix A and data in Appendix B[1]. Computerized oil spill models automatically do these calculations.

Figures 2-2, 2-3 and 2-4 show the effect of evaporation on the properties of oil viscosity, density and pour point.

[1] The evaporation curve of the oil in the wind tunnel is shown in Appendix B, plotting the volume fraction of oil evaporated, Fv, on the y-axis versus evaporative exposure, 2, on the x-axis, where 2 is the unit of time expressed in dimensionless form. Equations described in Appendix A and data in Table 2-2 of Appendix B can be used to convert this curve into a more usable form for estimating oil evaporation under various spill conditions of temperature, elapsed time and wind speed.

Table 2-2 Spill-Related Properties of MC252 Crude Oil

Spill-related properties	BP MC252 ENT-052210-178	API ° = 37.2	
Evaporation (Volume %)	0	34.50	44.66
Density (g/cm^3)			
15 °C	0.839	0.882	0.897
35 °C	0.825	0.868	0.883
Dynamic Viscosity (mPa.s)	at approx 460 s^{-1}		
15 °C	4.1	43	85
35 °C	1.4	10	23
Kinematic Viscosity (mm^2/s)			
15 °C	4.8	49	95
35 °C	1.7	12	26
Interfacial Tension (dyne/cm)			
Oil/ Air	23.5	26.8	30.1
Oil/ Seawater	23.3	22.6	22.5
Pour Point (°C)	<-9	6	6
Flash Point (°C)	<-8	54	100
Emulsion Formation-Tendency and Stability @		22.5 °C	
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content	0%	0%	0%
Emulsion Formation-Tendency and Stability @		34 °C	
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content	0%	0%	0%
ASTM Modified Distillation			
	Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
	IBP	84	39.8
	5	111.6	77.4
	10	124.4	91.7
	15	137	102.4
	20	151.2	115.8
	25	168.8	116
	30	188.2	126.4
	35	208	150
	40	227	129.7
	45	248	142.5

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\square\exp(C_2-C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
□ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 5472
C_2 = 12.90
C_3 = 5739

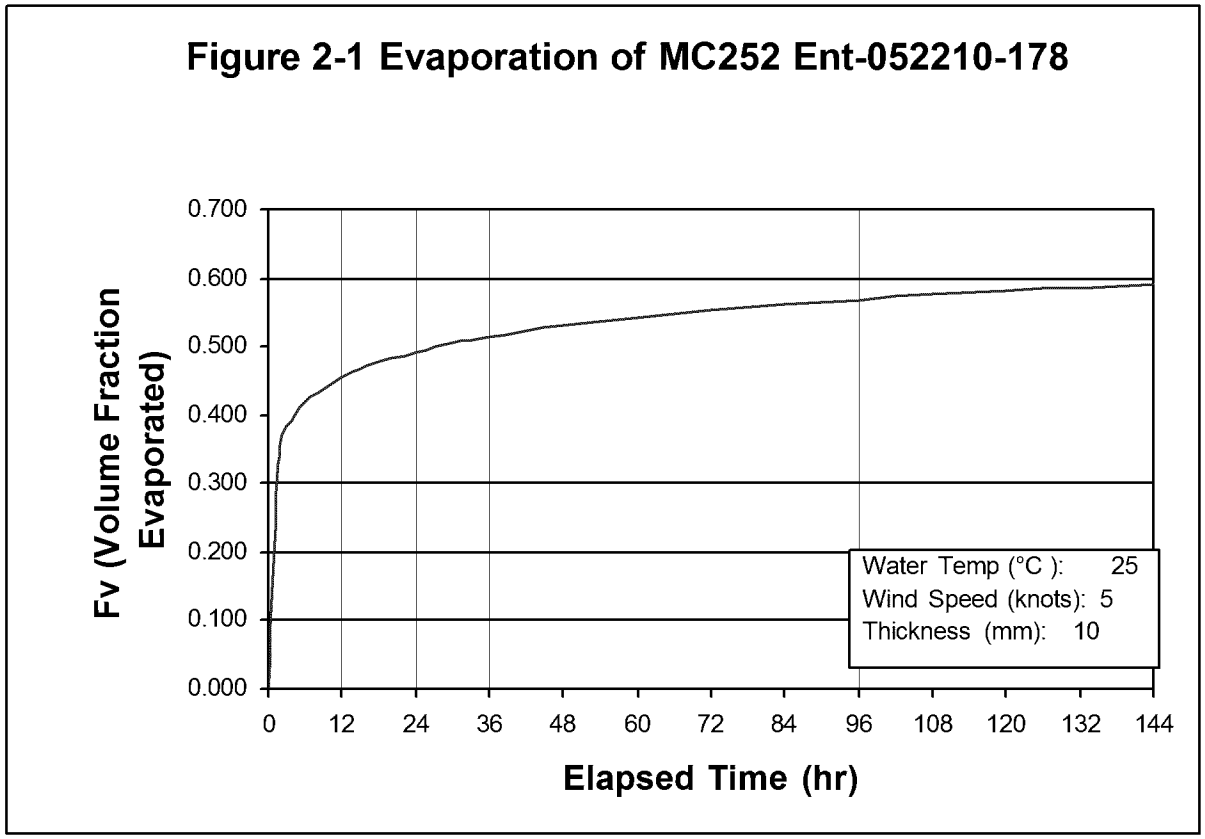
Figure 2-1 Evaporation of MC252 Ent-052210-178
Fv (Volume Fraction Evaporated)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
12
24
36
48
60
72
84
96
108
120
132
144
Elapsed Time (hr)
Water Temp (°C): 25
Wind Speed (knots): 5
Thickness (mm): 10

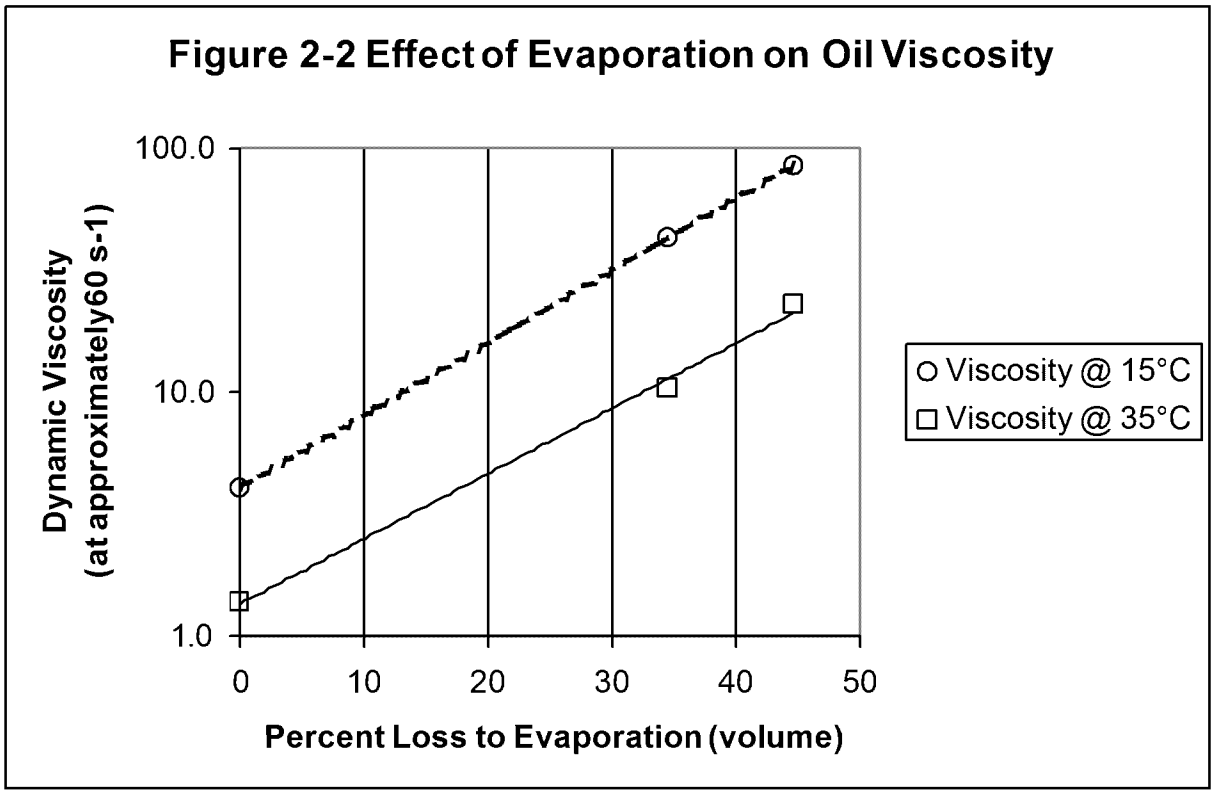
Figure 2-2 Effect of Evaporation on Oil Viscosity
Dynamic Viscosity (at approximately60 s-1)
100.0
10.0
1.0
0
10
20
30
40
50
Percent Loss to Evaporation (volume)
Viscosity @ 15°C
Viscosity @ 35°C

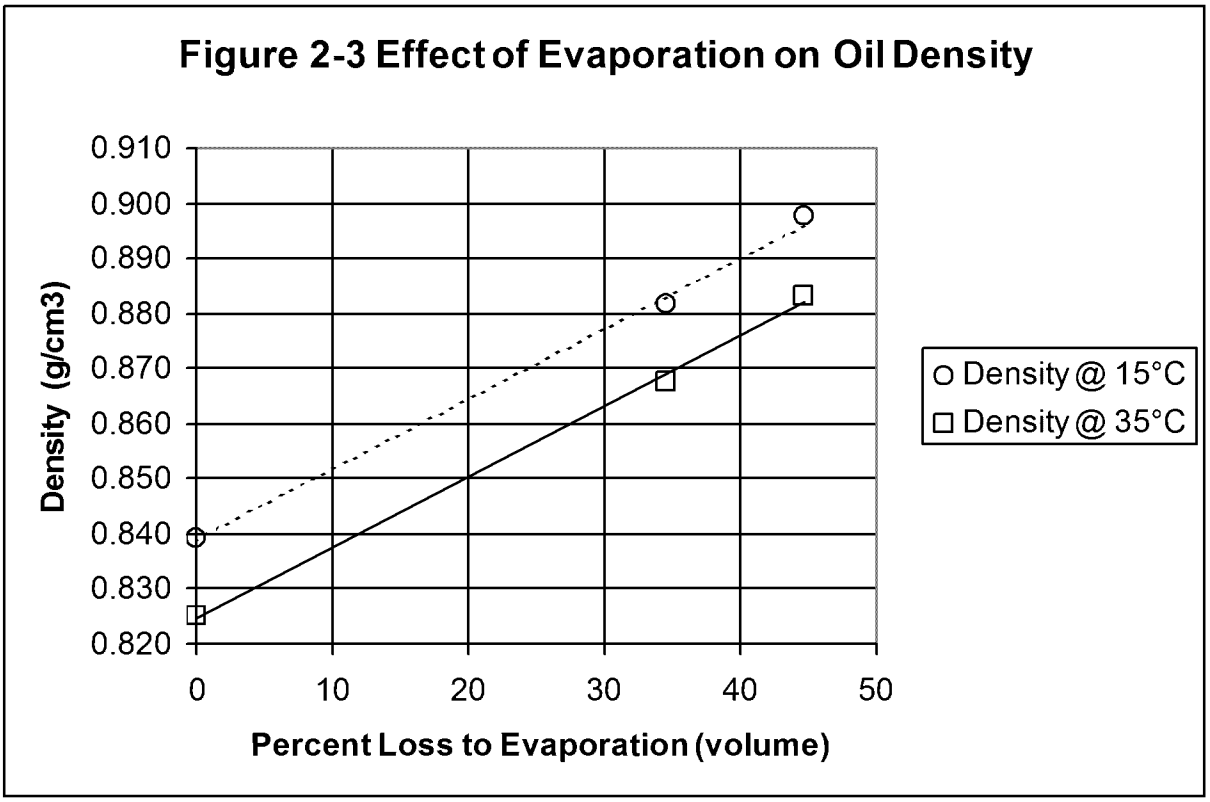
Figure 2-3 Effect of Evaporation on Oil Density
Density (g/cm3)
0.910
0.900
0.890
0.880
0.870
0.860
0.850
0.840
0.830
0.820
0
10
20
30
40
50
Percent Loss to Evaporation (volume)
Density @ 15°C
Density @ 35°C

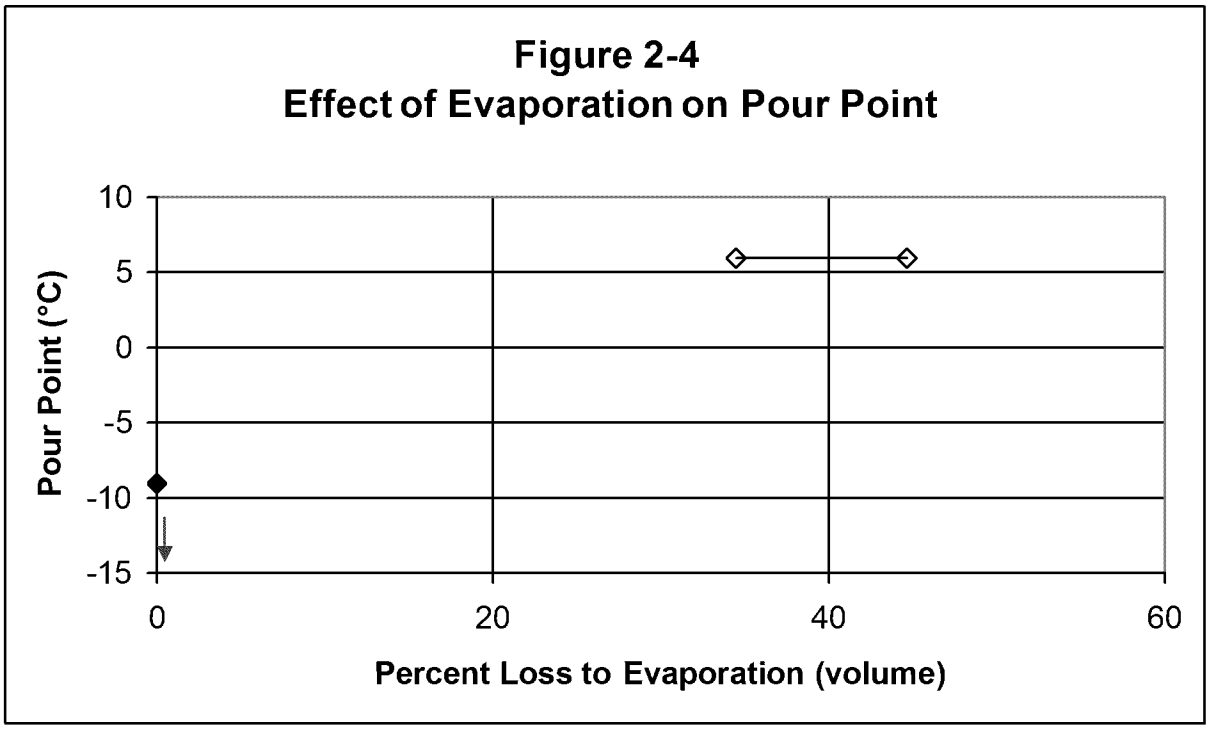
Figure 2-4
Effect of Evaporation on Pour Point
Pour Point (°C)
10
5
0
-5
-10
-15
0
20
40
60
Percent Loss to Evaporation (volume)

2.1.2 Density

MC 252 oil is a light crude oil, with a density of 0.839 g/cm^3 at 15°C (API gravity of 37.2°).

2.1.3 Viscosity

The oil has a very low viscosity that is typical of light oils. At 15°C the viscosity of the fresh oil is about 4.1 cP (mPa.s). The viscosity increases to 42.9 cP after 35% evaporation and to 85.1 cP after 45% evaporation. The crude oil exhibits minor non-Newtonian behavior (slightly pseudo-plastic, or shear-thinning, characteristics) at 15°C. It is a Newtonian fluid at 35°C.

2.1.4 Interfacial Tension

The oil/water interfacial tension of MC 252 ENT-052210-178 crude was measured using standard laboratory water with 35 ppt of salt. The value measured was 23.7 dynes/cm, which is in the range of most crude oils.

2.1.4 Pour Point

MC 252 ENT-052210-178 crude has a pour point of less than -9°C when fresh. This increases to 6°C at 35 and 45 percent evaporation.

2.1.5 Flash Point

MC 252 ENT-052210-178 has a low flash point (below -8°C) when fresh. This rises after 45% evaporation to 100°C.

2.1.6 Emulsification Tendency and Stability

From the viewpoint of spill countermeasures and slick persistence, emulsification is a very negative process because strongly emulsified oils are highly viscous — they can have ten to 100 times the viscosity of the parent oil. It is general believed that oils that have relatively high concentrations of asphaltenes are the most likely to form stable water-in-oil emulsions. Some oil spills do not form emulsion immediately, but once evaporation occurs and the asphaltene concentration increases, the emulsification process begins and usually proceeds quickly thereafter.

The MC 252 ENT-052210-178 crude oil has no tendency to form stable water-in oil emulsions when mixed with seawater. At sea, it is observed that MC 252 crude does eventually form stable emulsions. The reason that the ENT-052210-178 sample does not could be due to several factors:

- The ENT-052210-178 sample evaporated in the wind tunnel for two weeks is equivalent to only about 10 hours at sea for a 1-mm thick slick or 100 hours for a 10-mm thick slick and the onset of emulsification may not occur until greater degrees of evaporative exposure that this are reached.
- The sample may have been exposed to an anti-foaming agent and/or methanol during it's collection from the damaged riser by the RITT and this exposure may inhibit emulsification.

- Exposure to sunlight (not a part of the SL Ross weathering protocol) can produce photo-oxidation products that promote emulsification.

Enough of the two-week weathered sample from the wind tunnel remains to place a thinner slick back into the wind tunnel and further expose it to the equivalent of one week at sea for a 1-mm slick. The emulsification of this sample will then be measured. As well, during the earlier alternative field-testing program, surface samples of the slick were collected and shipped to the SL Ross lab. Aliquots of these will be subjected to the laboratory emulsification test to determine their emulsification characteristics.

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APPENDIX A. OIL PROPERTY TEST METHODOLOGY AND RELATIONSHIP TO SPILL BEHAVIOR

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A.1 EVAPORATION

The oil was divided into three aliquots. Two aliquots were weathered in a wind tunnel: one for two days and one for two weeks. Depending on the conditions at a spill site, this is typically equivalent to a few hours and a few days at sea. In addition, the fresh oil was subjected to a modified ASTM distillation (ASTM D86-90, modified in that both liquid and vapor temperature are measured) in order to obtain two oil-specific constants for evaporation prediction purposes. Evaporation is correlated using Evaporative Exposure (θ), a dimensionless time unit calculated by:

$$\theta = kt/x$$

where: k = a mass transfer coefficient [m/s] *(determined experimentally in the laboratory wind tunnel or by an equation related to wind speed for spills at sea)*
t = elapsed time [s]
x = oil thickness [m]

The distillation information is used in conjunction with the wind tunnel data to predict evaporation rates for oil spills at sea.

A.2 PHYSICAL PROPERTIES

The oils were subjected to the analyses outlined in Table 1. Test temperatures are chosen to represent typical values for the region for those tests that are temperature-sensitive, such as density and viscosity.

Table 1: Test procedures for oil analysis

Property	Test Temperature(s)	*Equipment*	Procedure
Evaporation	Ambient	Wind Tunnel ASTM Distillation Apparatus	ASTM D86
Density	15° and 35 °C	Anton Paar Densitometer	ASTM D4052
Viscosity	15° and 35 °C	Brookfield DV III+ Digital Rheometer c/w Cone and Plate	Brookfield M/98-211
Interfacial Tension	Room Temperature	CSC DuNouy Ring Tensiometer	ASTM D971
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
Emulsification Tendency/Stability	15° and 35 °C	Rotating Flask Apparatus	(Mackay and Zagorski 1982; Hokstad and Daling 1993)

A.2.1 Densit y

Density, the mass per unit volume of the oil (or emulsion), determines how buoyant the oil is in water. The common unit of density is grams per millilitre or cubic centimetre (g/mL or g/cm^3); the SI unit is kg/m^3, which is numerically 1000 times the value in g/mL. The density of spilled crude oil increases with weathering and decreases with increasing temperature. Density affects the following spill processes:

- Sinking - if the density of the oil exceeds that of the water it will sink;
- Spreading - in the early stages of a spill, more dense oils spread faster;
- Natural dispersion - more dense oils stay dispersed more easily; and,
- Emulsification stability - dense oils form more stable emulsions.

A.2.2 Viscosit y

Viscosity is a measure of the resistance of oil to flowing, once it is in motion. The common unit of dynamic viscosity is the centi-Poise (cP); the SI unit is the milli-Pascal second (mPas), which is numerically equivalent to the centi-Poise. The common unit of kinematic viscosity (calculated by multiplying the dynamic viscosity by the density) is the centi-Stoke (cSt) the SI unit is the square millimetre/second (mm^2/s), which is numerically equivalent to the centi-Stoke. The viscosity of spilled crude oil increases as weathering progresses and decreases with increasing temperature. Viscosity is one of the most important properties from the perspective of spill behavior and affects the following processes:

- Spreading - viscous oils spread more slowly;
- Natural and chemical dispersion - highly viscous oils are difficult to disperse;
- Emulsification tendency and stability - viscous oils form more stable emulsions; and,
- Recovery and transfer operations - more viscous oils are generally harder to skim and more difficult to pump.

A.2.3 Interfacial Tension

Interfacial tension is a measure of the surface forces that exist between the interfaces of the oil and water, and the oil and air. The common unit of interfacial tension is the dyne/cm; the SI unit is the milli-Newton/metre (mN/m), which is numerically equivalent to the dyne/cm. Chemical dispersants work by reducing the oil/water interfacial tension to allow a given mixing energy (i.e., sea state) to produce smaller oil droplets. Emulsion breakers also work by lowering the oil/water interfacial tension; this weakens the continuous layer of oil surrounding the suspended water droplets and allows them to coalesce and drop out of the emulsion. Interfacial tensions (oil/air and oil/water) are fairly insensitive to temperature, but are affected by evaporation. Interfacial tension affects the following processes:

- Spreading - interfacial tensions determine how fast an oil will spread and whether the oil will form a sheen;
- Natural and chemical dispersion - oils with high interfacial tensions are more difficult to disperse naturally, chemical dispersant work by temporarily reducing the oil/water interfacial tension;
- Emulsification rates and stability; and,

- Mechanical recovery - oleophilic skimmers (e.g., rope-mop and belt skimmers) work best on oils with moderate to high interfacial tensions.

A.2.4 Pour Point

The pour point is the lowest temperature (to the nearest multiple of 3 °C) at which crude oil will still flow in a small test jar tipped on its side. Near, and below this temperature, the oil develops a yield stress and, in essence, gels. The pour point of an oil increases with weathering. Pour point affects the following processes:

- Spreading - oils at temperatures below their pour points will not spread on water;
- Viscosity - an oil's viscosity at low shear rates increases dramatically at temperatures below its pour point;
- Dispersion - an oil at a temperature below its pour point may be difficult to disperse; and,
- Recovery - crude oil below its pour point may not flow towards skimmers or down inclined surfaces in skimmers

A.2.5 Flash Point

The flash point of crude oil is the temperature at which the oil produces sufficient vapors to ignite when exposed to an open flame or other ignition source. Flash point increases with increasing evaporation. It is an important safety-related spill property.

A.2.6 Emulsification Tendency and Stability

The tendency of crude oil to form water-in-oil emulsions (or "mousse") and the stability of the emulsion formed are measured by two numbers: the Emulsification Tendency Index (Zagorski and Mackay 1982, Hokstad and Daling 1993) and the Emulsion Stability (adapted from Fingas *et al.* 1998). The Emulsification Tendency Index is a measure of the oil's propensity to form an emulsion, quantified by extrapolating back to time = 0 the fraction of the parent oil that remains (i.e., does not cream out) in the emulsion formed in a rotating flask apparatus over several hours. If a crude oil has an Emulsification Tendency Index between 0 and 0.25 it is unlikely to form an emulsion; if it has a Tendency Index between 0.25 and 0.75 it has a moderate tendency to form emulsions. A value of 0.75 to 1.0 indicates a high tendency to form emulsions. Recently the Emulsion Stability assessment has been changed to reflect the four categories suggested by Fingas *et al.* 1998. Emulsion types are selected based on water content, emulsion rheology and the visual appearance of the emulsion after 24 hours settling. The four categories, and their defining characteristics, are:

1. Unstable – looks like original oil; water contents after 24 hours of 1% to 23% averaging 5%; viscosity same as oil on average
2. Entrained Water – looks black, with large water droplets; water contents after 24 hours of 26% to 62% averaging 42%; emulsion viscosity 13 times greater than oil on average
3. Meso-stable – brown viscous liquid; water contents after 24 hours of 35% to 83% averaging 62%; emulsion viscosity 45 times greater than oil on average
4. Stable – the classic "mousse", a brown gel/solid; water contents after 24 hours of 65% to 93% averaging 80%; emulsion viscosity 1100 times greater than oil on average

Under the old emulsion stability assessment scheme, the stability was determined by the fraction of the original oil that remained in the emulsion after 24-hours settling (0 to 0.25 = unstable, 0.25 to 0.75 = fairly stable, 0.75 to 1 = very stable).

Both the Tendency Index and Stability generally increase with increased degree of evaporation. Colder temperatures generally increase both the Tendency Index and Stability (i.e., promote emulsification) unless the oil gels as the temperature drops below its pour point and it becomes too viscous to form an emulsion. Emulsion formation results in large increases in the spill's volume, enormous viscosity increases (which can reduce dispersant effectiveness), and increased water content (which can prevent ignition of the slicks and *in situ* burning).

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APPENDIX B. OIL PROPERTY ANALYSIS RESULTS FOR MC 252 ENT-052210-178 CRUDE OIL

Oil Weathering

BP MC252 ENT-052210-178

	Tray 7	Tray 8	Average Air Temp	
Tray Mass (g)	240.4	240.8	24.7	°C

Volume Weathered(ml)	970
Volume for 2cm thick	969.50
Tray thickness (m)	0.02001031

Date/Time	Mass of Oil + Tray Tray 7 (g)	Mass of Oil + Tray Tray 8 (g)	Mass of Oil Tray 7 (g)	Mass of Oil Tray 8 (g)	Fm Tray 7	Fm Tray 8	Oil Density (g/cm^3)	Fv Tray 7	Fv Tray 8
07/06/2010 17:17	1032.7	1040.2	792.3	799.4	0.000	0.000	0.832	0.000	0.000
07/06/2010 17:50	1001.2	1009.5	760.8	768.7	0.040	0.038	0.837	0.046	0.045
07/06/2010 19:00	963.1	971.6	722.7	730.8	0.088	0.086	0.844	0.101	0.099
07/06/2010 19:30	949.0	957.7	708.6	716.9	0.106	0.103	0.847	0.121	0.119
07/06/2010 22:35	927.1	936.0	686.7	695.2	0.133	0.130	0.850	0.152	0.149
08/06/2010 10:30	833.6	839.6	593.2	598.8	0.251	0.251	0.868	0.282	0.282
08/06/2010 19:30	815.1	822.3	574.7	581.5	0.275	0.273	0.871	0.307	0.305
09/06/2010 10:22	795.8	800.7	555.4	559.9	0.299	0.300	0.874	0.333	0.334
09/06/2010 17:10	786.8	791.8	546.4	551.0	0.310	0.311	0.876	0.345	0.345
10/06/2010 10:13		776.3		535.5		0.330	0.879		0.366
11/06/2010 13:45		763.3		522.5		0.346	0.881		0.383
14/06/2010 13:16		742.2		501.4		0.373	0.885		0.410
16/06/2010 9:48		732.0		491.2		0.386	0.887		0.423
17/06/2010 11:15		728.4		487.6		0.390	0.887		0.428
21/06/2010 16:45		713.9		473.1		0.408	0.890		0.447

Fv vs. Theta Modeling

Evaporative Exposure (Corrected)	Model Evaporate (Fv)
0.0	0.000
199.0	0.108
621.1	0.165
802.0	0.178
1917.5	0.224
6228.9	0.288
9485.1	0.311
14863.8	0.335
17324.0	0.343
23492.6	0.360
33454.1	0.379
59328.6	0.410
75440.6	0.423
84648.3	0.429
121370.6	0.449

	2-day	2-week
Fm	0.310	0.408

	2-day	2-week
Fv	0.345	0.447

Density **BP MC252 ENT-052210-178**

Measurements

Mass Evaporated (Fm)	Density (g/cm^3)	Temperature (°C)
0	0.838	16.6
0	0.823	37.8
0.31	0.880	17.3
0.31	0.866	37.4
0.41	0.896	17.1
0.41	0.881	38.2
0	0.832	24.69
0.31	0.875	24.69
0.41	0.891	24.69

slope	0.142
intercept	0.832
r^2	0.999

Density Constants for SL Ross Model

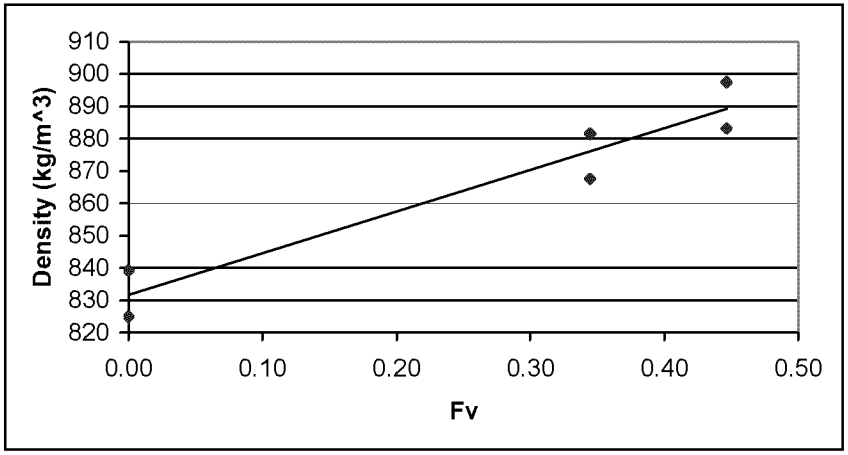
Density Constant 1 (slope, kg/m^3)	128.770
Density Constant 2 ($kg/K.m^3$)	0.705

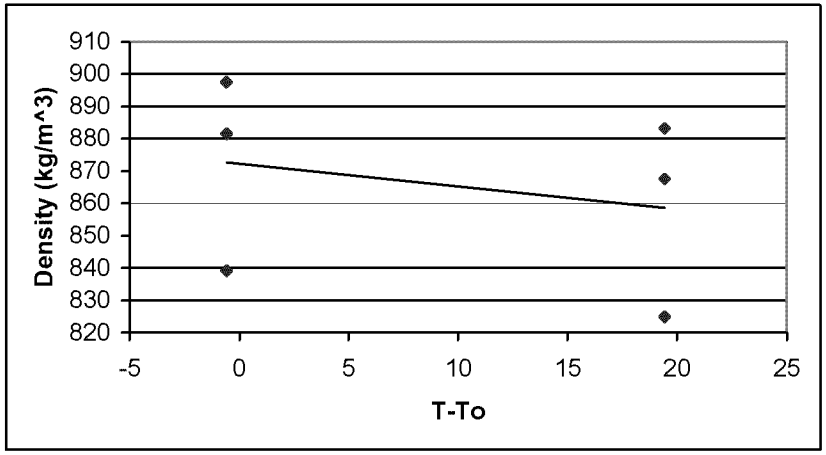
API Gravity

Standard Density Temperature, To (K)	288.72
Standard Density (kg/m^3)	838.736
API Gravity @ 15.5°C	37.21

Calculations

Temperature (°C)	Density (g/cm^3)	Density (kg/m^3)	Volume Evaporated (Fv)	T-To (K)
15	0.839	839	0	-0.56
15	0.882	882	0.345	-0.56
15	0.897	897	0.447	-0.56
35	0.825	825	0	19.44
35	0.868	868	0.345	19.44
35	0.883	883	0.447	19.44
15.5	0.897	897	0.000	





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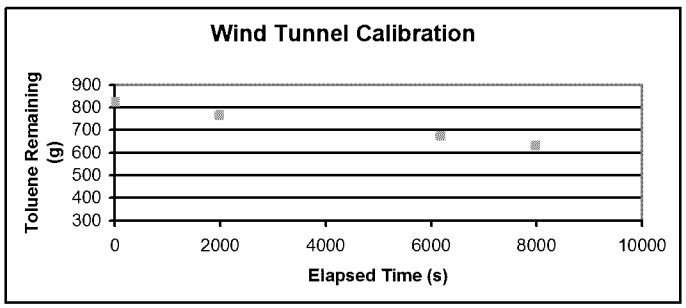
Wind Tunnel Calibration **Toluene**

Tray Mass (g)

Elapsed Time (s)	Mass Toluene Tray 9 (g)	Tray 6
0	825.0	829.2
1980	765.3	776.1
6180	673.2	686.7
7980	630.7	645.7
19080	549.1	567.0

	Tray 9	Tray 6	Average
slope	-0.01384046	-0.013238	-0.013539

E (kg/s)	-1.3539E-05		
Wind Tunnel Temperature, T (K)	297.8499	24.69	°C
Toluene Vapor Pressure, P (kPa)	3.733		
Ideal Gas Constant (R, kPa.m^3/kg.mol.K)	8.314		
Molecular Weight of Toluene (W, kg/kg.mol)	92.13		
Tray Area (A, m^2)	0.048475		
K = ERT/APW (m/s)	-0.002011016		



ASTM Distillation **BP MC252 ENT-052210-178**

200 ml Fresh oil

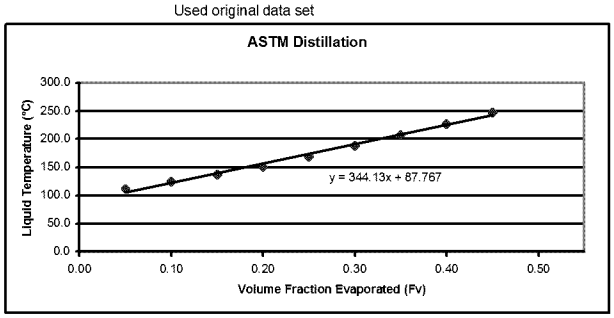
Water Subtracted

Volume Distilled (mL)	Fraction Distilled (Fv)	Temperature Liquid (°C)	Vapor (°C)
IBP	0.00	84.0	39.8
10	0.05	111.6	77.4
20	0.10	124.4	91.7
30	0.15	137.0	102.4
40	0.20	151.2	115.8
50	0.25	168.8	116.0
60	0.30	188.2	126.4
70	0.35	208.0	150.0
80	0.40	227.0	129.7
90	0.45	248.0	142.5

slope	344.1
intercept	87.8

Distillation Constant A (slope, K)	344.1
Distillation Constant B (intercept, K)	360.9

Used original data set



Mackay Constants **BP MC252 ENT-052210-178**
(automated)

Point	Fv	Tb/T	H	ln(H)
1	0.022	1.238	2.244E-04	-8.402
2	0.072	1.295	1.287E-04	-8.958
3	0.109	1.338	1.089E-04	-9.125
4	0.134	1.367	2.737E-05	-10.506
5	0.215	1.461	3.071E-05	-10.391
6	0.293	1.551	7.128E-06	-11.851
7	0.319	1.581	5.345E-06	-12.139
8	0.339	1.604	4.785E-06	-12.250
9	0.356	1.623	3.308E-06	-12.619
10	0.374	1.644	1.708E-06	-13.280
11	0.396	1.670	1.060E-06	-13.757
12	0.417	1.693	8.178E-07	-14.017
13	0.426	1.704	5.036E-07	-14.501

	calculated	adjusted
Fv vs. Theta B (-slope)	12.30515	15.9
Fv vs. Theta A (intercept)	7.032316	12.9

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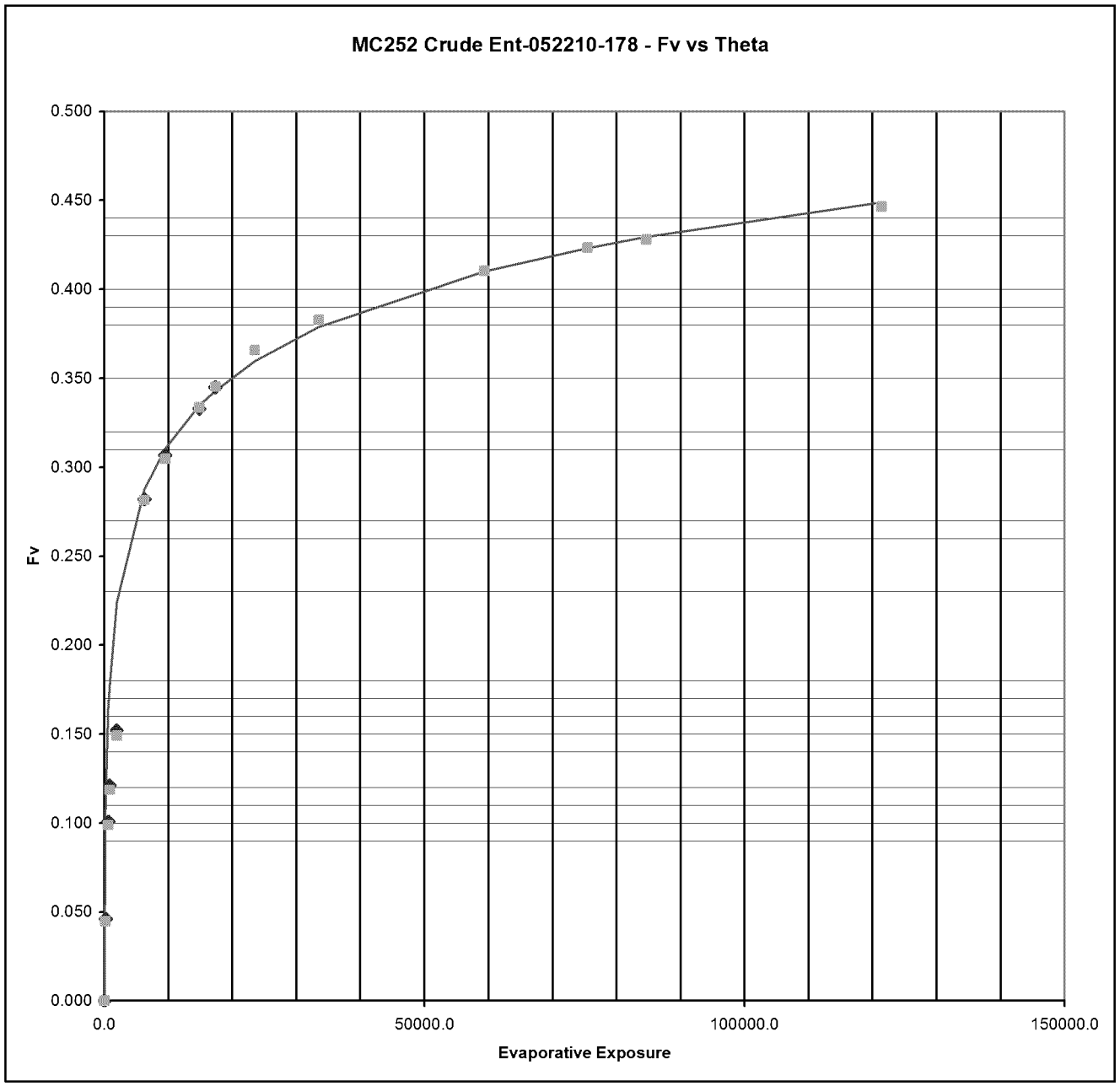

MC252 Crude Ent-052210-178 - Fv vs Theta
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
Fv
0.0
50000.0
100000.0
150000.0
Evaporative Exposure

Viscosity **BP MC252 ENT-052210-178**

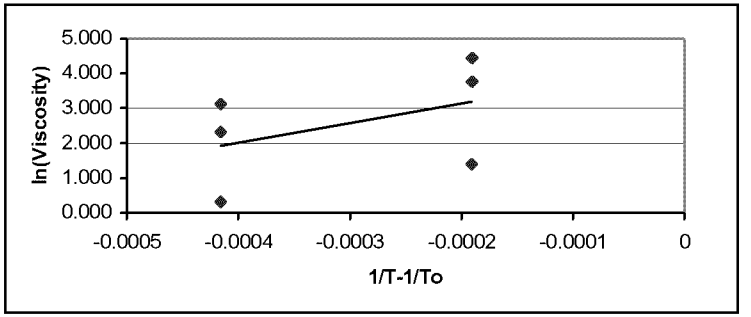
Mass Evaporated (Fm)	Viscosity (cP)	Temperature (°C)	rpm	Spindle #	Shear Rate (s^{-1})	ln(Viscosity)
0	4.1	15.0	120.0	CP-42	461.0	1.399
0	1.4	35.0	120.0	CP-42	461.0	0.329
0.31	42.9	15.0	120.0	CP-42	461.0	3.759
0.31	10.3	35.0	120.0	CP-42	461.0	2.332
0.41	85.1	15.0	120.0	CP-42	461.0	4.444
0.41	22.8	35.0	120.0	CP-42	461.0	3.127

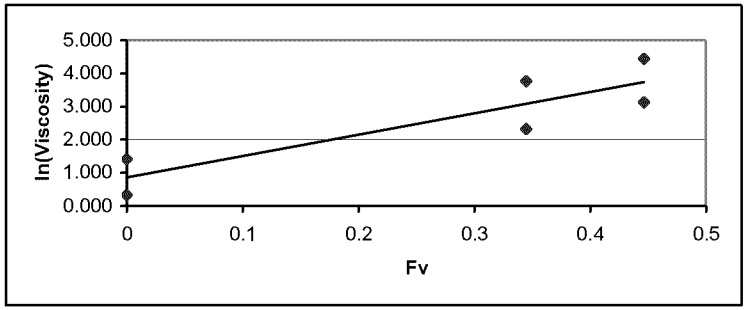
Volume Evaporated (Fv)	Viscosity (cP)	Temperature (°C)	ln(Viscosity)	1/T-1/To (K^{-1})
0	4.1	15.0	1.399	-0.000190564
0	1.4	35.0	0.329	-0.000415685
0.34	42.9	15.0	3.759	-0.000190443
0.34	10.3	35.0	2.332	-0.000415685
0.45	85.1	15.0	4.444	-0.000190443
0.45	22.8	35.0	3.127	-0.000415685

Volume Evaporated (Fv)	Viscosity 1°C (cP)	Viscosity 15°C (cP)
0	4.1	1.4
0.34	42.9	10.3
0.45	85.1	22.8

Viscosity Constants for SL Ross Model

Standard Viscosity Temperature (K)	273.16
Standard Viscosity (cP)	9.03
Viscosity Constant 1	6.49
Viscosity Constant 2 (K^{-1})	5646.99





Pour Point — BP MC252 ENT-052210-178

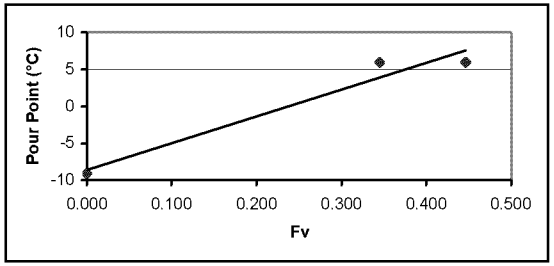
Test Results

Fv	Pour Point Measured (°C)	Pour Point Reported (°C)	
0.000	<-10	-9	less than
0.345	5	6	
0.447	5	6	

slope 36.11327
intercept -8.528878

Pour Point Constants for SLR Spill Model

Initial Pour Point (K)	264.6211
Pour Point Constant	0.136472



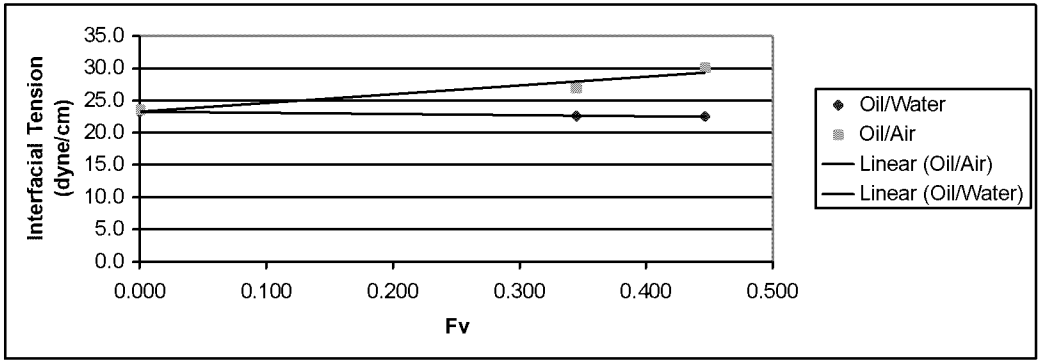
Interfacial Tension — BP MC252 ENT-052210-178

Fv	Interfacial Tension Oil/Water (dyne/cm)	Interfacial Tension Oil/Air (dyne/cm)	Dial Reading Oil/Water (dyne/cm)	Dial Reading Oil/Air (dyne/cm)	Correction Factor (F) Oil/Water	Correction Factor (F) Oil/Air
0.000	23.3	23.5	23.7	26.4	0.985	0.893
0.345	22.6	26.8	22.4	30.0	1.007	0.896
0.447	22.5	30.1	22.1	33.4	1.019	0.900

slope	-1.841	13.365
intercept	23.273	23.300

Interfacial Tension Constants for SL Ross Model

Oil/Water Interfacial Tension (dyne/cm)	23.273
Oil/Water Interfacial Tension Constant	-0.079
Oil/Air Interfacial Tension (dyne/cm)	23.300
Oil/Air Interfacial Tension Constant	0.574



Flash Point — BP MC252 ENT-052210-178

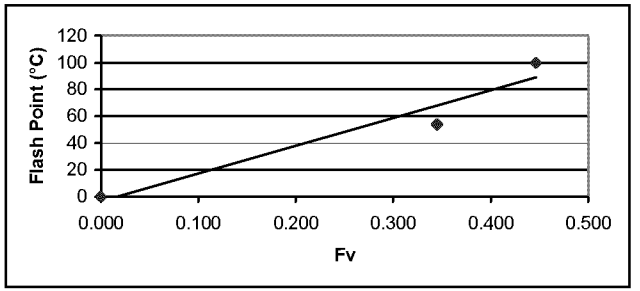
Test Results

Fv	Flash Point (°C)
0.000	<-8
0.345	54
0.447	100

Flash Point Constants for SLR Spill Model

Initial Flash Point (K)	170.989
Flash Point Constant	2.647

slope	452.664693
intercept	170.989269



SL Ross Model — BP MC252 ENT-052210-178

Modeling Constants

Standard Density	838.736	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	128.770	kg/m3
Density Constant 2	0.70499	kg/K.m3
Standard Viscosity	9.03203	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	6.4856	
Viscosity Constant 2	5646.99	K-1
Oil/Water Interfacial Tension	23.2729	dyne/cm
Air/Oil Interfacial Tension	23.3002	dyne/cm
Oil/Water Interfacial Tension Constant	-0.07910	
Air/Oil Interfacial Tension Constant	0.57362	
Initial Pour Point	264.621	K
Pour Point Constant	0.13647	
ASTM Distillation Constant A (slope)	344.133	K
ASTM Distillation Constant B (intercept)	360.927	K
Emulsification Delay	9999999999	
Initial Flash Point	170.989	K
Flash Point Constant	2.64733	
Fv vs. Theta A	12.90000	
Fv vs. Theta B	15.90000	
B.Tg	5471.72	
B.To	5738.73	

Emulsification Formation - Tendency and Stability **BP MC252 ENT-052210-178**

Emulsification Tendency and Stability - 23°C

Test Results		
300ml H2C	22.5	°C
oil @	39.0	°C
mixing don	22.7	°C
settling dor	22.7	°C
Final 24 hr	22.7	°C

two replicates of each oil

		Fresh Oil				Weathered Two Days				Weathered Two Weeks			
	All measurements in mm	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil
	Start	0	10	0	10	0	10	0	10	0	10	0	10
	After first hour mixing	10	0	10	0	11	0	11	0	10	0	10	0
	plus 10 minutes	0	9	0	9	10	0	0	9	0	9	10	0
	plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	After second hour mixing	0	9	0	9	10	0	10	0	10	0	10	0
	plus 10 minutes	0	9	0	9	0	9	10	0	10	0	10	0
	plus 20 minutes	0	9	0	9	0	9	10	0	10	0	10	0
	plus 30 minutes	0	9	0	9	0	9	10	0	0	9	10	0
	After third hour mixing	0	8	0	9	10	0	10	0	10	0	10	0
	plus 10 minutes	0	9	0	9	10	0	10	0	0	9	0	9
	plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	After fourth hour mixing	0	9	0	9	10	0	10	0	10	0	10	0
	plus 10 minutes	0	9	0	9	0	9	0	9	10	0	10	0
	plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
Appearance	Brown solid	0		0		0		0		0		0	
	Brown viscous liquid	X		X		X		X		X		X	
	Black with large droplets	0		0		0		0		0		0	
	Looks like oil	X		X		X		X		X		X	
	plus 24 hour	0	9	0	9	0	9	0	9	0	9	0	9

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content (after 24 hr)	0%	0%	0%

Emulsification Tendency and Stability - 35°C

Test Results

300ml H2C	34.0 °C
oil @	40.0 °C
mixing don	36.0 °C
settling dor	22.0 °C
Final 24 hr	36.0 °C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil
Start	0	0	0	10	0	10	0	10	0	10	0	10
After first hour mixing	0	9	0	9	0	9	0	9	0	9	0	9
plus 10 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
After second hour mixing	0	9	0	9	0	9	0	9	0	9	0	9
plus 10 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
After third hour mixing	0	9	0	9	0	9	0	9	0	9	0	9
plus 10 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
After fourth hour mixing	0	9	0	9	0	9	0	9	0	9	0	9
plus 10 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
Appearance: Brown solid	0		0		0		0		0		0	
Appearance: Brown viscous liquid	0		0		0		0		0		0	
Appearance: Black with large droplets	0		0		0		0		0		0	
Appearance: Looks like oil	X		X		X		X		X		X	
plus 24 hour	0	9	0	9	0	9	0	9	0	9	0	9

note: 0

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content (after 24 hr)	0%	0%	0%

Viscosity Measurements with Brookfield DV-III+ Rheometer

Nominal Test Temperature	15.0				35.0			
	Viscosity	RPM	Spindle	Shear Rate	Viscosity	RPM	Spindle	Shear Rate
Fresh	4.1	120.0	CP-42	461.0	1.4	120.0	CP-42	461.0
2 Day Weathered	42.9	120.0	CP-42	461.0	10.3	120.0	CP-42	461.0
2 Week Weathered	85.1	120.0	CP-42	461.0	22.8	120.0	CP-42	461.0

	Spindle	RPM	% Torque	Viscosity cP	Shear Rate	Temp °C	
Fresh	CP-42	15	0.3	2.6	57.6	14.9	
		30	0.8	3.4	115.0	14.9	
		45	1.5	3.7	173.0	14.9	
		60	1.8	3.8	230.0	14.9	
		90	2.8	4.0	346.0	14.9	
		120	3.8	4.1	461.0	14.9	<===
		180	5.8	4.1	691.0	14.9	
		250	8.1	4.2	960.0	14.9	
2 Day Weathered	CP-42	15	6.8	58.0	57.6	14.9	
		30	12.3	52.5	17.4	14.9	
		45	17.4	49.5	173.0	14.9	
		60	22.3	47.6	230.0	14.9	
		90	31.5	44.8	346.0	14.9	
		120	40.2	42.9	461.0	14.9	<===
		180	57.0	40.5	691.0	14.9	
		250	75.6	38.7	960.0	14.9	
2 Week Weathered	CP-42	15	15.1	128.9	57.6	15.1	
		30	26.9	114.8	115.0	15.1	
		45	37.1	105.5	173.0	15.0	
		60	46.3	98.8	230.0	15.0	
		90	63.7	90.6	346.0	15.0	
		120	79.8	85.1	461.0	15.0	<===
		180	-over-	-over-	691.0	15.1	
Fresh	CP-42	15	0.1	0.9	57.6	35.0	
		30	0.2	0.9	115.0	35.0	
		45	0.5	1.4	173.0	35.0	
		60	0.7	1.5	230.0	35.0	
		90	1.0	1.4	346.0	35.0	
		120	1.3	1.4	461.0	35.0	<===
		180	2.2	1.6	691.0	35.0	
		250	3.0	1.5	960.0	35.0	
2 Day Weathered	CP-42	15	1.2	10.2	57.6	35.0	
		30	2.4	10.2	115.0	35.0	
		45	3.7	10.5	173.0	35.0	
		60	4.9	10.5	230.0	35.0	
		90	7.3	10.4	346.0	35.0	
		120	9.7	10.3	461.0	35.0	<===
		180	14.4	10.2	691.0	35.0	
		250	19.9	10.2	960.0	35.0	
2 Week Weathered	CP-42	15	2.8	23.9	57.6	35.0	
		30	5.5	23.5	115.0	35.0	
		45	8.3	23.6	173.0	35.0	
		60	10.9	23.3	230.0	35.0	
		90	16.1	22.9	346.0	35.0	
		120	21.4	22.8	461.0	35.0	<===
		180	31.6	22.5	691.0	35.0	
		250	43.4	22.2	960.0	35.0	

Appendix 9

A9 Expert Resumes

Mr. Alan A. Allen has over 43 years experience as a technical advisor and field supervisor involving hundreds of oil spills around the world. He has developed specialized strategies and equipment for the prevention, surveillance and control of oil spills; and he has conducted many hundreds of oil spill training courses under arctic, temperate and tropical conditions. Mr. Allen is listed as a technical advisor for emergency response to oil spills in numerous emergency response plans worldwide. A few of the spills on which he has worked include the Santa Barbara blowout (1969), the Mizushima tank failure in Japan (1974), the *Ixtoc* blowout off Mexico (1979), the *Exxon Valdez* grounding (1989), the Gulf of Arabia war-related spills (1991), the *Sea Prince* grounding off South Korea (1995), the Deepwater Horizon blowout in the Gulf of Mexico (2010), and a number of pipeline spills onshore and in wetlands.

Dr. Michel Boufadel is Professor and Chair of the Department of Civil and Environmental Engineering at Temple University, Philadelphia, Pennsylvania, USA. He is a Professional Engineer (Environmental Engineering) in the Commonwealth of Pennsylvania (USA). He is also a Professional Hydrologist (hydrogeology) as accredited by the American Institute of Hydrology (USA). His area of expertise is Environmental Hydrology, where he develops methods to account for changes in the environment due to natural and anthropogenic stressors. He has been the lead researcher on various projects funded by the Oil Spill Research program within the United States Environmental Protection Agency (USEPA). He is currently investigating the lingering of the Exxon Valdez oil (1989) in the beaches of Prince William Sound, where he and his team conducted field studies on various beaches and are exploring remediation technologies for dealing with the 20-year old spill. Dr. Boufadel is author of numerous articles in publications such as NATURE geoscience, Environmental Science and Technology, the Journal of Environmental Engineering, Environmental Geology, Journal of the American Water Resources Association, Journal of Contaminant Hydrology, and Journal of Stochastic Environmental Research and Risk Assessment. The work of Dr. Boufadel has been reported in various media outlets such as the New York Times, the Washington Post, and the BBC World News and numerous international media outlets.

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Mr. Sky Bristol leads a computer and information science research and development effortwith the U.S. Geological Survey (USGS), pursuing a concept called the Integrated Information Environment. Before coming to the USGS in 2004, Sky held various positions with the U.S. Fish and Wildlife Service (USFWS) as a biologist in the Environmental Contaminants Program and an engineer and developer with the Information Resource Management Program. Sky was educated as a wildlife biologist and criminologist at the University of New Mexico, learning computer and information science as a secondary vocation in the course of creating program in these areas for the USFWS and USGS.

Dr. Thomas S. Coolbaugh is a Distinguished Scientific Associate with ExxonMobil Research & Engineering. Dr. Coolbaugh has extensive experience in a variety of research settings as a research scientist and research leader and currently leads ExxonMobil's downstream oil spill response technology group. Dr. Coolbaugh earned a B.A., magna cum laude in Chemistry from Amherst College, and a Ph.D. in Chemistry from the California Institute of Technology with Prof. Robert Grubbs, 2005 Nobel laureate in Chemistry. He also earned an M.S. in Management of Technology from Polytechnic University (New York).

Mr. Per Daling is a Senior Research Scientist at Marine Environmental Technology Dept. at SINTEF. He has 30 years of experience within the field of oil pollution, and has been project manager and scientist responsible for many research programs involving weathering and behaviour of oil at sea, field and laboratory testing of oil spill dispersants and countermeasure techniques and oil spill planning. Mr. Daling has authored or co-authored 40 refereed publications, and more than 150 non-refereed publications, papers and invited presentations. He has a MSc in Organic Analytical Chemistry from Institute of Chemistry, University of Trondheim.

Dr. Merv Fingas was Chief of the Emergencies Science Division of Environment Canada for over 30 years and is currently working privately in Western Canada. His specialities include; spill dynamics and behaviour, spill treating agent studies, remote sensing and detection, and in-situ burning. He has over 750 papers and publications in the field. Dr. Fingas has been an editor of the Journal of Hazardous Materials for 6 years. He has served on two committees on the National Academy of Sciences of the United States on oil spills including the recent 'Oil in the Sea'. He is chairman of several

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ASTM and inter-governmental committees on spill matters. Dr. Fingas has a PhD in environmental physics from McGill University, three masters degrees; chemistry, business and mathematics, all from University of Ottawa.

Dr. Deborah French-McCay is a Principal at Applied Science Associates (ASA, Narragansett, RI, USA), where she specializes in quantitative assessments and modeling of oil and chemical releases: transport and fates, exposure, bioaccumulation of pollutants by biota, toxicity, and effects on populations and aquatic ecosystems. Dr. French McCay was principal investigator in the development of NRDA models, established in the US Federal regulations for simplified assessments under CERCLA and the Oil Pollution Act. She has been principal investigator and primary author of more than one hundred technical reports and papers, and is an internationally recognized expert in oil spill fate and effects modeling. Dr. French-McCay received her bachelor's degree in Zoology from Rutgers in 1974 and her Ph.D. in Biological Oceanography from the University of Rhode Island in 1984

Dr. Ron Goodman attended the University of Saskatchewan and graduated with a Bachelor of Arts in Science with specialization in physics. He undertook graduate studies at McMaster University in Hamilton and obtained a PhD. in nuclear physics in 1964. Innovative Ventures Ltd. (IVL) was started by Dr. Goodman in 1971 to consult on Arctic Environmental issues. Joining Imperial Oil in 1978, he developed the only industry-based oil-spill research program in Canada. He served as the manager of surveillance and tracking for the Exxon Valdez response during 1989. Dr. Goodman retired from Imperial Oil in 2000, and reactivated Innovative Ventures Ltd. IVL has been involved in the JESSICA spill in the Galapagos Islands and the rail spill at Wabamun, Alberta Canada. He has been in the oil-spill technology business for thirty-fiveyears, specializing in remote sensing, arctic oil-spill response and oil-spill models. Dr. Goodman has served on a number of national and international committees including IMO/ MEPC and ASTM. He has published over 200 papers.

Dr. Ali Khelifa is Head of the Spill Modelling Laboratory at the Emergencies Science and Technology Section of Environment Canada. He received his Master in 1992 and PhD in 1998 in Environmental Hydraulics from Laval University in Québec in Canada. Dr. Khelifa has conducted extensive research on transport and fate of pollutants spilled in the environment using computer and laboratory modelling for the last 20 years. The last nine years of his

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research were devoted to developing quantitative understanding of the fate of physically and chemically dispersed oils in the aquatic environment. He has authored over a hundred of scientific papers and technical reports and his extensive contribution related to oil dispersion and oil-sediment interaction is internationally recognized.

Dr. Robert Jones is a Chemist in NOAA's Office of Response and Restoration, Emergency Response Division, He is extensively involved in the development of computer models used to predict the fate and transport of chemicals in the environment and is a member of the spill response team.
Dr. Jones received his B.S. in Chemistry from Xavier University, and his Ph.D. in Physical Chemistry from Indiana University. After graduation he worked as a research associate at the National Institute of Standards and Technology in Washington D.C. Prior to joining NOAA in 1988, Dr. Jones was an assistant professor in the chemistry department at Western Washington University.

Mr. Patrick Lambert is a chemist with twenty years experience in the environmental field of chemical and oil spill research and development, and twenty-three years of laboratory experience in both the private and public sectors. He is Head of Field Work and Response, Emergencies Science and Technology Section, Environment Canada. He has was part of the science team in numerous oil spill projects such as the Newfoundland Offshore Burn Experiment and has extensive operational experience with contaminated sites, environmental emergency response, contaminated site and counter-terrorism related.

Dr. Kenneth Lee is a senior research scientist and Director of the Centre for Offshore Oil and Gas Environmental Research, Fisheries and Oceans Canada. The centre is responsible for the coordination of a national strategic program in environmental and oceanographic research relating to oil and gas activities. Dr. Lee is the recipient of Fisheries and Oceans Canada's Prix d'Excellence (Science) for his research contributions on environmental issues associated with offshore oil and gas activities; and the Government of Canada's Federal Partners on Technology Transfer (FPTT) Leadership Award for the development of oil spill countermeasures. He currently serves as a Committee Member of NATO's Science for Peace and Security Program.

Dr. Ira Leifer has a Ph.D. in bubble-mediated air-sea interaction from the

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Georgia Institute of Technology, Earth and Atmospheric Sciences Department. Over the last decade, he has been a leader in research related to natural seepage, including numerical bubble modeling, video observations of bubbles including oily bubbles, multibeam sonar bubble plume observations, remote sensing of atmospheric methane and of oil slicks by imaging spectroscopy, weathering of oil slicks from natural seepage, and in situ measurements of light n-alkanes in the air and water. Research sites have spanned the Gulf of Mexico, to Santa Barbara Channel, to Norwegian and Russian Arctic waters, from submarines to research vessels, to airplanes.

Dr. William (Bill) J. Lehr is Senior Scientist at the Office of Response and Restoration of the National Oceanic and Atmospheric Administration (NOAA). He was previously Spill Response Group Leader for the same organization. Dr. Lehr has also served as an adjunct professor for the World Maritime University and oil spill consultant for UNESCO. Dr. Lehr is a world-recognized expert in the field of hazardous chemical spill modeling and remote sensing of oil spills. He has served as guest editor for the journal, Spill Science and Technology and the Journal of Hazardous Materials and as Co-Chair of the International Oil Weathering Committee. NOAA and the United States Coast Guard have awarded him several medals for his spill response efforts at major spill incidents of national or international significance. He has numerous publications in the field. Dr. Lehr holds a Ph.D. in Physics from Washington State University.

Dr. Alan Mearns is Senior Staff Scientist, Ecology, with NOAA's Emergency Response Division (ERD), Office of Response and Restoration. Dr. Mearns holds a PhD in Fisheries from the University of Washington, and Master of Science and Bachelor of Science degrees from California State University at Long Beach. He is past leader of the Biology Division of the Southern California Coastal Water Research Project and served as Ecologist for the NOAA Puget Sound MESA Program. He has provided support to the US Coast Guard and the NOAA Scientific Support Coordinators (SSC's) on numerous oil spills throughout the US and internationally. He supports numerous oil spill science training programs, is a member of several technical advisory committees in Alaska and has recently started a third decade of annual shoreline monitoring in Prince William Sound. He has received various awards from California State University and NOAA.

Dr. Edward B. Overton is Professor Emeritus in the Department of Environmental Sciences, School of Coast and the Environment at LSU He received his B.S.(1965) and Ph.D.(1970) degrees from the University of Alabama, Tuscaloosa. His research interests include understanding the fates and distributions of hydrocarbons following an oil spill, the environmental chemistry of hazardous chemicals, and the detection of environmental pollutants at the site of sample collection. Dr. Overton held the Clairborne Chair in Environmental Toxicology and Air Quality prior to his retirement, and was honored as an LSU Distinguished Faculty in 2008, and was the 1996 Louisiana Technologist of the Year.

Dr. James Payne has been involved in oil-spill research for over 36 years, including work at the Woods Hole Oceanographic Institution, the University of California Bodega Marine Laboratory, Science Applications International Corporation, and the last 12 years as President of Payne Environmental Consultants, Incorporated. He has conducted oil fate and behavior research and studies on oil-spill dispersants since 1979, and he has served on four National Academy of Sciences/National Research Council Committees dealing with petroleum in the marine environment. Most recently he served on the NRC Committee on Understanding Oil Spill Dispersants.

Dr. Antonio Possolo is a statistician and Chief of the Statistical Engineering Division at the National Institute of Standards and Technology (NIST, U.S. Dept. of Commerce). He has been a statistician at General Electric and at Boeing, and has taught at the University of Washington in Seattle and at Princeton University. His areas of specialty include statistical modeling of spatio-temporal data and uncertainty analysis. Dr. Possolo holds a Ph.D in Statistics from Yale University.

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Appendix 10

A10 Reviewer Comments and Replies

Sixteen reviewers (see Table 1) with diverse background were selected by the Coastal Response Research Center to review all or part of the report. Fourteen responded within the allotted time frame. We would like to thank all the reviewers for their efforts under conditions that required expeditious action on their part. While the list of names is provided in this Appendix, individual comments were provided to the team anonymously. One should not, for example, identify Reviewer 1 with the first name in Table 1. Page numbers refer to the unedited draft report and may not correspond to those in the final report.

First	Last	Affiliation
Eric	Adams	Massachusetts Institute of Technology (MIT) Dept. of Mechanical Engineering
Kathryn	Burns	Austrailian Institute of Marine Sciences, Organic Geochemist, Water Quality Team
Robert	Chen	University of Massachusetts Boston, Environmental Earth and Oceans Sciences
Kurt	Hansen	U.S. Coast Guard, Research & Development Center
Terry	Hazen	Lawrence Berkeley National Laboratory - Ecology Dept.
Wolfgang	Konkel	ExxonMobil
Buzz	Martin	Texas General Land Office - Oil Spill Prevention & Response
Joseph	Mullin	Bureau of Ocean Energy Management, Regulation & Enforcement (BOEMRE)
Michael	O'Brien	Internation Tanker Owners Pollution Federation Ltd. (ITOPF)
Rob	Swift	University of New Hampshire, Mechanical Engineering/Ocean Engineering
Terry	Wade	Texas A & M
Xiaomong	Wang	Florida State University, Dept. of Mathematics
Tom	Weber	Center for Coastal & Ocean Mapping
Steven	Werely	Purdue University

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Reviewers' comments are in italics and replies are in plain text.

Reviewer 1:

This section focuses on estimating the amount of oil recovered by surface skimmers. The total amount of oil and water mixture held in tanks on the skimmers is measurable, but the percent that is actually oil, referred to as the recovery efficiency (RE), is needed to calculate the amount of oil collected. The report states that a RE of 33% was used based on "prior studies" (no reference). To assess whether this is a reasonable value, the types of skimmers employed would have to be taken into account. Oliophilic mechanisms such as disk and drum skimmers can have RE's of 90% or better (see, for example, Schulze, 1998). Suction or weir skimmers, on the other hand, typically have RE values of a few percent unless the slick is unnaturally thick and the surface is without waves. Thus assuming an average RE for the skimming fleet should be based on the distribution of skimmer types (as well, of course, sea state and slick thickness).

It should also be pointed out that determining the water content in recovered oil and water mixtures is a standard laboratory analysis done at the OHMSETT oil spill test facility. It would seem that their protocol could be adapted to either on-board determination of RE or representative samples could be transported to a shore laboratory for RE analysis.

Skimmers were the most commonly-used mechanical devices used to remove oil from the Gulf water surface. These skimmers varied greatly in size, application, and capacity, as well as in recovery efficiency and water pickup. (Schulze, 1998; Schwartz, 1979). In the particular case of the Gulf oil spill the major issue is the amount of water recovered. A skimmer's performance is affected by a number of factors including the thickness of the oil being recovered, the extent of weathering and emulsification of the oil, the presence of debris, and weather conditions at the time of recovery operations. A skimmer's overall performance is usually determined by a combination of its recovery rate and the percentage of oil recovered. The maximum amount of oil that a skimmer could recover is called the 'Nameplate Recovery Rate' and is typically provided by the manufacturer of a skimmer (Fingas, 2010; Meyer et al, 2009). A similar definition is the 'Effective Daily Recovery Capacity', which is the amount that a skimmer could recover in daylight hours under ideal conditions. The recovery rate is the volume of oil recovered under specific conditions. It is measured as volume per unit of time, e.g., m^3/h, and is usually given as a range. If a skimmer takes in a lot of water, it is detrimental to the overall efficiency of an oil spill recovery operation. The

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summary results of performance testing on various types of skimmers are given in Table 1 (Schulze, 1998;Fingas, 2010).

Table 2 shows the three most important values of skimmer performance, ORR, TE, and RE. This is a sample table showing a fraction of the skimmers tests reported in the reference (Fingas, 2010). The Oil Recovery Rate(ORR) is the quantitative rate in volume per unit time, usually m^3/hour and is corrected for water recovery. The throughput efficiency (TE) is applicable only to advancing skimmers. The throughput efficiency is the percentage of oil presented to a skimmer versus that recovered, in percent. The recovery efficiency (RE) is the percent of oil recovered out of the total oil and water recovered. For the Gulf recovery effort, the RE is the most important factor. We know the total liquids recovered, but we do not know exactly how much oil was in this liquid and therefore must estimate the actual oil recovered. Table 2 shows that the average RE of the skimmers in wave conditions is 33%.

The emulsion recovered typically contained 30- 60% water (Appendix 6). Using 40% as an average water fraction, the typical amount of oil in the recovered mixture is 0.6 X 0.33 or 0.20 (20%). The amount of liquid recovered was 735,000 barrels and thus the amount of oil recovered was about 20% of this or 147,000 barrels.

1 Schulze, R., *Oil Spill Response Performance Review of Skimmers*, ASTM Manual Series, ASTM, 1998

2 Schwartz, S.H., Performance Tests of Four Selected Oil Spill Skimmers, *AMOP*, 493, 1979

3 Fingas, M.F., Weather Effects on Oil Spill Countermeasures, Chapter 13 in *Oil Spill Science and Technology*, p. 339-426,2010

4 Meyer P., W. Schmidt, J.-E. Delgado, D. DeVitis, S. Potter, E. Haugstad and M. Crickard, Application of the American Society of Testing and Materials' (ASTM) New Skimmer Test Protocol, *AMOP*, 323, 2009

5 SINTEF, Laboratory study of the dispersibility of DWH surface emulsion, 2010

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Table 1 Performance of Typical Skimmers

	Recovery Rate (m^3/hr) for given oil type*			Percent
Skimmer Type	**Light Crude**	**Heavy Crude**	**Bunker C**	**Oil****
Oleophilic Skimmers				
small disc	0.2 to 2			80 to 95
large disc	10 to 20	10 to 50		80 to 95
brush	0.5 to 20	0.5 to 2	0.5 to 2	80 to 95
large drum	10 to 30			80 to 95
small drum	0.5 to 5			80 to 95
large belt	1 to 20	3 to 20	3 to 10	75 to 95
inverted belt	10 to 30			85 to 95
rope	2 to 20	2 to 10		
Weir Skimmers				
small weir	0.5 to 5	2 to 20		20 to 80
large weir	30 to 100	5 to 10	3 to 5	50 to 90
advancing weir	5 to 30	5 to 25		30 to 70
Elevating Skimmers				
paddle conveyer	1 to 10	1 to 20	1 to 5	10 to 40
Submersion Skimmers				
large	1 to 80	1 to 20		70 to 95
Suction Skimmers				
small	0.3 to 2			3 to 10
large trawl unit	2 to 40			20 to 90
large vacuum unit	3 to 20	3 to 10		10 to 80
Vortex/Centrifugal Skimmers				
centrifugal unit	0.2 to 10			2 to 20

* Recovery rate depends very much on the thickness of the oil, type of oil, sea state, and many other factors

** This is the percentage of oil in the recovered product or recovery rate. The higher the value, the less the amount of water and thus the better the skimmers' performance

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Table 2 Skimmer Performance (Sample cases)*

Skimmer	Year of Test	Oil Type	Oil Viscosity mPa. S	Slick Thick. mm	#of Tests	Speed m/s	Wave height m	Wave Conditions	ORR m^3/h	TE %	RE %
Harbour/small skimmers											
Skimming Barrier	1977		200	120	3	0.25	calm		58.2		56
Skimming Barrier	1977		200	120	5	0.25	0.3	harbour chop	47.4		34.5
Skimming Barrier	1977		200	120	4	0.5	0.3	regular	71.7		48.9
Sirene Skimming Barrier	1979		545	3	1	0.75	calm		15.8	11	26
Sirene Skimming Barrier	1979		545	3.2	1	0.38	0.6	harbour chop	18.6	99	31
Sirene Skimming Barrier	1979		545	3.2	1	0.38	0.5	regular	16.4	99	27
Lori Brush Skimmer	1979	med. oil	600	ns	1	1.5	calm		0.96		78
Lori Brush Skimmer	1979	med. oil	600	ns	1	0.75	0.16	regular	0.35		81
Disc skim. - flat -CCG tests	1993	lt. crude	5 to 50	10	1	0	0.4	regular			65
Disc skim. - flat -CCG tests	1993	lt. crude	5 to 50	10	1	0	0.8	harbour chop			48
Disc skim. - flat -CCG tests	1993	lt. crude	5 to 50	25	1	0	calm				96
Disc skim. -T-disk -CCG tests	1993	lt. crude	5 to 50	10	1	0	0.4	regular			46
Disc skim. -T-disk -CCG tests	1993	lt. crude	5 to 50	10	1	0	0.8	harbour chop			24
Paddle skimmer	1977	heav. oil	1900	26	1	0	calm		9.4	91	84
Paddle skimmer	1977	heav. oil	1900	26	1	0	0.2	regular	4.8	70	18
Rope Mop towed single	1978	med. oil	793	5	1	1.3	0.6	harbour chop	5.7		49
Rope Mop towed single	1978	med. oil	793	5	1	1.5	0.6	harbour chop	5		46
Oil Mop ZRV	1976	lt. crude	65	4 ave	1	1.25	calm		7	36	23
Oil Mop ZRV	1976	lt. crude	65	4 ave	1	1.5	0.6	harbour chop	4.8	21	10
Marco Belt skimmer	1976	heav. oil	837	8 to 11	6	0.5	calm		11.5	85	57
Marco Belt skimmer	1976	heav. oil	837	8 to 11	4	1.5	calm	harbour chop	20.6	62	76
DIP 2001	1973	Alberta crude	8	.7 ave	1	1.3	calm		2.7	88	30
DIP 2001	1975	Arab crude	24	0.5	1	1	calm		0.9	77	94
DIP 2001	1975	Arab crude	24	1	1	0.5	0.4	natural	0.9	81	95
Stationary skim. - Manta Ray	1975	DOP	79	20	6		calm		20.1		27
Stationary skim. - Manta Ray	1975	DOP	79	20	1		0.6	harbour chop	15.2		22

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Stationary skim. - Skim pak	1980	medium	200	7	3		calm		2.5		8
Stationary skim. - Skim pak	1980	medium	200	7	1		0.26	regular	2		7
Destroil weir skimmer	1979	heavy	810	5	5		calm		16.2		69
Destroil weir skimmer	1979	heavy	810	5	2		0.47	harbour chop	11.5		59
GT-185	1988	Bunker c	11700		1		0.4	regular	15		50
GT-185	1988	Terra Nova	100-600		1		calm		30		100
Walosep	1988	Bunker c	>100k		1		calm		38		2
Walosep	1988	Bunker c	>100k		1		0.4	regular	10		2
Veegarm towed weir	1980			1	1	0.25	calm		11	100	8
Veegarm towed weir	1980				1	0.25	1.9	regular	10	40	5
Veegarm towed weir	1980	light	9	2	1	0.25	0.19	harbour chop	5	60	5
Averages (taken from whole Table)					476		mixed wave conditions		15	58	**44**
										under test conditions	
* See reference 3 for the full table								under typical wave conditions			**33**

Reviewer 2:

Page 11, paragraph 2: This paragraph is not based on data and only media reports from some dramatized news conferences. I would not include this speculation.

Paragraph is modified to note that extensive DHS oil on the bottom has not been confirmed in the ongoing sampling programs.

Page 39, paragraph 1:

The factors affecting biodegradation rates are as follows:

1. Type of oil

2. limiting nutrients, P, N, O, and in the ocean Fe

3. Concentration of the oil

4. how weathered the oil is

5. oil droplet size

6. adaption of microbial community to long-term episodic events like natural seeps.

The purpose of the report is to describe the oil budget calculator, not provide an in-depth study of long-term weathering processes. Therefore, we feel it would be inappropriate to expand on the admittedly brief discussion of biodegradation.

Reviewer 3:

P 7, line 2 remove: if slightly dull
P 8, Item 4, Line 2-3: replace bottom with lower water column
P 9, Line 3-4, rephrase: Hence, this oil is assumed to have already lost all oil that might evaporate.
P 10, Para 3, Line 4: Formed an emulsion when surfacing.... on
P 11, Para 1 Line 6, formed emulsion on the water surface within Km's of wellhead. This needs to be consistent.
P11, Para 1, last line: this sentence is unclear

Revisions made for the above.

P 11, Para 2, Line 3: Basing anything here on News Reports would seem to be a dramatic flaw. The news reports were abysmally incorrect with respect to all aspects of the science of the DWH spill.

Paragraph is modified to note that the claim of extensive DWH oil on the bottom has not been confirmed in the ongoing sampling programs.

P 12, Para 2, Line 6: Can "44% oil percentage" be replaced with a unitless GOR (Gas Oil Ratio) for accuracy and understanding here and throughout the document? (e.g. P14, para 1, Line13)

We have kept the units of the cited report for consistency.

P 14, Para 1, Line 13: Should high not be low?
P 14, Para 2, Line 9: Replace globs with accumulations of droplets or particles

Section text revised

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P 15, Para 2, Line 1: Replace old saying with proverb.
P 15, Para 2, Line 3: Replace unimportant with less important
P 17, Para 2, Line 5: Is this naturally or chemically dispersed oil?
P 19, Para3, Last line: to the wind speed and temperature
P 20, Para 2 , Line 4: from the sea

P 22, Figure 8 and all additional similar figures: Please make a table, these are indecipherable

Figure 8 and similar figures have been removed

P 22, Para 4, Line 5: I am not familiar with cubic seconds. My utilization of horizontal and vertical spreading rates have been as m2/sec.Check here and following

The unit of m^2/sec^3 relates to the energy dissipation rate and not to spreading. It is equivalent to energy per unit mass per unit time.

P 27, Last line: remove =
P 28, Para 1, Line 4: Less oil, not more oil
P 28, Figure 12, Move under 9a Header.
P 29, Section 9a, Location of tables and figures is awkward and needs to be revised.

Revisions made

P 30, Table 2 Concentration as what units, also please provide detail regarding these samples, e.g. depth sampled, time after dispersants applied, measured how, etc. If this is a scattershot of nonspecific sampling, please say so.

New table 2 Heading inserted

P 31, Last line: for
P 36, Para 2, Line 2: to
P 36, Para 3, Line 8: What evidence is there that oil settled to bottom in offshore areas?

The text was revised to say some of the oil has combined with sediment in the water column and settled to the bottom in the nearshore or, perhaps, offshore areas.

P 39, Does this paper not deserve conclusions? We've spent 39 pages getting to this point, provide the DWH Mass Balance.

New mass balance figures included in Section 14

Reviewer 4:

Generating a modeling tool such as the Oil Budget Calculator is no simple task, not least because there is a paucity of information – both theoretical and empirical - on which to base it. The need for better information on which to base the model is apparent throughout much of the document, with a few exceptions (e.g., section 6 on Evaporation). Still, assembling the Calculator seems to have been a worthwhile exercise for two reasons: 1) it provides a framework for assembling actionable data; 2) it highlights areas where the information gaps are the largest (e.g., direct observations of subsea dispersant effectiveness). I would encourage the further development of this tool both through efforts to better model the processes (e.g., chemical and natural subsurface dispersion) and by adding more capability to the model. If the latter could be done in such a way that the model could adaptively tune itself to new scenarios using field data (see comment 4. below), it could become very powerful.

There are several technical issues which should be addressed. These are listed below. In addition, the writing of this document should be tightened up considerably. There are better editors than myself for doing this, so I won't provide an exhaustive list of corrections, but will say that there are many ambiguous comments or phrases (e.g., a "good" fraction; "very" rapid;) and several unnecessary comments and colloquialisms (e.g., filling out an ICS209 is "slightly dull"; "the old saying that oil and water do not mix…'). Physical interpretations and definitions for the rate constants do not belong in an appendix – this makes following the body of the text too onerous. The figures that take the form of Figure 8 are totally non-intuitive – this information should be provided in a much clearer way. Clearly, this document is in draft form – a thorough polishing and reworking is warranted.

Corrections to the language have been implemented. Unfortunately, multiple authors and strict publication deadlines prohibit extensive wordsmithing or style uniformity. Figure 8 and similar figures have been removed.

1. *The amount of subsurface dispersed oil is assumed to be high (seemingly, greater than 25% of the oil based on the combination of rate constants), although the data presented here do not seem to either support or refute that assessment. If the goal is to bring a conservative*

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assessment (from the perspective of not underestimating the response resources required, such as skimmers, burners, surface dispersant, amount of subsurface chemical dispersant – the "lesser of two evils" - to be used,etc.) to the Unified Command, as was stated, than I would have to conclude that the analysis of the dispersed oil at the bottom was incorrect (too high). I recognize that there have been many observations of subsurface oil, and would not be surprised to learn that enough oil made it into the subsurface to have a large and long term impact (in fact, I would be more surprised to learn the opposite). But given that 4.9 million barrels were released, even this finding would not suggest that a large fraction of the oil was dispersed into the subsurface . That is, it is conceivable that even 5% of 4.9 million barrels of oil could have a large, long term impact (clearly, better methods for empirically determining the amount of subsurface oil are needed). Specific comments along the lines of this theme follow.

I do not see how the LISST data support the hypothesis that "much" of the oil released was dispersed into the water column, as stated on page 22, or that they "suggest the high effectiveness of the chemical dispersants…from subsurface application" as stated in appendix 6. Assuming that equations (13) and (14) are correct (and they need to be better supported than a personal communication with Lasheras), it does seem reasonable to expect that the only way to generate these small droplets is through the use of chemical dispersant (otherwise, it would seem that the smallest characteristic size of a droplet would be about 1 mm). However, the LISST measurements only provide estimates of these very small droplets – they don't appear to say anything about the relative quantity of the small droplets compared to larger droplets. Based on these measurements, it appears just as likely that the application of subsea dispersant was ineffective, and that only a small fraction of chemically dispersed bubbles was created, some of which eventually had the eventual fate of being sampled. From the perspective of figuring out how much surface oil can be responded to, it would seem more conservative (and just as likely based on these measurements) to say that only a small amount of oil was dispersed and that the chemical dispersant was ineffective.

Equation 13 is supported by the two preceding references to peer reviewed publications. Equation 14 has been proposed by Hinze (1955). It gives an estimate of the characteristic droplet size in a dispersion process based on the assumption that the dynamic pressure forces due to turbulent fluctuations control droplet formation due to breakup. It is provided in this report for background only (it is not used in the Calculator). The natural dispersion model itself is a variation of the Delvigne model, commonly used to estimate natural dispersion.

The LISST data found oil droplets in the locations consistent with dispersed

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oil and subsurface current patterns. The lack of such droplets would be a strong indicator of little dispersion. Therefore, the Report states that these findings lend support to the hypothesis of significant dispersion, while citing other findings that do not support this hypothesis. As noted in the report, the experts were unable to reach a consensus on the amount of dispersion and a compromise value was used for the Calculator. This is obviously an area that requires further research.

Hinze, J.O., (1955). Fundamentals of the hydrodynamic mechanism of splitting in dispersion processes. AIChE Journal, Vol. 8 (4), 289-295.

Due to the limitations of available technologies in droplet size measurement (for example, current available LISST can only go as deep as 300 m, LOPC has detection limit of > 100 um and resolution of 10^6 counts/m^3), the present LISST method has been used to monitor small particles generated in the water column by retrieving water column samples using Niskin bottles and surface bucket sampler. It is unfortunately that the current method did not measure the full spectrum of droplet size distributions in subsurface, and in particular, there were large uncertainties and measurement gaps for large particles. However, it is not true to say that "they don't appear to say anything about the relative quantity of the small droplets compared to larger droplets". As a matter of fact, the data presented in Figures A7-5~8 are the fractions of small particles (d < 68.8um) to the total particles in an expanded range between 2.5 and 157 um. Similarly, Figures A7-9~12 present cumulative particle size fractions between 2.5 and 157 um, too. These data all indicate that the vast majority of the measured particles are within the defined small particle frame (i.e., d < 68.8 um), and therefore support our conclusion that dispersion of oil was effective at subsurface. However, we do emphasize there are tremendous amount of unknowns in terms of efficacy evaluation of the subsurface dispersant injection, and the knowledge gaps in this regard must be bridged in the forthcoming research activities now that the importance of this issue has come into light.

Are Payne's reports of oil droplets at depths greater than 2 km (page 22) supported by any other measurements (e.g., CDOM fluorometer, hydrocarbon fluorometer, DO, etc.)? What is the mechanism by which the oil droplets sank through the water column into a stable deeper plume? Most importantly, how can these type of observations be translated into the stated assessment that there was a "large amount of dispersion"? That is, why couldn't Payne have been observing the result of a small amount of dispersion? If Payne had a way to extrapolate a few observations to a general behavior, it should be clearly stated here. Otherwise, the conservative approach (from the perspective of figuring out how much surface oil can be responded to) would be to assume that Payne's observations support a small amount of dispersion.

The report of dispersed oil droplets between 1000 and 1200 m was based on: 1) visual (video and digital photographic) observations of droplets (0.5-3 mm) in the water column and impinging on a down-ward facing grid mounted on the ROV; 2) video and digital recording of said droplets with white (tungsten) and "black light" illumination: 3) CDOM fluorometry; 4) DO anomalies or "sags" in the water-column within that depth range; and 5) GC/MS measurements of PAH in dissolved (filtered) seawater samples and SHC plus PAH associated with particulate-phase components (trapped on 0.7 um glass fiber filters) from finite water samples collected at these depths. In addition, the dispersed droplet concentrations were high enough to be observed by sonar (670 kHz) on the ROV, and we photographed droplets of different sizes (between 100 and 500 micrometers) at different depths using the Holographic Camera provided by Cabell Davis of WHOI.

These plumes were observed consistently within this depth range on two cruises on the M/V Jack Fitz in the May-June time-frame out to 4 km from the well head, and other vessels observed similar DO anomalies and fluorometer signals elsewhere at distances up to 18 km from the well head during that period. These other vessels did not have the ROV and video/digital photography to document the droplet sizes, but the chemistry data on whole water samples collected between 1000 and 1300 m yielded similar PAH and SHC patterns documenting the presence of dissolved components and whole oil droplets. More recently (in August and September 2010), PAH components associated with finite oil droplets in this depth range have been measured by UV/fluorescence using AquaTracka fluorometers and confirmed by GC/MS well beyond 200 km from the well head. Measurements above and below these depths do not show the oil signal. In more recent cruises, the Aqua Tracks signals also corresponded with DO anomalies at the same depth.

With regard to the mechanism of how these droplets reached this depth, it is important to stress that we are not implying that they were dispersed at the surface and somehow «sank» or were entrained to 1000 m. Rather, we believe that the physically (and chemically) dispersed oil released from the well head at depth broke up to yield finite droplets that advected away from the well as they slowly rose toward the surface, and that those droplets removed from the rapidly rising gas plume and within a particular size range became entrained within a density or stratification layer at this depth. Particle size measurements clearly indicated that the larger droplets were still slowly rising (between 1300 and 1000 m), and that smaller droplets were left behind over time. This entrainment of smaller oil droplets in the 0.2 – 3 mm size range follows the expected behavior described by Socolofsky and Adams (2002, 2003), where oil is detrained (along with seawater) from the plume as it ascends through a density-stratified ocean and passes a level of neutral buoyancy. Such detrainment events are clearly evident in laboratory mea-

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surements of gas and water plumes and in field experiments of oil and gas mixtures released at depth (Masutani and Adams 2000; Adams and Socolofsky 2005), and evidence for such detrained oil droplets was observed in subsurface plumes between 1300 and 1000 m from numerous vessels and over 4-5 months.

Masutani, S., and E. Adams. 2000. Experimental study of multiphase plumes with application to deep ocean oil spills. Final report to U.S. Dept of Interior, Minerals Management Service. Contract No. 1435-01-98-CT-30946. http://www.mms.gov/tarprojects/377.htm.

Socolofsky, S. and E. Adams. 2002. Multiphase plumes in uniform and stratified crossflow. J. Hydr. Res., 40: 661-672.

Socolofsky, S. and E. Adams. 2003. Liquid volume fluxes in stratified multiphase plumes. J. Hydr. Engrg. 129: 906-914.

Adams, E.E. and S. A. Socolofsky. 2005. Review of Deep Oil Spill Modeling Activity Supported by the Deep Spill JIP and Offshore Operator's Committee. Final Report.

It seems odd, and not very conservative, to assume that 1 gallon of dispersant generates 20 gallons of dispersed oil at the surface and 90 gallons of dispersed oil subsurface. Multiplying these values by k3 and k2 respectively, it appears that 1 gallon of dispersant would generate 2 gallons of dispersed surface oil, or 40 gallons of dispersed subsurface oil if deployed at depth. This disparity should be clearly addressed.

The expected subsurface DOR is 40 and the expected surface DOR is 10. The reason for the disparity is explained in sections 9a and 9b. In many respects, the subsurface operations were ideal dispersant applications. The oil was fresh and in direct contact with the dispersant. There was significant turbulent energy. This was not always the case for the surface operations.

The report states on page 30 that the best (most) direct evidence collected during the spill suggested that 6-7% of the oil – in a plume where models expected the subsurface plume to be – was dispersed near the bottom (apparently negating the remote sensing estimate on page 13). Presumably this was both chemically and naturally dispersed. So why not use 6-7% rather than the approximately 5 times this amount suggested by the rate constants?

The Camilli study concluded that 6-7% of the BTEX leaking from the well was required to support the plume that they found. This defines a lower bound to the dispersed oil, not an upper bound since one cannot presume

that they detected all of the subsurface oil. The Camilli study is not in contradiction to the AVIRIS findings since the latter looked at the cumulative amount of oil that both made it to the surface and did not evaporate. Also, it must be noted that the remote sensing estimate has a high degree of uncertainty.

Even if the chemical dispersant was effective, just because a droplet is small doesn't necessarily mean it takes a long time to get to the surface. If the volume fraction of the dropletsis high enough, there can be a net transport upward that is faster than the individual rise speed of the droplets. If bubbles are added to the mix – and they apparently constitute 56% of the mix as stated on page 12 of this report – the upward net transport can be even greater (this type of group behavior can be demonstrated in the extreme by going to a bar and ordering a pint of Guiness and watching the individually buoyant bubbles flow downward). A conservative assessment of the amount of surfacing oil should either explain why this net transport isn't happening, or conversely it should take it into account.

The reviewer is correct. In the dynamic zone above the riser (the first tens of meters or more, depending on the intensity of jet), the vertical transport of small droplets is mostly controlled by the jet flow and its bouncy, and later on by the flow induced by the movement of large oil droplets and gas bubbles rising to surface. Above this dynamic zone there is abundant evidence that gas bubbles will separate from the plume of oil-gas mixture (explained in Section 3) and the small droplets will continue to rise to the surface according to their terminal rising velocity controlled by their size and effective density. In deep waters, the last process is dominant (because of the long distance the droplets have to travel to reach the sea surface), while in relatively shallow water (water depth of few tens of meters or possibly hundred meters) the first process (induced upward transport) becomes dominant and cannot be neglected in accessing oil movement to the sea surface. The depth at the DWH oil spill is 1.5 km, which is large enough to assume that oil droplets will travel the major part of this depth according to their terminal rising velocity as explained above and shown from previous well blowout incidents, field experiences and modeling (Johansen, 2000, 2003; Johansen et al., 2001, 2010; Chen and Yapa, 2007; Yapa and Chen, 2004)."

Chen F., and Yapa, P.D., (2004). Estimating the Oil Droplet Size Distributions in Deepwater Oil Spills. Journal of Hydraulic Engineering, 133(2), pp. 197-207.

Johansen, O., (2003). Development and verification of deep-water blowout models. Marine Pollution Bulletin. 47, pp. 360–368.

Johansen, O., (2000). DeepBlow - a Lagrangian Plume Model for Deep Water Blowouts. Spill Science & Technology Bulletin, 6 (2), pp. 103-111.

Johansen, O., Rye, H., and Durgut I., (2010). Generalized integral plume model for simulation of marine discharges. In AMOP proceeedings, Environment Canada, Ottawa, 1, pp. 863-878.
Johansen, O., H. Rye, A.G. Melbye, H.V. Jensen, B.Serigstad, T. Knutsen (2001). Deep Spill Jip Experimental Discharges of Gas and Oil at Helland Hansen, Technical Report STF66 F01082, 159p.
Yapa, P.D., and Chen F., (2004). Behavior of Oil and Gas from Deepwater Blowouts. Journal of Hydraulic Engineering, 130(6), pp. 540-553

The report (p13) assumes that gas associated with the plume dissolved before reaching the surface. Without evidence to the contrary, I find it hard to believe that the surface flow around the bubble would push enough oil on a bubble surface to the downstream hemisphere so that the gas transfer rate out of the bubble or methane-seawater contact was not appreciably changed. Although the oil budget does not keep track of gas, adsorption of oil onto gas bubbles is a mechanism by which the oil can surface more quickly and by which smaller droplets can reach the surface. Therefore, it is not sufficient (or conservative, from the calculator perspective) to simply neglect the gas, especially when it is estimated to be more than 50% of the discharge volume (page 12).

Although the mechanism suggested by the reviewer is perhaps possible and worthy of further study, it does not reflect existing understanding of subsurface well blowouts, as discussed in the references cited. As stated on page 8, the Calculator is not a research tool.

The model inherently appears to assume that the oil that is skimmed, naturally dispersed, or evaporated at the surface is negligible compared to the oil that is burned (see calculation of W). This may have been accurate for DWH (I couldn't say), but it doesn't seem to be appropriate to assume that this will always be correct.

This is not correct. The model does not neglect skimmed, naturally dispersed or evaporated oils. These are important in the oil budget calculations. Skimmed oil is counted as shown in equation A1.7), naturally dispersed in equation A1.11, and evaporated oil is counted by the terms $k_4Z(t) + k_5W(t-1)$ in equation A1.10. The note "(neglecting natural surface dispersion and skimming)" mentioned in the report applies to calculation of evaporation from the previous day and still available on day t, as mentioned in the report "The oil that rose to the surface on day t-1 and is still left". This "old" oil is estimated by the intermediate variable W.

*The report states that some 18,000 barrels of subsea dispersant were used, and multiplying this by (1-k7)*90*k2 (from equation 2) gives 700,000 barrels of chemically dispersed oil in the subsurface. Figures 1 and 2 in Appendix 2 (example outputs from day 86, the last day dispersant was used, I believe)*

*gives an answer of only about 400,000 barrels. Why is this different? Note that 90*k2Vcb should always have been smaller than the government estimate of the discharge even when 12 gallons/minute of subsurface dispersant was being used.*

Figures 1 and 2 in Appendix 2 refer to the earlier version of the Oil Budget Calculator (version 1.3) while the formulas listed in the Report are those for the present version (2.0). See Appendix 2, Figure 3 for the equivalent tables using the new formulas.

2. *One of the stated goals is to provide the UC with actionable data even when there is missing or incomplete data. I'm wondering what happens when the estimate of the discharge is either not available or has a very high level of uncertainty. If stated too low, this would presumably result in a response (dispersant, skimmers, etc.) that was too low, if state too high, this would result in too much dispersant deployed and inefficiency (too many skimmers floating around). If either of these scenarios occur, I don't see any built-in mechanism (e.g., feedback) that allows the calculator to adjust, which could render the calculator ineffective. Given the uncertainty surrounding the flow rate for a significant portion of the DWH spill timeframe, this seems likely to occur. I would suggest that future work include exploration of feedback mechanisms. One that readily comes to mind is tracking the daily amount of oil estimated to be reaching the surface, which is $V_{RE} - V_{DC}/(1-k_7) - V_{DN}/(1-k_7)$, and comparing it with the daily amount of oil skimmed and burned (normalized by effort) . One could imagine a scenario in which such a tracking mechanism is used to tune the basic model inputs (e.g. the leak discharge rate), which in turn gives the response the indirect ability to tune decisions for which the result is difficult to monitor (e.g., amount of subsurface dispersant). Place holders for new feedback mechanisms (advances in technologies to assess surfaced or subsurface oil amounts or characteristics) could also be added.*

Mass balance was used by another group to estimate flow rate during DWH. Certainly having a corrective feedback mechanism in future model applications would be useful.

3. *Considering that V_{DC} cannot be greater than V_{RE} by definition, the "max" in equation (3) does not seem to be necessary.*

True, but it does not affect the calculations. Equation was written this way for consistency .

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4. *It seems misleading to state that a similarity between DWH and Ixtoc is that relief wells were used to stem the flow in both cases. Didn't DWH utilize a cap to almost completely stem the flow? In any case, what is the relevance of the method of stemming the flow to the assessment of oil fate and transport before the flow is stemmed?*

The use of relief wells is mentioned because in both cases this was the final method to assure no future leakage and because it was believed during both responses that this was possibly the ultimate method to stop the flow. For IXTOC, this proved to be the case. As noted by the Reviewer, DWH was successfully capped at the top.

5. *In describing the difference between DWH and Ixtoc, it is stated that Ixtoc I oil formed a "chocolate mousse." Wasn't this also observed in DWH? I recall seeing something that could be described as a "mousse", at any rate.*

Both oils emulsified although the Deepwater Horizon spill formed a less stable emulsion and took longer to emulsify.

6. *On page 11, there is a statement suggesting that "current news reports" provide evidence that a scientific hypothesis (that a "good" fraction of the oil is settling to the bottom) is true. Given the inaccuracies often associated with press reports, and the lack of peer review associated with news media report, I would suggest that the report only state that such a hypothesis exists but has not yet been evaluated, and that references to the news media be deleted. Further, what is a "good" fraction? These kind of ambiguous statements found throughout the document.*

Sentence discussing bottom oil is modified to note that these reports have not been confirmed

7. *What is a "glob" of oil (page 14)?*

Corrected

I don't see how the 5-10% dissolution rate is supported. It would seem to me that in order to assess this, you would need to know a) the oil composition; b) the dissolution rates as a function of droplet size (not solubility – presumably the Gulf of Mexico is still under-saturated; c) the droplet size distribution. I don't see that any of this is sufficiently known to estimate a dissolution rate. The text makes the case that some oil will dissolve, but does not go further. This should be addressed; if it is a guess, than this should be clearly stated

Dissolution was only considered as a separate process for dispersed subsurface oil (less than 100 micron droplet size). As stated in the Report, the dissolution rate depends directly upon surface area, which was proportionally larger per volume spilled for this spill incident compared to a normal surface spill by factors of 100 to 1000. Mackay and Leinonen (1977) concluded that, for droplets less than 100 microns in diameter, dissolution is very rapid for any component that will dissolve at all. Using the known composition of the oil, we arrived at the 5-10% number.

Reviewer 5:

This document needs a more straightforward description of what the major processes are that need to be considered. Once the simple formula is provided then they can describe their more sophisticated formulas for deriving the estimate. Here is a simplified example of how they should proceed. The fate of oil in the marine environment has been of concern for many years and the major processes determining its fate are known in relative terms. A budget can be constructed which would contain these parameters:

Total oil discharged = TD
Oil Recovered before entering the ocean = REC
Oil Dissolved/Dispersed = DD
Oil on sediments/shore = SED
Oil on the ocean surface = SURF
Oil evaporated = EV
Oil Biodegraded = BD
Oil Burned =BUR
Oil Skimmed = SK

Then the following equation can be used:

$$TD = REC + DD + SED + SURF + EV + BD + BUR + SK$$

The National Incident Command (NIC) is most interested in the surface oil (SURF) as that is where they can attempt to burn skim or disperse the oil or set up booms to keep the oil from sensitive ecosystems. The equation is therefore solved to estimate this term:

$$SURF = TD - (REC + DD + SED + EV + BD + BUR + SK)$$

Since the spill occurred offshore where the suspended sediment load is small sedimentation near the spill site is not likely to be a major term in this budget

for this spill. This term for the offshore areas was assumed to be comparatively small. The NIC was trying to keep the oil of the shore. Once on the shore it is difficult to estimate the amount of oil stranded and how much of that oil is recovered. This oil budget calculator does not attempt to estimate this process, but includes this oil with the surface oil. The equation for the calculater is therefore:

SURF + SED = Other Oil = TD – (REC + DD + EV + BD + BUR + SK)

The budget then uses the physical properties of the oil, estimated rates and developed a model to calculate and estimate the above parameters. Modelers and other experts will need to comment on how well they were able to estimate these parameters. Based on my review of the parameters that the oil budget calculator used it has captured the most important aspects. While SED can be assumed small it does not mean it is not important especially for selected near shore areas and perhaps some off shore areas.

Spilled oil undergoes a number of processes. Dispersion and evaporation are just two examples. Collectively they are called weathering. The circumstances surrounding the Deepwater Horizon incident resulted in interdependence of these processes. To address this the approach taken was to follow a logic structure beginning at the wellhead and the released oil. Unfortunately, interdependencies of the weathering/cleanup processes made the simple approach proposed by the Reviewer not possible. For example, evaporation depends upon surface oil but surface oil depends upon the amount of oil that disperses subsurface. The formulas chosen by the development team were as simple as we believed possible while still retaining these basic dependencies. However, a descriptive narrative has been added to the section before the formal equations are presented.

My conclusion is that they have oil budget calculator used it has captured the most important aspects of the fate of the oil.

The Oil Budget Calculator is designed to capture short-term oil behavior as it affects response. Environmental Impact Assessment studies are needed to track the ultimate fate of the oil.

Specific sections Comments

Dissolution and Evaporation:

I discuss these sections together as it make since for the calculator to talk about these processes together. The discussion in these sections is very good. They explains how the unique aspects of this spill led to enhanced

dissolution even of sparingly soluble components. Based on the paucity of studies they have done a good job of estimating dissolution process. And since the same components of the oil are more water soluble and more volatile it makes since to combine as a process called "weathering" as it is difficult to establish which was the dominate process. Separating the two processes is also of limited value for the NIC. Some editorial comments:

Page 17 Figure 6. The open and filled circles are not labeled.

We are reluctant to modify a figure produced by someone outside the development group. The original figure appeared in the proceedings of the 1987 Oil Spill Conference.

Page 17 ...lose between 5-10% of its volume. Is this also 10 % of the mass since mass in used in the calculator.

The Calculator uses volume in its calculations and output. However, oil density changes little so that mass and volume percentages are quite similar.

Page 18 "The Oil Budget Calculator groups these terms" change "terms" to "dissolution and evaporation".
Page 19 Figure caption change to ...alkanes below C-14 have been removed...

Change implemented

Residual Oil (in my letter) or **Other Oil** (in draft document) plus **Program Structure & Interface** (Appendix 2 Oil Budget Calculator-Web-based Tool)).

In the equations I provided above the Other Oil is equivalent to my term SURF + SED. This is the most important parameter for the NIC. This is the oil that they have the oil that they have to attempt to mitigate (skim, disperse, burn) or contain (booms) and the proportions that they were unable to keep from the shore. In short it is the number they wanted calculated. The final test of this Oil Budget Calculator is was it of value to the NIC to make management decisions. It would be good to include in this report a statement by the NIC that this Oil Budget Calculator was useful or that they think it would be helpful in the event of future spills. They are the ultimate primary users. It is also important to attempt to improve these estimates as the results contradict some of the original unrealistic predictions.

We agree that the ultimate judge of the usefulness of the Calculator was/is the unifiedcommand. The development team was encouraged by the support given to its development by the NIC who are reviewing future plans for the tool.

Other Comments:

Figures 8, 9, 13, 15 and 16 appear to be taken from appendix 2 figure 4. It would be better to just use that figure in the main text and delete the other figures as they are hard to understand until you see figure 4 Appendix 3.

Figure 8 and other related figures have been removed.

Appendix 2 Figure 1 and 3 (which are actually tables unless the colors have some significance) appear to be the same accept rounding. One should be eliminated or the reason to have both explained.

Specific Comments:

Page 7 A copy of ICS 209 should be available as an appendix.

A copy of the ICS 209 form has been added as an Appendix

Page 8 The model uses not assumes. This whole page should use the same terminology found in Figure 1 Appendix 2. For example "(1) Subtract off direct recovery from total amount escaping from the reservoir", just say recovered. This section is extremely had to follow and should be edited by a non-technical person.

A challenge in a document of this type is to reconcile precise technical terminology with more common descriptions. 'Direct recovery' is used to distinguish this oil from other oil recovered by, for example, skimming operations. We have simplified the equation expressions, added an introductory narrative to them and added a table of acronyms to the final version to assist the reader.

Page 12 Par 3 add surface after water.
Page 14 ...converted to hydrates at a much higher level... do you mean shallower depth or deeper depth?

Shallower depth

Page 22 (representing a 200 -250C+ residue) is this a boiling point? Need to explain.

50degC+ residue is that the residue has lost all components with boiling point below 250degC

Page 25 Par 1. change "disappeared during" to was not on the surface after

Page 27 last line half=of ?
Page 32 Par 2. 2 to 3 mm thick…. Oil with emulsions…delete typically. …mm or less thick.
Page 35 Simple measurement of barge oil!!! This should be made a requirement!!

We agree when practical.

Page 39 (5) this is self advertisement and should be deleted. What is real code? Is there fake code!!

We disagree with this conclusion. A weakness of oil spill science in the past was translating new ideas into practical tools.

Page 39 (6) Jargon. Explain what the "Interface" you are talking about is. Consider deleting this as it seems to serve no purpose.

One of the key challenges for the team was to provide to the unified command output that is simple to understand yet captures the uncertainty in the estimates. We believe this is a topic that requires more research.

Conclusion

My conclusion is that this model appears to provide a valid estimation of the source and fate of the oil from the DWH incident. It generally agrees with what has been found by previous oil spill research and currently available research on this specific incident.

Unfortunately, the ultimate fate of the oil is more complicated than can be calculated by this tool. Environmental impact assessment is ongoing and will provide a more complete picture than the Oil Budget Calculator.

Reviewer 6:

<u>The OBC as an NRDA tool?</u>
The introduction in particular and the paper overall set the scene well and describe the operational needs that led to the creation of the OBC, the limitations that this development faced, and the authors' overall (and reasonable) conclusion that the OBC outputs "only need to be accurate to the extent that they correctly inform cleanup decisions and do not lead to errors in response actions." (p. 5) Explicit warnings are also made that the OBC tool is not appropriate for damage assessment. While there is no protection against misuse, perhaps the

paper could describe more explicitly just why the OBC is not appropriate as an NRDA tool.

The Oil Budget Calculator is unsuitable for NRDA because it does not track the final fate and environmental impact of the spilled oil. This is explicitly stated on page 3 of the report.

The problem with DOR

The model is a nest of part-weathering, part-response/fate equations describing processes that are partly simultaneous, partly consecutive. For example, while subsurface dissolution is nicely modelled as occurring after subsurface dispersion (i.e. consecutive processes), chemical dispersion, skimming and in-situ burning on the sea surface are all allowed to happen at the same time (simultaneous processes).

One key problem we have with the model is that a great part of the results (in fact, all the consecutive elements, such as evaporation, dispersion and dissolution) are based on the theoretical volume of oil that can be dispersed by a given quantity of dispersant (i.e. DOR = dispersant-to-oil ratios). These are the $90V_{CB}$ and $20\ V_{CS}$ elements of the equations. The issue is that outputs are measured solely in terms of inputs, albeit with the correction factors k_2 and k_3 (which must capture not only the 'encounter rate' of the dispersant application, but also all other technical and environmental factors that may influence the dispersant application). The Appendix (in particular) explains that outputs are measured on the basis of inputs, but we do not believe that this makes it acceptable.

In the real world, DORs are meant as a planning guideline, an indication as to the quantity of dispersant that should be made available (i.e. what should be put in), not the end result (i.e. what comes out). Further, they refer to the dispersibility of surface slicks of a certain thickness (0.1mm according to the ITOPF Technical Paper quoted).

The matter is made worse by the fact that the DOR figures come up so many times in the same equation/ model. For example, if the model equations are solved simultaneously for total evaporation/ dissolution (not even dispersion!), the $90V_{CB}$ component comes up numerous times in relation to:

- *Day t evaporation of non-chemically dispersed at bottom oil (that just rose)*
- *Day t evaporation of non-naturally dispersed at bottom oil (that just rose)*
- *Day t evaporation of non-chemically dispersed at bottom oil from the previous day(s)*
- *Day t evaporation of non-naturally dispersed at bottom oil from the previous day(s)*
- *Day t dissolution of chemically dispersed at bottom oil*

- *Day t dissolution of naturally dispersed at bottom oil*

The use of DOR to define effectiveness was based upon industry familiarity with this approach. Similar results would have been produced if the development team had used fraction dispersed as a function of dispersant applied to available oil with an upper limit on the fraction allowed. What is really needed is solid research to empirically determine effectiveness.

Multiple expert coefficients.
Although the model makes logical sense when analysed part by part, when the equations are solved simultaneously there are numerous places where the educated guesses of experts are multiplied by a series of other such educated guesses. For example, the 2 nd day surface evaporation (with coefficient k_5) is a function of the first day evaporation (with coefficient k_4) which is a function of sub-surface natural dispersion (with coefficient k_1) which is a function of sub-surface chemical dispersion (with coefficient k_2) which is a function of theoretical sub-surface chemical dispersibility (i.e. DOR = 90). In other words, that part of the overall evaporation function which looks like:

$$k_5 W(t-1)$$

really takes the following form when solved for "W" which includes "Z" which includes "Y" which includes "X":

$$+k_5\left[(1-k_4)\left[(1-k_1)\left[V_{RE}(t)-k_2 90 V_{CB}(t-1)\right]\right]-V_{BU}(t)\right]$$

As can be seen, if the equation is solved, the results include such elements as: $k_5 * k_4 * k_1 * k_2 * 90 * V_{CB}$ which is the multiplication of 5 guesses by the observed number of drums of dispersant applied. It is very, very hard to accept this as a meaningful result.
Naturally, the paper includes a number of various variance histograms for each of the main fate/ recovery alternatives, and the Appendix includes a long and detailed statistical model based on repeated computer simulations (i.e. the Monte Carlo analysis),. These do not, however, in our opinion, get over the fact that there are very few variables in the overall set of theoretical equations which are actually populated by real measurements, observations, or even observation-based estimates.
While an argument could be made that having an inaccurate result, even if far from reality, may be more useful than having no result at all when faced with emergency-phase decision making, it cannot be stressed enough that it is not appropriate to use the results in post-spill evaluations of impact or response actions.

The Reviewer is correct in assessing that these numbers chiefly rest upon the experienced judgment of the dispersant experts consulted for this project. However, using expert judgment when hard data is not available is often employed in many fields.

We agree that there are many alternative ways of re-writing the equations that describe the simplified model that we have adopted for the fate of the oil. Some of these may appear counter-intuitive. The formulation we have settled on represents our particular way of viewing the chronology, chemical reactions, and phase changes affecting the spilled oil, which is based on our own, varied experience with oil spills into the ocean. One of our colleagues, who has no expertise in this specific area, and merely as an exercise, did use our description of these processes to formulate an alternative set of equations, independently of our formulation. This alternative had shortcomings that were obvious to those with expertise in the subject. However, it produced estimates for the different volumes that we track that were within the uncertainty range of the estimates that the equations we did use had produced. This suggests that the simplified model we have adopted is fairly robust to varied interpretations, and that rather different sets of equations that may be used to represent our understanding may end-up bringing about no more than relatively minor changes to the bottom line.

Regarding the comment on the 2nd day surface evaporation, this is evaluated by the following expression after development and assuming that $V_{DC}=(1-k_7)\ k_2 90 V_{CB}$ and $V_{DN}=(1-k_7)\ k_1\ [V_{RE}- V_{DC}/(1-k_7)]$:

$$k_5 (1-k_4)\ (1-k_1)\ [V_{RE}- k_2 90 V_{CB}] - k_5 V_{BU}$$

This expression includes terms that are function of one rate constant such as $k_5\ V_{RE}$ and $k_5\ V_{BU}$, terms that are function of two rate constants such as $k_5\ k_1\ V_{RE}$ and $k_5 k_4\ V_{RE}$, terms that are function of three rate constants such as $k_5 k_4 k_1\ V_{RE}$ and $k_5 k_2\ 90\ V_{RE}$, and terms that are function of four and five rate constants such as the one mentioned in the reviewer comment. Of course, the terms that include less rate constants have more influence on the end results than the one multiplied with four and five rate constants, given that all the rate constants are less than or equal to 1. The other terms were kept in the equations of the Calculator for logical consistency and for transparency of the method used.

The uncertainty analysis certainly was done assuming that the rate constants were like realized values of independent random variables, whose probability distributions expressed the knowledge that the subject-matter experts had about their values. This assumption, of statistical independence, clearly is questionable for at least some of them. For this reason, Appendix 1 describes a study of the sensitivity of the conclusions to this assumption, by considering the effects that substantial dependence between several of them would bring about. As it turned out, this lowered the lower endpoint of the confidence interval for the volume of residual oil (or, "other oil"), but hardly changed the upper endpoint, meaning that the assumption of independence

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actually was conservative, at least for the variables considered in the sensitivity study.

Re-coalescence

The model has no explicit mechanism by which some part of the initially-dispersed (sub-surface or surface) oil re-coalesces and rises to join the surface oil. One could, of course, say that the oil that disperses in the model is, by definition, only that which is permanently dispersed. We do not believe that this is a particularly neat solution, given the important discussion in the spill world on the fact that naturally-dispersed oil tends to be less permanently dispersed than chemically-dispersed oil.

Near the riser, it is possible for dispersed oil droplets to collide and form larger droplets due to the abundance of oil droplets and sufficient mixing energy. However, due to the relatively low concentration of oil away from the source, the collision frequency of droplets is very small when one moves away from the riser. Thus, the conditions there are not favorable for coalescence. Any coalescence would compete with shear forces breaking up the larger droplets. There may be an intermediate area where coalescence dominates. The impact of coalescence near the riser might affect the overall effectiveness of dispersant but would be included in the wide uncertainty range selected for oil dispersion.

Dissolution from chemically- vs. naturally-dispersed oil

Related to the point just above, it would be expected that the (mean) droplet size for chemically- and naturally-dispersed oil would differ. This would surely have an important impact on the sub-surface dissolution potential (i.e. k_7), even disregarding the question of effect of droplet size on dispersion stability (as discussed above). In other words, k7 might be best split into two separate coefficients (e.g. k_{7C} and k_{7N}).

Mean droplet size would be considerably smaller for chemically dispersed oil. Mean droplet size for natural dispersion would be expected to be much larger than our cutoff value of 100 micron diameter. However, some droplets would be 100 microns or smaller. These are the ones considered naturally dispersed. Mackay and Leinonen (1977) concluded that, for droplets less than 100 microns in diameter, dissolution is very rapid for any component that will dissolve at all.

Emulsion & Emulsion effects for surface dispersant effectiveness

There is no explicit modelling of emulsion formation in spite of the fact that this was an important process in this incident. Likewise, there is no discussion of the effect of emulsification on surface dispersant effectiveness. This is a key factor, considering the practical experience that shows that emulsions, if dispersible at all, require greater quantities of dispersant than non-emulsified (surface) slicks.

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Emulsification is not a process that directly contributes to mass balance in the way that, for example, does evaporation. The observation that the oil did emulsify is reflected in the burn estimates and in the effectiveness of surface dispersion. Both were reduced to account for the characteristic behavior change of oil that has emulsified. Certain experts thought that the reduction was insufficient, a judgment summarized by Alternate View 1.

Weather & response activity

We find no explicit variables to account for variations in the weather and how these might have affected the response success, for example surface dispersion operations.

Several of the report authors have developed much more complex oil fate and behavior models than the Oil Budget Calculator. However, these models required more detailed input than the design specifications allowed for the Calculator. Sea state, in particular, affects surface processes but, for this spill, varied both temporally and spatially. Also, the subsurface release and extended duration of the leak were not compatible with the standard fate and behavior model used by NOAA and USCG for routine spills. Recommendation 5 suggests expanding existing modeling capabilities so that perhaps this difficulty will not arise in future incidents.

Equations

While we find no mathematical fault in the equations, there are places where slightly different forms would leave the equations more easily interpretable.

For example:

Equation number	*As presented*	*More easily followed form*
A1.4	$Y(t) = V_{RE}(t) - \frac{V_{DC}(t)}{(1-k_7)}$	$= V_{RE}(t) - k_2 90 V_{CB}(t)$ *or* $= V_{RE}(t) - k_2 X(t)$
	Interpretation: Oil volume available to natural dispersion (and subsequent rising to the surface for that part that does not disperse), once chemical dispersion at the well head has run its course.	

A1.8	$Z(t) = V_{RE}(t) - \frac{V_{DB}(t)}{(1-k_7)}$	$= (1-k_1)(V_{RE}(t) - k_2 90 V_{CB}(t))$ *or* $= (1-k_1)Y(t)$
	Interpretation: Oil that rises to the surface after chemical and natural dispersion has run its course.	
Part of A1.10	$\frac{k_7 V_{DB}(t)}{(1-k_7)}$	$+k_7 k_2 X + k_7 k_1 Y$
	Interpretation: That part of the subsurface chemically-dispersed and naturally dispersed oil that dissolves into the water column	

While the proposed forms to represent the three equations appear to be simpler than what is proposed in Appendix 1, these simplifications do not respect logical consistency in the formulation and the solution of the problem. The "min" and "max" functions were introduced in equations A1.3, A1.5, A1.9, A1.11, and A1.12 to ensure that the oil volume is conserved and no non-realistic results are generated in the Calculator.

Conclusions

The equations on which the OBC is based offer an interesting theoretical study of many of the fate and weathering processes relevant for a sub-sea blowout incident such as the DWH. There are some elements which could be added to the model such as explicit weather (e.g. wind, waves), emulsification, re-coalescence of dispersed oil, or refined such as droplet-size-based dissolution.

As a practical tool, however, the OBC suffers the same shortcomings of most mass-balance efforts: lack of real-world observations. In this case, lack of actual observations of dispersion effectiveness in particular render the overall result practically meaningless. The only true observations in the model appear to have been the volume of oil/water mix collected by skimming operations (traditionally a very suspect measure of actual oil volume collected), the volume of oil dispersant used (probably reasonably well counted but utterly meaningless in terms of estimating actually-dispersed oil), and the number and approximate size of in situ burns (a very rough value for a very rare activity).

One could argue that having the OBC result, although an inaccurate number, was better than having no number. The truth is, however, that the overall result could have been no better or no worse without it. In fact, the response operations were guided primarily by 1) the visible presence of oil, whether it was escaping from the wellhead, on the surface in the form of slicks that could be burned, skimmed, or dispersed, 2) the availability of resources, and 3) non-

technical concerns (such as the maximum daily-dosage of subsurface dispersant application).

The Oil Budget Calculator was only one tool among many that the unified command used to make response decisions. As with any tool, it has its strengths and limitations. The skill of the decision maker is to utilize all the tools available in an appropriate manner to optimize the response. Based upon the request by the NIC for this tool, and its continued usage during the spill, we must conclude that they found some value in it.

Reviewer 7:

General;

I thought the report was informative and as precise as was possible under the constraints of the available data. Errors and uncertainties were identified. I was specifically asked to review Oil properties, Dissolution and long-term processes. I think each section was adequately presented under the terms of reference.

I suggest you provide a list of acronyms for all the various agencies, etc. "in situ" or "in situ" is not consistently presented in the report

A list of acronyms will be included.

I have the flowing specific suggestions to the text.
P12 p 2. L 6. "an average"...
P13 p1 L4 "considerably larger"
Fig 3. Define bopd in the figure caption.
Fig. 7 *The blue series is not described. Presumably it is a surface oil sample taken near the source. Thus the title should be amended to read "..., floating oil samples immediately adjacent to the source (red,blue).....*

The blue series is not a sample collected at the surface, but came from a sample from dispersant efficiency testing.

P. 20 p2. L10 "data provided (to, by???) BP"

Provided by BP. Correction will be made in the text.

Fig. 8 should be moved up 2 paragraphs to appear under its description.

P27 under Fig 11. L3 delete "when" L 7. delete "="

P27 under Fig 11. I could not see a conclusion from this paragraph. The issue of dispersant efficacy is left hanging. A statement that says there is no conclusion possible from the sattelite data would be useful.

Sentence added

However, May 11th and May 12th show similar surface expressions although the latter should be displaying more oil. Therefore, these observations provide inconclusive results.

P 29-30. Delete reference to Fig 13 here as the same sentence appears on P 13 just above the figure.
P31 last L "from"

P38 p1 L8 What is the basis for concluding hydrocarbon degradation in the water column occurs without oxygen drawdown? This needs to be expanded to clarify and justify this statement.

Hydrocarbon degradation doesn't occur without oxygen utilization. There was draw down, as discussed in the JAG 2 report. The fact that the DO2 drawdown was not as high as expected is most likely do to mixing as described in Appendix 2 of the JAG 2 report.

References:
P. 12 Yapa 2010 should be et.al.
P 19 Kirsten et al 1984 is not in the list
There are several citations in this section where multiple citations are not properly presented
Eg: P. 20 (Payne, Kirsten et al., 1984) should be (Payne et al, 1984; Kirsten et al., 1984)
There are 3 such citations on Page 20. Other sections of the report do it properly.

References in the list but not cited in text or figures
These should be cited, deleted or added as "additional useful references" or some such.

Belore, R. (2003). "Large wave tank dispersant effectiveness testing in cold water". International Oil Spill Conference; Prevention, Preparedness, Response and Restoration, Perspectives for a Cleaner Environment: April 6-11, 2003, Vancouver, British Columbia, Canada, pp 381-385.

Belore, R.C.; Trudel, B.K.; Lee, K. (2005). "Correlating wave tank dispersant effectiveness tests with at-sea trials". International Oil Spill Conference; Prevention, Preparedness, Response, and Restoration: May 15-19, 2005, Miami Beach Convention Center, Miami Beach, Florida, pp 65-70.
Brandvik, P.; Daling, P.S.; Lewis, A.; Lunel, T. (1995). "Measurements of dispersed oil concentrations by in-situ UV fluorescence during the Norwegian experimental oil spill with Sture blend". In Proceedings, Eighteenth Arctic Marine Oil Spill Program Technical Seminar, June 14-16, 1995, West Edmonton Mall Hotel, Edmonton, Alberta, Canada. Ottawa, Ont.: Environment Canada. pp. 519-535.
Brutsaert, W. (1982). Evaporation into the Atmosphere: Theory, History, and Applications. Dordrecht, D. Reidel Publishing Company.
Colcomb, K.; Salt, D.; Peddar, M.; Lewis, A. (2005). "Determination of the limiting oil viscosity for chemical dispersion at sea". In 2005 International Oil Spill Conference; Prevention, Preparedness, Response, and Restoration: May 15-19, 2005, Miami Beach Convention Center, Miami Beach, Florida. Washington, D.C.: American Petroleum Institute. pp. 53-58.
Daling, P.S.; Brandvik, P.J.; Reed, M. (1998). "Dispersant experience in Norway: dispersant effectiveness, monitoring, and fate of dispersed oil". In Dispersant Application in Alaska: A Technical Update, Anchorage Hilton Hotel, Anchorage, Alaska, March 18 and 19, 1998. Cordova, Ak.: Prince William Sound Oil Spill Recovery Institute. pp. 111-146.
Fiocco, R.J.; Daling, P.S.; DeMarco, G.; Lessard, R.R. (1999). "Advancing laboratory/field dispersant effectiveness testing". In Beyond 2000, Balancing Perspectives: Proceedings: 1999 International Oil Spill Conference: March 8-11, 1999, Seattle, Washington. Washington, D.C.: American Petroleum Institute. pp. 177-185.
Lehr, W.; Jones, R.; Evans, M.; et al. (2002). «Revisions of the ADIOS Oil Spill Model", Environmental Modeling & Software, Vol 17, Issue 2, pp. 191-199.
Lewis A.; Crosbie, A.; Davies, L.; Lunel, T. (1998b). "Dispersion of emulsified oil at sea". AEA Technology report. AEAT-3475. AEA Technology, National Environmental Technology Centre (NETCEN, Didcot, Oxfordshire, England.
Lewis A.; Crosbie, A.; Davies, L.; Lunel, T. (1998). "Large scale field experiments into oil weathering at sea and aerial application of dispersants". In Proceedings: Twenty-First Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, June 10 to 12, 1998, West Edmonton Mall Hotel, Edmonton, Alberta, Canada. Ottawa, Ont.: Environment Canada. pp. 319-344.
Lunel, T.; Rusin, J.; Bailey, N.; Halliwell, C.; Davies, L. (1997). "The net environmental benefit of a successful dispersant operation at the Sea Empress incident". In Proceedings: 1997 International Oil Spill Conference: Improving Environmental Protection: Progress, Challenges, Responsibilities: April 7-10, 1997, Fort Lauderdale, Florida. Washington, D.C.: American Petroleum Institute. pp. 185-194.

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Lunel, T.; Lewis, A. (1999). "Optimization of oil spill dispersant use". In Beyond 2000, Balancing Perspectives: Proceedings: 1999 International Oil Spill Conference: ---44--- March 8-11, 1999, Seattle, Washington. Washington, D.C.: American Petroleum Institute. pp. 187-193.
Mackay, D.; Matsugu, R.M. (1973). "Evaporation rates of liquid hydrocarbon spills on land and water." Canadian Journal of Chemical Engineering, Vol. 51, pp. 434- 439.
National Research Council (1989) Using Oil Spill Dispersants in the Sea, National Academy Press, Washington DC, 335 pp.

Reviewer 8:

General comment. In the report use laboratory not lab.

Page 6, Top Paragraph, Third sentence – "Other longer-term processes" Name the processes are the authors referring to.

Sentence revised

Other longer-term processes such as biodegradation, photo-oxidation, and sedimentation may have an impact on the environment but are less amenable to response decisions

Page 7, Top paragraph, second sentence. Suggest changing "..usually a simple, if slightly dull, process" to "... usually a straightforward process." Do not minimize the task of correctly filling out Form ICS 209.

Page 8, (2) Determine the bottom chemical dispersion amount. The equation uses a term $90k_2$. Why was 90 used? I reviewed Appendix 1. I see that k_2 is the constant for subsurface chemical dispersion Table A1.2. on pp. A1.9. Why was 90 added to the constant?

All the rate constants are defined in such a manner that they vary between 0 and 1. In the model, the DOR for subsurface dispersants has a maximum possible of 90. Therefore, the 90 appears as a scaling factor.

Page 10. The Ixtox Spill. First paragraph, last sentence refers to depth of the well "about 50 m". Last paragraph, First sentence has depth as "approximately 165 feet (51 m). Be consistent.

Comment for Section 3.0 Ixtoc spill - I suggest when comparing Ixtoc to DWH add the fact that that distance to shore was a factor in differences.

Comment for Section 3.0 Ixtoc spill – I suggest mentioning that dispersant application was more closely targeted for DWH than Ixtoc. During Ixtoc, dispersants were applied very close to shore, in the surf zone, and at the entrances to tidal creeks and other waterways.

Page 13, Top paragraph, Start of Third sentence. Is something missing at the start? The sentence starts out with "estimated"
Or does the sentence start out with the citation (Lehr , 2001….)? Not clear to the reviewer.

Page 27. Last paragraph. The multi-spectral scanner measures the thickness and distribution of the oil slick in coastal and offshore waters in real-time. I suggest the explanation of the 4-picture sequence be explained in better detail.

Explanation expanded

Found a number of references in Section 15 not in the report.

Belore (3002)
Belore et al (2005)
Brandvick et at (1995)
Brutsaert (1982)
Colcomb (2005)
Daling (1998)
Fiocco (1999)
Lehr (2002)
Lewis (1998b)
Lewis (1998)
Lunel (1997)
Lunel (1999)
Mackay (1973)
Mackay (1975)
NRC (1989)
The IXTOC I Oil Spill

Appendix 1 – Reference Section. No reference for W.N. Venables (2002) in the appendix.

The reference to Venables & Ripley (2002) is made on page A1.10 (Appendix 1), and the reference itself is specified on page A1.17.

Reviewer 9:

Overall: There were problems in following the calculations as the descriptions were in the front and the equations in the appendix. It is not clear if the equations had any background or references. Did the authors develop them independently or was there a background or previous papers on each? I also had difficulties following the Appendixes due to lack of consistent numbering.

A challenge in constructing a report of this nature is the diversity of the audience. We anticipate readers who will gravitate to the intricate mathematics of Appendix 1 while others will wish to see only the descriptive explanation of the model. As an imperfect compromise, the authors have chosen to provide the basic equations with a descriptive narrative at the beginning of the report, leaving the more complex mathematics to the Appendix. The equations themselves were constructed specifically for the calculator, based upon mass balance preservation and the spill experiences of the development team. Previous algorithms were used or modified for specific processes and are referenced in the main text.

Consider putting in Resumes for the other contributors so that when they are referenced through "Personal Communication", readers know their background to add credibility. (especially Yappa and Galt)

There are important differences between the major report contributors, who have all read the report and determined that it was acceptable for external review and the other contributors who may have not read the report in its entirety. We have chosen to acknowledge the latter's help but do not believe it would be appropriate to put them in an Appendix of major contributor resumes.

Check all figures and move so that they are placed conveniently. (For example, Figure 7 is on page 19 but referenced on page 20 and figure 8 should be placed before Section 7 On page 21.

Individual Comments.
1) Table of Contents: appendix names not consistent with titles in Appendix themselves.

2) page 8, report goes right into equations without enough explanation. Try adding a couple of sentences at top of page 8 after straightforward: Something like "There are eight general categories for identifying the mass balance and…"

Additional introductory material is added, including a narrative explanation

of the equations

3) page 8-9, any specific references to these equations? If not, consider stating "These equations are based on…". Also consider putting a copy of Table A1.1 near beginning of report.

See the new narrative.

4) page 22, the range of volume figures used throughout is confusing. Consider placing the left-hand line under the rectangle and labeling the individual dotted/shaded areas. It is not clear what these are showing unless somehow they are combined at the end to show range.

Figure 8 and similar figures in the report have been deleted.

5) page 23, again are equations from NRC 2003 or ADIOS2?

Equations are adapted from the Delvigne-Sweeney dispersion model (Delvigne and Sweeney, 1988)

6) move figure 12 to page 29.
7) page 39. Why are results given in Appendix?

Model results will be added to Section 14.

8) Appendix 1 is confusing due to multiple page numbers.

This has been improved pursuant to the reviewer's observation.

9) Need a better link from main section of report to Appendix 1. Note that there are 16 equations with limited explanations.

Appendix 1 provides the mathematical underpinning of the model. The purpose of the main section is to provide the science behind it. Section 2 provides an explanation of the important equations that control the processes. Deleted in this explanation, are auxiliary equations that sum results for graphing.

10) Table A1.2 – Not completely clear if and how rate constants are related to estimates given in main section.

Toward the end of each section is a discussion of the range of values that can be expected for that process. For example, the section on natural dispersion defines 20 % as the expected fraction of oil that will naturally disperse with a

range between 10% and 30%. This translates into an expected value for k_1 of 0. 2 with a range between 0.1 and 0.3.

11) Appendix 3, consider wrapping text in title cells so that all number can fit on single page for easier reading.

12) Appendix 4, need better explanation of how samples were collected and analyzed. Just a brief paragraph that provides more than the Figure titles.
13) Appendix 6, need to state in first paragraph that "this Appendix does not provide information on the in-situ monitoring.
14) Consider describing test apparatus/process. For example, is the water sample poured through a column that the LISST monitors?
15) Consider adding more information about sampling depths, etc.
16) Appendix 7 – Label and reference all tables and figures in Appendix B. Had much difficulty in correlating with explanations.

Appendices 4 through 7 reproduce already published reports reprinted here with the owners' permission to provide completeness to the report. We cannot modify them.

Reviewer 10:

Overall, this is a well-written document, with a clear objective of advising response options rather than being a comprehensive scientific study. The document references the literature of spill science well, and appropriate experts have contributed to various aspects of the report. It appears that the calculator was useful to inform response options over the summer. Below are several detailed comments:

The Executive Summary summarized the report well for the most part. Extra emphasis on the differences between a deep water spill such as this one and much more common surface spills should be made to overcome misconceptions that most managers will hold having only experienced shallow waters spills.

Introductory paragraph added to the Executive Summary

An estimate of the oil budget should be included in the Executive Summary. Maybe even just the pie chart (Figure 2 in the web-based tool section)

While there is much to be said for including the results in the executive summary, it was also recognized that this could lead to some readers

proceeding no further. The development team believes that it is essential to understand the purpose and limitations of the calculator before considering its results. As a compromise, the results are now included in Section 14 of the report where the Calculator itself is assessed.

Degradation rate of the oil components should be evaluated quantitatively if possible. Over the timescales relevant to the response, degradation rates are seen to be significant. Degraded oil should be a fate in Figure 2 pie chart.

The development team believes that this would lead the use of the Calculator away from response toward damage assessment, something that it is ill-suited to assist.

The changing composition of the oil should be part of the analysis. While this may seem to be too much detail for response, some fractions of oil are more toxic (will have bigger impacts) than others, so response options should consider the composition (e.g. toxicity) of the remaining oil in addition to just the total amount.

A good point but it exceeds the purpose of the Oil Budget Calculator since it is only about the oil budget. We have tried to stay as close as possible to the standard ICS 209 output categories. See new Appendix that includes that part of the ICS 209 form that deals with the oil budget.

The pie chart seems to be a good instantaneous visual for making decisions. If uncertainty could be built into the graphic, that would be very effective.

I think this is a point where you would finduniversal agreement among the Calculator developers. The challenge has been to provide that uncertainty explanation and yet keep the output graphic clear and understandable. We are still working on it. See recommendation number 6 at the end of Section 14.

My biggest criticism of the report is the handling of dissolution vs. evaporation of the oil. The discussion in Section 5 is good. It is most likely that dissolution of lower molecular weight hydrocarbons will occur at a much higher proportion for a deep water spill compared with a shallow water spill, especially as oil was dispersed. The processes of evaporation and dissolution, while similar, are not identical, and should not be treated as such in the sense that they will affect the composition of remaining oil differently. Of larger concern is that the composition of oil will be altered in sub-surface oil as well as surface samples, so the sampling protocols and expected compositions of oil would be different than for a shallow water spill. The ultimate fate of dissolved oil will not be considered with this model, and in some senses, dissolved oil is the most toxic as it is readily bioavailable. I would suggest the

dissolved quantities be separated from the evaporated quantities. Evaporative losses require no response as atmospheric processes act on wholly different spatial and temporal scales. The dissolved "losses" means that there is a significant amount of oil still in the ocean that needs consideration if not some hydrophobic recovery option.

Your points are well taken here and the group had considerable discussion about the merits of separating the two processes into two categories. Certainly, any environmental impact assessment calculation would be required to do that. However, this is strictly a response tool, and from the responder's point of view, there is no further cleanup applicable to evaporated or dissolved oil. Plus, we did not believe we had sufficient sample data to distinguish between the two overlapping processes. Therefore, we reluctantly kept them together. As more data become available, we may wish to revisit this decision.

The Longer Term Processes section was indeed needed in this report, even though it does not affect short-term response efforts. This section describes the processes of photodegradation and biodegradation. The literature review and discussion were good. A simple table illustrating the quantitative removal of various components of oil would be useful in communicating the fact that photo- and biodegradation are important processes that can remove (or at least change composition) of a significant amount of oil in the environment. Conditions (mainly temperature and depth) need to be included. This understanding of longer term impacts should affect decisions that are made in the short term, in that the ultimate fate and impact of the oil must be weighed against costs of response.

We included the section on longer-term processes to provide background to those who are new to spill science. We are wary of expanding this section because there are others preparing much more complete and detailed analysis on these phenomena that should be the true reference sources on the subject.

In the assessment and future plans section, #2 states that practical operational tools are needed to characterize droplet size. Has the LISST-100 (Sequoia) particle size analyzer been considered? It measures particle size in 32 size class bins from 1-55 um by laser, Mie scattering. An Optical Plankton Counter (e.g. Brooke Ocean Technologies)uses laser shadow graphs to measure particles from 100 um to over 1.5 mm. If these instruments cannot be used, it would be useful to know why not. If they were not tested, maybe they could be mentioned in the future plans section.

As noted in Appendix 7, the LISST-100X was used for particle size analysis

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on the R/V Brooks McCall and the R/V Ocean Veritas. The accompanying documentation outlined the limitations of using the LISST in the bench-top mode for the provision of data for the calculation of total dispersed oil for calculation of mass balance. However, the mission was to verify if the chemical oil dispersants were effective by quantifying the formation of smaller oil droplets and to identify the presence of the subsurface oil plume. This was conducted successfully. However, in the bench top mode utilized, explained in Appendix 7, the team could not trust the data in the larger size class bins. At the time of the spill, Sequoia had discontinued the manufacture of of a LISST for deepwater deployment (>300m for the LISST-100X) due to the lack of sales (and apparent problems with leaks). A LISST DEEP (depth range of 2500-6000m) is now in production as direct result of demand generated by the Gulf of Mexico spill that will resolve some of the limitations of using the LISST in bench top mode.

A Laser Optical Plankton Counter (LOPC), developed by Dr. Alex Herman at Department of Bedford Institute of Oceanography, Fisheries and Oceans Canada, measures particles >100um. NOAA is currently deploying a LOPC with a *Moving Vessel Profiler* (MVP™) in the Gulf of Mexico. A new prototype for the monitoring of plankton in ballast water with a lower size limit of > 20 um is being evaluated. For the sampling work in the Gulf of Mexico, the sampling team chose to use the LISST-100X as chemically dispersed oil typically results in an increase in oil particles in the <10um size range. It is important to note that both the LISST and LOPC cannot distinguish oil droplets from other particles.

Regarding future plans, there is a need to evaluate the various other in situ instruments that may be capable of measuring of oil droplet size. Years ago, Dr. Jim Bonner at Texas A&M evaluated field instruments including the LISST for real time in-situ crude oil concentration measurements but not oil droplet size distributions.

For work in the Gulf of Mexico, the sampling team chose to use the LISST-100X as chemically dispersed oil typically results in an increase in oil particles in the <10um size range. It is important to note that both the LISST and LOPC cannot distinguish oil droplets from other particles.

Figures 4&5 of the Web-based tool section were informative in that the estimates were fairly close from worst case to best case so that the inherent uncertainty was not very large. I would agree with the report that some visual representation of the uncertainty in the calculator would help decision makers dramatically.

We agree.

Reviewer 11:

The report contains a lot of good information, and the approach to the budget calculations is sound. However, the draft could be improved in several ways. Firstly, it is somewhat uneven in its coverage (e.g., stronger coverage of surface processes such as evaporation and surface dispersibility than on corresponding sub-surface processes). Secondly, it would benefit the reader to include results of at least the base case budget, obtained using the calculator, in the main text and the Executive Summary, instead of just the appendix. Most importantly, I wonder if the motivation for the report should be expanded. The stated objective was for "response advice only and…not… any other purpose." This may be literally true but it seems very limited. Everyone understands that there was at least some oil in each of the "pieces of the pie", and there was a tacit assumption that it was worth responding to any oil that was amenable to clean-up. (A lot of effort was put into skimming surface oil even though it only amounted to 3% of the total release.) Do we really need a budget calculator for this purpose? Given the enormity of the spill, its environmental consequences, the fact that the opportunity for most clean-up procedures has passed, the threat of future spills, and our uncertainty regarding much of the science, a far more important motivation would to better understand the underlying processes affecting the oil's fate. And this calculator makes a good place to start. More specific comments (many minor) are provided below by section.

The Oil Budget Calculator was developed to meet response needs only and the group would strongly counsel against using it for any other purpose. The report was written to document for the external scientific community the inner workings of the Calculator and provide recommendation for future research.

Page 8 (and elsewhere). In several places the report refers to dispersed oil "at" the bottom. "Near" the bottom would be more descriptive.

Page 8. In calculating the chemically dispersed "bottom" oil (eq 2), the factor 90 is not explained. Nor is the factor 20 in eq 7 in the subsequent discussion of chemically dispersed surface oil. (I assume these relate to the respective DORs?)

Your assumption is correct. The two values relate to the respective maximum DOR and are used in the equations as scaling factors so that the rate constants will have a maximum range of 0-1.

Page 9. Since chemically dispersed surface oil is time dependent (efficiency

decreases with weathering, like evaporation), was consideration given to introducing time dependent (day 1, day 2...) values for k_3 as is done for evaporation (k_4 and k_5)?

This was considered. However, surface dispersant operations were applied to oil slicks at various states of weathering. Therefore, it would have been logistically impossible to assign a t-value to the sprayed surface oil.

Page 11, paragraph 2 mentions "Current news reports..." and Page 12, paragraph 1 mentions "At the time of this document preparation...". Better to include the date (or at least month) since the information may not be current when it is read.

Page 13, paragraph 2. The Clark et al (2010) study estimates a minimum amount of surface oil on May 17 as 66,000 to 120,000 bbl, but implies the value could have been as high as 500,000 bbl (a little less than 1/3 of the oil spilled at that point) which is the value used in the calculator. This fraction (~1/3) seems quite high, especially since, subsequent to May 17, sub-surface recovery and dispersant use would dramatically reduce the oil reaching the surface, and ongoing evaporation and natural surface dispersion would reduce the equilibrium fraction of oil on the surface.

The NASA/AVIRIS system was measuring cumulative oil remaining on the surface by mid-May. Through April and early May, burning, direct capture, and subsurface dispersant usage were limited, leaving more surface oil. Some of this early oil, probably emulsified, would still be on the surface during the NASA ER/2 flights. However, we agree that this would be at the high end of our estimates.

Pages 13 (bottom) and 14 (top) discuss the gas portion of the release and mention that a large portion of the gas dissolved and hence may never have made it to the surface. Is there observational evidence (or modeling) that suggests that ANY significant fraction of the gas made it to the surface? The paragraph mentions the potential for hydrate formation. Clearly hydrates were formed within the confining spaces of some of the earlier containment vessels, but was there evidence of their formation in the free plume? (If so, please indicate.) Since the principle components of natural gas (methane, ethane and propane) have different hydrate stability zones, it would be helpful to know the composition of the natural gas. Concentrations are given in Appendix 4, but I gather this is just for the oil. Steve Masutani from U. Hawaii performed some nice experiments demonstrating the effect that an oil film has in inhibiting hydrate formation on a gas bubble (Masutani and Adams, 2000).

See revised text. Leifer (2010) modeled plume behavior based on observations presented in Camilli et al. (2010) and concluded that the gas phase of the plume dissolved in the mid-water column and deeper and was transported by oil plume processes to the thermocline. Only gas components dissolved in oil reached the sea surface to exsolve and evaporate. As a result, atmospheric measurements (Leifer et al., 2010, in progress) do not show enhancement in atmospheric methane (except associated with flaring). In contrast, hexane and large organic compounds were enhanced. Tow sled video data (Asper, unpublished, 2010), showed extensive plumes of orange-white material uncommon to the deep sea (i.e., not marine snow), which was interpreted as oily hydrate flakes in the depth where others have reported enhanced CDOM (a fluorometric indicator of oil, albeit with very poor sensitivity).

Leifer, I., et al. (2010 in progress), Air quality implications of the Great Macondo Oil Spill.

Page 14, last paragraph. It is mentioned that the tiny oil droplets were continually exposed to uncontaminated Gulf waters and hence their dissolution was not controlled by equilibrium factors. It seems likely that much of the sub-surface oil was contained in thick (hundreds of meters in the horizontal and at least tens of meters in the vertical) intrusions with fluxes of thousands of cubic meters per second. So even without exposure to ambient GoM water, dissolution would not likely have been constrained by equilibrium build-up.

Point noted. The development team is cautious about reaching extensive conclusions on dissolved hydrocarbons while studies are ongoing.

Page 15 (Fig 4 on droplet rise velocity). It would be helpful to give the density of the oil that was assumed, and to expand the graph to the physically more interesting lower diameter range.

The graph was meant to illustrate the fact that the rise velocity for even larger droplets was small enough that the transit time to the surface was long. See the discussion and reference by Spaulding. The fresh oil density was 0.85 gm/cm3 (API 35).

Page 15 (and elsewhere). Much of the most useful information in the report has been provided by the experts, and cited as personal communication (Yapa on this page; also Galt, Lasheras elsewhere) or unpublished reports (Lewis). Can additional information be provided when there is no formal reference?

Common in spill response is research that is used before it is formally documented. The Oil Budget Calculator is one example. We hope that these

experts will formally publish their findings but are reluctant to release their private communications beyond what is necessary in the report. In all cases we have tried to cite published references to supplement their unpublished comments.

Page 17, paragraph 2. It was estimated that any oil exposed to conditions that could lead to dissolution would lose 5-10% of its volume... Presumably this explains the mean value of 0.075 for k_7? (It would help reinforce the readers' understanding if this was mentioned.) Can the authors relate Fig 6 showing the dissolution potential vs C-number to the oil composition in Appendix 4 to show the reader where the 5-10% comes from?

A dissolution potential of 5-10 % is a rough estimate based on earlier experiences from dissolution studies of various oils (referred to Melbye et al 1999 in the report) and with the present available chemistry of the DWH crude oil. Unfortunately, the detailed chemistry of the BTEX'es are not specified in the appendix 4 data. (which will be a significant contribution to the dissolution potential). That is why we ended up in this relatively wide span of 5-10 %. It is therefore difficult to directly relate the dissolution from the chemistry data in appendix 4 to Fig. 6.

More specific estimate of the dissolution potential will be calculated when the more detailed data of the crude oil chemistry are available.

Page 22 (Figure 8, and others like it). The range of volumes (mean and with uncertainty) relative to the total spill (4.9 Mbbl) is clear, but what does the placement of the colored bar mean? Is there a horizontal bar chart invisioned that aims to add all of these up? (I know there is a pie chart in Appendix 2.)

Figure 8 and similar figures have been removed

Pages 21 (bottom) and 22 (top). The discussion of emulsification is useful but brief. Where do the percentages (16 to 38) come from?

Most crude oils and petroleum products require weathering (evaporation) before they will form emulsions (NAS, 2000) This weathering is necessary to increase the viscosity and the asphaltene/resin content to the point where the next water-in-oil type is possible. Oils from similar oil fields have a tendency to form similar emulsions with similar weathering tendencies. It should also be noted that there are some exceptions to this as well. Table 2 shows the emulsification tendencies of Gulf of Mexico oils (Fingas, 2009). Table 2 shows that oils that formed stable emulsions had weathering percentages of 37.7, 26.2, 16.4, 25.5, 22.6, 24, and 35.2%. These averaged 26.8%.

1 NAS, *Oil in the Sea III, Inputs, Fates and Effects*, National Research Council, National Academies Press, Washington, D.C., 2002

2 Fingas, M. and B. Fieldhouse, Studies on Crude Oil and Petroleum Product Emulsions: Water Resolution and Rheology, *Colloids Surf. A*, 67, 2009

Table 2	Stable Emulsions from Gulf Oils										
	Weathering	to form emulsions								Complex	Water
Oil	%	Visual	Density							Modulus	Content
	evap.	Stability	(@15C)	Viscosity	Saturates	Aromatics	Resins	Asphaltenes	Stability	(mPa)	(%w/w)
Garden Banks 426	37.7	Stable	0.8993	136	56	32	10	3	588	8.00E+04	64.7
Mississippi Canyon 72	26.2	Stable	0.9095	195	52	34	11	3	1128	2.20E+05	74.4
Mississippi Canyon 807	16.4	Stable	0.9375	491	39	41	13	7	111	5.45E+04	67.5
Mississippi Canyon 807	25.5	Stable	0.9582	3454	31	43	18	8	46	1.60E+05	65.4
Neptune Spar (Viosca Knoll 826)	22.6	Stable	0.8986	187	61	29	8	2	4947	9.25E+05	62.5
Viosca Knoll 826	24	Stable	0.9067	325	59	29	8	3	1046	3.40E+05	64.1
Viosca Knoll 990	35.2	Stable	0.8905	91	62	28	8	2	1075	9.8E+04	63.9
average	26.8										
of weathering of Louisiana											
crudes to yield Stable emulsions											

Were there no direct measurements of emulsification in oil samples from the DWH spill?

Only very limited emulsion analysis was available at the time of the Calculator construction. It indicated a weak and easily broken emulsion.

How has percent emulsification been used in the budget? Was it used? (Since emulsified oil was skimmed and presumably could no longer be evaporated, does it matter to the budget calculator what its percentage was?) Where does the analysis from Appendix 7 enter the discussion?

The observed tendency of the oil to emulsify was used in reducing the effectiveness for burning and surface dispersion.

Page 22, Section 8, paragraph 2. Is there a reference for "Payne reports plumes of oil droplets…"?

See reply to the Fourth Reviewer of a similar question.

Page 23, paragraph 2 mentions that using 100 microns as an upper bound diameter for dispersible droplets is conservative (presumably in view of the fact that somewhat larger droplets are also slow to rise). It should be mentioned that this is conservative in that it may overestimate the amount of oil reaching the surface, but is NON conservative in estimating the oil retained sub-surface. Aren't both fractions important?

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By overestimating surface oil, and hence oil that potentially could be subject to further recovery, we meet the Calculator definition of conservative. It may not be conservative in regard to environmental impact.

Page 23, eq 12. Is the ratio reversed? As written R appears to be the dispersed mass due to leaking pipe divided by dispersed mass due to breaking waves

Corrected expression inserted

Page 24, top. There is a huge (2.5 order of magnitude) difference in the predicted "theoretical" dissipation rate (Eq 13) of 7 m^2/s^3 and the Martinez-Bazen et al. (1999) value of 0.02 m^2/s^3 (rate = 0.003 U_o^3/D_o). The latter rate is based on actual measurements, but the measurements are for a pure water jet near the orifice, while the dissipation rate in a real oil/gas leak would be higher due to the turbulence introduced by the bubbles and droplets. Thus the real dissipation rate is likely to be in between as the authors state. (It would help to give the exit velocity and pipe diameter so that the reader could verify these computed dissipation rates.) Compounding the uncertainty in dissipation rates are the differences between a sub-surface oil plume and a surface oil slick. A sub-surface oil plume is reasonably steady and uniform (in an Eulerian framework), whereas surface wave conditions are quite patchy over space and time scales of tens of meters and hours. On the other hand, surface oil has a time window of a few days during which it is dispersible, while an oil parcel traveling through a plume has a window of only a few tens of seconds, since dissipation rate drops off rapidly with distance. (The dissipation rate is proportional to the plume velocity (which decreases) cubed divided by the plume diameter (which increases).) In view of the above, quantitative calculation of the rates of subsurface and surface natural dispersion are quite uncertain. Also, could the authors provide more explanation as to where the 10 to 30% figures come from?

Your observations are correct and illustrate the challenges faced in estimating subsurface dispersion, both natural and chemical. One of the unsettled points among the experts, for example, was whether there was sufficient mixing time between the surfactant and the oil for effective dispersion. Following the rule to be conservative, the lower dissipation rate of Martinez-Bazen is used, minimizing natural dispersion and increasing oil on the surface. The minimum natural dispersion value is considered to be the lowest credible estimate consistent with Camilli et al. (2010) and the maximum the largest estimate consistent with the AVIRIS and LISST results.

Information on exit velocity and pipe dimensions can be found in the FRTG report, Deepwater Horizon Release, Estimate by PIV, 215 pp. (2010),

available on the USGS Deepwater Horizon website.

Page 31, second paragraph. It would be helpful to have more information about how the dispersants were added sub-surface. For example, how close to the plume was the narrow diameter wand held by a ROV? The high plume velocity would have introduced an entrainment (radially inward towards the plume) velocity of about 10% of the local plume centerline velocity, and this entrainment velocity should have carried dispersant into the plume if it were released anywhere near the plume edge.

The team did not have access to videos of dispersant injection, only data on the volume of dispersant used.

Page 31, bottom. There appears to be little consensus among the report authors as to the effectiveness of sub-surface dispersant use, making this a prime topic for further research. My feeling is that it was probably quite effective. In addition to the arguments presented by "Alternative View 2" on page 29, we know that vertical profiles of fluorescence (indicating oil), typically showed a major intrusion a few hundred meters above the seafloor, with much smaller intrusions similarly spaced above the first intrusion. (See figure from one of the R/V Brooks McCall surveys below.) I believe that the intrusions contain oil that is detrained (along with seawater) from the plume as it ascends through a density-stratified ocean and passes a level of neutral buoyancy. Such detrainment events are clearly evident in laboratory measurements of gas and water plumes (Socolofsky and Adams, 2002, 2003). Oil droplets would follow the seawater into the intrusion only if they were small, with insignificant rise velocity, as if chemically dispersed. (A small amount of dissolved oil could also be included in the intrusions.)

Many of our experts would agree with your conclusions. Unfortunately, others, including another reviewer, disagree. All would agree that there is little consensus on the subject and further research is required.

Appendix 1 (Uncertainty). I did not have time to do this section justice, but it appears to be solid. I do question if the k-values in Table A1.2 should be called "rate" constants. Rate constants usually have dimensions of reciprocal time, whereas the values of k are dimensionless.

We have used the expression "rate constant" by force of analogy with chemical kinetics, and agree with the reviewer that this may not have been the most accurate characterization for these constants: alternatives that came to mind, including "efficiency constants" and "yield factors", also suggest analogies that could be deemed deficient. Since we believe that the risk of misinterpretation is minor, we have chosen to retain this expression.

Appendix 2 (Oil budget calculator). The appendix should have a number (2) and its title should match that listed in the TOC. (Appendix 5 also needs a number.) These are small points, but "Figures" 1 and 3 are actually tables. It would also be nice to make the figure and table numbering consistent with the rest of the report, e.g., Figure A2.1, etc. Similar comments apply to other appendices.

Appendix 5 (SINTEF dispersibility study). The MNS tests were conducted for 5 minutes; for how long were the IFP tests conducted? Was there any thought given to similar studies with sub-surface oil like that in the plume (unweathered but subjected to relatively high energy for short periods of time)?

Appendix 6 (LISST measurements). Paragraph 1 of page 1 refers to both bench top LISST measurements (of collected samples brought onboard) and continuous in-situ measurements with the instrument deployed at specific depths. The text only describes the former. Were the in-situ measurements not useful? It seems they would have avoided some of the issues described on pages 2 and 3 concerning the finite handling times and corresponding loss of large droplets. I gather that the droplet size distributions (both discrete and cumulative) are number distributions, but it is not clear. For example, the captions for Figures 5-8 indicate that the figures plot the FRACTIONS of the total measured particles that are small, while the text that refers to these figures (third paragraph of page 3) suggests that the vast majority of VOLUME fractions ...are ...small. Assuming the plotted distributions are by number, it would help to also include cumulative mass (or volume) distributions so the reader could determine the droplet diameters below which a give portion of the dispersed oil was contained. The text mentions (last paragraph of page 3) that the median diameters are nearly 20-30 microns; however my reading of Figures 9-12 suggest that these ranges are closer to 9 to 16%. Figures 4, 5, 8, 9 and 12 are mis-numbered. It would also help if figure numbers were consistent with the whole oil budget calculator report instead of (or in addition to) starting over with each new appendix. (This comment refers to several appendices.)

The in situ measurements are very useful. The data analysis is currently ongoing and cannot be included here due to the deadline of this report.

All the LISST data presented in this appendix are based on volume concentration and are expressed in ul/l. This is stated on the first page of this Appendix.

Figures 4,5,8,9 and 12 were mislabelled. Their corrections are suggested in this response (see 2 above).

Note the x-axis of Figures A7-9~12 (Cumulative particle-size distribution is expressed as bin number, see Table 2 of this appendix for corresponding lower, medium, and upper size of each bin. For example, bin # 9 has medium size of 10.2um, and bin # 16 has medium size of 32.5 um.

Appendix 7 (Ross oil properties report). Table 2-2 gives MC252 oil properties at temperatures of 15 and 35 °C. What was the temperature of the oil as it emerged from the pipe? Much of the oil resided/resides in intrusions a few hundred meters above the seabed where the temperature is ~5 °C. It would help to know oil properties (especially density) at these temperatures. Can the authors suggest a reasonable way to extrapolate from the data at 15 and 35 °C? It is too bad that the emulsification tests were conducted with a 2 cm thick oil which is mentioned in the text as a possible reason the oil in the lab did not emulsify, while the oil in the field did. It makes sense to repeat the tests with a 1 mm thick sample as suggested. Has this been done already? Also why would a 20 mm thick sample weathered for two weeks (336 hr) correspond to a 1 mm field sample exposed for 10 hrs? Wouldn't it be 336/20 = 17 hrs?

Appendices 5 through 8 reproduce already published reports reprinted here with the owners' permission to provide completeness to the report. We cannot modify them. However, the author of Appendix 6 has offered the following reply. The IFT test is a dilution test conducted over a test periode of 1 hour. Both the medium/high energy MNS method and low-energy IFP method are both standard laboratory methods designed to test the relative effectiveness of dispersnt applied on surface oil/emulsions. In order to simulate and study the effectiveness of dispersant injection into a sub-surface oil plume, special designed laboratory test systems have to be constructed.

Appendix 8 (Expert resumes). Michel Boufadel is not represented.

He is now included

References

Masutani, S., and E. Adams. 2000. Experimental study of multiphase plumes with application to deep ocean oil spills. Final report to U.S. Dept of Interior, Minerals Management Service. Contract No. 1435-01-98-CT-30946. http://www.mms.gov/tarprojects/377.htm.
Socolofsky, S. and E. Adams. 2002. Multiphase plumes in uniform and stratified crossflow. J. Hydr. Res., 40: 661-672.
Socolofsky, S. and E. Adams. 2003. Liquid volume fluxes in stratified multiphase plumes. J. Hydr. Engrg. 129: 906-914.

Reviewer 12:

Overall, a very good document. I have only minor suggestions to offer.

Page: 3, Executive Summary
I really like the line "It is important to remember that the Deepwater Horizon incident was an emergency, not an experiment" from your introduction on page 5. You should consider incorporating it somewhere in your Executive Summary.

We also thought it was an important point but concluded that it would require too much additional explanatory material if it was added to the Executive Summary.

Page: 20, 1st paragraph
Since you mention the temperature of the oil here, it might be helpful to state the relationship between the oil's temperature and water temperature if it has not been previously stated.

Oil temperature is assumed to be the same as the water temperature. Report is revised to clarify this point.

Page: 21, 2nd full paragraph
In the sentence beginning with "The stronger color …" , replace the word "stronger" with "darker".

Page: 22
Figure 8 (and the other, similar figures) is a confusing graphic. I understand what the writer is trying to do, but this is unconventional to the point that it may cause confusion for some readers. It contains too many elements that are not important: height of the box and position of the shaded portion within the box.

Figure 8 and similar figures have been removed.

In Section 8, 2nd paragraph
The acronym LISST should be defined (Laser In-Situ Scattering and Transmissometry) at first use.

Page: 23
First paragraph
I can't tell if the sentence beginning with "ADIOS2 suggests that …" is part of the previous paragraph or if it's supposed to be the start of a new paragraph.

Second paragraph,
For the sentence beginning with "Also, ADIOS2, following …" delete the word "Also" so that the sentence reads "ADIOS2, following standard guidelines …".

Page: 25, 2nd paragraph
In the sentence beginning with "As before, the stronger color …" , replace the word "stronger" with "darker".

Page: 26
There's something wrong with the color assignments for the bars in this graph. There's some strange optical effect that makes it difficult to view.

Adjusted.

Page: 27
Second paragraph, second sentence
Add the phrase "and regionally approved" so that it reads "… is a Federal cooperatively designed and regionally approved …".

Figure 11
What is the blue rectangle that overlaps the 5/10 A.M. circular image?
Also, the legend for this figure is not legible.

Figure replaced

Last paragraph
There's a typo in the sentence that begins with "If the dispersant …" after the word "half" there's an "=" sign that shouldn't be there.

Page: 28
Second paragraph
The sentence that reads "Analysis was undergoing at the time …" should read "Analysis was ongoing at the time …".

Third paragraph
The sentence that reads "Given this limited nature …" should read "Given the limited nature …".

Reviewer 13:

The document is longer than I expected with 156 pages and the content goes well beyond my own expertise.

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The document addresses an urgent and difficult problem of estimating oil budget in the gulf due to the Deepwater Horizon Spill. Moreover, the authors tried to simplify the process so that the output (Calculator) can be used by non-specialized staff. The various kind of simplification leads to huge uncertainties. The authors have done a very good job in addressing many of these uncertainties. However, I'm not fully convinced that all these uncertainties are properly quantified (this is due partly to the limited time and the length of the document). There are also a few other minor issues:
1. Low resolution of some of the mathematical symbols and equations;
2. A few misconception (typo) such as the relationship between the kinematic viscosity and dynamic viscosity in A.2.2.

Reviewer 14:

General thoughts on each section:

1. *Introduction: no comments*
2. *Purpose and brief description: seems well thought through. The formulae seem to be well constructed and shouldn't lead to absurdities like more oil evaporating than leaving the well head. However, it seems that something like this should have appeared in the literature already from previous disasters yet there are no citations in this section.*
3. *Previous experience Ixtoc: Good discussion of most relevant previous case.*
4. *Leak Rate and Subsurface Oil Behavior: good discussion, no criticisms.*
5. *Dissolution: well referenced but out of my area of expertise*
6. *Evaporation: "To simplify data entry, requirements to enter variable wind speeds were eliminated. Cumulative evaporation is sensitive to oil composition and temperature but is relatively insensitive to wind speed." This statement should be supported, preferably with a citation to the literature. Evaporation rates depend strongly on temperature and also on the relative saturation of the air with the compound evaporating (for example, relative humidity in the case of water evaporating). It may be that keeping track of wind speed is prohibitively complicated and the model needs to be simplified but that argument is not well made.*

While the evaporation rate is sensitive to wind speed, cumulative evaporation depends upon the mole fractions of the hydrocarbons that make up the oil. If high wind on day 1 cause large amounts of evaporation, there will be less volatile hydrocarbons the next day, slowing evaporation rate. Calm winds on the first day lowers evaporation, making more of the volatile factions able to evaporate later. The cumulative fraction remains much the same after a

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few days in both cases, although second order effects such as evaporation reducing oil available for dispersion exist, but are not included in the calculator.

7. *Weathering Estimation by Emulsification: no comment*
8. *Natural Dispersion: good discussion, good references to the appropriate literature*
9. *Chemical Dispersion: there seems to be quite a diversity of opinion on the effectiveness of dispersants. In keeping with the nature of this report, a judgment needed to be made to estimate the amount of oil remaining in the sea. However, it is clear that more scientific research needs to be conducted into the use of dispersants, both on the surface and sub-surface.*
10. *Burning: good discussion*
11. *Mechanical Recovery: good discussion*
12. *Other Oil: this seems to be another area of considerable uncertainty.*
13. *Longer Term Processes: another area for future research.*
14. *Assessment and Future Plans: it is clear that we should learn from this terrible disaster. I hope that the recommendations (some of which I echo in my review) of this panel for future research are heard and acted upon so that we can more effectively respond to future accidents.*

Itemized list of spelling and grammar errors

Page 9, the following sentence fragment does not make sense: "Disperse the surface oil that is available for surface dispersion, after subtracting evaporation and burning,…"
Page 11, "chocolate mouse" should be "chocolate mousse" unless the quoted source also made this mistake.
Page 12, "The DOE/FRTG consensus generally accepted a average value of 44% oil percentage by …" 'a' should be 'an'.
Page 13, "This is considerable larger than the common maximum…", should be 'considerably'.
Page 13, Figure 3 has text on it saying "62 bopd" and the like. These labels should say "62 kbopd".
Page 20, "the two weathered oils (green and purple) collected from th sea surface on or around 16 May." The word 'the' is misspelled.
Page 22, "Payne reports plumes of oil droplets at depth over 2 km." awkward sentence.
Page 27, "…then more than half =of the released oil…" misplaced '='.

ED_001324_00007564-00215

Oil Budget Calculator

Deepwater Horizon

Layout and design by Jason D. McIntosh - www.5dcreative.com

To: Conmy, Robyn[conmy.robyn@epa.gov]
Cc: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Wed 8/31/2016 3:20:44 PM
Subject: FW: ENVIRONMENTAL PROTECTION AGENCY - 40 CFR Parts 110 and 300 - [EPA-HQ-OPA-2006-0090; FRL-9689-9-OSWER] - RIN 2050-AE87 - National Oil and Hazardous Substances Pollution Contingency Plan - ACTION: Proposed rule.
Comments on EPA 40 CFR Parts 100 and 300Proposed Merv.doc
EPA-HQ-OPA-2006-0090-0266_PWSRCAC.pdf

R:

Did you get pinged by Merv on the BFT/other testing protocol for Sub J? We got this message from ERT.

Attached are new comments from Merv (Word Doc) as well as the PWSRCAC comments (PDF) that were submitted to the public docket. What they/Fingas are now sending seems to be an excerpt/reshuffle from pages 31-40 of their submission. Thinking we would respond to Fingas with something like:

Thank you for your interest in the proposed regulatory amendments to Subpart J of the National Contingency Plan. Please note that the Agency had already received in the public docket comments from the Prince William Sound Regional Citizens Advisory Committee (PWSRCAC), and will be considering them along with all other public comments submissions.

The Agency will acknowledge these comments received as late comments given that the public comment period is now closed.

Were just wondering. V

From: Mickunas, Dave
Sent: Wednesday, August 31, 2016 8:42 AM
To: Wilson, Gregory <Wilson.Gregory@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>
Cc: Merv Fingas <fingasmerv@shaw.ca>

Subject: ENVIRONMENTAL PROTECTION AGENCY - 40 CFR Parts 110 and 300 - [EPA-HQ-OPA-2006-0090; FRL-9689-9-OSWER] - RIN 2050-AE87 - National Oil and Hazardous Substances Pollution Contingency Plan - ACTION: Proposed rule.

Good Morning,

Dr. Fingas headed and developed the Environment Canada's oil program for many years and still is very involved with this field since his retirement. He requested that I contact someone involved with the above document. As a member of the Prince William Sound Regional Citizens Advisory Committee (PWS RCAC), he has concerns with the methods that are employed with this document. Please see his comments in the attached file. He is requesting that the testing data and rationale be provided for the changes to the previous used techniques. If you are the correct individuals to discuss this information, please contact Dr. Fingas directly. If not, please forward this request to the proper party. If you have any other questions or comments, please contact me.

Best regards,
David B. Mickunas
Trace Atmospheric Gas Analyzer (TAGA) Laboratories Coordinator
US EPA/Environmental Response Team
109 T.W. Alexander Drive
Mail Code E343-04
Research Triangle Park, NC 27711
919 541 4191 (office)
609 865 1574 (cellular)

Comments on EPA 40 CFR Parts 100 and 300
Proposed Rule

by

Prince William Sound Regional Citizens Advisory Committee
(PWS RCAC)
Anchorage, Alaska

General

These comments will be related in more detail to specific sections in the proposed rules.
1. Use of Standards - The committee is surprised that many of the proposed methods do not use established standards. In fact in some cases, inappropriate methods are proposed when there are standards already in existence by well-known standardization agencies such as ASTM, ANSI, ISO, etc.

Specific Comments

Page 65-66 - TPH measurement - Standard methods should be noted for TPH method. These include:
-ASTM, Standard Test Methods for Comparison of Waterborne Petroleum Oils by Gas Chromatography, ASTM Method D3328-06, ASTM International, West Conshohocken, PA, 2011
-American Society for Testing and Materials (ASTM). Oil spill identification by gas chromatography and positive ion electron impact low resolution mass spectrometry. ASTM D5739–00, ASTM International, W. Conshohocken, PA. 2010
-US EPA, Volatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8260D. The U.S. Environmental Protection Agency's Office of Solid Waste
-US EPA, Semivolatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8270D. The U.S. Environmental Protection Agency's Office of Solid Waste
-EPA 610 –Polynuclear Aromatic Hydrocarbons
-EPA 8000a- Determinative Methods for Chromatography
-EPA 8100a- Polyaromatic Hydrocarbons
-CEN (European Committee for Standardization), Oil Spill Identification-Waterborne Petroleum and Petroleum Products. Part 2: Analytical Methodology and Interpretation of Results, CEN/TC BT120, 2010
-US EPA, Semivolatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8270D. The U.S. Environmental Protection Agency's Office of Solid Waste
-Nordtest, Oil Spill Identification, Method NT CHEM 001 (2nd ed.), ISSN 0783-l 692, Finland, 1, 1991 (Current 2015)

Page 87 - 92 - Baffled Flask Test - PWS RCAC is surprised that a non-standard method is proposed for this testing when there are standard tests which are used around the world (ASTM F2059-06(2012) Standard Test Method for Laboratory Oil Spill Dispersant Effectiveness Using the Swirling Flask). More will be stated about this later, as the PWS RCAC notes that the proposed analytical method to be used with the Baffled Flask Test is non-standard and inappropriate and does not follow EPA's own standards. Alternatives to this could include – substituting a standard method for the colorimetric one (UV adsorption); such as one of the TPH methods noted above, substituting the analytical method in the Swirling Flask standard or adopting the ASTM standard Swirling Flask.

Page 186 and on – Baffle flask test – Of particular concern is the use of an unacceptable and non-standard analytical method (UV absorption – actually colorimetric). There are many concerns with this:

1. The methods have never been reviewed in a chemical journal – the references of Sorial and Venosa are published in Engineering journals.
2. The authors are not chemists: Sorial is an engineer, Venosa a biologist, Koran, etc. are engineering students
3. This is akin to a chemist publishing a new toxicology method in a chemical journal. This would have no credibility.
4. Acceptable chemical methods would need to be published in journals such as Talanta, Journal of Chromatography, Trends in Analytical Chemistry, Spectrochemica
5. The proposed method is contrary to science – Oil does not have an absorption band. Oil consists of thousands of compounds, each of which reacts with light in a different way.
6. This method has long since been shown to be flawed and incorrect. (Fingas, M.F., B. Fieldhouse and Z. Wang, "Dispersant Testing - Study on Analytical and Test Procedures", in *Proceedings of the Twenty-Seventh Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 807-841, 2004 and Fingas, M.F., B. Fieldhouse, Z. Wang, L. Sigouin, M. Landriault and J.V. Mullin, "Analytical Procedures for Dispersant Effectiveness Testing", in *Proceedings of the Twenty-Second Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 231-241, 1999)
7. All chemical analytical methods should adhere to the 3-C's principle – Certified chemists working in Certified laboratories using Certified procedures.
8. There are many labs who can do the swirling flask test in an appropriate way.
9. Why propose a new method when a standard one has been perfected over 20 years?
10. No reference standards are proposed with the colorimetric method.
11. If one does a literature search on chemical analysis for oil one finds thousands of references – not one of which refers to UV adsorption or colorimetry.
    Examples of a few of thousands of such references are:

-Drozdova, S., Ritter, W., Lendl, B., Rosenberg, E. Challenges in the determination of petroleum hydrocarbons in water by gas chromatography (hydrocarbon index), 2013 **Fuel** 113, 527-536
-Fingas, M., Fieldhouse, B., Wang, Z. Dispersant testing - Study on analytical and test procedures 2004, Environment Canada Arctic and Marine Oil Spill Program Technical Seminar **(AMOP)** Proceedings,27, 2, 807-817
-Wang, Q., Yan, Z., Sun, B., Zhu, X., Liu, H. The application of GC in the study of the effect of oil spill dispersant, 2014, **Journal of Chemical and Pharmaceutical Research**, 6, 5, 106-111
-Bowman, D.T., Slater, G.F., Warren, L.A., McCarry, B.E. Identification of individual thiophene-, indane-, tetralin-, cyclohexane-, and adamantane-type carboxylic acids in composite tailings pore water from Alberta oil sands 2014 **Rapid Communications in Mass Spectrometry**, 28, 19, 2075-2083
-Fabbri, D., Adamiano, A., Torri, C., GC-MS determination of polycyclic aromatic hydrocarbons evolved from pyrolysis of biomass. 2010, Analytical and Bioanalytical Chemistry, 397, 1, 309-317

-Sauer, T., Boehm, P. The use of defensible analytical chemical measurements for oil spill natural resource damage assessment 2005, 2005 International Oil Spill Conference, **IOSC** 2005 8817

Alternatives to the flawed analytical method could include –

1: substituting a standard method for the flawed colorimetric one (UV adsorption); such as one of the TPH methods:

-ASTM, Standard Test Methods for Comparison of Waterborne Petroleum Oils by Gas Chromatography, -ASTM Method D3328-06, ASTM International, West Conshohocken, PA, 2011

American Society for Testing and Materials (ASTM). Oil spill identification by gas chromatography and positive ion electron impact low resolution mass spectrometry. ASTM D5739–00, ASTM International, W. Conshohocken, PA. 2010

-US EPA, Volatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8260D. The U.S. Environmental Protection Agency's Office of Solid Waste

-US EPA, Semivolatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8270D. The U.S. Environmental Protection Agency's Office of Solid Waste

-EPA 610 –Polynuclear Aromatic Hydrocarbons

-EPA 8000a- Determinative Methods for Chromatography

-EPA 8100a- Polyaromatic Hydrocarbons

CEN (European Committee for Standardization), Oil Spill Identification-Waterborne Petroleum and Petroleum Products. Part 2: Analytical Methodology and Interpretation of Results, CEN/TC BT120, 2010

-US EPA, Semivolatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8270D. The U.S. Environmental Protection Agency's Office of Solid Waste

-Nordtest, Oil Spill Identification, Method NT CHEM 001 (2nd ed.), ISSN 0783-1 692, Finland, 1, 1991(current as of 2015)

2. Substituting the analytical method in the Swirling Flask standard but using the Baffled Flask ASTM F2059-06(2012) Standard Test Method for Laboratory Oil Spill Dispersant Effectiveness Using the Swirling Flask

3. Adopting the ASTM standard Swirling Flask which is a long-standing accepted standard ASTM F2059-06(2012) Standard Test Method for Laboratory Oil Spill Dispersant Effectiveness Using the Swirling Flask

Note, that in any case the numbers on page 174 and following would require replacing.

Page 205 – note that appropriate methods are suggested for analyzing TPH – these could be used as well to analyze the TPH in the Baffled Flask.

Regional Citizens' Advisory Council / "Citizens promoting environmentally safe operation of the Alyeska terminal and associated tankers."

In Anchorage: 3709 Spenard Road / Suite 100 / Anchorage, Alaska 99503 / (907) 277-7222 / FAX (907) 277-4523
In Valdez: P.O. Box 3089 / 130 South Meals / Suite 202 / Valdez, Alaska 99686 / (907) 834-5000 / FAX (907) 835-5926

MEMBERS

Alaska State Chamber of Commerce
Chugach Alaska Corporation
City of Cordova
City of Homer
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Community of Tatitlek
Cordova District Fishermen United
Kenai Peninsula Borough
Kodiak Island Borough
Kodiak Village Mayors Association
Oil Spill Region Environmental Coalition
Port Graham Corporation
Prince William Sound Aquaculture Corporation

April 16, 2015

EPA Docket Center (EPA/DC)
Docket ID No. EPA-HQ-OPA-2006-0090
1200 Pennsylvania Avenue NW
Washington, DC 20460

RE: Prince William Sound Regional Citizens' Advisory Council Comments on 40 CFR Parts 110 and 300, National Contingency Plan Subparts A and J

Dear Administrator McCarthy,

The Prince William Sound Regional Citizens' Advisory Council (PWSRCAC or Council) is an independent non-profit corporation whose mission is to promote environmentally safe operation of the Valdez Marine Terminal and associated tankers. Our work is guided by the Oil Pollution Act of 1990 and our contract with Alyeska Pipeline Service Company. PWSRCAC's 18 member organizations are communities in the region affected by the 1989 Exxon Valdez oil spill, as well as commercial fishing, aquaculture, Native, recreation, tourism and environmental groups.

The Environmental Protection Agency (EPA) proposed rule to update Subpart J of the National Contingency Plan is comprehensive and includes substantive technical and scientific analysis. PWSRCAC has reviewed the proposed rule and we submit these comments on behalf of our member organizations.

The enclosed document first presents a series of general comments that frame our major concerns and priorities. We then provide detailed comments and recommendations on technical issues raised in the proposed rule. PWSRCAC appreciate the opportunity to provide EPA with these comments.

Sincerely,

Mark Swanson
Executive Director

Amanda Bauer
Board President

Thane Miller
Vice President

Jim Herbert
Treasurer

Andrea Korbe
Member-at-Large

Bob Shavelson
Member-at-Large

Patrick Duffy
Member-at-Large

955.105.150416.SubpartJCmts

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General Comments

Council Position on Dispersant Use in Prince William Sound

PWSRCAC has taken a leading role in researching chemical dispersant efficacy and toxicity in our region. Our chemical dispersants program has been in place since 1997, and through this program we have funded a number of research studies, literature reviews, and technical analyses. In 2006, our Council adopted the following position on dispersant use in the Prince William Sound region:

> *After years of observing dispersant trials, dispersant effectiveness monitoring, advising and sponsoring independent research regarding chemical dispersant use, it is the position of the Prince William Sound Regional Citizens' Advisory Council (the Council) that dispersants should not be used on Alaska North Slope crude oil spills in the waters of our region. Until such time as chemical dispersant effectiveness is demonstrated in our region and shown to minimize adverse effects on the environment, the Council does not support dispersant use as an oil spill response option. Mechanical recovery and containment of crude oil spilled at sea should remain the primary methodology employed in our region.*

PWSRCAC appreciates the Historical Background provided by EPA in the Statutory Authority section of the proposed rule, because it affirms the longstanding preference for mechanical recovery as a primary oil spill response tool, with dispersants as an alternative **only** "if other control measures are judged to be inadequate or infeasible." This is an important concept that still applies today, as mechanically containing and recovering spilled oil is always preferred over other spill treatment options because mechanical recovery is the only option that removes oil from the environment.

While PWSRCAC does not support dispersant use in our region, we understand that chemical dispersants are a secondary response tool that can and have been used both in our region and in other areas of the United States. For as long as dispersants remain as part of the National Response Framework, we advocate for a strong science-based approach to dispersant use guidance and decision-making. Our comments identify several areas where EPA could enhance the proposed rule by clarifying the thresholds or procedures for incorporating scientific data into response planning and operations.

Cautious Approach to Use of Chemical Agents

PWSRCAC applauds EPA for clarifying, through this proposed rule, that the agency has the responsibility and authority under the Clean Water Act not only to establish a Schedule for oil spill treating agents, but also to identify the waters and quantities in which they may be safely used. The National Contingency Plan (NCP) clearly establishes mechanical recovery as the primary and preferred oil spill removal method, and decisions to treat an oil spill with chemicals must be made in a cautious and deliberate manner.

PWSRCAC believes that through the proposed rule, EPA is making it very clear to manufacturers, the response community, and the general public that chemical agents should only be applied to oil spills when there is clear, science-based evidence that these agents will (1) be effective in treating the oil spill such that the adverse impacts of the oil spill will be reduced, and (2) not pose the risk of enhanced toxicity from the

treated oil or the agent itself. PWSRCAC strongly supports this cautious approach, and we have identified several areas in the proposed rule where EPA should add clarifying language to reinforce this critical concept.

PWSRCAC also recommends that EPA acknowledge that entities potentially affected by this proposed rule include a broad range of constituents who rely on the health of the marine ecosystem, including commercial fishing, subsistence uses, tourism, recreation, passive uses, and traditional and customary use.

Emphasis on Science-Based Decision-making

PWSRCAC strongly supports EPA's emphasis of science-based decision-making in the proposed rule. We recommend that wherever possible, the Schedule should establish quantitative limits or thresholds for chemical and biological agents. These thresholds will inform both preauthorization planning and On-Scene Coordinator (OSC) decision-making during an incident.

PWSRCAC has supported significant scientific research into dispersants and oil spill treating agents; many of our peer-reviewed studies are cited in the proposed rule. We have cited our comments to the published literature wherever possible, and many of our comments note areas where the proposed rule does not necessarily reflect the prevailing knowledge as captured in scientific publications.

While it is important to ground oil spill response policy and decision-making in science, it is equally important that EPA acknowledge areas where the foundational science contains uncertainties. In the wake of the Deepwater Horizon spill response, there has been significant effort among federal agencies and leading researchers to clarify areas where there is consensus about chemical treating agents (primarily dispersants), and areas where uncertainty prevails. In light of this fact, we encourage EPA to be as transparent as possible about areas where scientific data is sparse or consensus is lacking. In order for the public to have confidence in oil spill response decision-making, there must be clear and plain acknowledgement of scientific uncertainty.

PWSRCAC also recommends that EPA consider and acknowledge the fact that the current rulemaking, like the previous Subpart J regulation, relies upon manufacturer-provided science on both efficacy and toxicity. This creates an inherent conflict of interest, and while EPA is establishing parameters and criteria for these studies, we suggest that the agency go a step further and observe or supervise independent science to verify results of manufacturer studies.

PWSRCAC maintains a dispersants research literature synthesis and database, updated annual, which we recommend as a reference.[1]

Toxicity and Sub-chronic Effects of Chemical Agents

Petroleum oil products are a highly complex set of chemicals that consist of a variety of constituent components, many of which are toxic to humans, flora and fauna. Toxic impacts may be acute or chronic, direct or indirect. Chemical or biological agents used

[1] http://www.pwsrcac.org/programs/environmentalmonitoring/dispersants/dispersant-literature-reviews/

to treat oil spills may influence the toxicity of oil products and their constituents, and it is critical to compile as much information as possible about potential toxicities before treating agents are applied to a spill. Ongoing studies from the Deepwater Horizon well blowout show that dispersant use during that spill had adverse impacts to respiratory function in both humans and fish (Fu et al., 2015; UAB, 2015).

EPA has traditionally relied upon a limited set of toxicity tests on a few select species to establish toxicity data for oil spill treating agents. Two temperate species have been used as the basis for toxicity evaluations, even for areas like Alaska where these species do not exist. Toxicity testing has been limited to a narrow range of acute effects that may overlook other important mechanisms through which chemical treating agents may cause harm to wildlife and the environment. The proposed changes to Subpart J make some adjustments to the testing approach, but these are not sufficient to inform a complete understanding of toxicity, particularly for sub-chronic effects.

PWSRCAC recommends expanded requirements for toxicity testing to evaluate the full spectrum of potential adverse endocrine, immune, or developmental effects to human populations or the environment. A multi-species, system-level approach is essential to accurately predict both the protective and detrimental effects to both humans and the natural environment from the application of dispersants to accidentally released oil. We recommend that EPA consider how other programs – such as drinking water or food safety – assess potential toxicity to humans and the environment and apply the same rigor to chemical agents. The proposed new focus that addresses endocrine disruptors is an excellent first step.

Emphasis on Preauthorization

The proposed rule heavily emphasizes the preauthorization process. PWSRCAC recognizes that preauthorization planning is important and should be undertaken in a collaborative and scientifically rigorous manner. However, we are concerned that EPA is over-emphasizing preauthorization at the potential expense of case-by-case decision-making. The proposed rule correctly notes that given recent advances in connectivity, it is much easier for OSCs to consult with natural resource trustees and subject matter experts to inform all aspects of oil spill response. Since it is so much easier to convene a discussion in real time, case-by-case decision-making should be feasible for most spills, eliminating the need to prescribe decisions through pre-authorization. Wherever possible, consultation with trustees and scientific experts should be a priority – even in cases where preauthorization is in place.

The emphasis on preauthorization planning also creates the false impression that oil spill treating agents are regularly or commonly used in the U.S. With the exception of the Deepwater Horizon oil spill, non-mechanical oil spill response methods are still the exception, not the rule. Given how infrequently oil spill treating agents are used, the amount of time and energy devoted to preauthorization planning may be better allocated to establishing a strong mechanism for case-by-case decision-making or other types of oil spill preparedness and planning.

Case-by-case decision-making is important because there are still significant uncertainties about the efficacy and toxicity of oil spill treating agents. Most of the

data that is used to inform decision-making is derived from laboratory experiments that are often a poor proxy for real-world performance. Preauthorization plans cannot foresee all possible circumstances during which a spill response may occur, and the effectiveness and toxicity of treating agents is influenced by a complex and nuanced array of inputs. Five years after the Deepwater Horizon spill, there are still significant gaps in knowledge about the effectiveness and toxicity of subsea dispersant use. A recent report by the U.S. Geological Society notes that there is insufficient science to support dispersant use decision-making (Holland-Bartels and Pierce, 2011). We simply do not have reliable science to foresee the short and long-term consequences of oil treating agents; therefore, the precautionary principle must be applied during all incidents, even when they occur within the bounds of preauthorization.

PWSRCAC recommends that EPA refocus the proposed rule to ensure that case-by-case decision-making processes are assured wherever possible, even in areas where oil spill treating agents have been preauthorized. No plan can substitute for professional judgment, real-time data, and local knowledge.

OSC Discretion and Decisionmaking

The proposed rule represents a significant improvement over the current Subpart J process, which requires that manufacturers of oil spill treating agents p rovide documentation to the EPA. EPA then reviews the documentation for accuracy and, if complete, publishes to the Schedule. This system relied on the OSC to evaluate the information in the Schedule and to "judge whether and in what quantities a product may be used to control a potential discharge." The proposed changes to Subpart J would assign a more active role to the EPA in reviewing and vetting the information submitted by a manufacturer, and would require EPA to make a determination about whether or not to include a product on the Schedule based on a technical review of the data. This is a major improvement over the current system, and PWSRCAC strongly supports EPA's proposal to take a more active role in reviewing submissions to the Schedule.

However, we are concerned that the proposed rule as written gives the OSC broad discretion to override preauthorization and make exceptions to virtually all components of the proposed rule. While the OSC will presumably have a strong background in pollution response and incident management, this person may not have the scientific or technical background to make decisions that override Subpart J product listings and regional preauthorization planning . The value of preauthorization planning is the fact that subject matter exper ts and natural resource trustees have a clear role in developing these plans and policies. Similar rigor should be applied to case-by-case decision-making.

The proposed rule as written empowers the OSC to use real-time data to inform decision-making. PWSRCAC supports this idea of science-based decision-making, but cautions that the OSC may not have sufficient independent expertise to interpret and apply such data. Natural resource trustees with local knowledge must have an active role in response decisions regarding chemical or biological agents. The Area Committee (AC) and Subarea Committees (unique to Alaska), State and Federal Trustee Agencies, Tribal entities, and Scientific Support Coordinator (SSC) all play important

advisory roles to inform the OSC about scientific issues related to the use of oil spill treating agents.

PWSRCAC recommends that EPA revise the rule to create clear accountability for the OSC to consult with subject matter experts and trustee agencies. It should also clarify where consultation vs. concurrence is required to override preauthorization plans or make independent decisions about oil spill treating agents.

Unilateral Authority of EPA Administrator

PWSRCAC has strong concerns about the proposed language that would give the EPA Administrator, under Subpart H, unilateral authority to bypass both Subpart J and regional preauthorization plans. As a national political appointee, the EPA Administrator should not be in the position to overrideconsensus decisions or policies developed by local natural resource trustees. This option undermines both Subpart J and the preauthorization planning process. PWSRCAC does not believe that decisions about local application of spill treating agents in Alaska should be made in Washington, D.C. by a single agency head. We therefore recommend removing this provision from the proposed rule. If it is retained, we suggest that the EPA Administrator should be required to obtain concurrence from his or her counterpart within federal trustee agencies- i.e. the NOAA Administrator, DOI Secretary, etc.

PWSRCAC recommends that EPA require that in any case where exceptional decisions are made to use oil spill treating agents - whether that decision originate with the OSC or the EPA Administrator - a transparent public record must explain these decisions and their scientific rationale.

Subsurface Dispersant Use

PWSRCAC has concerns about the manner in which the proposed rule considers subsurface dispersant use as an established approach. PWSRCAC does not believe that there is enough data demonstrating that dispersants add value to subsurface oil spill response. In an area like Prince William Sound, where we do not have exploration and production but do have the potential for a subsea release from a damaged or s unken tanker, we are concerned about the potential for the new Subpart J rule to open the door to preauthorized use of subsurface dispersants in Alaska.

The unprecedented and highly contested use of dispersants during Deepwater Horizon seems to be considered by EPA as justification for expanding dispersant use and encouraging preauthorization for subsea releases, when there is very little science to support subsea dispersant use decision-making. Techniques for measuring effectiveness of subsurface dispersant applications are unproven. Oil that came ashore during the Deepwater Horizon oil spill contained dispersant, indicating that some proportion of the "dispersed" oil actually impacted the shoreline. In fact, a mixture of oil and dispersants continues to make landfall, years after this spill.Non-degraded oil has been documented throughout the Gulf of Mexico environment. All of this casts serious doubts on the efficacy of the subsurface dispersant application during that spill, and certainly points to the need for additional research before subsurface dispersants can be considered a mature spill treatment option.

The State-of-Science for Dispersant Use in Arctic Waters working group, a consortium of leading dispersant scientists in which PWSRCAC participates, has expressed uncertainty about the effectiveness of subsea dispersants under some conditions, and about the ability to measure effectiveness for sub-surface applications.

For these reasons, PWSRCAC urges the EPA to remove subsurface dispersant application from Subpart J at this time, and revisit the issue in the future when there is more definitive science to inform the tradeoffs involved in applying dispersants to subsurface oil spills.

Consensus Standards

The proposed rule contains a number of new or changed requirements for efficacy and toxicity testing for chemical and biological agents, with the goal of using standard, repeatable approaches that will make it easier to compare results across products and manufacturers. The State-of-Science for Dispersant Use in Arctic Waters working group is in the process of establishing a consensus opinion about the importance of standardization in dispersant testing and monitoring methods, and they have noted in their deliberations that standard measurement methods are crucial to acceptable data generation.

PWSRCAC advocates for the use of consensus standards where available to ensure consistent methodologies are applied during scientific testing. We are concerned that EPA is proposing to abandon the consensus standard for dispersant effectiveness that has been in place for years and is currently used in 20 countries, including the U.S. We understand that there are advantages and disadvantages of both the existing (swirling flask) and proposed (baffled flask) technique for dispersant effectiveness testing, and we recommend that EPA ensure that, if the standard technique is changed, comparable standards are provided for the baffled flask test. It is most important to ensure that efficacy tests are carried out in a controlled and replicable manner. EPA should ensure that – regardless of the technique - dispersant efficacy tests are conducted by **certified** chemists working in **certified** laboratories using **certified** procedures (ASTM swirling flask test).

PWSRCAC agrees that the development of new consensus standards may be appropriate to inform scientific testing and comparison of oil spill treating agents. We recommend that any new standards adopted in Subpart J meet the following criteria: (1) improve reproducibility of the tests within a laboratory; (2) certified cross validation between laboratories; (3) provide adequate discrimination between agents being tested; and (4) facilitate testing of all necessary variables (such as temperature and salinity) that may influence efficacy or toxicity.

Sinking Agents

The Statutory Authority section of the proposed rule makes note of the historic prohibition of sinking agents, which dates back to 1984. PWSRCAC strongly supports EPA's ban on the use of sinking agents in the proposed rule. However, we are concerned that the rule creates some ambiguity about other agents that may act like sinking agents under certain conditions (such as oil mineral aggregates or clays), and we urge EPA to clarify that *any agent that causes oil to sink to the bottom is considered*

a sinking agent under conditions that may lead to sinking, and is therefore banned from use in U.S. waters.

Reliance on Responsible Party and Manufacturer Science

Throughout the proposed rule, requirements are proposed for testing and monitoring to be conducted by the Responsible Party, (RP) at the time of a spill, or the Chemical Agent manufacturer (for listing agents on theSchedule). PWSRCAC strongly urges the EPA to consider all possible opportunities to require independent science or rigorous peer review of all studies that are conducted by the RP or vendor. When a spill occurs, the RP faces significant civil and criminal liability based on environmental damages, including damages caused by spill treatment decisions. This creates a conflict of interest for assessing potential adverse impacts from treating agents.

Similarly, the product manufacturers and vendors have a financial interest in selling their product, and therefore have a motive to present results that might overestimate potential effectiveness or understate toxicity. We recommend that the EPA consider opportunities to audit or independently vet studies to ensure fairness and transparency.

Detailed Comments on Proposed Rule

Dispersants (40 CFR §110.4)

Summary: EPA proposes to revise this section to link the rule with the new and amended regulatory definitions for Subpart J product categories in 40 CFR §300.5.

Comments
PWSRCAC has provided comments under 40 CFR §300.5.

Definitions (40 CFR §300.5)

Summary: EPA proposes revisions to §300.5 that amend the definitions for Bioremediation agents, Burning agents, Chemical agents, Dispersants, Sinking agents, and Sorbents. EPA is proposing to remove the definitions for surface collecting agent and for miscellaneous oil spill control agent (MOSCA).

Comments
PWSRCAC finds that on the whole, these new definitions add clarity. We believe that it is important to clearly define treating agents to make sure that agents included on the Schedule are appropriately categorized and are used as intended. For example, many products currently sold as solidifiers, under the current Schedule, are actually sorbents.

Recommendations

- PWSRCAC recommends that language be added to the definition for each agent and substance clarifying that it is "not likely to cause additional harm, either alone or in combination with oil, to public health or welfare or to the environment."
- PWSRCAC recommends that each definition specifically state whether the substance is, or is not, intended to be removed from the environment.

Bioremediation Agents

Summary: EPA proposes to revise the definition of bioremediation agents.

Comments
PWSRCAC finds that the definitions of "biodegradation" and "bioremediation" oversimplify these processes, which may result in only partial biodegradation or partial bioremediation, which may potentially result in more toxic intermediate products.

PWSRCAC is also concerned about the use of non-indigenous bioremediation agents that could potentially colonize the area where they are released, and we suggest that the definition prohibit the use of biological agents that could result in non-indigenous species colonization, which could have significant ecosystem impacts.

PWSRCAC supports the inclusion of fungi in the definition of biological agents and the use of mycoremediation. Fungi have been found to be effective at degrading the complex PAHs. PWSRCAC has included several references regarding mycoremediation that support our comments.

Recommendations

- PWSRCAC recommends that the definitions of biodegradation and bioremediation be expanded to include the possibility that partial biodegradation or partial bioremediation may occur in the environment, and may potentially result in more toxic intermediate products.
- PWSRCAC recommends that the definition of bioremediation agents include a ban on agents that may result in the colonization of non-indigenous species.
- PWSRCAC supports the inclusion of fungi in the definition of biological agents and the use of mycoremediation.

Burning Agents

Summary: EPA proposes a revised definition of burning agents and is considering including ignition devices in the definition.

PWSRCAC supports the inclusion of ignition devices in this category, and we suggest that EPA develop corresponding requirements to evaluate toxicity associated with combustion products and burn residues. Studies of in-situ burn residues from the Deepwater Horizon spill confirmed that the chemical and physical properties of the oil are changed during in-situ burning (Shigenaka et al., 2015). Therefore, it is equally important to evaluate potential toxicity influences that may result from the use of burning agents to treat oil spills similar to the way in which chemical or biological agents may alter oil properties and influence toxicity.

Recommendations

- PWSRCAC recommends that EPA require toxicity testing of burning agents, of combustion products (smoke plumes), and also of the burn residue that results from application of burning agents to oil slicks.

Chemical Agents

Summary: EPA proposes a revised definition of chemical agents to distinguish them from biological agents and remove agent categories that are being eliminated, prohibited or amended.

Comments
EPA proposes to revise the definition of chemical agents to identify them as being "designed to facilitate the removal of oil." PWSRCAC takes exception with the use of the term "remove." This definition is aspirational and potentially misleading and does not make clear that chemical agents do not **remove oil** and do not necessarily mitigate harm (i.e. recognize that there may be a trade-off of harms).

PWSRCAC does not support the use of sinking agents, including chemical and biological agents that meet other definitions (e.g. solidifier, sorbent, dispersant) but may cause oil to submerge or sink under certain conditions.Inclusion of a definition for sinking agents in the context of other agents that may be put on the Schedule contradicts EPA's stated policy against the use of sinking agents to treat oil spills.

The final rule should make it very clear which chemical agents are intended to be removed from the environment, and which are not.

Recommendations

- PWSRCAC recommends revising the definition of Chemical Agents to clarify that they do not necessarily remove oil from the environment, they treat oil.
- PWSRCAC recommends that sinking agents be removed from the definition of chemical agents.
- PWSRCAC recommends that the definition of Chemical Agents should clearly delineate between agents that are intended to be removed from the environment and those that are not.

Dispersants

Summary: EPA proposes a revised definition of dispersants.

Comments
The proposed definition addresses the process through which dispersants "assist in mitigating the consequences of a discharge."PWSRCAC finds this language to be somewhat leading, and we suggest replacement of this language to communicate that dispersants are intended to modify an oil discharge, but that their mitigation effects are situationally dependent and by no means guaranteed. Later in the proposed rule (page 3394), EPA acknowledges that "applying dispersant to an oil discharge does not result in the physical recovery of oil to the environment." In fact, dispersants treat the oil such that it is no longer available for physical recovery, and the application of dispersants in cases may make it more difficult to recover spilled oil in cases when dispersion is temporary and the oil eventually coalesces and resurfaces (Fingas, 2005).

Recommendations

- PWSRCAC recommends rewording the definition of dispersants to emphasize that they do not necessarily mitigate a discharge.

Sinking Agents

Summary: EPA proposes a revised definition of sinking agents to specify that these agents purposely sink the oil to the bottom of a water body. The new rule would ban the use of sinking agents.

Comments
PWSRCAC supports the inclusion of sinking agents in the list of prohibited agents proposed for §300.910(e). However, we find that the proposed definition of sinking agents does not clearly align with that section, and may potentially create confusion around the use of substances that cause oil to submerge or sink.
Any agent applied to an oil slick with the intention of causing the oil to submerge or sink below the surface will render that oil no longer available for mechanical recovery.

Any agent that causes oil to submerge below the water surface in a given waterbody should be characterized as a sinking agent, even treating agents that also qualify for other categories (e.g. dispersants, solidifiers, sorbents). The State-of-Science for Dispersant Use in Arctic Waters working group reached preliminary consensus on the fact that chemical dispersants can facilitate the formation of oil-mineral aggregates (OMA), potentially causing the oil to sink: *"The effect of chemical dispersants to oil in the presence of adequate suspended particulate material and mixing energy will increase the rate of formation of OMA."* While the working group report noted that OMAs will only sink under certain conditions, PWSRCAC is concerned that such scenarios result in a dispersant that functions like a sinking agent.

Recommendations

- PWSRCAC recommends that EPA ban dispersant use under conditions where OMA formation is likely and sinking is possible.We have included a list of references about the potential for OMA formation at the end of this document.

Solidifiers

Summary: EPA proposes to define solidifiers as substances that change oil chemically and cause it to become a cohesive mass intended for collection.

Comments
PWSRCAC does not support the use of solidifiers, as they offer no measurable advantage over sorbents or mechanical recovery. They have limited practicality, may cross-link or react with other substances, and require immediate removal from the environment. There has been very limited effectiveness testing on solidifiers, and few recent studies. PWSRCAC has included in our Reference list a series of reports on solidifiers that support our position.

Recommendations

- PWSRCAC recommends that EPA remove solidifiers from the Schedule.

Sorbents

Summary: EPA proposes to identify sorbents as substances consisting of: (1) natural organic substances (e.g., feathers, cork, peat moss, and cellulose fibers such as bagasse, corncobs, and straw); (2) inorganic/mineral compounds (e.g., volcanic ash, perlite, vermiculite, zeolite, clay); and (3) synthetic compounds (e.g., polypropylene,

polyethylene, polyurethane, polyester). EPA requests comments on whether additional materials should be included in the definition, and also on the inclusion of the phrase "that are generally collected and recovered from the environment," citing the potential for removal of sorbents to cause more harm than good in certain environments. EPA also requests comments about characterizing particulate matter (e.g. clay) as sorbents.

Comments
PWSRCAC supports the proposed definition of sorbent, with the exception of clays and oil mineral aggregates (OMAs), which are intended to be land-based sorbents and should be prohibited for use on water even in cases when the oil/clay or oil/OMA particles are expected to be less dense than water .

Recommendations
- PWSRCAC recommends that EPA clearly require that all sorbent materials must be recovered from the environment, and that sorbent use is not authorized in the event that the sorbents cannot be removed from the environment.
- PWSRCAC supports a ban on the use of particulate sorbents (clay) on water.
- PWSRCAC supports a ban on the use of OMA technologies on water.

Surface Washing Agents

Summary: EPA proposes to revise the term and definition of surface washing agents from singular to plural for consistency with other definitions, and to clarify that these agents are meant to be removed from the environment.

Comments:
PWSRCAC supports the definition of surface washing agents, with the clarification that these agents must be removed from the environment.

Recommendations
- PWSRCAC recommends that EPA clearly require that all surface washing agents must be recovered from the environment.

Authorization of Use (40 CFR§300.910)

Summary: EPA proposes to reorganize and add titles to this section, add several requirements addressing the storage and use of agents, notification of agent use and recovery from the environment, and revise language to clarify established EPA policy regarding the requirement for an OSC to authorize use of any oil spill treating agent.

Comments
Subpart J should include as much specific, quantifiable information and direction as possible to assist Regional Response Teams (RRTs) and ACs with the preauthorization planning process. It is particularly important for EPA to clearly identify cases where treating agent use should not be preauthorized.

Recommendations
- PWSRCAC recommends that EPA clearly delineate conditions under which use should not be preauthorized.
- PWSRCAC recommends that preauthorization plans clearly acknowledge that there may be times or places where use of chemical or biological agents is not

appropriate, even if it is preauthorized. The response decision-making process must take into account allfactors that could influence the effectiveness or impacts of chemical or biological agent use.
- PWSRCAC recommends that the Schedule explicitly state that chemical or biological agents may only be used for their intended use within a specific category so that, for example, an agent that is listed as a surface washing agent cannot be authorized for use as a dispersant.

Preauthorization Planning §300.910(a)

Summary: EPA proposes to clarify the preauthorization planning process.

Comments
PWSRCAC supports the requirement for a regular review cycle for preauthorization plans to address revisions of the Schedule, and also supports the other parameters identified as triggers for a preauthorization plan review (SONS, new threatened or endangered species, changes to worst case discharge estimates,emergent scientific information, or other major changes). However, we are concerned about the need to balance information currency with the need to have established plans in place so that the public understands current policy. In Alaska, our Dispersant Use Authorization plan has been in flux for over a year, resulting in a situation where there is no clear, established policy.[2]

The proposed rule also addresses the decision-making process used to develop preauthorization pl ans. While the concept of preauthorization is rooted in the need to expedite decision-making, its application must carefully consider that each spill is unique and a range of variables may influence the effectiveness of a dispersant. There may be times or places where dispersant use is not appropriate, even if preauthorization is in place.

PWSRCAC supports EPA's proposals to expand consideration of waterbody characteristics, like salinity, in the context of both efficacy testing and preauthorization. PWSRCAC supports this approach, and suggests that Subpart J should provide clear direction to the RRT and OSC to consider not just the waterbody salinity, but other characteristics like circulation patterns, mixing energy, presence of endangered or threatened species, critical habitats, seasonal changes, sediment levels, etc. when authorizing the use of chemical agents. In Alaska, we have developed the following list of criteria to consider before deciding to use dispersants in our marine waters, and we suggest that EPA consider including these in Subpart J guidance.

- **Bathymetry** - it is generally recognized that adequate mixing and dilution of dispersants should occur if applied in waters deeper than 10 fathoms (or 60 feet) depth provided there is sufficient energy for mixing. The 10 fathom contour is a standard depth contour line included on National Oceanic and Atmospheric Administration marine charts.
- **Distance from shore** - an adequate buffer needs to be established to reduce the chances of applying dispersants to sensitive shorelines/nearshore areas and to

[2] Annex F to the Alaska Unified Plan was issued as a draft in September 2013 and is not yet finalized. http://alaskarrt.org/Files/ARRT%20Oil%20Dispersant%20Authorization%20Plan_Draft%209-25-13.pdf

ensure that drifting dispersant and/or dispersed oil mixtures do not adversely affect intertidal and benthic biota.

- **Wind and currents** - areas where there is generally little movement of water would not provide sufficient mixing energy for effective dispersant use. With higher wind speeds (beginning at 12 - 14 meters per second (26.8 to 31.3 miles per hour)), the benefits of dispersant application start to diminish compared to natural dispersion.
- **Salinity** – most dispersants are made for use in saltwater and are not effective in fresh water or waters with a salinity of less than 15 parts per thousand.
- **Temperature** - dispersant effectiveness will be affected by ambient water temperatures, with more complete dispersion in warmer waters.
- **Response equipment** - the availability and time to mobilize response equipment may affect whether dispersants can be used.
- **Shoreline types** - certain shoreline types (e.g., gravel, mixed sand and gravel, coarse-grained sand beaches, and marshes) may trap oil for long periods.The amount of wave energy (e.g., protected inlets vs. high-energy exposed beaches) will also affect oil retention and persistence.
- **Sensitive habitats** - certain habitats where biota breed, rear young, feed, or congregate (e.g., eelgrass beds, kelp beds, saltwater marshes, and designated critical habitats for threatened or endangered species) may be adversely affected by oil and/or dispersed oil.
- **Sensitive species including threatened or endangered species** – these species may be adversely affected by oil and/or dispersed oil.
- **Other areas designated for special use or protection**-these areas (e.g., national and state parks, national wildlife refuges, and wildness areas) may be adversely affected by oil and/or dispersed oil.
- **Historic properties** - these resources (e.g. archeological and historic resources) may be adversely affected by oil and/or dispersed oil.
- **Human use activities** - these activities (e.g., subsistence, fishing, and boating activities) may be adversely affected by oil and/or dispersed oil.
- **Public and private facilities** – these facilities (e.g., fish hatcheries, aquaculture and mariculture facilities, public water intakes, and docks) may be adversely affected by oil and/or dispersed oil).

Preauthorization planning should take into account all of the factors that may impact dispersant effectiveness. The State-of-Science for Dispersant Use in Arctic Waters working group reachedpreliminary consensus on the importance of several factors on dispersant effectiveness, including temperature, persistence of compounds, and weathering and emulsification.Their deliberations emphasize the importance of considering how temperature may influence the physical properties of oil and, in turn, its dispersibility. This group of scientists has also established consensus that the environmental persistence of dispersants is influenced by environmental conditions. It is critical that the decision-making process provide sufficient flexibility, even in cases of preauthorization, to consider how these ephemeral factors may influence the potential effectiveness or toxicity of dispersants or other chemical agents.

We support EPA's suggestion thatexplicit concurrence, rather than consultation, should be achieved among resource trustees – including states adjacent to the federal waters – for all preauthorization plans. We recommend that the rule explicitly

recognize tribal governments as well, and also require concurrence from potentially impacted tribal entities in accordance with Executive Order 13175.

PWSRCAC also believes that it is important to include not just the RRTs but also the ACs (and, in Alaska, Subarea Committees) in the preauthorization planning process, as the ACs typically cover a smaller geographic area and have more extensive local knowledge.

PWSRCAC supports EPA's proposal to include specific procedures for withdrawal of concurrence of preauthorization plans to allow trustee agencies the flexibility to change their position in the event that conditions change.

PWSRCAC disagrees with EPA's proposal to replace the word "potential" with "likely" in reference to the sources and types of oil that might be spilled. We believe that "potential" is a broader, more conservative term that is appropriate for preauthorization planning. Determination of "likely" spill sources would require a standard methodology for risk categorization in order to ensure standard application across preauthorization plans.

Finally, PWSRCAC encourages EPA to consider that preauthorization planning cannot possibly foresee all potential circumstances, and that whenever possible, decisions about oil spill treating agents should be made at the time of an incident based on the specific incident and best available science. Even if dispersants or oil treating agents are preauthorized in a given location or time, it is prudent to proceed cautiously with their application and to continuously evaluate efficacy and effects. To this end, we suggest that EPA encourage preauthorization plans to require field tests prior to full-scale applications, even in cases where use is preauthorized.

Recommendations

- PWSRCAC recommends that the EPA require that the public be provided with an opportunity to review and comment on preauthorization plans during each review cycle.
- PWSRCAC recommends that preauthorization plans should be required to specify not only geographic designations but also to set threshold limits for waterbody characteristics including salinity, circulation, mixing energy, seasonal changes, sensitive species, sediment load, freshwater plumes, and other factors that could influence the fate, behavior, or impacts of dispersed oil.
- PWSRCAC recommends that the EPA include in the new rule some requirement that preauthorization planning take into account the impact of temperature on oil properties and, thus, their dispersability.
- PWSRCAC recommends that the EPA include in the new rule some requirement that preauthorization planning take into account the persistence of dispersant compounds based on the environmental conditions. Preauthorization is not appropriate during conditions that would favor long-term persistence of dispersant compounds.
- PWSRCAC recommends that the EPA include in the new rule some requirement that preauthorization planning take into account the impact of weathering and emulsification on oil viscosity and, thus, dispersability.

- PWSRCAC recommends that explicit concurrence from resource trustee agencies, state agencies, tribal governments, RRT and AC members should be achieved in developing preauthorization plans.
- PWSRCAC recommends retaining the term "potential" rather than "likely" in the context of the types of oil that might be discharged.
- PWSRCAC recommends that EPA require preauthorization plans to compel field tests, even in preauthorization areas, prior to full scale applications, to ensure efficacy and evaluate toxicity before full scale operations begin.

Use of Agents on Oil Discharges Not Addressed by a Preauthorization Plan §300.910(b)

Summary: EPA proposes to clarify the authorities and responsibilities for use of agents on the Schedule in situations not addressed by a preauthorization plan.

Comments
PWSRCAC supports the requirement that the OSC notify the RRT representatives from the EPA, affected states, and DOC/DOI natural resource trustees as soon as possible. We also support the distinction in the proposed rule that the OSC should go beyond consultation and seek concurrence from trustee agencies whenever an exception is considered. These trustee agencies have critical knowledge and resource stewardship responsibilities that should be incorporated into the decision-making process. We agree with the EPA that modern communication technology should enable rapid collaboration, and that there is no reason that the OSC should need to make unilateral decisions.

Recommendations
- PWSRCAC recommends that OSCs should be required to notify the RRT, EPA, affected states, and trustee agencies as soon as possible when an exception is considered, and that concurrence of all parties should be required prior to making decisions about uses not addressed by a preauthorization plan.

Burning Agents §300.910(c)

Summary: EPA proposes to revise this section to provide greater flexibility to the OSC in authorizing the use of burning agents for in-situ burning.
Comments
PWSRCAC does not oppose the use of burning agents to enhance in-situ burning of a spill; however, we believe that it is important to ensure that any burning agent applied to an oil slick be fully combustible, and that the potential toxicities of the burning agent alone, the combusted oil slick (smoke), and the burn residue be considered in the decision-making process.

Recommendations
- PWSRCAC recommends that EPA require toxicity and efficacy testing for burning agents that are listed in Subpart J to inform decision-making about burning agent use based on effectiveness of the agent in igniting a slick under a range of conditions and the potential toxicity of the burning agent itself and combustion byproducts (smoke and residue).

Exceptions §300.910(d)

Summary: EPA proposes to clarify the intent of the exception provision, which gives the OSC authority to authorize the use of products not on the Schedule in order to prevent or substantially reduce a threat to human life.

Comments
PWSRCAC has significant concerns about the unilateral decision-making authority that this provision would grant the OSC. We do not agree with the EPA's hypothetical example of the type of situation where a chemical agent not on the Schedule would be justified for use to mitigate a threat to human life. The proposed rule suggests that a spill of highly flammable petroleum products in harbors or near inhabited areas may justify the use of a product not on the Schedule if the agent would, "in the OSC's professional judgment...ef fectively and expeditiously mitigate the threat to human life." PWSRCAC is not aware of any instances where chemical or biological treating agents (with the exception of firefighting foam, which we do not believe are included in Subpart J) have been used on highly flammable product in a confined space, and we do not believe that OSCs would necessarily have an appropriate background in chemistry to make such decisions.

PWSRCAC supports the requirement for concurrence from the RRT for continued use of a substance not on the Schedule, although we suggest that the time period could be shortened from 48 to 24 hours or less. When an oil spill occurs, the RRT members with natural resource trustee roles will be engaged almost immediately and should have a role in decision-making as soon as possible.

Recommendations

- PWSRCAC recommends that EPA withdraw the exception for purpose of mitigating threats to human life, unless the agency can provide a more realistic example of a situation where such an exception would clearly protect human life.
- PWSRCAC recommends that the OSC be required to seek concurrence from the RRT for continued use of a substance not on the Schedule within 24 hours or less.

Prohibited Agents §300.910(e)

Summary: EPA proposes to clarify that the prohibition of sinking agents applies to all agents that act as sinking agents when mixed with oil and to certain other agents with specific toxic components.

Comments
PWSRCAC strongly supports the prohibition of the use of nonylphenols (NP).
Given the significant adverse impacts of NPs cited in the proposed rule, PWSRCAC does not believe that cost considerations should justify the continued use of products containing these harmful agents to treat oil spills. We also support a broader prohibition on agen ts that contain endocrine disrupting compounds (EDC). However, we have some concerns about the techniques that would be used to do this type of testing.

In addition to the presence of endocrine disrupting compounds or prohibited agents in dispersants themselves, PWSRCAC is also concerned that EPA ensure that the byproducts of dispersed oil do not contain such substances. Many toxic compounds found in oil (e.g. PAH) require metabolic activation to express toxicity. These are further metabolized to less active forms which are excreted. Microbial degradation may take slightly different metabolic routes. In either case the metabolites may enter the water column where they may exert toxic effects either directly or indirectly.

PWSRCAC strongly opposes the use of sinking agents and believe that the list of prohibited agents should include any agents with the potential to cause oil to sink based on the receiving environment.

Recommendations

- PWSRCAC recommends that EPA ban from the Schedule any agents containing nonylphenols or endocrine disrupting compounds.
- PWSRCAC recommends that EPA also ensure agents included on the Schedule will not cause oil to degrade in a manner such that its byproducts contain any prohibited substances. We request that EPA provide additional information about the types of tests or analyses that could be applied to make these types of determinations.
- PWSRCAC recommends that EPA include sinking agents in the list of prohibited agents, with the acknowledgement that agents may act as sinking agents depending upon the location, timing, and waterbody where the spill occurs.

Storage and Use of Agents §300.910(f)

Summary: EPA proposes to add language to require the OSC to authorize use of agents only when they have been stored under conditions specified in the Schedule by the submitter.

Comments

PWSRCAC disagrees with EPA's proposal to require owners or operators that store chemical or biological agents to ensure that they do not degrade into more toxic byproducts once the manufacturer's expiration date has passed. The purpose of an expiration date is to ensure product safety and integrity. Once the expiration date has passed, the product should be disposed.

Recommendations

- PWSRCAC recommends that EPA require that expired chemical agents should be disposed.

Supplemental Testing, Monitoring, and Information §300.910(g)

Summary: EPA proposes to revise this section to provide greater flexibility to the RRTs to require supplemental toxicity and efficacy testing.

Comments

PWSRCAC supports EPA's removal of the qualifier "when developing preauthorization plans" to provide greater flexibility for RRTs to require supplementary toxicity and efficacy testing data about an agent even when preauthorization plans are not being developed. We also support EPA's proposal to give the RRT authority to request that

the OSC require the RP to conduct additional monitoring of a product use during a discharge to support operational decision-making.

PWSRCAC supports EPA's proposal to include "ecosystem" along with area and site-specific concerns that may be considered in evaluating toxicity, although we believe that EPA should provide additional information and examples about methodologies that can be used to evaluate ecosystem impacts. Certainly the current approach, where toxicity data is derived from a narrow range of tests on two temperate species, does not sufficiently inform the full range of potential toxicities from chemical agents, particularly in cold water regions.

Recommendations

- PWSRCAC recommends expanding the requirements for supplemental testing and monitoring to allow RRTs to request additional efficacy and toxicity testing during a discharge or at any time.
- PWSRCAC recommends including ecosystem-level toxicity effects as a required component of toxicity testing.
- PWSRCAC recommends a full EPA Tier 1 endocrine disruptor screening of the dispersed oil water accommodated fraction for any dispersant-oil combination that has not previously been screened.

Recovery of Agents from the Environment §300.910(h)

Summary: EPA proposes to add this section, requiring that the RP, with OSC oversight, remove from the environment any solidifiers, sorbents and surface washing agents used to treat an oil spill.

Comments

PWSRCAC supports EPA's proposal to specify the agent categories where substances are intended to be removed from the environment following their use (solidifiers, sorbents, and surface washing agents). PWSRCAC agrees with EPA that the RP should have ultimate responsibility for removal of these products, with oversight from the OSC. However, we suggest that that EPA create requirements that ensure that authorization of use for these substances be contingent upon the development of a feasible removal plan based on the specific incident. We also suggest that EPA establish some penalty for failure to remove these substances from the environment following their use.

Recommendations

- PWSRCAC recommends that the Schedule clearly delineate which agents are intended to be removed from the environment following their use (solidifiers, sorbents, and surface washing agents).
- PWSRCAC recommends that authorization of use for of these agents should be contingent upon the development of a feasible removal plan based on the specific incident.
- PWSRCAC recommends that the RP should be assessed a penalty in the event that an agent is not recovered from the environment.

Reporting of Agent Use §300.910(i)

Summary: EPA proposes to add this section, requiring that the OSC report to the RRT certain information about the use of a chemical or biological agent within 30 days of completion of use or, alternately, at some interval agreed upon by the RRT. EPA is also requesting comments on whether notification of the public should also be included in the reporting requirement.

Comments
PWSRCAC supports the 30-day reporting standard, and we
strongly support EPA's proposal to include public notification as part of the 30-day notification requirement.

Recommendations

- PWSRCAC recommends that EPA establish a 30-day reporting requirement for the OSC to report to the RRT in the event of a chemical or biological agent use.
- PWSRCAC recommends that public notification should be a required component of this notification.

Monitoring the Use of Dispersants (40 CFR §300.913)

Summary: EPA proposes to add a new requirement for the RP to conduct efficacy and ecological effects monitoring for subsurface applications and for surface applications for spills over 100,000 gallons and for applications that exceed 96 hours in duration.

Comments
PWSRCAC believes that strong monitoring protocols should be in place to ensure efficacy and evaluate ecological impacts of dispersant use. PWSRCAC agrees with EPA that comprehensive monitoring is essential to "determine the overall effectiveness of dispersants and should transcend from the initial dispersant application to include the transport and environmental effects of the dispersant and dispersed oil in the water column." However, we are concerned that existing monitoring methods may not have the capability to achieve this expectation. For all monitoring programs, baseline samples should be required for the area of proposed application before any application of dispersants

The State-of-Science for Dispersant Use in Arctic Waters working group identified a number of outstanding issues and questions associated with dispersant monitoring that should be weighed in this rulemaking. These include the difficulties in estimating mass balance of dispersed oil during atsea applications, and the fact that monitoring by visual observation and fluorimeters provide only relative estimates of dispersant application effectiveness. Although actual field application of dispersants has occurred only a handful of times in the U.S., there have been consistent challenges in measuring field effectiveness with available monitoring techniques and technologies.

PWSRCAC believes that it is EPA's responsibility to create realistic expectations for OSCs and the public about the capabilities and limitations of dispersant monitoring technologies. It is critical that monitoring data be presented in the context of technological limits and scientific uncertainty. Given that the largest field application of dispersants in U.S. waters occurred during the Deepwater Horizon well blowout, we encourage EPA to make public the full record of To dispersant efficacy monitoring

results and raw data from all monitoring activities conducted during this response. Data from particle size analysis and fluorescence measurements of oil droplet size distributions at the wellhead during dispersant application and during times when no dispersants were applied would provide valuable information both for OSCs and for the public in understanding the potential efficacy of dispersants.

PWSRCAC agrees with EPA that field monitoring provides critical amplifying information to supplement laboratory test data regarding dispersant effectiveness and environmental effects. It is important that as dispersant science continues to evolve, field and laboratory data are collated to understand the transferability of lab results to the real world.

PWSRCAC supports EPA's suggestion that monitoring requirements should include thresholds for application based on the quantity of dispersants used within a given timeframe. The EPA has a duty under the Clean Water Act to prevent the dumping of harmful chemicals into the environment, and there should be thresholds for automatically ceasing dispersant application to ensure that this line is not crossed.

Dispersant monitoring data is of high interest to the public, and should be made available immediately and in raw form for public review.

Recommendations

- PWSRCAC recommends that the EPA require dispersant monitoring data to include an acknowledgement of technological limits and scientific uncertainty, to better inform OSC decision-making and ecological risk assessment.
- PWSRCAC recommends that EPA require dispersant monitoring to include pre-application monitoring of biological resources.
- PWSRCAC urges EPA to release (or compel the USCG to release) the results of dispersant efficacy monitoring during the Deepwater Horizon oil spill to clarify the effectiveness of that application and to provide an example of the type of information and analysis that can be derived from existing monitoring technologies and protocols.
- PWSRCAC recommends that EPA create a standard process for collecting field data from dispersant applications for the purpose of validating and amplifying information collected in the laboratory. In this way, information from past dispersant applications may be drawn upon to inform future use, along with laboratory test data.
- PWSRCAC recommends that EPA establish conservative thresholds for maximum dispersant application volumes over time.
- PWSRCAC recommends that EPA require dispersant monitoring results to be made available immediately to the public.

Dispersant Application

Summary: EPA proposes to require the RP to document its product choice and selection rationale based on the oil type, flow rate, discharge location, and efficacy/toxicity data. It also requires specific documentation of the dispersant application including rates, volumes, application methods, equipment, etc.

Comments

The parameters that are to be considered for dispersant application listed in the proposed rule are very focused on a well blowout or similar continuous release.In areas like Prince William Sound where spill risks are primarily derived from vessels and facilities, dispersant application parameters may be different. The rule should consider all potential spill sources and types, not just well blowouts.

PWSRCAC also has concerns with EPA's suggestion to rely on the RP to provide estimates of well blowout flow rates or spill volumes as the basis of dispersant application dosing. There is a long history of Responsible Parties underestimating or obscuring spill volume estimates. These numbers should be derived by independent government agencies or academia.

The State-of-Science for Dispersant Use in Arctic Waters working group reached preliminary consensus on the major limiting factors for effective dispersion, which include: high viscosity from the initial oil or as a result of weathering or lower temperatures; emulsification; dispersant formulation; dose rate; mixing energy; water salinity; and potential for dilution. These parameters should be explicitly listed in the Schedule.

Recommendations

- PWSRCAC recommends that EPA expand the discussion of dispersant application parameters to address vessel-source spills, which are the primary marine oil spill risk in many regionsof the U.S.
- PWSRCAC recommends that spill volume estimates should be developed by government or academia, not by the RP.
- PWSRCAC recommends that the EPA include the following parameters specifically in the documentation requirement to rationalize dispersant use: oil viscosity, emulsification, dispersant formulation, dose rate, mixing energy, water salinity, and potential for dilution.

Water Column Sampling

Summary: EPA proposes to require the RP to collect background water column samples in areas not affected by the discharge, and also in the dispersed oil plume. The EPA proposes specific analytic parameters (droplet size distribution, fluorometry, fluorescent signatures, dissolved oxygen, total petroleum hydrocarbons, carbon dioxide, methane, heavy metals, turbidity, water temperature, pH, and conductivity).

Comments

PWSRCAC found a number of areas where the water column sampling requirements and recommended methods require clarification to ensure scientific and technical accuracy. EPA should clarify that only aromatic constituents of crude oil fluoresce at visible and near ultraviolet wave lengths, and that fluorescent properties, especially emission maximum and fluorescent intensity, both tend to increase with the number of aromatic rings, and number of non-carbon (nitrogen, oxygen, or sulfur) in the compound. This means that the least abundant oil constituents contribute most significantly to any fluorometer reading. The polar aromatic compounds , which contribute the most fluorescence, are also more soluble in seawater than corresponding aromatic hydrocarbons and thus are more likely to dissolve away from the dispersed oil droplets into the seawater phase.

EPA should clarify that while droplet size measurement is important, droplet size measuring instruments also needed to include fluorometers or similar instruments to ensure that the droplets they are measuring are indeed oil. It is also critical to acknowledge that the physical environment of fluorescent compounds can dramatically alter the observed fluorescence. Increased polarity from sources such as salinity, pH, and hydrophobicity from the presence of surfactants such as those found in dispersants, all influence the intensity of the observed fluorescence.

To avoid confusion EPA should clarify that the fluorometers currently used to monitor fluoresence *in-situ* use either filters or narrow bandpass lamps to excite samples at specific wavelengths and broad wavelength filters to allow emissions at a number of wavelengths. The most common output from an in-water instrument is a signal, which is not oil specific and is only an approximate indication of oil in the water. The discussion of "fluoresence signatures" requires instruments which can measure fluorescence across a number of wavelengths that have traditionally been found in the laboratory. However, recent advances in miniaturization or electronics; including diode array detectors, have allowed development of smaller, more durable instruments which can be used on vessels and even subsurface arrays. It should also be noted that most dispersants show a fluorescent signal as well.

The discussion of water column sampling for total petroleum hydrocarbons (TPH) does not specify a standard method, but there are several available (as listed with the references at the end of this document). EPA should specify one or more standard methods for measuring TPH.

PWSRCAC supports the inclusion of heavy metals as an analytic parameter for water column sampling. We also support the inclusion of turbidity testing, and suggest that this data should be directly considered in evaluating the potential for treating agents to act as sinking agents. In cases where high turbidity may cause treated oil to sink, the use of agents should not be authorized.

Recommendations

- PWSRCAC recommends that EPA clarify that while droplet size measurement is important for water column sampling, droplet size measuring instruments also needed to include fluorometers or similar instruments to ensure that the droplets they are measuring are indeed oil.
- PWSRCAC recommends that EPA clarify the inability of in-water fluorometers to distinguish oil signals and the relevance to water column sampling.
- PWSRCAC recommends that EPA specify that a standard method must be used for TPH measurements in water column samples.
- PWSRCAC recommends the inclusion of heavy metals in water column sampling parameters.
- PWSRCAC recommends including turbidity testing in water column analysis, and using the data to analyze the potential for treating agents to act as sinking agents. In cases where high turbidity may cause treated oil to sink, the use of agents should not be authorized.

Oil Distribution Analyses

Summary: EPA proposes that the RP (with OSC consultation) characterize the dispersant effectiveness and oil distribution to inform sampling locations.

Comments
The proposed rule requires that decision-making about how and where to sample the water column to estimate dispersant effectiveness should be derived from predictive models about dispersed oil movement and distribution. However, there are few proven methods for doing this. The State-of-Science for Dispersant Use in Arctic Waters working group reached preliminary consensus on the fact that it is difficult to anticipate the physical transport of dispersed oil, and that extrapolation of lab and tank tests on physical transport and chemical behaviour of oil to the field is complex.

Recommendations

- PWSRCAC recommends that the EPA acknowledge that the available methods for anticipating the movement of dispersed oil plumes are limited and may complicate the monitoring process. Sampling and monitoring programs should acknowledge uncertainties about where an oil plume may go or how it may behave.

Ecological Characterization

Summary: EPA proposes that the RP (with OSC consultation) characterize ecological receptors, their habitats, and exposure pathways, including sensitive life stages, transient or migratory species, breeding activities, and threatened or endangered species that may be exposed to oil, dispersed oil, and dispersant. The EPA and OSC would be required to use this information to inform acute toxicity monitoring and consideration of ecotoxicity benchmarks (EB).

Comments
PWSRCAC agrees with EPA that ecological characterization is important to evaluating exposure pathways for various receptors, but we believe that this should be done by independent scientists, and not by the RP because of an obvious conflict of interest with the natural resource damage assessment (NRDA) process.

Marine ecosystems vary significantly across the U.S., and ecotoxicity assessment in Arctic and subarctic regions cannot be assessed with the same parameters that would be applied to temperate marine ecosystems. We suggest that sensitive receptors and toxicity thresholds should be developed at the local/regional level by trustee agencies based on the marine ecosystem, food web, abundance of primary and secondary producers, and other factors that influence ecotoxicity .

Rather than relying on the RP and OSC to develop *ad hoc* ecological characterizations and toxicity thresholds concurrent with the spill response, ecological monitoring plans should be developed by the AC and RRTs during the planning process and implemented as appropriate in the event that treating agents are applied.

Recommendations

- PWSRCAC recommends that EPA require AC and RRTs to characterize ecological receptors at risk and establish thresholds that are specific to their region, rather than relying on the RP, who has an obvious conflict of interest.

Immediate Reporting

Summary: EPA proposes requiring that the RP immediately report to the OSC any deviation of more than 10 percent of the hourly subsurface dispersant use rate. EPA is considering whether a similar requirement should apply to surface applications. EPA also proposes to require the immediate reporting of ecological receptors.

Comments
PWSRCAC supports the concept that there should be a threshold for reporting deviations from the planned application rates; however, as noted previously, we do not support subsurface dispersant application.

PWSRCAC strongly supports a requirement for immediate reporting in the case of deviations of more then 10 percent for surface applications. However, we recommend that the EPA clarify through this rule that DOR is an approximate measurement based on very rough estimates of the volume of oil that is being treated by the dispersant; operationalizing this requirement may prove challenging. All such reports should also be made public.

Recommendations
- PWSRCAC recommends that EPA require reporting of any deviations in dispersant applications of more than 10 percent of intended dosage, with an acknowledgement of the margin of error involved in estimating dosage rates based on uncertainties about slick volume.
- PWSRCAC recommends that all reports be simultaneously made public.

Daily Reporting

Summary: EPA proposes daily reporting of sampling and data analyses (within 24 hours of collection) to inform operational decision-making, with an allowance for analytical methods requiring additional time to take no more than 5 days, unless authorized by the OSC.

Comments
PWSRCAC supports the 24-hour timeframe for data analysis to inform operational decision-making. However, we are concerned that existing sampling and analytical methods may not provide complete or accurate information.PWSRCAC requests that the EPA identify suggested methods or models that can accurately estimate the "daily transport of dispersed and non-dispersed oil" with sufficient accuracy to inform the coordination and scheduling of monitoring activities, as proposed in this section of the draft rule. As with other provisions, we believe that all reporting should be made public immediately and without censorship.

Recommendations
- PWSRCAC recommends that EPA require 24-hour turnaround for sampling data, and that this information be simultaneously made public.

- PWSRCAC recommends that EPA identify suggested methods or models that can accurately estimate the "daily transport of dispersed and non-dispersed oil" with sufficient accuracy to inform the coordination and scheduling of monitoring activities.

Data Requirements (40 CFR §300.915)

Summary: EPA proposes to revise and reorganize this section to include new testing and listing requirements for specific product categories.

General Product Information (40 CFR §300.915(a))

Summary: EPA proposes adding this section to consolidate general testing and listing requirements for all product categories. The general information requirements include: submitter, general product, supplier, product storage, product use, environmental fate, physical/chemical properties and formulation; microorganism information; NWQS contaminants, certification that the product does not include prohibited agents; testing laboratory information; laboratory testing data and reports; production capacity; and performance capabilities/benefits.

Comments

PWSRCAC supports the requirements for general product information, but we believe that the rule should provide additional specificity about the standards that must be used to derive some of the required information, such as physical and chemical properties, water quality contaminant levels, and environmental fate. All of this information should be made available to the public. Wherever possible, we believe that EPA should establish threshold limits above or below which agents do not qualify for listing on the Schedule.

PWSRCAC also notes EPA's choice of language to describe the requirements in this section of the proposed rule. Page 3381 describes the submission requirements as including "any other data or certification informing the product's performance capabilities or environmental benefits." PWSRCAC finds the use of the term "benefits" to be somewhat leading, and contradictory of the general precautionary approach that EPA takes elsewhere in the rule. The benefits of a treating agent will depend upon a number of factors. We suggest that it would be more accurate to request information about "potential benefits and drawbacks," which would more accurately inform decision-making.

Recommendations

- PWSRCAC recommends that the standards by which physical and chemical properties are determined should be specified in the EPA rule.
- PWSRCAC recommends that the standards by which NWQS contaminants are measured should be specified in theEPA rule.
- PWSRCAC recommends that the standards by which environmental fate information is determined should be specified in the EPA rule.
- PWSRCAC recommends that the EPA rule require that accredited laboratories must use standard methods and materials and list all materials and methods in their submitted reports.
- PWSRCAC recommends that all of this information be made publicly available for products that are listed on the Schedule.

- PWSRCAC recommends that EPA establish thresholds that can be used to screen agents and prevent agents that contain persistently bioaccumulating or environmentally persistent products from being included on the Schedule.
- PWSRCAC recommends that EPA ensure that the final rule discusses "benefits and drawbacks" together, rather than presuming a product will be beneficial under all circumstances.

Dispersant Testing and Listing Requirements (40 CFR §300.915(b))

Summary: EPA proposes new toxicity and efficacy testing requirements, limitations for use, and requirements for listing dispersants to the Schedule.

Comments

PWSRCAC supports the proposed requirement to conduct testing at two temperatures but suggest that an internationally accepted standard should be noted and listed with the supplied data. PWSRCAC understands that EPA considered limiting dispersant authorization based on oil type and temperature but ultimately dismissed this approach. While we understand EPA's concerns about specifying limits for dispersant use based on temperature and oil type, we disagree with EPA's conclusion that it makes sense to authorize only products that are effective on both types of oil at both temperatures. We believe that it is prudent to be as specific as possible within the Schedule about conditions in which a dispersant may or may not be effective. The waters of the U.S. span a range of conditions.This is of particular concern to us because dispersants are less effective under cold or arctic conditions than in temperate waters.

PWSRCAC agrees with the conclusion that dispersants have lower effectiveness in low salinity water. PWSRCAC suggests that a minimum salinity be specified for application and suggest that this number be 20 ppt. Similarly, there should be temperature limits below which dispersants are not effective; PWSRCAC suggests that this should be 10°C. Both of these thresholds are supported by published literature.

PWSRCAC supports a complete ban on the use of dispersants in freshwater without exception, and we support a ban on subsurface dispersant use until the underlying science and state of practices is more mature.

Recommendations

- PWSRCAC recommends conducting dispersant effectiveness and toxicity tests at two temperatures using an internationally accepted standard (see reference list at end of this document).
- PWSRCAC recommends that dispersant authorization should specify a temperature range for effectiveness, so that it would be possible to include a dispersant on the Schedule with the intent that it be used in one temperature range but not another (i.e. some dispersants may be used in temperate but not cold waters).
- PWSRCAC recommends that a minimum salinity threshold of 20 ppt and a minimum temperature of 10°C be established to prevent dispersant use in low salinity or low temperature environments, where they will not be effective. Both of these thresholds are supported by published literature (see Reference list under Dispersant Effectiveness at end of this document).

- PWSRCAC recommends a complete ban on subsurface dispersant use.

Surface Washing Agent Testing and Listing Requirements (40 CFR §300.915(c))

Summary: EPA proposes new toxicity and efficacy testing requirements, limitations for use, and requirements for listing surface washing agents to the Schedule.

Comments
PWSRCAC supports the use of the Environment Canada surface washing agent test. This test has been used by several agencies for many years and a very large database on product effectiveness exists. This test also has a high reliability.

PWSRCAC suggests that EPA should require toxicity testing of surface washing agent and oil combinations to determine whether the addition of surface washing agents may enhance or alter toxicity of the oil.

Recommendations
- PWSRCAC recommends using the Environment Canada surface washing agent test.
- PWSRCAC recommends that EPA require toxicity testing of surface washing agent treated oil.

Bioremediation Agent Testing and Listing Requirements (40 CFR §300.915(d))

Summary: EPA proposes new toxicity and efficacy testing requirements, limitations for use, and requirements for listing bioremediation agents to the Schedule.

Comments
PWSRCAC suggests that standard methods be used to analyze biodegradation products. The oxygenated products of biodegradation are often such that they may not be captured by gas chromatography methods and may require other methods of analysis.

PWSRCAC believes that toxicity tests with oil bioremediation-oil mixtures should be carried out to ensure that there is no combined toxicity of the oil-agent mixtures. We have included several references on bioremediation agents at the end of this document that we recommend EPA review in finalizing this rule.

Recommendations
- PWSRCAC recommends that EPA require the use of standard methods to analyze biodegradation products, and that the methods used are appropriate for measuring all byproducts.
- PWSRCAC recommends that toxicity tests with bioremediation agent-oil mixtures should be carried out to ensure that there is no combined toxicity of the oil-agent mixtures.

Solidifier Testing and Listing Requirements (40 CFR §300.915(e))

Summary: EPA proposes new toxicity and efficacy testing requirements, limitations for use, and requirements for listing solidifiers to the Schedule.

Comments

PWSRCAC has concerns about the use of solidifiers to treat oil spills. Many of the products on the market are actually sorbents, albeit polymeric adsorbents that draws the oil inside the mass. EPA must clearly delineate between solidifiers and sorbents.

PWSRCAC is also concerned that the use of oil spill solidifiers precludes the use of other mechanical countermeasures. Boom and skimmers are meant to deal with liquid oil. Once a solidifier is applied to the slick, it becomes too heavy and viscous for mechanical recovery, eliminating this option.Oil that is treated with a solidifier must still be removed from the environment, and this process is time critical to avoid the potential for the solidified oil to increase in density and sink.

Recommendations

- PWSRCAC recommends that EPA remove solidifiers from the Schedule, and that the definitions of solidifiers and sorbents clearly delineate their differences.

Confidential Business Information (40 CFR §300.950)

Summary: EPA proposes to revise and clarify the allowable confidential business information (CBI) claims in a submission package.

Comments

PWSRCAC does not support the characterization of Confidential Business Information (CBI) for products listed on the Schedule. We believe that EPA's duty under the Clean Water Act requires full disclosure of all information about the chemical formulation of agents listed in the Schedule. There must be full public disclosure of the components of oil treating agents as well as their precise formulations in order to assess potential exposure and toxicity.

In Alaska, much of our population relies on the ma rine environment for subsistence foods. In the event that oil spill treating agents are released in areas that are used for subsistence, all information about oil spill treating agents and the byproducts of treated oil must be fully available for public review and evaluation.

Recommendations

- PWSRCAC recommends that EPA reject any applications to the Product Schedule that characterize information as CBI, with no exceptions.

Addition of a Product to the Schedule (40 CFR §300.955)

Summary: EPA proposes to consolidate and reorganize information about the process of getting a product on the Schedule.

Changes to a Listed Product(40 CFR §300.955(e))

Summary: EPA proposes new regulatory text regarding notification of changes to a listed product.

Comments

PWSRCAC supports the proposal to require notification of EPA within 30 days of any changes to general product information, and the automatic triggers (i.e. changes to chemical compounds or concentrations) that would require retesting of the product.

We suggest that EPA expand this requirement to provide the RRT with the authority to request retesting of any product following a field application where the product is ineffective or determined to have adverse impacts.

Recommendations

- PWSRCAC recommends that EPA adopt the requirement for notification of changes to a listed product within 30 days.
- PWSRCAC recommends adding a provision that gives the RRT authority to request retesting of any product following a field application.

Transitioning Listed Products from the Current Schedule to the New Schedule(40 CFR §300.955(f))

Summary: EPA proposes new regulatory requirements for transitioning production on the current Schedule to the new Schedule.

Comments

PWSRCAC supports EPA's approach to requiring all products to undergo evaluation under the new process, and the development of a transition process to facilitate this.

Recommendations

- PWSRCAC recommends implementation of the transition process as proposed.

Removal of a Product from the Schedule (40 CFR §300.970)

Summary: EPA proposes to add basis for removal of products from the Schedule, EPA notification of decision, and appeals process

Comments

PWSRCAC supports EPA's proposed basis for removing products from the Schedule. We also suggest that members of the publicshould be provided with an opportunity to request removal of a product from the Schedule.

Recommendations

- PWSRCAC recommends that EPA implement this proposal with the addition of a provision that allows members of the public to petition the EPA for remov al of a product from the Schedule.

Requirements for Product Testing Protocols and Summary Test Data (Appendix C to Part 300)

Summary: EPA proposes to revise Appendix C to contain testing protocols and summary test data requirements for standard efficacy and toxicity tests.

Comments

PWSRCAC is concerned that many of the proposed methods do not use established standards. In fact in some cases, inappropriate methods are proposed when there are standards already in existence by well-known standardization agencies such as ASTM, ANSI, ISO, etc.

It is important that EPA clearly distinguish between screening tests, that are meant to compare treating agents based on relative measurements, and tests that are meant to simulate or predict the performance of treating agents in the field. The testing required for the Schedule falls into the first category, and it is critical for OSCs, RRTs, trustee agencies and the public to understand this difference. Data resulting from these tests may be useful in comparing products, but may not be sufficient to predict performance in a particular situation.

The State-of-Science for Dispersant Use in Arctic Waters working group reached preliminary consensus on the differences between lab test methods and field results for dispersant effectiveness testing, noting: *"Dispersant effectiveness varies between lab test methods and is not expected to represent field results. These tests are used for screening of dispersants and oils, conducting physical studies, developing new dispersants, or broadly informing field effectiveness potential."*

Recommendations

- PWSRCAC encourages the use of consensus standards where available.
- PWSRCAC recommends that the EPA explicitly describe the utility and limits of screening tests, particularly as they relate to potential field applications. Screening tests are not predictive of field performance and test values provide relative, not absolute, measurements.

Dispersant Baffled Flask EfficacyTest (BFT)

Summary: EPA is proposing a change from the swirling flask to the baffled flask dispersant effectiveness test protocol.

Comments

PWSRCAC is concerned that EPA is proposing a non-standard method for efficacy testing when there is already a standard test that is used in the U.S. and around the world (ASTM F2059-06 (2012) Standard Test Method for Laboratory Oil Spill Dispersant Effectiveness Using the Swirling Flask). The ASTM swirling flask test has been in use for 20 years, is well accepted in peer-reviewed chemistry journals, and there are numerous laboratories that are proficient in its application.

PWSRCAC does not believe that colorimetric methods are appropriate, and a review of the professional literature confirms that there are other standard methods in place that are widely used and accepted among chemists (Drozdova et al., 2014; Fingas et al., 2004; Wang et al., 2014; Bowman et al., 2014; Fabbri et al., 2010; Sauer and Boehm, 2005). We recommend the use of TPH methodsrather than the colorimetric (UV adsorption) method proposed. The UV method is confounded by the fact that oil consists of an array of components that each react to light differently, and it cannot reliably distinguish components of oil vs. dispersed oil. We have included a list of standards that apply to TPH analysis at the end of this document.

PWSRCAC believes it is most important to ensure that efficacy tests are carried out in a controlled and replicable manner. In this case, EPA should focus their effort on ensuring that dispersant efficacy tests are conducted by **certified** chemists working in **certified** laboratories using **certified** procedures (ASTM swirling flask test).

Recommendations

- PWSRCAC recommends TPH methods rather than colorimetric (UV adsorption) methods.
- PWSRCAC recommends that EPA ensure that all dispersant efficacy testing adhere to the principle of "3 C's": tests are conducted by **certified** chemists working in **certified** laboratories using **certified** procedures.

Dispersant Toxicity Testing

Summary: EPA proposes changes to dispersant toxicity testing.

Comments

PWSRCAC supports the proposal to require toxicity testing for the dispersant alone and for dispersed oil on both test oils. It is critical that toxicity testing be as comprehensive as possible, and adequately consider short- and long-term impacts. The State-of-Science for Dispersant Use in Arctic Waters working group noted that acute toxicity testing may miss some delayed mortality and other adverse ecological impacts: *"Data from standard acute LC50 and EC50 tests can miss delayed mortality and may also miss other adverse ecologically important endpoints that are expressed over a longer period of time."*

PWSRCAC also remains concerned that analysis of toxicological impacts should not rely on a single species, but should take into consideration indirect ecosystem-level and trophic effects of dispersed oil. Both crude oil and dispersants are complex mixtures -- oil contains many constituents which have not been well characterized chemically or toxicologically. Dispersants may contain constituents that are not routinely measured in standard toxicology analyses. Many long-term consequences of short-term exposures such as endocrine disruption, reproductive failures, and developmental disorders, are not detected by the short-term tests required in this Proposed Rule.

PWSRCAC also supports the addition of toxicity testing focused on evaluating potential human health impacts of dispersants and dispersed oil, in order to protect the health and safety of responders and the public. A suite of human toxicity teststhat evaluate all potential exposure routes to responders and the public – e.g. inhalation, skin irritation, etc. – should be submitted as part of the documentation for dispersants listed in the Schedule.

Because it is impossible for toxicity testing to foresee all long -term adverse health impacts to humans and the environment, we believe that it is critical to conduct rigorous long-term monitoring of species exposed to dispersants and dispersed oil. Information from long-term monitoring should then feed back into the toxicity testing to help understand the impact of unexpected toxic components or byproducts.

PWSRCAC appreciates EPA's consideration that longer chronic toxicity tests are needed, but we are concerned that the proposed approaches are still not adequate to test for long term, possible multi-generational, effects from short term exposures to dispersed oil. We suggest inclusion of Tier 1 screening for endocrine disrupting compounds as an example of the type of analysis necessary to assess the complex sublethal effects that may be caused by exposure to dispersed oil fractions.

Recommendations

- PWSRCAC recommends that wherever practicable, dispersant toxicity test species should either be indigenous to the spill area or have been shown to be appropriate surrogates for species from the area.
- PWSRCAC recommends that dispersants should undergo toxicity testing that specifically examines potential human toxicity through all potential routes of exposure for responders and the public.
- PWSRCAC recommends that toxicity testing be required for both dispersed oil and dispersants.
- PWSRCAC recommends that a full EPA EDSTAC Tier 1 screening be required for all dispersants and the water accommodated fraction of all test oils before products are approved for listing on the Schedule.

Standard Acute Toxicity Test for Bioremediation Agents, Surface Washing Agents, Herding Agents, and Solidifiers

Comments

PWSRCAC is concerned about the use of non-indigenous or genetically engineered bioremediation agents that may colonize areas where they are being applied. We are also concerned about the potential for toxicity from the partial degradation products of bioremediation.

Recommendations

- PWSRCAC recommends that EPA prohibit the use of non-indigenous or genetically engineered bioremediation agents that may colonize areas where they are being applied.
- PWSRCAC recommends that oil samples from shore areas subject to bioremediation be tested periodically for the production of toxic partial degradation products.

Reference List

PWSRCAC provides the following list of references, organized by topic area, which are cited either as individual publications or by topic area within our comments. We recommend that EPA thoroughly review this literature in finalizing the rule, to ensure that all policy reflects the best and most recent peer-reviewed scientific literature.

Bioremediation Agents

Fingas, M., "Analyzing Oxidized and Biodegraded Hydrocarbons", in Proceedings of the Thirty-seventh Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada, Ottawa, Ontario, pp. 870-883, 2014.

Chemical Analysis of Oil (Analytic Methods)

Drozdova, S., Ritter, W., Lendl, B., Rosenberg, E. Challenges in the determination of petroleum hydrocarbons in water by gas chromatography (hydrocarbon index), 2013 **Fuel** 113, 527-536

Fingas, M., Fieldhouse, B., Wang, Z. Dispersant testing - Study on analytical and test procedures 2004, Environment Canada Arctic and Marine Oil Spill Program Technical Seminar **(AMOP**) Proceedings,27, 2, 807-817

Wang, Q., Yan, Z., Sun, B., Zhu, X., Liu, H. The application of GC in the study of the effect of oil spill dispersant, 2014, **Journal of Chemical and Pharmaceutical Research**, 6, 5, 106-111

Bowman, D.T., Slater, G.F., Warren, L.A., McCarry, B.E. Identification of indi vidual thiophene-, indane-, tetralin-, cyclohexane-, and adamantane-type carboxylic acids in composite tailings pore water from Alberta oil sands. 2014 **Rapid Communications in Mass Spectrometry**, 28, 19, 2075-2083

Fabbri, D., Adamiano, A., Torri, C., GC-MS determination of polycyclic aromatic hydrocarbons evolved from pyrolysis of biomass. 2010, Analytical and Bioanalytical Chemistry, 397, 1, 309-317

Sauer, T., Boehm, P. The use of defensible analytical chemical measurements for oil spill natural resource damage assessment 2005, 2005 International Oil Spill Conference, **IOSC** 2005 8817

Dispersant Analytic Testing Methods

Fingas, M.F., B. Fieldhouse and Z. Wang. 2004. Dispersant Testing - Study on Analytical and Test Procedures. *Proceedings of the Twenty-Seventh Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 807-841.

Fingas, M.F., B. Fieldhouse, Z. Wang, L. Sigouin, M. Landriault and J.V. Mullin. 1999. Analytical Procedures for Dispersant Effectiveness Testing. *Proceedings of the Twenty-Second Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 231-241.

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EPA 610 –Polynuclear Aromatic Hydrocarbons

EPA 8000a- Determinative Methods for Chromatography

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To: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Mon 5/16/2016 5:22:40 PM
Subject: NCP/Subpart J Presentations/Briefings: Reggie Briefing 2/11/16; Sea Grant Legal Framework Presentation 12/15/15; Barron SETAC Updated 7/10/14; NCP Overview
Reggie Briefing 2_11_16.docx
Legal Framework Dispersants_comments.pptx
Presentation Barron SETAC 2012_GWv2.pptx
NCP overview.pptx

To: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Wed 8/31/2016 2:43:49 PM
Subject: FW: ENVIRONMENTAL PROTECTION AGENCY - 40 CFR Parts 110 and 300 - [EPA-HQ-OPA-2006-0090; FRL-9689-9-OSWER] - RIN 2050-AE87 - National Oil and Hazardous Substances Pollution Contingency Plan - ACTION: Proposed rule.
signed_subpart_j_proposed_rule_01-09-15_efficacy testing.pdf
Comments on EPA 40 CFR Parts 100 and 300Proposed Merv.doc
EPA-HQ-OPA-2006-0090-0266_PWSRCAC.pdf

Went into the docket an pulled out the PWSRCAC comments. What they/Fingas are sending seems to be an excerpt/reshuffle from pages 31-40 of their submission. I think we respond to Fingas and cc Mickunas.

Suggested draft response to this message:

Thank you for your interest in the proposed regulatory amendments to Subpart J of the National Contingency Plan. Please note that the Agency had already received in the public docket comments from the Prince William Sound Regional Citizens Advisory Committee (PWSRCAC), and will be considering them along with all other public comments submissions.

The Agency will acknowledge these comments received as late comments given that the public comment period is now closed.

From: Mickunas, Dave
Sent: Wednesday, August 31, 2016 8:42 AM
To: Wilson, Gregory <Wilson.Gregory@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>
Cc: Merv Fingas <fingasmerv@shaw.ca>
Subject: ENVIRONMENTAL PROTECTION AGENCY - 40 CFR Parts 110 and 300 - [EPA-HQ-OPA-2006-0090; FRL-9689-9-OSWER] - RIN 2050-AE87 - National Oil and Hazardous Substances Pollution Contingency Plan - ACTION: Proposed rule.

Good Morning,

Dr. Fingas headed and developed the Environment Canada's oil program for many years and still is very involved with this field since his retirement. He requested that I contact someone involved with the above document. As a member of the Prince William Sound Regional Citizens Advisory Committee (PWS RCAC), he has concerns with the methods that are employed with this document. Please see his comments in the attached file. He is requesting that the testing data and rationale be provided for the changes to the previous used techniques. If you are the correct individuals to discuss this information, please contact Dr. Fingas directly. If not, please forward this request to the proper party. If you have any other questions or comments, please contact me.

Best regards,

David B. Mickunas
Trace Atmospheric Gas Analyzer (TAGA) Laboratories Coordinator
US EPA/Environmental Response Team
109 T.W. Alexander Drive
Mail Code E343-04
Research Triangle Park, NC 27711
919 541 4191 (office)
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Comments on EPA 40 CFR Parts 100 and 300
Proposed Rule

by

Prince William Sound Regional Citizens Advisory Committee
(PWS RCAC)
Anchorage, Alaska

General

These comments will be related in more detail to specific sections in the proposed rules.
1. Use of Standards - The committee is surprised that many of the proposed methods do not use established standards. In fact in some cases, inappropriate methods are proposed when there are standards already in existence by well-known standardization agencies such as ASTM, ANSI, ISO, etc.

Specific Comments

Page 65-66 - TPH measurement - Standard methods should be noted for TPH method. These include:
-ASTM, Standard Test Methods for Comparison of Waterborne Petroleum Oils by Gas Chromatography, ASTM Method D3328-06, ASTM International, West Conshohocken, PA, 2011
-American Society for Testing and Materials (ASTM). Oil spill identification by gas chromatography and positive ion electron impact low resolution mass spectrometry. ASTM D5739–00, ASTM International, W. Conshohocken, PA. 2010
-US EPA, Volatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8260D. The U.S. Environmental Protection Agency's Office of Solid Waste
-US EPA, Semivolatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8270D. The U.S. Environmental Protection Agency's Office of Solid Waste
-EPA 610 –Polynuclear Aromatic Hydrocarbons
-EPA 8000a- Determinative Methods for Chromatography
-EPA 8100a- Polyaromatic Hydrocarbons
-CEN (European Committee for Standardization), Oil Spill Identification-Waterborne Petroleum and Petroleum Products. Part 2: Analytical Methodology and Interpretation of Results, CEN/TC BT120, 2010
-US EPA, Semivolatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8270D. The U.S. Environmental Protection Agency's Office of Solid Waste
-Nordtest, Oil Spill Identification, Method NT CHEM 001 (2nd ed.), ISSN 0783-l 692, Finland, 1, 1991 (Current 2015)

Page 87 - 92 - Baffled Flask Test - PWS RCAC is surprised that a non-standard method is proposed for this testing when there are standard tests which are used around the world (ASTM F2059-06(2012) Standard Test Method for Laboratory Oil Spill Dispersant Effectiveness Using the Swirling Flask). More will be stated about this later, as the PWS RCAC notes that the proposed analytical method to be used with the Baffled Flask Test is non-standard and inappropriate and does not follow EPA's own standards. Alternatives to this could include – substituting a standard method for the colorimetric one (UV adsorption); such as one of the TPH methods noted above, substituting the analytical method in the Swirling Flask standard or adopting the ASTM standard Swirling Flask.

Page 186 and on – Baffle flask test – Of particular concern is the use of an unacceptable and non-standard analytical method (UV absorption – actually colorimetric). There are many concerns with this:

1. The methods have never been reviewed in a chemical journal – the references of Sorial and Venosa are published in Engineering journals.
2. The authors are not chemists: Sorial is an engineer, Venosa a biologist, Koran, etc. are engineering students
3. This is akin to a chemist publishing a new toxicology method in a chemical journal. This would have no credibility.
4. Acceptable chemical methods would need to be published in journals such as Talanta, Journal of Chromatography, Trends in Analytical Chemistry, Spectrochemica
5. The proposed method is contrary to science – Oil does not have an absorption band. Oil consists of thousands of compounds, each of which reacts with light in a different way.
6. This method has long since been shown to be flawed and incorrect. (Fingas, M.F., B. Fieldhouse and Z. Wang, "Dispersant Testing - Study on Analytical and Test Procedures", in *Proceedings of the Twenty-Seventh Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 807-841, 2004 and Fingas, M.F., B. Fieldhouse, Z. Wang, L. Sigouin, M. Landriault and J.V. Mullin, "Analytical Procedures for Dispersant Effectiveness Testing", in *Proceedings of the Twenty-Second Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 231-241, 1999)
7. All chemical analytical methods should adhere to the 3-C's principle – Certified chemists working in Certified laboratories using Certified procedures.
8. There are many labs who can do the swirling flask test in an appropriate way.
9. Why propose a new method when a standard one has been perfected over 20 years?
10. No reference standards are proposed with the colorimetric method.
11. If one does a literature search on chemical analysis for oil one finds thousands of references – not one of which refers to UV adsorption or colorimetry.
    Examples of a few of thousands of such references are:

-Drozdova, S., Ritter, W., Lendl, B., Rosenberg, E. Challenges in the determination of petroleum hydrocarbons in water by gas chromatography (hydrocarbon index), 2013 **Fuel** 113, 527-536
-Fingas, M., Fieldhouse, B., Wang, Z. Dispersant testing - Study on analytical and test procedures 2004, Environment Canada Arctic and Marine Oil Spill Program Technical Seminar **(AMOP)** Proceedings,27, 2, 807-817
-Wang, Q., Yan, Z., Sun, B., Zhu, X., Liu, H. The application of GC in the study of the effect of oil spill dispersant, 2014, **Journal of Chemical and Pharmaceutical Research**, 6, 5, 106-111
-Bowman, D.T., Slater, G.F., Warren, L.A., McCarry, B.E. Identification of individual thiophene-, indane-, tetralin-, cyclohexane-, and adamantane-type carboxylic acids in composite tailings pore water from Alberta oil sands 2014 **Rapid Communications in Mass Spectrometry**, 28, 19, 2075-2083
-Fabbri, D., Adamiano, A., Torri, C., GC-MS determination of polycyclic aromatic hydrocarbons evolved from pyrolysis of biomass. 2010, Analytical and Bioanalytical Chemistry, 397, 1, 309-317

-Sauer, T., Boehm, P. The use of defensible analytical chemical measurements for oil spill natural resource damage assessment 2005, 2005 International Oil Spill Conference, **IOSC** 2005 8817

Alternatives to the flawed analytical method could include –

1: substituting a standard method for the flawed colorimetric one (UV adsorption); such as one of the TPH methods:

-ASTM, Standard Test Methods for Comparison of Waterborne Petroleum Oils by Gas Chromatography, -ASTM Method D3328-06, ASTM International, West Conshohocken, PA, 2011

American Society for Testing and Materials (ASTM). Oil spill identification by gas chromatography and positive ion electron impact low resolution mass spectrometry. ASTM D5739–00, ASTM International, W. Conshohocken, PA. 2010

-US EPA, Volatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8260D. The U.S. Environmental Protection Agency's Office of Solid Waste

-US EPA, Semivolatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8270D. The U.S. Environmental Protection Agency's Office of Solid Waste

-EPA 610 –Polynuclear Aromatic Hydrocarbons

-EPA 8000a- Determinative Methods for Chromatography

-EPA 8100a- Polyaromatic Hydrocarbons

CEN (European Committee for Standardization), Oil Spill Identification-Waterborne Petroleum and Petroleum Products. Part 2: Analytical Methodology and Interpretation of Results, CEN/TC BT120, 2010

-US EPA, Semivolatile Organic Compounds by Gas Chromatography/Mass spectrometry (GC/MS), Method 8270D Revision 4. SW-846 Method 8270D. The U.S. Environmental Protection Agency's Office of Solid Waste

-Nordtest, Oil Spill Identification, Method NT CHEM 001 (2nd ed.), ISSN 0783-1 692, Finland, 1, 1991(current as of 2015)

2. Substituting the analytical method in the Swirling Flask standard but using the Baffled Flask ASTM F2059-06(2012) Standard Test Method for Laboratory Oil Spill Dispersant Effectiveness Using the Swirling Flask

3. Adopting the ASTM standard Swirling Flask which is a long-standing accepted standard ASTM F2059-06(2012) Standard Test Method for Laboratory Oil Spill Dispersant Effectiveness Using the Swirling Flask

Note, that in any case the numbers on page 174 and following would require replacing.

Page 205 – note that appropriate methods are suggested for analyzing TPH – these could be used as well to analyze the TPH in the Baffled Flask.

Regional Citizens' Advisory Council / "Citizens promoting environmentally safe operation of the Alyeska terminal and associated tankers."

In Anchorage: 3709 Spenard Road / Suite 100 / Anchorage, Alaska 99503 / (907) 277-7222 / FAX (907) 277-4523
In Valdez: P.O. Box 3089 / 130 South Meals / Suite 202 / Valdez, Alaska 99686 / (907) 834-5000 / FAX (907) 835-5926

MEMBERS

Alaska State Chamber of Commerce
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Cordova District Fishermen United
Kenai Peninsula Borough
Kodiak Island Borough
Kodiak Village Mayors Association
Oil Spill Region Environmental Coalition
Port Graham Corporation
Prince William Sound Aquaculture Corporation

April 16, 2015

EPA Docket Center (EPA/DC)
Docket ID No. EPA-HQ-OPA-2006-0090
1200 Pennsylvania Avenue NW
Washington, DC 20460

RE: Prince William Sound Regional Citizens' Advisory Council Comments on 40 CFR Parts 110 and 300, National Contingency Plan Subparts A and J

Dear Administrator McCarthy,

The Prince William Sound Regional Citizens' Advisory Council (PWSRCAC or Council) is an independent non-profit corporation whose mission is to promote environmentally safe operation of the Valdez Marine Terminal and associated tankers. Our work is guided by the Oil Pollution Act of 1990 and our contract with Alyeska Pipeline Service Company. PWSRCAC's 18 member organizations are communities in the region affected by the 1989 Exxon Valdez oil spill, as well as commercial fishing, aquaculture, Native, recreation, tourism and environmental groups.

The Environmental Protection Agency (EPA) proposed rule to update Subpart J of the National Contingency Plan is comprehensive and includes substantive technical and scientific analysis. PWSRCAC has reviewed the proposed rule and we submit these comments on behalf of our member organizations.

The enclosed document first presents a series of general comments that frame our major concerns and priorities. We then provide detailed comments and recommendations on technical issues raised in the proposed rule. PWSRCAC appreciate the opportunity to provide EPA with these comments.

Sincerely,

Mark Swanson
Executive Director

Amanda Bauer
Board President

Thane Miller
Vice President

Jim Herbert
Treasurer

Andrea Korbe
Member-at-Large

Bob Shavelson
Member-at-Large

Patrick Duffy
Member-at-Large

955.105.150416.SubpartJCmts

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General Comments

Council Position on Dispersant Use in Prince William Sound

PWSRCAC has taken a leading role in researching chemical dispersant efficacy and toxicity in our region. Our chemical dispersants program has been in place since 1997, and through this program we have funded a number of research studies, literature reviews, and technical analyses. In 2006, our Council adopted the following position on dispersant use in the Prince William Sound region:

> *After years of observing dispersant trials, dispersant effectiveness monitoring, advising and sponsoring independent research regarding chemical dispersant use, it is the position of the Prince William Sound Regional Citizens' Advisory Council (the Council) that dispersants should not be used on Alaska North Slope crude oil spills in the waters of our region. Until such time as chemical dispersant effectiveness is demonstrated in our region and shown to minimize adverse effects on the environment, the Council does not support dispersant use as an oil spill response option. Mechanical recovery and containment of crude oil spilled at sea should remain the primary methodology employed in our region.*

PWSRCAC appreciates the Historical Background provided by EPA in the Statutory Authority section of the proposed rule, because it affirms the longstanding preference for mechanical recovery as a primary oil spill response tool, with dispersants as an alternative **only** "if other control measures are judged to be inadequate or infeasible." This is an important concept that still applies today, as mechanically containing and recovering spilled oil is always preferred over other spill treatment options because mechanical recovery is the only option that removes oil from the environment.

While PWSRCAC does not support dispersant use in our region, we understand that chemical dispersants are a secondary response tool that can and have been used both in our region and in other areas of the United States. For as long as dispersants remain as part of the National Response Framework, we advocate for a strong science-based approach to dispersant use guidance and decision-making. Our comments identify several areas where EPA could enhance the proposed rule by clarifying the thresholds or procedures for incorporating scientific data into response planning and operations.

Cautious Approach to Use of Chemical Agents

PWSRCAC applauds EPA for clarifying, through this proposed rule, that the agency has the responsibility and authority under the Clean Water Act not only to establish a Schedule for oil spill treating agents, but also to identify the waters and quantities in which they may be safely used. The National Contingency Plan (NCP) clearly establishes mechanical recovery as the primary and preferred oil spill removal method, and decisions to treat an oil spill with chemicals must be made in a cautious and deliberate manner.

PWSRCAC believes that through the proposed rule, EPA is making it very clear to manufacturers, the response community, and the general public that chemical agents should only be applied to oil spills when there is clear, science-based evidence that these agents will (1) be effective in treating the oil spill such that the adverse impacts of the oil spill will be reduced, and (2) not pose the risk of enhanced toxicity from the

treated oil or the agent itself. PWSRCAC strongly supports this cautious approach, and we have identified several areas in the proposed rule where EPA should add clarifying language to reinforce this critical concept.

PWSRCAC also recommends that EPA acknowledge that entities potentially affected by this proposed rule include a broad range of constituents who rely on the health of the marine ecosystem, including commercial fishing, subsistence uses, tourism, recreation, passive uses, and traditional and customary use.

Emphasis on Science-Based Decision-making

PWSRCAC strongly supports EPA's emphasis of science-based decision-making in the proposed rule. We recommend that wherever possible, the Schedule should establish quantitative limits or thresholds for chemical and biological agents. These thresholds will inform both preauthorization planning and On-Scene Coordinator (OSC) decision-making during an incident.

PWSRCAC has supported significant scientific research into dispersants and oil spill treating agents; many of our peer-reviewed studies are cited in the proposed rule. We have cited our comments to the published literature wherever possible, and many of our comments note areas where the proposed rule does not necessarily reflect the prevailing knowledge as captured in scientific publications.

While it is important to ground oil spill response policy and decision-making in science, it is equally important that EPA acknowledge areas where the foundational science contains uncertainties. In the wake of the Deepwater Horizon spill response, there has been significant effort among federal agencies and leading researchers to clarify areas where there is consensus about chemical treating agents (primarily dispersants), and areas where uncertainty prevails. In light of this fact, we encourage EPA to be as transparent as possible about areas where scientific data is sparse or consensus is lacking. In order for the public to have confidence in oil spill response decision-making, there must be clear and plain acknowledgement of scientific uncertainty.

PWSRCAC also recommends that EPA consider and acknowledge the fact that the current rulemaking, like the previous Subpart J regulation, relies upon manufacturer-provided science on both efficacy and toxicity. This creates an inherent conflict of interest, and while EPA is establishing parameters and criteria for these studies, we suggest that the agency go a step further and observe or supervise independent science to verify results of manufacturer studies.

PWSRCAC maintains a dispersants research literature synthesis and database, updated annual, which we recommend as a reference.[1]

Toxicity and Sub-chronic Effects of Chemical Agents

Petroleum oil products are a highly complex set of chemicals that consist of a variety of constituent components, many of which are toxic to humans, flora and fauna. Toxic impacts may be acute or chronic, direct or indirect. Chemical or biological agents used

[1] http://www.pwsrcac.org/programs/environmentalmonitoring/dispersants/dispersant-literature-reviews/

to treat oil spills may influence the toxicity of oil products and their constituents, and it is critical to compile as much information as possible about potential toxicities before treating agents are applied to a spill. Ongoing studies from the Deepwater Horizon well blowout show that dispersant use during that spill had adverse impacts to respiratory function in both humans and fish (Fu et al., 2015; UAB, 2015).

EPA has traditionally relied upon a limited set of toxicity tests on a few select species to establish toxicity data for oil spill treating agents. Two temperate species have been used as the basis for toxicity evaluations, even for areas like Alaska where these species do not exist. Toxicity testing has been limited to a narrow range of acute effects that may overlook other important mechanisms through which chemical treating agents may cause harm to wildlife and the environment. The proposed changes to Subpart J make some adjustments to the testing approach, but these are not sufficient to inform a complete understanding of toxicity, particularly for sub-chronic effects.

PWSRCAC recommends expanded requirements for toxicity testing to evaluate the full spectrum of potential adverse endocrine, immune, or developmental effects to human populations or the environment. A multi-species, system-level approach is essential to accurately predict both the protective and detrimental effects to both humans and the natural environment from the application of dispersants to accidentally released oil. We recommend that EPA consider how other programs – such as drinking water or food safety – assess potential toxicity to humans and the environment and apply the same rigor to chemical agents. The proposed new focus that addresses endocrine disruptors is an excellent first step.

Emphasis on Preauthorization

The proposed rule heavily emphasizes the preauthorization process. PWSRCAC recognizes that preauthorization planning is important and should be undertaken in a collaborative and scientifically rigorous manner. However, we are concerned that EPA is over-emphasizing preauthorization at the potential expense of case-by-case decision-making. The proposed rule correctly notes that given recent advances in connectivity, it is much easier for OSCs to consult with natural resource trustees and subject matter experts to inform all aspects of oil spill response. Since it is so much easier to convene a discussion in real time, case-by-case decision-making should be feasible for most spills, eliminating the need to prescribe decisions through pre-authorization. Wherever possible, consultation with trustees and scientific experts should be a priority – even in cases where preauthorization is in place.

The emphasis on preauthorization planning also creates the false impression that oil spill treating agents are regularly or commonly used in the U.S. With the exception of the Deepwater Horizon oil spill, non-mechanical oil spill response methods are still the exception, not the rule. Given how infrequently oil spill treating agents are used, the amount of time and energy devoted to preauthorization planning may be better allocated to establishing a strong mechanism for case-by-case decision-making or other types of oil spill preparedness and planning.

Case-by-case decision-making is important because there are still significant uncertainties about the efficacy and toxicity of oil spill treating agents. Most of the

data that is used to inform decision-making is derived from laboratory experiments that are often a poor proxy for real-world performance. Preauthorization plans cannot foresee all possible circumstances during which a spill response may occur, and the effectiveness and toxicity of treating agents is influenced by a complex and nuanced array of inputs. Five years after the Deepwater Horizon spill, there are still significant gaps in knowledge about the effectiveness and toxicity of subsea dispersant use. A recent report by the U.S. Geological Society notes that there is insufficient science to support dispersant use decision-making (Holland-Bartels and Pierce, 2011). We simply do not have reliable science to foresee the short and long-term consequences of oil treating agents; therefore, the precautionary principle must be applied during all incidents, even when they occur within the bounds of preauthorization.

PWSRCAC recommends that EPA refocus the proposed rule to ensure that case-by-case decision-making processes are assured wherever possible, even in areas where oil spill treating agents have been preauthorized. No plan can substitute for professional judgment, real-time data, and local knowledge.

OSC Discretion and Decisionmaking

The proposed rule represents a significant improvement over the current Subpart J process, which requires that manufacturers of oil spill treating agents p rovide documentation to the EPA. EPA then reviews the documentation for accuracy and, if complete, publishes to the Schedule. This system relied on the OSC to evaluate the information in the Schedule and to "judge whether and in what quantities a product may be used to control a potential discharge." The proposed changes to Subpart J would assign a more active role to the EPA in reviewing and vetting the information submitted by a manufacturer, and would require EPA to make a determination about whether or not to include a product on the Schedule based on a technical review of the data. This is a major improvement over the current system, and PWSRCAC strongly supports EPA's proposal to take a more active role in reviewing submissions to the Schedule.

However, we are concerned that the proposed rule as written gives the OSC broad discretion to override preauthorization and make exceptions to virtually all components of the proposed rule. While the OSC will presumably have a strong background in pollution response and incident management, this person may not have the scientific or technical background to make decisions that override Subpart J product listings and regional preauthorization planning . The value of preauthorization planning is the fact that subject matter exper ts and natural resource trustees have a clear role in developing these plans and policies. Similar rigor should be applied to case-by-case decision-making.

The proposed rule as written empowers the OSC to use real-time data to inform decision-making. PWSRCAC supports this idea of science-based decision-making, but cautions that the OSC may not have sufficient independent expertise to interpret and apply such data. Natural resource trustees with local knowledge must have an active role in response decisions regarding chemical or biological agents. The Area Committee (AC) and Subarea Committees (unique to Alaska), State and Federal Trustee Agencies, Tribal entities, and Scientific Support Coordinator (SSC) all play important

advisory roles to inform the OSC about scientific issues related to the use of oil spill treating agents.

PWSRCAC recommends that EPA revise the rule to create clear accountability for the OSC to consult with subject matter experts and trustee agencies. It should also clarify where consultation vs. concurrence is required to override preauthorization plans or make independent decisions about oil spill treating agents.

Unilateral Authority of EPA Administrator

PWSRCAC has strong concerns about the proposed language that would give the EPA Administrator, under Subpart H, unilateral authority to bypass both Subpart J and regional preauthorization plans. As a national political appointee, the EPA Administrator should not be in the position to overrideconsensus decisions or policies developed by local natural resource trustees. This option undermines both Subpart J and the preauthorization planning process. PWSRCAC does not believe that decisions about local application of spill treating agents in Alaska should be made in Washington, D.C. by a single agency head. We therefore recommend removing this provision from the proposed rule. If it is retained, we suggest that the EPA Administrator should be required to obtain concurrence from his or her counterpart within federal trustee agencies- i.e. the NOAA Administrator, DOI Secretary, etc.

PWSRCAC recommends that EPA require that in any case where exceptional decisions are made to use oil spill treating agents - whether that decision originate with the OSC or the EPA Administrator - a transparent public record must explain these decisions and their scientific rationale.

Subsurface Dispersant Use

PWSRCAC has concerns about the manner in which the proposed rule considers subsurface dispersant use as an established approach. PWSRCAC does not believe that there is enough data demonstrating that dispersants add value to subsurface oil spill response. In an area like Prince William Sound, where we do not have exploration and production but do have the potential for a subsea release from a damaged or s unken tanker, we are concerned about the potential for the new Subpart J rule to open the door to preauthorized use of subsurface dispersants in Alaska.

The unprecedented and highly contested use of dispersants during Deepwater Horizon seems to be considered by EPA as justification for expanding dispersant use and encouraging preauthorization for subsea releases, when there is very little science to support subsea dispersant use decision-making. Techniques for measuring effectiveness of subsurface dispersant applications are unproven. Oil that came ashore during the Deepwater Horizon oil spill contained dispersant, indicating that some proportion of the "dispersed" oil actually impacted the shoreline. In fact, a mixture of oil and dispersants continues to make landfall, years after this spill.Non-degraded oil has been documented throughout the Gulf of Mexico environment. All of this casts serious doubts on the efficacy of the subsurface dispersant application during that spill, and certainly points to the need for additional research before subsurface dispersants can be considered a mature spill treatment option.

The State-of-Science for Dispersant Use in Arctic Waters working group, a consortium of leading dispersant scientists in which PWSRCAC participates, has expressed uncertainty about the effectiveness of subsea dispersants under some conditions, and about the ability to measure effectiveness for sub-surface applications.

For these reasons, PWSRCAC urges the EPA to remove subsurface dispersant application from Subpart J at this time, and revisit the issue in the future when there is more definitive science to inform the tradeoffs involved in applying dispersants to subsurface oil spills.

Consensus Standards

The proposed rule contains a number of new or changed requirements for efficacy and toxicity testing for chemical and biological agents, with the goal of using standard, repeatable approaches that will make it easier to compare results across products and manufacturers. The State-of-Science for Dispersant Use in Arctic Waters working group is in the process of establishing a consensus opinion about the importance of standardization in dispersant testing and monitoring methods, and they have noted in their deliberations that standard measurement methods are crucial to acceptable data generation.

PWSRCAC advocates for the use of consensus standards where available to ensure consistent methodologies are applied during scientific testing. We are concerned that EPA is proposing to abandon the consensus standard for dispersant effectiveness that has been in place for years and is currently used in 20 countries, including the U.S. We understand that there are advantages and disadvantages of both the existing (swirling flask) and proposed (baffled flask) technique for dispersant effectiveness testing, and we recommend that EPA ensure that, if the standard technique is changed, comparable standards are provided for the baffled flask test. It is most important to ensure that efficacy tests are carried out in a controlled and replicable manner. EPA should ensure that – regardless of the technique - dispersant efficacy tests are conducted by **certified** chemists working in **certified** laboratories using **certified** procedures (ASTM swirling flask test).

PWSRCAC agrees that the development of new consensus standards may be appropriate to inform scientific testing and comparison of oil spill treating agents. We recommend that any new standards adopted in Subpart J meet the following criteria: (1) improve reproducibility of the tests within a laboratory; (2) certified cross validation between laboratories; (3) provide adequate discrimination between agents being tested; and (4) facilitate testing of all necessary variables (such as temperature and salinity) that may influence efficacy or toxicity.

Sinking Agents

The Statutory Authority section of the proposed rule makes note of the historic prohibition of sinking agents, which dates back to 1984. PWSRCAC strongly supports EPA's ban on the use of sinking agents in the proposed rule. However, we are concerned that the rule creates some ambiguity about other agents that may act like sinking agents under certain conditions (such as oil mineral aggregates or clays), and we urge EPA to clarify that *any agent that causes oil to sink to the bottom is considered*

a sinking agent under conditions that may lead to sinking, and is therefore banned from use in U.S. waters.

Reliance on Responsible Party and Manufacturer Science

Throughout the proposed rule, requirements are proposed for testing and monitoring to be conducted by the Responsible Party, (RP) at the time of a spill, or the Chemical Agent manufacturer (for listing agents on theSchedule). PWSRCAC strongly urges the EPA to consider all possible opportunities to require independent science or rigorous peer review of all studies that are conducted by the RP or vendor. When a spill occurs, the RP faces significant civil and criminal liability based on environmental damages, including damages caused by spill treatment decisions. This creates a conflict of interest for assessing potential adverse impacts from treating agents.

Similarly, the product manufacturers and vendors have a financial interest in selling their product, and therefore have a motive to present results that might overestimate potential effectiveness or understate toxicity. We recommend that the EPA consider opportunities to audit or independently vet studies to ensure fairness and transparency.

Detailed Comments on Proposed Rule

Dispersants (40 CFR §110.4)

Summary: EPA proposes to revise this section to link the rule with the new and amended regulatory definitions for Subpart J product categories in 40 CFR §300.5.

Comments
PWSRCAC has provided comments under 40 CFR §300.5.

Definitions (40 CFR §300.5)

Summary: EPA proposes revisions to §300.5 that amend the definitions for Bioremediation agents, Burning agents, Chemical agents, Dispersants, Sinking agents, and Sorbents. EPA is proposing to remove the definitions for surface collecting agent and for miscellaneous oil spill control agent (MOSCA).

Comments
PWSRCAC finds that on the whole, these new definitions add clarity. We believe that it is important to clearly define treating agents to make sure that agents included on the Schedule are appropriately categorized and are used as intended. For example, many products currently sold as solidifiers, under the current Schedule, are actually sorbents.

Recommendations

- PWSRCAC recommends that language be added to the definition for each agent and substance clarifying that it is "not likely to cause additional harm, either alone or in combination with oil, to public health or welfare or to the environment."
- PWSRCAC recommends that each definition specifically state whether the substance is, or is not, intended to be removed from the environment.

Bioremediation Agents

Summary: EPA proposes to revise the definition of bioremediation agents.

Comments
PWSRCAC finds that the definitions of "biodegradation" and "bioremediation" oversimplify these processes, which may result in only partial biodegradation or partial bioremediation, which may potentially result in more toxic intermediate products.

PWSRCAC is also concerned about the use of non-indigenous bioremediation agents that could potentially colonize the area where they are released, and we suggest that the definition prohibit the use of biological agents that could result in non-indigenous species colonization, which could have significant ecosystem impacts.

PWSRCAC supports the inclusion of fungi in the definition of biological agents and the use of mycoremediation. Fungi have been found to be effective at degrading the complex PAHs. PWSRCAC has included several references regarding mycoremediation that support our comments.

Recommendations

- PWSRCAC recommends that the definitions of biodegradation and bioremediation be expanded to include the possibility that partial biodegradation or partial bioremediation may occur in the environment, and may potentially result in more toxic intermediate products.
- PWSRCAC recommends that the definition of bioremediation agents include a ban on agents that may result in the colonization of non-indigenous species.
- PWSRCAC supports the inclusion of fungi in the definition of biological agents and the use of mycoremediation.

Burning Agents

Summary: EPA proposes a revised definition of burning agents and is considering including ignition devices in the definition.

PWSRCAC supports the inclusion of ignition devices in this category, and we suggest that EPA develop corresponding requirements to evaluate toxicity associated with combustion products and burn residues. Studies of in-situ burn residues from the Deepwater Horizon spill confirmed that the chemical and physical properties of the oil are changed during in-situ burning (Shigenaka et al., 2015). Therefore, it is equally important to evaluate potential toxicity influences that may result from the use of burning agents to treat oil spills similar to the way in which chemical or biological agents may alter oil properties and influence toxicity.

Recommendations

- PWSRCAC recommends that EPA require toxicity testing of burning agents, of combustion products (smoke plumes), and also of the burn residue that results from application of burning agents to oil slicks.

Chemical Agents

Summary: EPA proposes a revised definition of chemical agents to distinguish them from biological agents and remove agent categories that are being eliminated, prohibited or amended.

Comments
EPA proposes to revise the definition of chemical agents to identify them as being "designed to facilitate the removal of oil." PWSRCAC takes exception with the use of the term "remove." This definition is aspirational and potentially misleading and does not make clear that chemical agents do not **remove oil** and do not necessarily mitigate harm (i.e. recognize that there may be a trade-off of harms).

PWSRCAC does not support the use of sinking agents, including chemical and biological agents that meet other definitions (e.g. solidifier, sorbent, dispersant) but may cause oil to submerge or sink under certain conditions.Inclusion of a definition for sinking agents in the context of other agents that may be put on the Schedule contradicts EPA's stated policy against the use of sinking agents to treat oil spills.

The final rule should make it very clear which chemical agents are intended to be removed from the environment, and which are not.

Recommendations

- PWSRCAC recommends revising the definition of Chemical Agents to clarify that they do not necessarily remove oil from the environment, they treat oil.
- PWSRCAC recommends that sinking agents be removed from the definition of chemical agents.
- PWSRCAC recommends that the definition of Chemical Agents should clearly delineate between agents that are intended to be removed from the environment and those that are not.

Dispersants

Summary: EPA proposes a revised definition of dispersants.

Comments
The proposed definition addresses the process through which dispersants "assist in mitigating the consequences of a discharge."PWSRCAC finds this language to be somewhat leading, and we suggest replacement of this language to communicate that dispersants are intended to modify an oil discharge, but that their mitigation effects are situationally dependent and by no means guaranteed. Later in the proposed rule (page 3394), EPA acknowledges that "applying dispersant to an oil discharge does not result in the physical recovery of oil to the environment." In fact, dispersants treat the oil such that it is no longer available for physical recovery, and the application of dispersants in cases may make it more difficult to recover spilled oil in cases when dispersion is temporary and the oil eventually coalesces and resurfaces (Fingas, 2005).

Recommendations

- PWSRCAC recommends rewording the definition of dispersants to emphasize that they do not necessarily mitigate a discharge.

Sinking Agents

Summary: EPA proposes a revised definition of sinking agents to specify that these agents purposely sink the oil to the bottom of a water body. The new rule would ban the use of sinking agents.

Comments
PWSRCAC supports the inclusion of sinking agents in the list of prohibited agents proposed for §300.910(e). However, we find that the proposed definition of sinking agents does not clearly align with that section, and may potentially create confusion around the use of substances that cause oil to submerge or sink.
Any agent applied to an oil slick with the intention of causing the oil to submerge or sink below the surface will render that oil no longer available for mechanical recovery.

Any agent that causes oil to submerge below the water surface in a given waterbody should be characterized as a sinking agent, even treating agents that also qualify for other categories (e.g. dispersants, solidifiers, sorbents). The State-of-Science for Dispersant Use in Arctic Waters working group reached preliminary consensus on the fact that chemical dispersants can facilitate the formation of oil-mineral aggregates (OMA), potentially causing the oil to sink: *"The effect of chemical dispersants to oil in the presence of adequate suspended particulate material and mixing energy will increase the rate of formation of OMA."* While the working group report noted that OMAs will only sink under certain conditions, PWSRCAC is concerned that such scenarios result in a dispersant that functions like a sinking agent.

Recommendations
- PWSRCAC recommends that EPA ban dispersant use under conditions where OMA formation is likely and sinking is possible.We have included a list of references about the potential for OMA formation at the end of this document.

Solidifiers

Summary: EPA proposes to define solidifiers as substances that change oil chemically and cause it to become a cohesive mass intended for collection.

Comments
PWSRCAC does not support the use of solidifiers, as they offer no measurable advantage over sorbents or mechanical recovery. They have limited practicality, may cross-link or react with other substances, and require immediate removal from the environment. There has been very limited effectiveness testing on solidifiers, and few recent studies. PWSRCAC has included in our Reference list a series of reports on solidifiers that support our position.

Recommendations
- PWSRCAC recommends that EPA remove solidifiers from the Schedule.

Sorbents

Summary: EPA proposes to identify sorbents as substances consisting of: (1) natural organic substances (e.g., feathers, cork, peat moss, and cellulose fibers such as bagasse, corncobs, and straw); (2) inorganic/mineral compounds (e.g., volcanic ash, perlite, vermiculite, zeolite, clay); and (3) synthetic compounds (e.g., polypropylene,

polyethylene, polyurethane, polyester). EPA requests comments on whether additional materials should be included in the definition, and also on the inclusion of the phrase "that are generally collected and recovered from the environment," citing the potential for removal of sorbents to cause more harm than good in certain environments. EPA also requests comments about characterizing particulate matter (e.g. clay) as sorbents.

Comments
PWSRCAC supports the proposed definition of sorbent, with the exception of clays and oil mineral aggregates (OMAs), which are intended to be land-based sorbents and should be prohibited for use on water even in cases when the oil/clay or oil/OMA particles are expected to be less dense than water .

Recommendations
- PWSRCAC recommends that EPA clearly require that all sorbent materials must be recovered from the environment, and that sorbent use is not authorized in the event that the sorbents cannot be removed from the environment.
- PWSRCAC supports a ban on the use of particulate sorbents (clay) on water.
- PWSRCAC supports a ban on the use of OMA technologies on water.

Surface Washing Agents

Summary: EPA proposes to revise the term and definition of surface washing agents from singular to plural for consistency with other definitions, and to clarify that these agents are meant to be removed from the environment.

Comments:
PWSRCAC supports the definition of surface washing agents, with the clarification that these agents must be removed from the environment.

Recommendations
- PWSRCAC recommends that EPA clearly require that all surface washing agents must be recovered from the environment.

Authorization of Use (40 CFR§300.910)

Summary: EPA proposes to reorganize and add titles to this section, add several requirements addressing the storage and use of agents, notification of agent use and recovery from the environment, and revise language to clarify established EPA policy regarding the requirement for an OSC to authorize use of any oil spill treating agent.

Comments
Subpart J should include as much specific, quantifiable information and direction as possible to assist Regional Response Teams (RRTs) and ACs with the preauthorization planning process. It is particularly important for EPA to clearly identify cases where treating agent use should not be preauthorized.

Recommendations
- PWSRCAC recommends that EPA clearly delineate conditions under which use should not be preauthorized.
- PWSRCAC recommends that preauthorization plans clearly acknowledge that there may be times or places where use of chemical or biological agents is not

appropriate, even if it is preauthorized. The response decision-making process must take into account allfactors that could influence the effectiveness or impacts of chemical or biological agent use.
- PWSRCAC recommends that the Schedule explicitly state that chemical or biological agents may only be used for their intended use within a specific category so that, for example, an agent that is listed as a surface washing agent cannot be authorized for use as a dispersant.

Preauthorization Planning §300.910(a)

Summary: EPA proposes to clarify the preauthorization planning process.

Comments
PWSRCAC supports the requirement for a regular review cycle for preauthorization plans to address revisions of the Schedule, and also supports the other parameters identified as triggers for a preauthorization plan review (SONS, new threatened or endangered species, changes to worst case discharge estimates,emergent scientific information, or other major changes). However, we are concerned about the need to balance information currency with the need to have established plans in place so that the public understands current policy. In Alaska, our Dispersant Use Authorization plan has been in flux for over a year, resulting in a situation where there is no clear, established policy.[2]

The proposed rule also addresses the decision-making process used to develop preauthorization pl ans. While the concept of preauthorization is rooted in the need to expedite decision-making, its application must carefully consider that each spill is unique and a range of variables may influence the effectiveness of a dispersant. There may be times or places where dispersant use is not appropriate, even if preauthorization is in place.

PWSRCAC supports EPA's proposals to expand consideration of waterbody characteristics, like salinity, in the context of both efficacy testing and preauthorization. PWSRCAC supports this approach, and suggests that Subpart J should provide clear direction to the RRT and OSC to consider not just the waterbody salinity, but other characteristics like circulation patterns, mixing energy, presence of endangered or threatened species, critical habitats, seasonal changes, sediment levels, etc. when authorizing the use of chemical agents. In Alaska, we have developed the following list of criteria to consider before deciding to use dispersants in our marine waters, and we suggest that EPA consider including these in Subpart J guidance.

- **Bathymetry** - it is generally recognized that adequate mixing and dilution of dispersants should occur if applied in waters deeper than 10 fathoms (or 60 feet) depth provided there is sufficient energy for mixing. The 10 fathom contour is a standard depth contour line included on National Oceanic and Atmospheric Administration marine charts.
- **Distance from shore** - an adequate buffer needs to be established to reduce the chances of applying dispersants to sensitive shorelines/nearshore areas and to

[2] Annex F to the Alaska Unified Plan was issued as a draft in September 2013 and is not yet finalized. http://alaskarrt.org/Files/ARRT%20Oil%20Dispersant%20Authorization%20Plan_Draft%209-25-13.pdf

ensure that drifting dispersant and/or dispersed oil mixtures do not adversely affect intertidal and benthic biota.

- **Wind and currents** - areas where there is generally little movement of water would not provide sufficient mixing energy for effective dispersant use. With higher wind speeds (beginning at 12 - 14 meters per second (26.8 to 31.3 miles per hour)), the benefits of dispersant application start to diminish compared to natural dispersion.
- **Salinity** – most dispersants are made for use in saltwater and are not effective in fresh water or waters with a salinity of less than 15 parts per thousand.
- **Temperature** - dispersant effectiveness will be affected by ambient water temperatures, with more complete dispersion in warmer waters.
- **Response equipment** - the availability and time to mobilize response equipment may affect whether dispersants can be used.
- **Shoreline types** - certain shoreline types (e.g., gravel, mixed sand and gravel, coarse-grained sand beaches, and marshes) may trap oil for long periods.The amount of wave energy (e.g., protected inlets vs. high-energy exposed beaches) will also affect oil retention and persistence.
- **Sensitive habitats** - certain habitats where biota breed, rear young, feed, or congregate (e.g., eelgrass beds, kelp beds, saltwater marshes, and designated critical habitats for threatened or endangered species) may be adversely affected by oil and/or dispersed oil.
- **Sensitive species including threatened or endangered species** – these species may be adversely affected by oil and/or dispersed oil.
- **Other areas designated for special use or protection**-these areas (e.g., national and state parks, national wildlife refuges, and wildness areas) may be adversely affected by oil and/or dispersed oil.
- **Historic properties** - these resources (e.g. archeological and historic resources) may be adversely affected by oil and/or dispersed oil.
- **Human use activities** - these activities (e.g., subsistence, fishing, and boating activities) may be adversely affected by oil and/or dispersed oil.
- **Public and private facilities** – these facilities (e.g., fish hatcheries, aquaculture and mariculture facilities, public water intakes, and docks) may be adversely affected by oil and/or dispersed oil).

Preauthorization planning should take into account all of the factors that may impact dispersant effectiveness. The State-of-Science for Dispersant Use in Arctic Waters working group reachedpreliminary consensus on the importance of several factors on dispersant effectiveness, including temperature, persistence of compounds, and weathering and emulsification.Their deliberations emphasize the importance of considering how temperature may influence the physical properties of oil and, in turn, its dispersibility. This group of scientists has also established consensus that the environmental persistence of dispersants is influenced by environmental conditions. It is critical that the decision-making process provide sufficient flexibility, even in cases of preauthorization, to consider how these ephemeral factors may influence the potential effectiveness or toxicity of dispersants or other chemical agents.

We support EPA's suggestion thatexplicit concurrence, rather than consultation, should be achieved among resource trustees – including states adjacent to the federal waters – for all preauthorization plans. We recommend that the rule explicitly

recognize tribal governments as well, and also require concurrence from potentially impacted tribal entities in accordance with Executive Order 13175.

PWSRCAC also believes that it is important to include not just the RRTs but also the ACs (and, in Alaska, Subarea Committees) in the preauthorization planning process, as the ACs typically cover a smaller geographic area and have more extensive local knowledge.

PWSRCAC supports EPA's proposal to include specific procedures for withdrawal of concurrence of preauthorization plans to allow trustee agencies the flexibility to change their position in the event that conditions change.

PWSRCAC disagrees with EPA's proposal to replace the word "potential" with "likely" in reference to the sources and types of oil that might be spilled. We believe that "potential" is a broader, more conservative term that is appropriate for preauthorization planning. Determination of "likely" spill sources would require a standard methodology for risk categorization in order to ensure standard application across preauthorization plans.

Finally, PWSRCAC encourages EPA to consider that preauthorization planning cannot possibly foresee all potential circumstances, and that whenever possible, decisions about oil spill treating agents should be made at the time of an incident based on the specific incident and best available science. Even if dispersants or oil treating agents are preauthorized in a given location or time, it is prudent to proceed cautiously with their application and to continuously evaluate efficacy and effects. To this end, we suggest that EPA encourage preauthorization plans to require field tests prior to full-scale applications, even in cases where use is preauthorized.

Recommendations

- PWSRCAC recommends that the EPA require that the public be provided with an opportunity to review and comment on preauthorization plans during each review cycle.
- PWSRCAC recommends that preauthorization plans should be required to specify not only geographic designations but also to set threshold limits for waterbody characteristics including salinity, circulation, mixing energy, seasonal changes, sensitive species, sediment load, freshwater plumes, and other factors that could influence the fate, behavior, or impacts of dispersed oil.
- PWSRCAC recommends that the EPA include in the new rule some requirement that preauthorization planning take into account the impact of temperature on oil properties and, thus, their dispersability.
- PWSRCAC recommends that the EPA include in the new rule some requirement that preauthorization planning take into account the persistence of dispersant compounds based on the environmental conditions. Preauthorization is not appropriate during conditions that would favor long-term persistence of dispersant compounds.
- PWSRCAC recommends that the EPA include in the new rule some requirement that preauthorization planning take into account the impact of weathering and emulsification on oil viscosity and, thus, dispersability.

- PWSRCAC recommends that explicit concurrence from resource trustee agencies, state agencies, tribal governments, RRT and AC members should be achieved in developing preauthorization plans.
- PWSRCAC recommends retaining the term "potential" rather than "likely" in the context of the types of oil that might be discharged.
- PWSRCAC recommends that EPA require preauthorization plans to compel field tests, even in preauthorization areas, prior to full scale applications, to ensure efficacy and evaluate toxicity before full scale operations begin.

Use of Agents on Oil Discharges Not Addressed by a Preauthorization Plan §300.910(b)

Summary: EPA proposes to clarify the authorities and responsibilities for use of agents on the Schedule in situations not addressed by a preauthorization plan.

Comments
PWSRCAC supports the requirement that the OSC notify the RRT representatives from the EPA, affected states, and DOC/DOI natural resource trustees as soon as possible. We also support the distinction in the proposed rule that the OSC should go beyond consultation and seek concurrence from trustee agencies whenever an exception is considered. These trustee agencies have critical knowledge and resource stewardship responsibilities that should be incorporated into the decision-making process. We agree with the EPA that modern communication technology should enable rapid collaboration, and that there is no reason that the OSC should need to make unilateral decisions.

Recommendations
- PWSRCAC recommends that OSCs should be required to notify the RRT, EPA, affected states, and trustee agencies as soon as possible when an exception is considered, and that concurrence of all parties should be required prior to making decisions about uses not addressed by a preauthorization plan.

Burning Agents §300.910(c)

Summary: EPA proposes to revise this section to provide greater flexibility to the OSC in authorizing the use of burning agents for in-situ burning.
Comments
PWSRCAC does not oppose the use of burning agents to enhance in-situ burning of a spill; however, we believe that it is important to ensure that any burning agent applied to an oil slick be fully combustible, and that the potential toxicities of the burning agent alone, the combusted oil slick (smoke), and the burn residue be considered in the decision-making process.

Recommendations
- PWSRCAC recommends that EPA require toxicity and efficacy testing for burning agents that are listed in Subpart J to inform decision-making about burning agent use based on effectiveness of the agent in igniting a slick under a range of conditions and the potential toxicity of the burning agent itself and combustion byproducts (smoke and residue).

Exceptions §300.910(d)

Summary: EPA proposes to clarify the intent of the exception provision, which gives the OSC authority to authorize the use of products not on the Schedule in order to prevent or substantially reduce a threat to human life.

Comments
PWSRCAC has significant concerns about the unilateral decision-making authority that this provision would grant the OSC. We do not agree with the EPA's hypothetical example of the type of situation where a chemical agent not on the Schedule would be justified for use to mitigate a threat to human life. The proposed rule suggests that a spill of highly flammable petroleum products in harbors or near inhabited areas may justify the use of a product not on the Schedule if the agent would, "in the OSC's professional judgment...ef fectively and expeditiously mitigate the threat to human life." PWSRCAC is not aware of any instances where chemical or biological treating agents (with the exception of firefighting foam, which we do not believe are included in Subpart J) have been used on highly flammable product in a confined space, and we do not believe that OSCs would necessarily have an appropriate background in chemistry to make such decisions.

PWSRCAC supports the requirement for concurrence from the RRT for continued use of a substance not on the Schedule, although we suggest that the time period could be shortened from 48 to 24 hours or less. When an oil spill occurs, the RRT members with natural resource trustee roles will be engaged almost immediately and should have a role in decision-making as soon as possible.

Recommendations

- PWSRCAC recommends that EPA withdraw the exception for purpose of mitigating threats to human life, unless the agency can provide a more realistic example of a situation where such an exception would clearly protect human life.
- PWSRCAC recommends that the OSC be required to seek concurrence from the RRT for continued use of a substance not on the Schedule within 24 hours or less.

Prohibited Agents §300.910(e)

Summary: EPA proposes to clarify that the prohibition of sinking agents applies to all agents that act as sinking agents when mixed with oil and to certain other agents with specific toxic components.

Comments
PWSRCAC strongly supports the prohibition of the use of nonylphenols (NP).
Given the significant adverse impacts of NPs cited in the proposed rule, PWSRCAC does not believe that cost considerations should justify the continued use of products containing these harmful agents to treat oil spills. We also support a broader prohibition on agen ts that contain endocrine disrupting compounds (EDC). However, we have some concerns about the techniques that would be used to do this type of testing.

In addition to the presence of endocrine disrupting compounds or prohibited agents in dispersants themselves, PWSRCAC is also concerned that EPA ensure that the byproducts of dispersed oil do not contain such substances. Many toxic compounds found in oil (e.g. PAH) require metabolic activation to express toxicity. These are further metabolized to less active forms which are excreted. Microbial degradation may take slightly different metabolic routes. In either case the metabolites may enter the water column where they may exert toxic effects either directly or indirectly.

PWSRCAC strongly opposes the use of sinking agents and believe that the list of prohibited agents should include any agents with the potential to cause oil to sink based on the receiving environment.

Recommendations

- PWSRCAC recommends that EPA ban from the Schedule any agents containing nonylphenols or endocrine disrupting compounds.
- PWSRCAC recommends that EPA also ensure agents included on the Schedule will not cause oil to degrade in a manner such that its byproducts contain any prohibited substances. We request that EPA provide additional information about the types of tests or analyses that could be applied to make these types of determinations.
- PWSRCAC recommends that EPA include sinking agents in the list of prohibited agents, with the acknowledgement that agents may act as sinking agents depending upon the location, timing, and waterbody where the spill occurs.

Storage and Use of Agents §300.910(f)

Summary: EPA proposes to add language to require the OSC to authorize use of agents only when they have been stored under conditions specified in the Schedule by the submitter.

Comments

PWSRCAC disagrees with EPA's proposal to require owners or operators that store chemical or biological agents to ensure that they do not degrade into more toxic byproducts once the manufacturer's expiration date has passed. The purpose of an expiration date is to ensure product safety and integrity. Once the expiration date has passed, the product should be disposed.

Recommendations

- PWSRCAC recommends that EPA require that expired chemical agents should be disposed.

Supplemental Testing, Monitoring, and Information §300.910(g)

Summary: EPA proposes to revise this section to provide greater flexibility to the RRTs to require supplemental toxicity and efficacy testing.

Comments

PWSRCAC supports EPA's removal of the qualifier "when developing preauthorization plans" to provide greater flexibility for RRTs to require supplementary toxicity and efficacy testing data about an agent even when preauthorization plans are not being developed. We also support EPA's proposal to give the RRT authority to request that

the OSC require the RP to conduct additional monitoring of a product use during a discharge to support operational decision-making.

PWSRCAC supports EPA's proposal to include "ecosystem" along with area and site-specific concerns that may be considered in evaluating toxicity, although we believe that EPA should provide additional information and examples about methodologies that can be used to evaluate ecosystem impacts. Certainly the current approach, where toxicity data is derived from a narrow range of tests on two temperate species, does not sufficiently inform the full range of potential toxicities from chemical agents, particularly in cold water regions.

Recommendations

- PWSRCAC recommends expanding the requirements for supplemental testing and monitoring to allow RRTs to request additional efficacy and toxicity testing during a discharge or at any time.
- PWSRCAC recommends including ecosystem-level toxicity effects as a required component of toxicity testing.
- PWSRCAC recommends a full EPA Tier 1 endocrine disruptor screening of the dispersed oil water accommodated fraction for any dispersant-oil combination that has not previously been screened.

Recovery of Agents from the Environment §300.910(h)

Summary: EPA proposes to add this section, requiring that the RP, with OSC oversight, remove from the environment any solidifiers, sorbents and surface washing agents used to treat an oil spill.

Comments

PWSRCAC supports EPA's proposal to specify the agent categories where substances are intended to be removed from the environment following their use (solidifiers, sorbents, and surface washing agents). PWSRCAC agrees with EPA that the RP should have ultimate responsibility for removal of these products, with oversight from the OSC. However, we suggest that that EPA create requirements that ensure that authorization of use for these substances be contingent upon the development of a feasible removal plan based on the specific incident. We also suggest that EPA establish some penalty for failure to remove these substances from the environment following their use.

Recommendations

- PWSRCAC recommends that the Schedule clearly delineate which agents are intended to be removed from the environment following their use (solidifiers, sorbents, and surface washing agents).
- PWSRCAC recommends that authorization of use for of these agents should be contingent upon the development of a feasible removal plan based on the specific incident.
- PWSRCAC recommends that the RP should be assessed a penalty in the event that an agent is not recovered from the environment.

Reporting of Agent Use §300.910(i)

Summary: EPA proposes to add this section, requiring that the OSC report to the RRT certain information about the use of a chemical or biological agent within 30 days of completion of use or, alternately, at some interval agreed upon by the RRT. EPA is also requesting comments on whether notification of the public should also be included in the reporting requirement.

Comments
PWSRCAC supports the 30-day reporting standard, and we
strongly support EPA's proposal to include public notification as part of the 30-day notification requirement.

Recommendations

- PWSRCAC recommends that EPA establish a 30-day reporting requirement for the OSC to report to the RRT in the event of a chemical or biological agent use.
- PWSRCAC recommends that public notification should be a required component of this notification.

Monitoring the Use of Dispersants (40 CFR §300.913)

Summary: EPA proposes to add a new requirement for the RP to conduct efficacy and ecological effects monitoring for subsurface applications and for surface applications for spills over 100,000 gallons and for applications that exceed 96 hours in duration.

Comments
PWSRCAC believes that strong monitoring protocols should be in place to ensure efficacy and evaluate ecological impacts of dispersant use. PWSRCAC agrees with EPA that comprehensive monitoring is essential to "determine the overall effectiveness of dispersants and should transcend from the initial dispersant application to include the transport and environmental effects of the dispersant and dispersed oil in the water column." However, we are concerned that existing monitoring methods may not have the capability to achieve this expectation. For all monitoring programs, baseline samples should be required for the area of proposed application before any application of dispersants

The State-of-Science for Dispersant Use in Arctic Waters working group identified a number of outstanding issues and questions associated with dispersant monitoring that should be weighed in this rulemaking. These include the difficulties in estimating mass balance of dispersed oil during atsea applications, and the fact that monitoring by visual observation and fluorimeters provide only relative estimates of dispersant application effectiveness. Although actual field application of dispersants has occurred only a handful of times in the U.S., there have been consistent challenges in measuring field effectiveness with available monitoring techniques and technologies.

PWSRCAC believes that it is EPA's responsibility to create realistic expectations for OSCs and the public about the capabilities and limitations of dispersant monitoring technologies. It is critical that monitoring data be presented in the context of technological limits and scientific uncertainty. Given that the largest field application of dispersants in U.S. waters occurred during the Deepwater Horizon well blowout, we encourage EPA to make public the full record of To dispersant efficacy monitoring

results and raw data from all monitoring activities conducted during this response. Data from particle size analysis and fluorescence measurements of oil droplet size distributions at the wellhead during dispersant application and during times when no dispersants were applied would provide valuable information both for OSCs and for the public in understanding the potential efficacy of dispersants.

PWSRCAC agrees with EPA that field monitoring provides critical amplifying information to supplement laboratory test data regarding dispersant effectiveness and environmental effects. It is important that as dispersant science continues to evolve, field and laboratory data are collated to understand the transferability of lab results to the real world.

PWSRCAC supports EPA's suggestion that monitoring requirements should include thresholds for application based on the quantity of dispersants used within a given timeframe. The EPA has a duty under the Clean Water Act to prevent the dumping of harmful chemicals into the environment, and there should be thresholds for automatically ceasing dispersant application to ensure that this line is not crossed.

Dispersant monitoring data is of high interest to the public, and should be made available immediately and in raw form for public review.

Recommendations

- PWSRCAC recommends that the EPA require dispersant monitoring data to include an acknowledgement of technological limits and scientific uncertainty, to better inform OSC decision-making and ecological risk assessment.
- PWSRCAC recommends that EPA require dispersant monitoring to include pre-application monitoring of biological resources.
- PWSRCAC urges EPA to release (or compel the USCG to release) the results of dispersant efficacy monitoring during the Deepwater Horizon oil spill to clarify the effectiveness of that application and to provide an example of the type of information and analysis that can be derived from existing monitoring technologies and protocols.
- PWSRCAC recommends that EPA create a standard process for collecting field data from dispersant applications for the purpose of validating and amplifying information collected in the laboratory. In this way, information from past dispersant applications may be drawn upon to inform future use, along with laboratory test data.
- PWSRCAC recommends that EPA establish conservative thresholds for maximum dispersant application volumes over time.
- PWSRCAC recommends that EPA require dispersant monitoring results to be made available immediately to the public.

Dispersant Application

Summary: EPA proposes to require the RP to document its product choice and selection rationale based on the oil type, flow rate, discharge location, and efficacy/toxicity data. It also requires specific documentation of the dispersant application including rates, volumes, application methods, equipment, etc.

Comments

The parameters that are to be considered for dispersant application listed in the proposed rule are very focused on a well blowout or similar continuous release.In areas like Prince William Sound where spill risks are primarily derived from vessels and facilities, dispersant application parameters may be different. The rule should consider all potential spill sources and types, not just well blowouts.

PWSRCAC also has concerns with EPA's suggestion to rely on the RP to provide estimates of well blowout flow rates or spill volumes as the basis of dispersant application dosing. There is a long history of Responsible Parties underestimating or obscuring spill volume estimates. These numbers should be derived by independent government agencies or academia.

The State-of-Science for Dispersant Use in Arctic Waters working group reached preliminary consensus on the major limiting factors for effective dispersion, which include: high viscosity from the initial oil or as a result of weathering or lower temperatures; emulsification; dispersant formulation; dose rate; mixing energy; water salinity; and potential for dilution. These parameters should be explicitly listed in the Schedule.

Recommendations

- PWSRCAC recommends that EPA expand the discussion of dispersant application parameters to address vessel-source spills, which are the primary marine oil spill risk in many regionsof the U.S.
- PWSRCAC recommends that spill volume estimates should be developed by government or academia, not by the RP.
- PWSRCAC recommends that the EPA include the following parameters specifically in the documentation requirement to rationalize dispersant use: oil viscosity, emulsification, dispersant formulation, dose rate, mixing energy, water salinity, and potential for dilution.

Water Column Sampling

Summary: EPA proposes to require the RP to collect background water column samples in areas not affected by the discharge, and also in the dispersed oil plume. The EPA proposes specific analytic parameters (droplet size distribution, fluorometry, fluorescent signatures, dissolved oxygen, total petroleum hydrocarbons, carbon dioxide, methane, heavy metals, turbidity, water temperature, pH, and conductivity).

Comments

PWSRCAC found a number of areas where the water column sampling requirements and recommended methods require clarification to ensure scientific and technical accuracy. EPA should clarify that only aromatic constituents of crude oil fluoresce at visible and near ultraviolet wave lengths, and that fluorescent properties, especially emission maximum and fluorescent intensity, both tend to increase with the number of aromatic rings, and number of non-carbon (nitrogen, oxygen, or sulfur) in the compound. This means that the least abundant oil constituents contribute most significantly to any fluorometer reading. The polar aromatic compounds , which contribute the most fluorescence, are also more soluble in seawater than corresponding aromatic hydrocarbons and thus are more likely to dissolve away from the dispersed oil droplets into the seawater phase.

EPA should clarify that while droplet size measurement is important, droplet size measuring instruments also needed to include fluorometers or similar instruments to ensure that the droplets they are measuring are indeed oil. It is also critical to acknowledge that the physical environment of fluorescent compounds can dramatically alter the observed fluorescence. Increased polarity from sources such as salinity, pH, and hydrophobicity from the presence of surfactants such as those found in dispersants, all influence the intensity of the observed fluorescence.

To avoid confusion EPA should clarify that the fluorometers currently used to monitor fluoresence *in-situ* use either filters or narrow bandpass lamps to excite samples at specific wavelengths and broad wavelength filters to allow emissions at a number of wavelengths. The most common output from an in-water instrument is a signal, which is not oil specific and is only an approximate indication of oil in the water. The discussion of "fluoresence signatures" requires instruments which can measure fluorescence across a number of wavelengths that have traditionally been found in the laboratory. However, recent advances in miniaturization or electronics; including diode array detectors, have allowed development of smaller, more durable instruments which can be used on vessels and even subsurface arrays. It should also be noted that most dispersants show a fluorescent signal as well.

The discussion of water column sampling for total petroleum hydrocarbons (TPH) does not specify a standard method, but there are several available (as listed with the references at the end of this document). EPA should specify one or more standard methods for measuring TPH.

PWSRCAC supports the inclusion of heavy metals as an analytic parameter for water column sampling. We also support the inclusion of turbidity testing, and suggest that this data should be directly considered in evaluating the potential for treating agents to act as sinking agents. In cases where high turbidity may cause treated oil to sink, the use of agents should not be authorized.

Recommendations

- PWSRCAC recommends that EPA clarify that while droplet size measurement is important for water column sampling, droplet size measuring instruments also needed to include fluorometers or similar instruments to ensure that the droplets they are measuring are indeed oil.
- PWSRCAC recommends that EPA clarify the inability of in-water fluorometers to distinguish oil signals and the relevance to water column sampling.
- PWSRCAC recommends that EPA specify that a standard method must be used for TPH measurements in water column samples.
- PWSRCAC recommends the inclusion of heavy metals in water column sampling parameters.
- PWSRCAC recommends including turbidity testing in water column analysis, and using the data to analyze the potential for treating agents to act as sinking agents. In cases where high turbidity may cause treated oil to sink, the use of agents should not be authorized.

Oil Distribution Analyses

Summary: EPA proposes that the RP (with OSC consultation) characterize the dispersant effectiveness and oil distribution to inform sampling locations.

Comments
The proposed rule requires that decision-making about how and where to sample the water column to estimate dispersant effectiveness should be derived from predictive models about dispersed oil movement and distribution. However, there are few proven methods for doing this. The State-of-Science for Dispersant Use in Arctic Waters working group reached preliminary consensus on the fact that it is difficult to anticipate the physical transport of dispersed oil, and that extrapolation of lab and tank tests on physical transport and chemical behaviour of oil to the field is complex.

Recommendations

- PWSRCAC recommends that the EPA acknowledge that the available methods for anticipating the movement of dispersed oil plumes are limited and may complicate the monitoring process. Sampling and monitoring programs should acknowledge uncertainties about where an oil plume may go or how it may behave.

Ecological Characterization

Summary: EPA proposes that the RP (with OSC consultation) characterize ecological receptors, their habitats, and exposure pathways, including sensitive life stages, transient or migratory species, breeding activities, and threatened or endangered species that may be exposed to oil, dispersed oil, and dispersant. The EPA and OSC would be required to use this information to inform acute toxicity monitoring and consideration of ecotoxicity benchmarks (EB).

Comments
PWSRCAC agrees with EPA that ecological characterization is important to evaluating exposure pathways for various receptors, but we believe that this should be done by independent scientists, and not by the RP because of an obvious conflict of interest with the natural resource damage assessment (NRDA) process.

Marine ecosystems vary significantly across the U.S., and ecotoxicity assessment in Arctic and subarctic regions cannot be assessed with the same parameters that would be applied to temperate marine ecosystems. We suggest that sensitive receptors and toxicity thresholds should be developed at the local/regional level by trustee agencies based on the marine ecosystem, food web, abundance of primary and secondary producers, and other factors that influence ecotoxicity .

Rather than relying on the RP and OSC to develop *ad hoc* ecological characterizations and toxicity thresholds concurrent with the spill response, ecological monitoring plans should be developed by the AC and RRTs during the planning process and implemented as appropriate in the event that treating agents are applied.

Recommendations

- PWSRCAC recommends that EPA require AC and RRTs to characterize ecological receptors at risk and establish thresholds that are specific to their region, rather than relying on the RP, who has an obvious conflict of interest.

Immediate Reporting

Summary: EPA proposes requiring that the RP immediately report to the OSC any deviation of more than 10 percent of the hourly subsurface dispersant use rate. EPA is considering whether a similar requirement should apply to surface applications. EPA also proposes to require the immediate reporting of ecological receptors.

Comments
PWSRCAC supports the concept that there should be a threshold for reporting deviations from the planned application rates; however, as noted previously, we do not support subsurface dispersant application.

PWSRCAC strongly supports a requirement for immediate reporting in the case of deviations of more then 10 percent for surface applications. However, we recommend that the EPA clarify through this rule that DOR is an approximate measurement based on very rough estimates of the volume of oil that is being treated by the dispersant; operationalizing this requirement may prove challenging. All such reports should also be made public.

Recommendations
- PWSRCAC recommends that EPA require reporting of any deviations in dispersant applications of more than 10 percent of intended dosage, with an acknowledgement of the margin of error involved in estimating dosage rates based on uncertainties about slick volume.
- PWSRCAC recommends that all reports be simultaneously made public.

Daily Reporting

Summary: EPA proposes daily reporting of sampling and data analyses (within 24 hours of collection) to inform operational decision-making, with an allowance for analytical methods requiring additional time to take no more than 5 days, unless authorized by the OSC.

Comments
PWSRCAC supports the 24-hour timeframe for data analysis to inform operational decision-making. However, we are concerned that existing sampling and analytical methods may not provide complete or accurate information.PWSRCAC requests that the EPA identify suggested methods or models that can accurately estimate the "daily transport of dispersed and non-dispersed oil" with sufficient accuracy to inform the coordination and scheduling of monitoring activities, as proposed in this section of the draft rule. As with other provisions, we believe that all reporting should be made public immediately and without censorship.

Recommendations
- PWSRCAC recommends that EPA require 24-hour turnaround for sampling data, and that this information be simultaneously made public.

- PWSRCAC recommends that EPA identify suggested methods or models that can accurately estimate the "daily transport of dispersed and non-dispersed oil" with sufficient accuracy to inform the coordination and scheduling of monitoring activities.

Data Requirements (40 CFR §300.915)

Summary: EPA proposes to revise and reorganize this section to include new testing and listing requirements for specific product categories.

General Product Information (40 CFR §300.915(a))

Summary: EPA proposes adding this section to consolidate general testing and listing requirements for all product categories. The general information requirements include: submitter, general product, supplier, product storage, product use, environmental fate, physical/chemical properties and formulation; microorganism information; NWQS contaminants, certification that the product does not include prohibited agents; testing laboratory information; laboratory testing data and reports; production capacity; and performance capabilities/benefits.

Comments

PWSRCAC supports the requirements for general product information, but we believe that the rule should provide additional specificity about the standards that must be used to derive some of the required information, such as physical and chemical properties, water quality contaminant levels, and environmental fate. All of this information should be made available to the public. Wherever possible, we believe that EPA should establish threshold limits above or below which agents do not qualify for listing on the Schedule.

PWSRCAC also notes EPA's choice of language to describe the requirements in this section of the proposed rule. Page 3381 describes the submission requirements as including "any other data or certification informing the product's performance capabilities or environmental benefits." PWSRCAC finds the use of the term "benefits" to be somewhat leading, and contradictory of the general precautionary approach that EPA takes elsewhere in the rule. The benefits of a treating agent will depend upon a number of factors. We suggest that it would be more accurate to request information about "potential benefits and drawbacks," which would more accurately inform decision-making.

Recommendations

- PWSRCAC recommends that the standards by which physical and chemical properties are determined should be specified in the EPA rule.
- PWSRCAC recommends that the standards by which NWQS contaminants are measured should be specified in theEPA rule.
- PWSRCAC recommends that the standards by which environmental fate information is determined should be specified in the EPA rule.
- PWSRCAC recommends that the EPA rule require that accredited laboratories must use standard methods and materials and list all materials and methods in their submitted reports.
- PWSRCAC recommends that all of this information be made publicly available for products that are listed on the Schedule.

- PWSRCAC recommends that EPA establish thresholds that can be used to screen agents and prevent agents that contain persistently bioaccumulating or environmentally persistent products from being included on the Schedule.
- PWSRCAC recommends that EPA ensure that the final rule discusses "benefits and drawbacks" together, rather than presuming a product will be beneficial under all circumstances.

Dispersant Testing and Listing Requirements (40 CFR §300.915(b))

Summary: EPA proposes new toxicity and efficacy testing requirements, limitations for use, and requirements for listing dispersants to the Schedule.

Comments

PWSRCAC supports the proposed requirement to conduct testing at two temperatures but suggest that an internationally accepted standard should be noted and listed with the supplied data. PWSRCAC understands that EPA considered limiting dispersant authorization based on oil type and temperature but ultimately dismissed this approach. While we understand EPA's concerns about specifying limits for dispersant use based on temperature and oil type, we disagree with EPA's conclusion that it makes sense to authorize only products that are effective on both types of oil at both temperatures. We believe that it is prudent to be as specific as possible within the Schedule about conditions in which a dispersant may or may not be effective. The waters of the U.S. span a range of conditions.This is of particular concern to us because dispersants are less effective under cold or arctic conditions than in temperate waters.

PWSRCAC agrees with the conclusion that dispersants have lower effectiveness in low salinity water. PWSRCAC suggests that a minimum salinity be specified for application and suggest that this number be 20 ppt. Similarly, there should be temperature limits below which dispersants are not effective; PWSRCAC suggests that this should be 10°C. Both of these thresholds are supported by published literature.

PWSRCAC supports a complete ban on the use of dispersants in freshwater without exception, and we support a ban on subsurface dispersant use until the underlying science and state of practices is more mature.

Recommendations

- PWSRCAC recommends conducting dispersant effectiveness and toxicity tests at two temperatures using an internationally accepted standard (see reference list at end of this document).
- PWSRCAC recommends that dispersant authorization should specify a temperature range for effectiveness, so that it would be possible to include a dispersant on the Schedule with the intent that it be used in one temperature range but not another (i.e. some dispersants may be used in temperate but not cold waters).
- PWSRCAC recommends that a minimum salinity threshold of 20 ppt and a minimum temperature of 10°C be established to prevent dispersant use in low salinity or low temperature environments, where they will not be effective. Both of these thresholds are supported by published literature (see Reference list under Dispersant Effectiveness at end of this document).

- PWSRCAC recommends a complete ban on subsurface dispersant use.

Surface Washing Agent Testing and Listing Requirements (40 CFR §300.915(c))

Summary: EPA proposes new toxicity and efficacy testing requirements, limitations for use, and requirements for listing surface washing agents to the Schedule.

Comments
PWSRCAC supports the use of the Environment Canada surface washing agent test. This test has been used by several agencies for many years and a very large database on product effectiveness exists. This test also has a high reliability.

PWSRCAC suggests that EPA should require toxicity testing of surface washing agent and oil combinations to determine whether the addition of surface washing agents may enhance or alter toxicity of the oil.

Recommendations
- PWSRCAC recommends using the Environment Canada surface washing agent test.
- PWSRCAC recommends that EPA require toxicity testing of surface washing agent treated oil.

Bioremediation Agent Testing and Listing Requirements (40 CFR §300.915(d))

Summary: EPA proposes new toxicity and efficacy testing requirements, limitations for use, and requirements for listing bioremediation agents to the Schedule.

Comments
PWSRCAC suggests that standard methods be used to analyze biodegradation products. The oxygenated products of biodegradation are often such that they may not be captured by gas chromatography methods and may require other methods of analysis.

PWSRCAC believes that toxicity tests with oil bioremediation-oil mixtures should be carried out to ensure that there is no combined toxicity of the oil-agent mixtures. We have included several references on bioremediation agents at the end of this document that we recommend EPA review in finalizing this rule.

Recommendations
- PWSRCAC recommends that EPA require the use of standard methods to analyze biodegradation products, and that the methods used are appropriate for measuring all byproducts.
- PWSRCAC recommends that toxicity tests with bioremediation agent-oil mixtures should be carried out to ensure that there is no combined toxicity of the oil-agent mixtures.

Solidifier Testing and Listing Requirements (40 CFR §300.915(e))

Summary: EPA proposes new toxicity and efficacy testing requirements, limitations for use, and requirements for listing solidifiers to the Schedule.

Comments

PWSRCAC has concerns about the use of solidifiers to treat oil spills. Many of the products on the market are actually sorbents, albeit polymeric adsorbents that draws the oil inside the mass. EPA must clearly delineate between solidifiers and sorbents.

PWSRCAC is also concerned that the use of oil spill solidifiers precludes the use of other mechanical countermeasures. Boom and skimmers are meant to deal with liquid oil. Once a solidifier is applied to the slick, it becomes too heavy and viscous for mechanical recovery, eliminating this option.Oil that is treated with a solidifier must still be removed from the environment, and this process is time critical to avoid the potential for the solidified oil to increase in density and sink.

Recommendations

- PWSRCAC recommends that EPA remove solidifiers from the Schedule, and that the definitions of solidifiers and sorbents clearly delineate their differences.

Confidential Business Information (40 CFR §300.950)

Summary: EPA proposes to revise and clarify the allowable confidential business information (CBI) claims in a submission package.

Comments

PWSRCAC does not support the characterization of Confidential Business Information (CBI) for products listed on the Schedule. We believe that EPA's duty under the Clean Water Act requires full disclosure of all information about the chemical formulation of agents listed in the Schedule. There must be full public disclosure of the components of oil treating agents as well as their precise formulations in order to assess potential exposure and toxicity.

In Alaska, much of our population relies on the marine environment for subsistence foods. In the event that oil spill treating agents are released in areas that are used for subsistence, all information about oil spill treating agents and the byproducts of treated oil must be fully available for public review and evaluation.

Recommendations

- PWSRCAC recommends that EPA reject any applications to the Product Schedule that characterize information as CBI, with no exceptions.

Addition of a Product to the Schedule (40 CFR §300.955)

Summary: EPA proposes to consolidate and reorganize information about the process of getting a product on the Schedule.

Changes to a Listed Product(40 CFR §300.955(e))

Summary: EPA proposes new regulatory text regarding notification of changes to a listed product.

Comments

PWSRCAC supports the proposal to require notification of EPA within 30 days of any changes to general product information, and the automatic triggers (i.e. changes to chemical compounds or concentrations) that would require retesting of the product.

We suggest that EPA expand this requirement to provide the RRT with the authority to request retesting of any product following a field application where the product is ineffective or determined to have adverse impacts.

Recommendations

- PWSRCAC recommends that EPA adopt the requirement for notification of changes to a listed product within 30 days.
- PWSRCAC recommends adding a provision that gives the RRT authority to request retesting of any product following a field application.

Transitioning Listed Products from the Current Schedule to the New Schedule(40 CFR §300.955(f))

Summary: EPA proposes new regulatory requirements for transitioning production on the current Schedule to the new Schedule.

Comments

PWSRCAC supports EPA's approach to requiring all products to undergo evaluation under the new process, and the development of a transition process to facilitate this.

Recommendations

- PWSRCAC recommends implementation of the transition process as proposed.

Removal of a Product from the Schedule (40 CFR §300.970)

Summary: EPA proposes to add basis for removal of products from the Schedule, EPA notification of decision, and appeals process

Comments

PWSRCAC supports EPA's proposed basis for removing products from the Schedule. We also suggest that members of the publicshould be provided with an opportunity to request removal of a product from the Schedule.

Recommendations

- PWSRCAC recommends that EPA implement this proposal with the addition of a provision that allows members of the public to petition the EPA for remov al of a product from the Schedule.

Requirements for Product Testing Protocols and Summary Test Data (Appendix C to Part 300)

Summary: EPA proposes to revise Appendix C to contain testing protocols and summary test data requirements for standard efficacy and toxicity tests.

Comments

PWSRCAC is concerned that many of the proposed methods do not use established standards. In fact in some cases, inappropriate methods are proposed when there are standards already in existence by well-known standardization agencies such as ASTM, ANSI, ISO, etc.

It is important that EPA clearly distinguish between screening tests, that are meant to compare treating agents based on relative measurements, and tests that are meant to simulate or predict the performance of treating agents in the field. The testing required for the Schedule falls into the first category, and it is critical for OSCs, RRTs, trustee agencies and the public to understand this difference. Data resulting from these tests may be useful in comparing products, but may not be sufficient to predict performance in a particular situation.

The State-of-Science for Dispersant Use in Arctic Waters working group reached preliminary consensus on the differences between lab test methods and field results for dispersant effectiveness testing, noting: *"Dispersant effectiveness varies between lab test methods and is not expected to represent field results. These tests are used for screening of dispersants and oils, conducting physical studies, developing new dispersants, or broadly informing field effectiveness potential."*

Recommendations

- PWSRCAC encourages the use of consensus standards where available.
- PWSRCAC recommends that the EPA explicitly describe the utility and limits of screening tests, particularly as they relate to potential field applications. Screening tests are not predictive of field performance and test values provide relative, not absolute, measurements.

Dispersant Baffled Flask EfficacyTest (BFT)

Summary: EPA is proposing a change from the swirling flask to the baffled flask dispersant effectiveness test protocol.

Comments

PWSRCAC is concerned that EPA is proposing a non-standard method for efficacy testing when there is already a standard test that is used in the U.S. and around the world (ASTM F2059-06 (2012) Standard Test Method for Laboratory Oil Spill Dispersant Effectiveness Using the Swirling Flask). The ASTM swirling flask test has been in use for 20 years, is well accepted in peer-reviewed chemistry journals, and there are numerous laboratories that are proficient in its application.

PWSRCAC does not believe that colorimetric methods are appropriate, and a review of the professional literature confirms that there are other standard methods in place that are widely used and accepted among chemists (Drozdova et al., 2014; Fingas et al., 2004; Wang et al., 2014; Bowman et al., 2014; Fabbri et al., 2010; Sauer and Boehm, 2005). We recommend the use of TPH methodsrather than the colorimetric (UV adsorption) method proposed. The UV method is confounded by the fact that oil consists of an array of components that each react to light differently, and it cannot reliably distinguish components of oil vs. dispersed oil. We have included a list of standards that apply to TPH analysis at the end of this document.

PWSRCAC believes it is most important to ensure that efficacy tests are carried out in a controlled and replicable manner. In this case, EPA should focus their effort on ensuring that dispersant efficacy tests are conducted by **certified** chemists working in **certified** laboratories using **certified** procedures (ASTM swirling flask test).

Recommendations

- PWSRCAC recommends TPH methods rather than colorimetric (UV adsorption) methods.
- PWSRCAC recommends that EPA ensure that all dispersant efficacy testing adhere to the principle of "3 C's": tests are conducted by **certified** chemists working in **certified** laboratories using **certified** procedures.

Dispersant Toxicity Testing

Summary: EPA proposes changes to dispersant toxicity testing.

Comments

PWSRCAC supports the proposal to require toxicity testing for the dispersant alone and for dispersed oil on both test oils. It is critical that toxicity testing be as comprehensive as possible, and adequately consider short- and long-term impacts. The State-of-Science for Dispersant Use in Arctic Waters working group noted that acute toxicity testing may miss some delayed mortality and other adverse ecological impacts: *"Data from standard acute LC50 and EC50 tests can miss delayed mortality and may also miss other adverse ecologically important endpoints that are expressed over a longer period of time."*

PWSRCAC also remains concerned that analysis of toxicological impacts should not rely on a single species, but should take into consideration indirect ecosystem-level and trophic effects of dispersed oil. Both crude oil and dispersants are complex mixtures -- oil contains many constituents which have not been well characterized chemically or toxicologically. Dispersants may contain constituents that are not routinely measured in standard toxicology analyses. Many long-term consequences of short-term exposures such as endocrine disruption, reproductive failures, and developmental disorders, are not detected by the short-term tests required in this Proposed Rule.

PWSRCAC also supports the addition of toxicity testing focused on evaluating potential human health impacts of dispersants and dispersed oil, in order to protect the health and safety of responders and the public. A suite of human toxicity teststhat evaluate all potential exposure routes to responders and the public – e.g. inhalation, skin irritation, etc. – should be submitted as part of the documentation for dispersants listed in the Schedule.

Because it is impossible for toxicity testing to foresee all long -term adverse health impacts to humans and the environment, we believe that it is critical to conduct rigorous long-term monitoring of species exposed to dispersants and dispersed oil. Information from long-term monitoring should then feed back into the toxicity testing to help understand the impact of unexpected toxic components or byproducts.

PWSRCAC appreciates EPA's consideration that longer chronic toxicity tests are needed, but we are concerned that the proposed approaches are still not adequate to test for long term, possible multi-generational, effects from short term exposures to dispersed oil. We suggest inclusion of Tier 1 screening for endocrine disrupting compounds as an example of the type of analysis necessary to assess the complex sublethal effects that may be caused by exposure to dispersed oil fractions.

Recommendations

- PWSRCAC recommends that wherever practicable, dispersant toxicity test species should either be indigenous to the spill area or have been shown to be appropriate surrogates for species from the area.
- PWSRCAC recommends that dispersants should undergo toxicity testing that specifically examines potential human toxicity through all potential routes of exposure for responders and the public.
- PWSRCAC recommends that toxicity testing be required for both dispersed oil and dispersants.
- PWSRCAC recommends that a full EPA EDSTAC Tier 1 screening be required for all dispersants and the water accommodated fraction of all test oils before products are approved for listing on the Schedule.

Standard Acute Toxicity Test for Bioremediation Agents, Surface Washing Agents, Herding Agents, and Solidifiers

Comments

PWSRCAC is concerned about the use of non-indigenous or genetically engineered bioremediation agents that may colonize areas where they are being applied. We are also concerned about the potential for toxicity from the partial degradation products of bioremediation.

Recommendations

- PWSRCAC recommends that EPA prohibit the use of non-indigenous or genetically engineered bioremediation agents that may colonize areas where they are being applied.
- PWSRCAC recommends that oil samples from shore areas subject to bioremediation be tested periodically for the production of toxic partial degradation products.

Reference List

PWSRCAC provides the following list of references, organized by topic area, which are cited either as individual publications or by topic area within our comments. We recommend that EPA thoroughly review this literature in finalizing the rule, to ensure that all policy reflects the best and most recent peer-reviewed scientific literature.

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EPA 8000a- Determinative Methods for Chromatography

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To: Conmy, Robyn[Conmy.Robyn@epa.gov]
Cc: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Mon 4/18/2016 2:57:19 PM
Subject: RE: purchase of Finasol OSR52

Thanks! Haven't heard from NALCO, will call sometime today to follow up. V

From: Conmy, Robyn
Sent: Monday, April 18, 2016 10:47 AM
To: peter.egan@total.com
Cc: Wilson, Gregory <Wilson.Gregory@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>
Subject: purchase of Finasol OSR52

Mr. Egan,

This follows up our telephone conversation of April 11.

As discussed, EPA is seeking to acquire a number of dispersant products listed on the NCP Subpart J Product Schedule for the purposes of both toxicity and efficacy testing. The product testing is intended to further inform currently proposed regulatory actions under Subpart J of the National Contingency Plan. The products will in addition be used to support our general research in the area of oil spill response.

Your product Finasol OSR52 has been identified as one of interest, as it is commonly stockpiled in the U.S. Not only could the product be encountered when presented with a response situation, but including this dispersant product in toxicity and efficacy testing studies will also allow for comparison and consistency with other existing and ongoing studies by EPA and other federal agencies. EPA's Office of Research and Development (ORD) will be conducting the dispersant studies.

At this time we are seeking 2 U.S. gallons of the product.

We appreciate your time and attention to this request.

Respectfully,

Robyn Conmy

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Robyn N. Conmy, Ph.D.

Research Ecologist

USEPA/NRMRL/LRPCD

26 West MLK Drive

Cincinnati, Ohio 45268

513-569-7090 (office)

513-431-1970 (EPA mobile)

727-692-5333 (Personal mobile)

conmy.robyn@epa.gov

To: Beasley, Lynn[Beasley.Lynn@epa.gov]; Bove, James[bove.james@epa.gov]
From: Principe, Vanessa
Sent: Mon 4/18/2016 2:56:32 PM
Subject: FYI - FW: purchase of Finasol OSR52

FYI

From: Conmy, Robyn
Sent: Monday, April 18, 2016 10:47 AM
To: peter.egan@total.com
Cc: Wilson, Gregory <Wilson.Gregory@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>
Subject: purchase of Finasol OSR52

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Robyn Conmy

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513-431-1970 (EPA mobile)

727-692-5333 (Personal mobile)

conmy.robyn@epa.gov

To: Bove, James[Bove.James@epa.gov]; Beasley, Lynn[Beasley.Lynn@epa.gov]; Conmy, Robyn[conmy.robyn@epa.gov]
Cc: Wilson, Gregory[Wilson.Gregory@epa.gov]; Vanroden, Victoria[Vanroden.Victoria@epa.gov]; Perry, Portia[Perry.Portia@epa.gov]
From: Principe, Vanessa
Sent: Wed 4/13/2016 3:05:31 PM
Subject: RE: RESENDING FOR ACTION - RE: "Script" for Dispersants Purchase Call

Jim/Lynn:

Per our conversations/feedback.

•□□□□□□□□ OEM was only involved in making the initial contact (because of a "use" waiver issue).

•□□□□□□□□ The email will be sent by ORD/Robyn, since they will be doing the purchase (revised below).

•□□□□□□□□ ORD has purchasing mechanisms in place (through either ORD directly or through their laboratory contract) to obtain supplies/materials/chemicals.

Robyn, please copy Greg, Lynn and I on your message out. Contact info: Mr. Peter Egan, TOTAL (peter.egan@total.com), UNITED STATES: (713) 297-1996.

We're good to go!

Thanks everybody, V

Mr. Egan:

This follows up our telephone conversation of April 11.

As discussed, EPA is seeking to acquire a number of dispersant products listed on the NCP Subpart J Product Schedule for the purposes of both toxicity and efficacy testing. The product testing is intended to further inform currently proposed regulatory actions under Subpart J of the National Contingency Plan. The products will in addition be used to support our general research in the area of oil spill response.

Your product Finasol OSR52 has been identified as one of interest, as it is commonly stockpiled in the U.S. Not only could the product be encountered when presented with a response situation, but including this dispersant product in toxicity and efficacy testing studies will also allow for comparison and consistency with other existing and ongoing studies by EPA and other federal agencies. EPA's Office of Research and Development (ORD) will be conducting the dispersant studies.

At this time we are seeking 2 U.S. gallons of the product.

We appreciate your time and attention to this request.

Respectfully,

From: Bove, James
Sent: Wednesday, April 13, 2016 10:22 AM
To: Beasley, Lynn <Beasley.Lynn@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>
Cc: Wilson, Gregory <Wilson.Gregory@epa.gov>; Conmy, Robyn <Conmy.Robyn@epa.gov>; Vanroden, Victoria <Vanroden.Victoria@epa.gov>; Perry, Portia <Perry.Portia@epa.gov>
Subject: RE: RESENDING FOR ACTION - RE: "Script" for Dispersants Purchase Call

This is ok from a legal perspective; agree that the contracting officer needs to be looped in. Sounds like Robyn may send this- likely best since ORD is procuring…

From: Beasley, Lynn
Sent: Wednesday, April 13, 2016 10:21 AM
To: Principe, Vanessa <Principe.Vanessa@epa.gov>
Cc: Wilson, Gregory <Wilson.Gregory@epa.gov>; Conmy, Robyn <Conmy.Robyn@epa.gov>; Bove, James <Bove.James@epa.gov>; Beasley, Lynn <Beasley.Lynn@epa.gov>; Vanroden, Victoria <Vanroden.Victoria@epa.gov>; Perry, Portia <Perry.Portia@epa.gov>
Subject: RE: RESENDING FOR ACTION - RE: "Script" for Dispersants Purchase Call

Vanessa – I had minor edits to your email. Is the contracting officer looped in to this?

Jim – are you ok from legal perspective?

Lynn

To: Conmy, Robyn[Conmy.Robyn@epa.gov]; Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Tue 4/12/2016 2:58:18 PM
Subject: RE: purchase fo finasol and corexit

We definitely got her voice mail yesterday, waiting to see if she calls back first.

I would give it a day perhaps, and then decide if we call again or send an email. What say you?

From: Conmy, Robyn
Sent: Tuesday, April 12, 2016 8:59 AM
To: Wilson, Gregory <Wilson.Gregory@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>
Subject: FW: purchase fo finasol and corexit

Mike Fulton (NOAA) says that Debbie Theriot was also their contact at NOAA. They were unable to purchase from them without signing the waiver that no toxicity testing would occur.

Want to try calling again? Or send an email to her instead of calling?

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Robyn N. Conmy, Ph.D.

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Cincinnati, Ohio 45268

513-569-7090 (office)

513-431-1970 (EPA mobile)

727-692-5333 (Personal mobile)

conmy.robyn@epa.gov

From: Mike Fulton - NOAA Federal [mailto:mike.fulton@noaa.gov]
Sent: Tuesday, April 12, 2016 8:41 AM
To: Conmy, Robyn <Conmy.Robyn@epa.gov>
Subject: Re: purchase fo finasol and corexit

Hi Robyn,

See below contact info for NALCO. You may have more success if you can sign a waiver that you won't use for toxicity testing. Good luck.

Mike

Debby.Theriot@nalco.com

281 263 7709

On Tue, Apr 12, 2016 at 7:58 AM, Conmy, Robyn <Conmy.Robyn@epa.gov> wrote:

> Thanks Mike. I spoke to a contact at Total yesterday and we are getting some Finasol. Nalco hasn't responded to a voicemail as of yet, so your contact at Nalco could be a huge help.

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Robyn N. Conmy, Ph.D.

Research Ecologist

USEPA/NRMRL/LRPCD

26 West MLK Drive

Cincinnati, Ohio 45268

513-569-7090 (office)

513-431-1970 (EPA mobile)

727-692-5333 (Personal mobile)

conmy.robyn@epa.gov

From: Mike Fulton - NOAA Federal [mailto:mike.fulton@noaa.gov]
Sent: Monday, April 11, 2016 5:00 PM
To: Conmy, Robyn <Conmy.Robyn@epa.gov>
Subject: Re: purchase fo finasol and corexit

Hi Robyn, Ultimately, We weren't able to get Corexit from Nalco, but I'll get you the contact info for both manufacturers.

On Monday, April 11, 2016, Conmy, Robyn <Conmy.Robyn@epa.gov> wrote:

Hi Mike,

Awhile back we had discussed NOAA's possible procurement of Corexit and Finasol for your toxicity work. Would you mind sharing the POC for Nalco and Total that were contacted in your hunt to procure the dispersants?

Thanks,

Robyn

<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>

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To: Bove, James[bove.james@epa.gov]; Beasley, Lynn[Beasley.Lynn@epa.gov]
Cc: Wilson, Gregory[Wilson.Gregory@epa.gov]; Conmy, Robyn[conmy.robyn@epa.gov]
From: Principe, Vanessa
Sent: Mon 4/11/2016 7:16:03 PM
Subject: RE: "Script" for Dispersants Purchase Call

Jim/Lynn:

DRAFT email to TOTAL contact re. our interest in procuring Finasol OSR52. Checking for any legal/procurement flags.

Of note – Mr. Egan said the waiver was no issue, that they are OK sending a free sample or making it available for purchase to EPA without any waiver.

Comments/edits?

Thanks! V

Mr Egan:

This follows up our telephone conversation of April 11.

As discussed, EPA is seeking to acquire a number of dispersant products listed on the NCP Subpart J Product Schedule for the purposes of both toxicity and efficacy testing. The product testing is intended to further inform currently proposed regulatory actions under Subpart J of the National Contingency Plan. The products will in addition be used to support our general research in the area of oil spill response.

Your product Finasol OSR52 has been identified as one of interest, as it is commonly stockpiled in the U.S. Not only will the product could be encountered when presented with a response situation, but including this dispersant product in toxicity and efficacy testing studies will also allow for comparison and consistency with other existing and ongoing studies by EPA and other federal agencies.

EPA's Office of Research and Development (ORD) will be conducting the dispersant studies. At this time we are seeking 2 U.S. gallons of the product. Our contact person for details of the purchase is Dr. Robyn Conmy of ORD. She can be reached at (513) 569-7090.

We appreciate your time and attention to this request. Please feel free to call me as well if you have any questions/concerns.

Respectfully,

Vanessa Principe

Chemical Engineer

Office Of Emergency Management

Office of Land and Emergency Management

U.S. Environmental Protection Agency

202-564-7913

From: Principe, Vanessa

Sent: Monday, April 11, 2016 11:06 AM
To: Bove, James <bove.james@epa.gov>
Cc: Wilson, Gregory <Wilson.Gregory@epa.gov>; Conmy, Robyn <conmy.robyn@epa.gov>
Subject: "Script" for Dispersants Purchase Call

Jim:

From our discussion last week, below is the "message" for a first conversation with NALCO and TOTAL about purchasing their dispersant products. Of import is the idea that we do not appear to threaten any action if they are not willing to sell without a waiver. Are we ok with the statements below? Just wanted something we all know is appropriate to speak from.

The plan is to make a call from HQ, with ORD also on the line as they would be the ones purchasing. Hoping to get to this today/tomorrow.

Thanks, V

We require 2 gallons.

We are not in a position to sign any waivers that would limit our use of the product.

[If a waiver is insisted upon] We will need to go back and discuss next steps internally.

To: Conmy, Robyn[Conmy.Robyn@epa.gov]; Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Mon 4/11/2016 3:14:40 PM
Subject: RE: Total and Nalco contacts

From the Technical notebook, the TOTAL contact is listed as:

FINASOL® OSR 52 (aka, SEACARE, ECOSPERSE 52)

TOTAL FLUIDES

UNITED STATES: (713) 297-1996

E-MAIL: david.doucet@total.com

WEBSITE: www.totalspecialfluids.com

(Mr. David Doucet)

From: Conmy, Robyn
Sent: Monday, April 11, 2016 10:37 AM
To: Wilson, Gregory <Wilson.Gregory@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>
Subject: Total and Nalco contacts

For the purchase of Finasol, DFO started by contacting Peter Egan with Total (peter.egan@total.com) who them in touch with the distributor for the East Coast, which was Clear Coast, llc. Contact there is Malcolm Gore (malcolm.gore@clearcoastllc.com).

For Nalco, all we have on file is the one from the NCPPRS

Nalco Environmental Solutions LLC
7705 Highway 90-A

Sugar Land, TX 77478
Product Management:
Office: (281) 263-7709
Mobile: (832) 851-5164
E-mail: debby.theriot@nalco.com
(Ms. Debby Theriot)

<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>/<>

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conmy.robyn@epa.gov

To: Conmy, Robyn[conmy.robyn@epa.gov]
Cc: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Mon 3/28/2016 4:10:39 PM
Subject: RE: DRAFT ICCOPR Minutes for Review and Comment
Draft Minutes ICCOPR FY16-2nd Quarter Meeting_3_9_16_OEM.docx

Robyn:

Same, but this time for the ICCOPR quarterly meeting.

Thanks! V

-----Original Message-----
From: Brooks, Rebecca J LT [mailto:Rebecca.J.Brooks@uscg.mil]
Sent: Friday, March 18, 2016 11:58 AM
To: Loring, Joseph B CAPT <Joseph.B.Loring@uscg.mil>; Weaver, James (USCG) <James.D.Weaver@uscg.mil>; Scott.A.Stoermer@uscg.mil; Ottenwaelder, Thomas A CDR <Thomas.A.Ottenwaelder@uscg.mil>; Sligh, Kevin M CIV <Kevin.M.Sligh@uscg.mil>; Carnegie, Tammie R LT <Tammie.R.Carnegie@uscg.mil>; Crecy, Stacey L LCDR <Stacey.L.Crecy@uscg.mil>; Platt, Jeffrey R LCDR <Jeffrey.R.Platt@uscg.mil>; Brooks, Rebecca J LT <Rebecca.J.Brooks@uscg.mil>; Maghini, Monica K CIV <Monica.K.Maghini@uscg.mil>; Hall, Gregory CDR (EDU) <Gregory.Hall@USCGA.EDU>; Fletcher, James E CIV <James.E.Fletcher@uscg.mil>; kurt.a.hansen@uscg.mil; Balsley, Alexander CIV <Alexander.Balsley@uscg.mil>; DiRenzo, Joseph CIV <Joseph.DiRenzo@uscg.mil>; mark.g.vanhaverbeke@uscg.mil; Catanach, Curtis P CIV <Curtis.P.Catanach@uscg.mil>; Chaves, Wendy <Wendy.G.Chaves@uscg.mil>; Jenkins, Shannon R CIV <Shannon.R.Jenkins@uscg.mil>; dave.westerholm@noaa.gov; scott.lundgren@noaa.gov; steve.lehmann@noaa.gov; john.kucklick@nist.gov; jason.boehm@nist.gov; Elena.Melchert@hq.doe.gov; Erica.Folio@Hq.Doe.Gov; kevin.easley@hq.doe.gov; david.moore@bsee.gov; Lori.Medley@bsee.gov; william.vocke@bsee.gov; joseph.levine@bsee.gov; Walter.Johnson@boem.gov; brian.zelenke@boem.gov; Jeff.Ji@boem.gov; barry_Forsythe@fws.gov; holly_herod@fws.gov; christina_kravitz@fws.gov; michael.carter@dot.gov; tom.thompson@dot.gov; robert.w.smith@dot.gov; james.merritt@dot.gov; David.Lehman@dot.gov; Steven.V.Cary@usace.army.mil; Andrew.J.Bruzewicz@usace.army.mil; Nathan.J.Lamie@usace.army.mil; Kemp.skudin@navy.mil; frank.stone@navy.mil; abe.nachabe@navy.mil; michael.s.dean@navy.mil; Stephanie A. Brown <stephanie.a.brown@navy.mil>; Conmy, Robyn <Conmy.Robyn@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>; Wilson, Gregory <Wilson.Gregory@epa.gov>; michael.j.green-

1@nasa.gov; wayne.yoder@dhs.gov; jfarrell@arctic.gov; Sarah.Helinek@csra.com; Rebecca.Weissman@csra.com
Subject: DRAFT ICCOPR Minutes for Review and Comment

Good morning all,

Attached are draft minutes from our ICCOPR meeting on March 9th. Please provide input on any changes to me via tracked changes/ comments in the document. I would appreciate any feedback by Friday, April 8th. Thanks for your time and have a great weekend!

Very respectfully,

LT Becca Brooks

U.S. Coast Guard Headquarters STOP 7516

Office of Marine Environmental Response Policy (CG-MER-3)

2703 Martin Luther King Jr. Ave SE

Washington, DC 20593-7516

Phone: 202-372-2259

To: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Fri 11/20/2015 9:36:01 PM
Subject: Papers
Li_Monitoring Dispersed Oil Droplet Size Distribution_IOSC_2011.pdf
Lee_Wave Tank Studies on Dispersant Effectiveness_CRRC_2009.pdf

Within these two references I don't find discussion specific to their statements.

Wave Tank Studies on Dispersant Effectiveness as a Function of Energy Dissipation Rate and Particle Size Distribution

A Final Report Submitted to
The Coastal Response Research Center

Submitted by

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Project Period: January, 2006 – January, 2009

Report Date: April 30, 2009

Coastal Response Research Center

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UNIVERSITY of NEW HAMPSHIRE

NOAA

Abstract

The use of chemical dispersants can be an effective means to combat oil spills at sea. There has been renewed interest in the use of chemical dispersants due to escalated oil spill incidents, logistical constraints of traditional spill response options, and the development of new generation, low-toxicity, high efficiency dispersant formulations for potential use on oils covering a greater viscosity range. For the assessment of chemical dispersant effectiveness under realistic sea states, test protocols are required to produce hydrodynamic conditions close to the mixing, transport and dilution effects found in the natural environment. To meet this requirement, a wave tank has been designed and constructed at the Bedford Institute of Oceanography (BIO) to evaluate chemical dispersant effectiveness under different wave conditions with energy levels ranging from regular non-breaking waves to plunging breakers. The hydrodynamics of these wave conditions were characterized using an autocorrelation function method applied to *in-situ* velocity measurements. Quantification of oil dispersant effectiveness was based on observed changes in dispersed oil concentrations and oil-droplet size distribution using a laser *in-situ* scattering and transmissometry particle size analyzer.

Evaluation of chemical dispersant effectiveness in a batch mode established quantitative relationships between dispersant effectiveness and energy dissipation rate under a variety of simulated wave conditions. The results indicated that 53% to 90% of the test crude oils have been dispersed in the presence of chemical dispersants and only 10% to 20% were dispersed under control conditions in the absence of chemical dispersant. The characterization of the *in-situ* dispersed oil droplet size distributions indicated that the physical dispersion generated mono-modal lognormal oil droplet size distributions of larger median diameters, whereas chemical dispersion produced bi- or tri-modal lognormal oil droplet size distributions of smaller median diameters over a wider range. The wave tank in flow-through mode simulating wave- and current-driven hydrodynamic conditions revealed that nearly 8 % to19 % of the test crude oils were dispersed and diluted under regular wave and breaking wave conditions, respectively, in the absence of dispersants. In the presence of dispersants, about 21% to 36% of the crude oils were dispersed and diluted under regular waves, and 42% to 62% under breaking waves. Consistently, physical dispersion under regular waves produced large oil droplets, whereas chemical dispersion under breaking waves created small droplets.

These data on the effectiveness of dispersants as a function of sea state are significant contributions to the development of improved predictive models on dispersant effectiveness and better operational guidelines for dispersant use. Results of our experiential studies using the wave tank system have advanced our mechanistic understanding of dispersant effectiveness under ambient field conditions. The research has shown that use of dispersants in deep water environments under moderately energetic wave conditions is a promising countermeasure technology for driving floating oil into the water column. Chemical dispersant Corexit 9500 is effective in all low, moderate and high energy test conditions, whereas SPC 1000 can also be very useful in moderate to higher energy conditions. Effective dispersion of oil to achieve small droplet formation is dependent on wave energy and the presence of a chemical dispersant. If either of these two factors is missing, dispersion can only take place in very high energy sea states. Use of chemical dispersants drastically reduces the time required for thorough dispersion

of oil into small oil droplets in the water column to take place in comparison to natural dispersion. When the window of opportunity for oil spill response is narrow (i.e. rapid remediation is critical due to proximity to environmentally sensitive areas), a quick and effective response such as what can be achieved using dispersants may be deemed necessary even under high energy conditions because of their ability to through accelerate the process and efficacy of oil dispersion into the water column and to facilitate oil biodegradation.

Keywords: Wave tank, energy dissipation rate, chemical dispersant effectiveness, particle size distribution, regular waves, breaking waves, currents.

Acknowledgments

This research was funded by the NOAA/UNH Coastal Response Research Center (NOAA Grant Number NA04NOS4190063, UNH Agreement Number 06-085). Additional funding resources are from the Panel of Energy Research and Development (PERD), U.S. EPA (contract No. 68-C-00-159) and Fisheries and Oceans Canada (A-Base). Essential technical and logistical support was provided by Matt Arsenault, Don Belliveau, Jay Bugden, Susan Cobanli, Matt Coady, Paul Kepkay, Jennifer Mason, Xiaowei Ma, John Niven, Peter Thamer and William Yeung. The findings, opinions and recommendations expressed in this report are those of the authors and do not necessarily reflect those of the sponsoring agencies or the University of New Hampshire.

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1.0 Introduction

Natural physical dispersion of oil spills through wave action results in the formation of oil-in-water emulsions of □m-scale oil droplets that are eventually diluted to concentrations below toxic threshold limits (Chapman et al. 2007; Kirby and Law 2008; Lee 2002; Li and Garrett 1998; Shaw 2003; Tkalich and Chan 2002). The importance of wave action for physical and chemical dispersion of oil has been recognized (Delvigne and Sweeney 1988; Li and Garrett 1998; Shaw 2003; Tkalich and Chan 2002). Breaking waves, in particular, play a crucial role in the dispersion of an oil slick by generating velocity shear to break up and transport oil in their turbulent flows (Li and Garrett 1998; Shaw 2003; Tkalich and Chan 2002).

The application of chemical dispersants accelerates dispersion of oil by reducing the oil-water interfacial tension, which facilitates droplet formation and results in reduced droplet collision rates as the oil is diluted in the water column (Chapman et al. 2007; Lessard and Demarco 2000; NRC 2005). In addition, chemical dispersants promote the formation of smaller droplets than those generated solely by physical dispersion, and can also change the surface thermodynamic properties of the oil to increase the stability of these small oil droplets in seawater. With the development of new formulations that are less toxic and more effective for the treatment of viscous oils, the application of chemical dispersants has recently gained popularity as one of the primary oil spill countermeasures for reducing the overall adverse impact of marine oil spills on the environment (NRC 1989; NRC 2005). In addition to operational convenience, the application of dispersants to oil slicks on the sea surface minimizes the harmful effects of floating oil on aquatic wildlife such as birds and marine mammals that frequent the water surface, and potentially mitigates the risk of oil slicks contaminating coastal and shoreline environments (NRC 2005).

Oil dispersion effectiveness depends on hydrodynamic conditions, the chemical properties of both dispersant and oil, and on various environmental factors such as water temperature and salinity (Fingas 2000; NRC 1989; NRC 2005). Oil dispersion effectiveness is determined by several related processes, including initial breakup of the oil slick into small oil droplets, transport and dilution of oil droplets in the water column, and coalescence and resurfacing of oil droplets. The formation of droplets occurs during oil breakup under the influence of mixing energy as the turbulent structure of breaking waves stretch and split the oil by velocity shear. The transport and dilution of oil droplets is then regulated by turbulent diffusion and wave propagation. Coalescence and resurfacing of oil is more likely to occur when the dispersed phase volumetric fraction (concentration) is high. Droplet coalescence kinetics are dependent on collision frequency (proportional to the shear and differential surfacing/settling velocity) and collision efficiency, which is determined by droplet surface thermodynamic properties. The resurfacing of oil is driven by the buoyancy force that is proportional to surface area or the square of droplet size.

Tests of chemical dispersant effectiveness are typically conducted on different scales, ranging from laboratory jar tests to meso-scale wave tank testing and large-scale field trials (NRC 2005). Bench-scale dispersant effectiveness tests (ASTM 2002; EPA 1996; Fingas et al. 1987) in the laboratory have been used for comparison of dispersant product effectiveness (Sorial et al. 2004a; Sorial et al. 2004b; Venosa et al. 2002) and for testing the effects of temperature, salinity

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and other environmental factors (Chandrasekar et al. 2005; Chandrasekar et al. 2006; Srinivasan et al. 2007). However, laboratory tests are inherently limited in simulating real field operational performance due to space constraints that are critical for transport and dilution efficiency. In the context of evaluating actual operations at sea, the utility of these tests is limited due primarily to failure to account for the critical dispersion processes in the water column (NRC, 2005). During the physical and chemical dispersion of oil spills, the initial break-up and submergence of a surface oil slick (as well as the secondary break-up of the oil into smaller droplets) depends on the turbulent structures, which also plays an important role in the vertical transport of oil droplets in the water column. To overcome the restrictions inherent in bench-scale tests, larger facilities are required to enable a more comprehensive evaluation of chemical dispersant effectiveness under a more realistic setting. Conversely, sea trials which are expensive and logistically challenging often lead to results that are inconclusive due to limitations in the level of replication and control of experimental variables. In response to an identified need for testing the performance of chemical dispersants under more realistic oceanographic and environmental conditions including wave-induced mixing energies (NRC 2005), a wave tank facility has been constructed at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia for reproducible, quantitative evaluation of chemical dispersant effectiveness under a variety of wave conditions.

To account for the important interplay between wave-propagation and wave- induced turbulence, we used the wave tank at BIO to allow for evaluation of chemical dispersant effectiveness under a variety of simulated wave conditions. This wave tank is capable of generating recurrent breaking waves at the same locations by using the frequency sweep technique (Funke and Mansard 1979), wherein a low frequency, fast-moving wave is superimposed onto a high frequency, slow-moving wave, causing the wave to increase in height until it breaks. In characterizing the hydrodynamics of different wave conditions, since the friction associated with velocity shear causes the dissipation of kinetic energy of the fluid, resulting in a temporal and spatial variation of the energy dissipation rate per unit mass of water (ε, in $W \cdot kg^{-1}$ water), the intensity of microscale turbulence of regular non-breaking and breaking waves was quantified by computing their energy dissipation rate using an autocorrelation function approach (Kaku et al. 2006a; Kresta and Wood 1993). The operational hypothesis is that ε plays a major role in the effectiveness of a dispersant, and hence it may serve as an important scalable parameter to characterize chemical dispersant effectiveness under different wave energy conditions in the field.

To understand the intrinsic mechanisms of dispersant effectiveness obtained in a testing system, it is important to measure the dispersed oil droplet size distributions and compare the data with those observed at sea (Lunel 1995). *In-situ* dispersed oil droplet size distributions are controlled by a variety of hydrodynamic and environmental variables. For example, the intensity of the turbulent mixing energy dictates the breakup of large oil droplets into smaller droplets and the depth of submergence of the droplets. The droplet size distributions are also affected by the collision frequency, which has been considered a function of system hydrodynamics, and collision efficiency, which is generally believed to represent the chemistry involved in the coalescence reactions. To date, the droplet-size distributions of physically and chemically dispersed oil have rarely been compared directly under hydrodynamic conditions approaching those existing in the field, and even fewer droplet-size distribution data have been reported in

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wave tank testing of dispersant effectiveness (NRC 2005). The latter report emphasized that existing databases must be expanded to determine whether and how factors such as energy dissipation rate, oil type, dispersant characteristics and dispersant use influence the droplet size distribution and formation kinetics. To address this need, the BIO wave tank was used to characterize and compare *in-situ* droplet size distributions of physically and chemically dispersed oil under a variety of non-breaking and breaking wave conditions in the experimental wave tank. The data generated in this study will be useful in optimizing operational guidelines, modeling transport and fate, and potentially evaluating biological effects of chemically dispersed oil.

This wave tank was originally developed to evaluate dispersant effectiveness under different reproducible wave energy conditions with energy dissipation rates similar to those that are encountered in the field. The main goal was to relate quantitatively dispersant effectiveness with energy dissipation rate for varying dispersant formulae, oil types and the weathering status of oil. The wave tank experiments conducted in a batch mode configuration demonstrated the significance of wave conditions to chemical dispersant effectiveness (Li et al. 2008a; Li et al. 2008b; Venosa et al. 2008). However, hydrodynamic characterization of the wave tank operated in the batch mode also revealed the presence of back-flowing underwater currents counter to the direction of the progressive waves generated by the wave maker. This recirculation mechanism is caused by the surface Stoke's drift of the progressive waves (Wickley-Olsen et al. 2008) and is a necessary condition applicable to the conservation of water mass. To counteract the backward underwater current flow and to allow for simulation of natural exposure levels that result from dilution of dispersed oil in an open environment influenced by waves, tides and currents, the wave tank was modified for operation in flow-through mode to simulate the influence of ocean currents. We studied dispersant effectiveness subjected to the combined actions of waves and currents. Such an experimental system allows for dilution caused by the undersea current carrying away the dispersed oil plume.

2.0 Objectives

This research program is a multi-disciplinary collaboration among scientists and engineers from government and academic institutions, whose collective knowledge contributed to produce a highly effective operational response activity and an improved understanding of the mechanism of dispersant action and their potential environmental effects. The objectives of this project are:

1) To quantify the natural rates of dispersion for various crude oils over a range of sea states (wave energies)
2) To quantify the effectiveness of representative oil dispersant formulations on different types of reference crude oils
3) To define the range of wave energy conditions over which dispersant formulations are most effective
4) To evaluate emerging methodologies for monitoring the concentration and size of dispersed oil droplets in seawater

Operational guidelines formulated with the results of our research will be used locally, regionally, nationally and internationally to train responders and decision-makers on how, why

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and when to apply dispersants to a spill to minimize harm to the environment. The outcome of our research is sound and robust because it is based on scientific facts, and it will stimulate exchanges of ideas among scientists to advance the use of this promising technology as a restoration and response activity. Through the planned outreach of project deliverables to on-scene coordinators and oil spill response organizations, CRRC will be recognized as a source of sound engineering practice in marine spill response. Students and post-docs have been used extensively as part of the laboratory field crew. This provided an excellent learning opportunity for them in their pursuit of higher education and training experience.

3.0 Methods

3.1 Wave generation and hydrodynamic characterization

Important parameters to describing a wave are its length and height, and the water depth over which it propagates (Dean and Dalrymple 1984). The length, L, or wavelength, is the distance from crest to crest (or trough to trough). The height is the vertical distance from trough to crest. The depth is the distance from half the wave height to the bottom of the ocean. Also important are the Still Water Level (SWL) and the Mean Water Level (MWL). The former is the depth of the water in the absence of waves, while the latter is an average water level over time. Shifting motion of the body of water could cause a change in the MWL, which would not be apparent in the SWL. According to Dean, et al, (1984) for the relative depth $h/L > 0.5$, the waves are considered deep water waves. Essentially, the waves do not "feel" the ocean floor. But this limit should be viewed qualitatively, because even for h/L as low as 0.3, one could still treat the wave as a deep-water wave (Melville et al. 2002).

For deep water (i.e., h/L >0.5) the first order theory indicates that the wavelength, L, is related to the wave period, T, by the equation

$$L \approx \frac{g}{2\pi} T^2 \qquad (1)$$

where g is the gravity. The celerity of the wave, or wave speed, is

$$C \approx \frac{L}{T} \approx \frac{g}{2\pi} T \qquad (2)$$

The above relation is through insertion of Eq. (1) in Eq. (2). Coastal engineering uses this relation as the "dispersion equation" (different from oil dispersion, the breakup of an oil slick into droplets). Take note that a wave with a larger period will travel faster than a wave with a smaller period. Dispersion of oil, i.e. the formation of small droplets from a slick, is not the same as the aforementioned concept.

Using the first order theory for deep water waves, the water profile $n(x,t)$ relative to the MWL is given by:

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$$\eta(x,t) = \frac{H}{2}\cos(k\,x - \sigma\,t) \qquad (3)$$

Where $n(x, t)$ is a function of position x and time t, H is the wave height (from crest to trough), k is the wave number defined as:

$$k = \frac{2\pi}{L} \qquad (4)$$

And σ is the angular (or radian) frequency defined as:

$$\sigma = \frac{2\pi}{T} \qquad (5)$$

The water velocity under a deep-water progressive wave to a second order approximation (Stoke's Theory) is given by:

$$u(x,z,t) = \frac{Hgk}{2\sigma}\cos(kx - \sigma t) + \frac{3H^2\sigma k}{16}e^{2kz}\cos 2(kx - \sigma t) \qquad (6)$$

and

$$w(x,z,t) = \frac{Hgk}{2\sigma}\sin(kx - \sigma t) + \frac{3H^2\sigma k}{16}e^{2kz}\sin 2(kx - \sigma t) \qquad (7)$$

Here we see that the water velocity decreases with depth. For a wave to break, the velocity of the water at the crest must be higher than the celerity. Traveling faster than the wave, the water mass at the crest will move faster than the wave and either "spill" or "plunge" ahead of the wave face.

Kinetic energy dissipates through laminar and turbulent shears in the water column. A relation between energy dissipation, ε and the absolute velocity gradient G (s^{-1}) at every location in the fluid (Camp and Stein 1943; Tennekes and Lumley 1999) is:

$$\varepsilon = \nu G^2 \qquad (8)$$

Where ν is the kinematic viscosity of water (approximately 10^{-6} m^2/s for water at 20 $^{\circ}$C). The hydraulic regime in the tank is turbulent due to the relatively large dimensions of the tank. In addition, in fairly broad situations the velocity gradient due to turbulence (i.e., the temporal variation of velocity at one location) is much larger than that due to variation of the velocity over space (Kaku et al. 2002; Rao and Brodkey 1972; Wu and Patterson 1989). For these reasons, we assume in this work that all mixing-related quantities (energy dissipation rate and absolute velocity gradients) are due solely to turbulence.

In turbulent mixing, large eddies carry the kinetic energy obtained from the general motion of the fluid (Batchelor 1970; Hinze 1955). These eddies break into smaller eddies, which in turn break

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into smaller eddies down to a scale known as the Kolmogorov scale where molecular viscosity effects become dominant (Kolmogorov 1949). The breaking waves in this study had a Kolmogorov scale,

$$\eta = \left(\frac{\nu^3}{\varepsilon}\right)^{\frac{1}{4}} \tag{9}$$

Kolmogorov scale is of approximately 100 microns near the surface.

Not all turbulent flows manifest churning and foaming. Thus, an apparently laminar flow could be in reality turbulent. A quantitative means to detect the presence of turbulence is through evaluation of the Fourier spectrum of the water velocity, which (the spectrum) represents the kinetic energy content at various scales. In turbulent flow, the spectrum has the following property (Kolmogorov 1949):

$$E \propto k^{-5/3} \tag{10}$$

where the symbol indicates proportionality. Thus, the spectrum has a power law behavior in function of the wave number. For a time series of measurements at a point, a turbulent flow has the following spectrum:

$$E \propto f^{-5/3} \tag{11}$$

where f represents the frequency of velocity fluctuations. Eq. 11 is valid in situations where Taylor's "frozen turbulence" hypothesis is applicable (Hinze 1955, p. 41; Monin and A.M.Yalgom 1971,1975, p.11). The hypothesis stipulates that turbulent eddies are advected without a change in their statistical properties, allowing inference of properties from a time series at a point. The small-scale structure of turbulence is independent of any orientation effects, and is thus locally isotropic. This cascade of energy can be detected through observance of the -5/3 slope in a spectrum.

In isotropic turbulence, the dissipation rate per unit mass is simplified to (Tennekes and Lumley 1972)

$$\varepsilon = 15\nu\overline{\left(\frac{\partial u_i}{\partial x_i}\right)^2} \tag{12}$$

where u_i (i=x, y, z) is the instantaneous velocity in any "i" direction. Considering the periodic motion of water due to waves, one may write:

$$u_i(s,t) = \overline{U}_i(s) + \overline{u}_i(s,t) + u_i'(s,t); i = x,\ y,\ z \tag{13}$$

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Where $\overline{U_i}$ is the time-averaged (mean) velocity that depends solely on location (it generally decreases with depth), $\overline{u_i}$ is the oscillatory component due to the oscillatory motion of waves (it depends on both location in the tank and time), and u_i' is the component due to turbulence. A moving average of the time series can give the oscillatory component of u_i (essentially a smooth line that would exist even in the absence of turbulence).

There are many methods for evaluating the energy dissipation rate. These are discussed in Kaku et al. (2006b) and references therein. In this work, the autocorrelation function approach is used, and it provides the energy dissipation rate as follows (Kresta and Wood 1993; Wu and Patterson 1989):

$$\varepsilon = A\frac{(u_{rms}')^2}{\tau_{E_i}} \tag{14}$$

where u_{rms}' is the root mean square (RMS) value of the turbulent component of velocity, A is a constant of order unity (one in this work), and τ_{Ei} is the integral time scale obtained by:

$$\tau_{E_i} = \int_0^{\infty} R_{E_i}\,dt \tag{15}$$

Where R_{Ei} is the temporal autocorrelation function,

$$R_{E_i} = \frac{\overline{u_i'(t)u_i'(t+\tau)}}{\overline{(u_i')^2}} \tag{16}$$

where τ is the time lag. Note that R_{Ei} is assumed the same in all direction, a direct consequence of the isotropic turbulence assumption. An upper limit of infinity is impractical in Eq. (15), and the point of first zero crossing (i.e., where the autocorrelation function reaches the value of zero) may be used (Wu et al. 1989).

The wave tank is 32 meters long, two meters high, 0.6 meter wide, and equipped with a flap-type wavemaker placed 1.5 m from the tank wall (Figure 1). The Acoustic Doppler Velocimeter (ADV) and wave gauge was placed 13.54 m from the wavemaker. Porous screens were placed opposite the wave maker to minimize reflection by dissipating wave energy upon passing of the waves through them.

Wave generation was obtained as a result of the rotation of an eccentric fly wheel. The flywheel was connected from one end to a motor and from the other to the flap via an actuator shaft. The flywheel was driven through a gear by a five horse-power (3.75 KW) motor. The motor runs at constant speed, thus producing a sinusoidal in time actuator motion of period T. The wavemaker generates waves of periods ranging from 0.2 to 2.5 seconds. Note that the flap-type wavemaker is more suitable to generate deep-water waves than the piston-type (Hughes 1990).

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Figure 1a

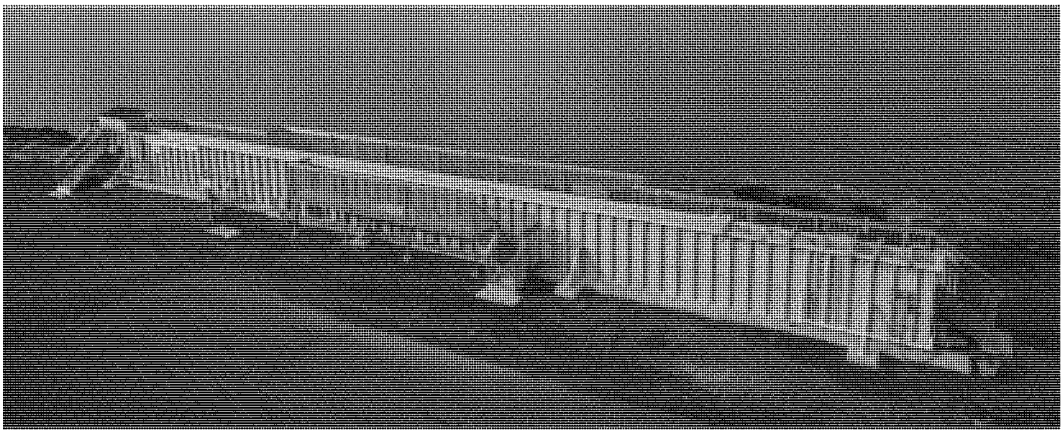

Figure 1b

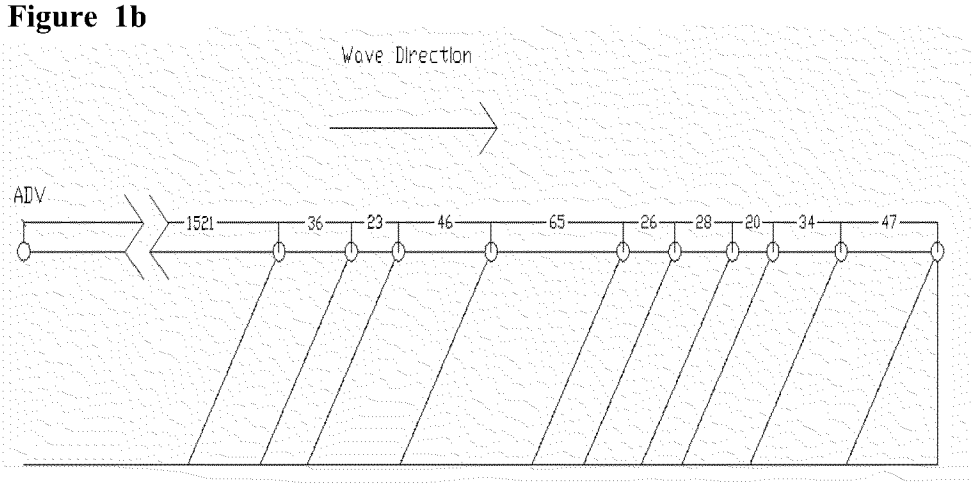

Figure 1c

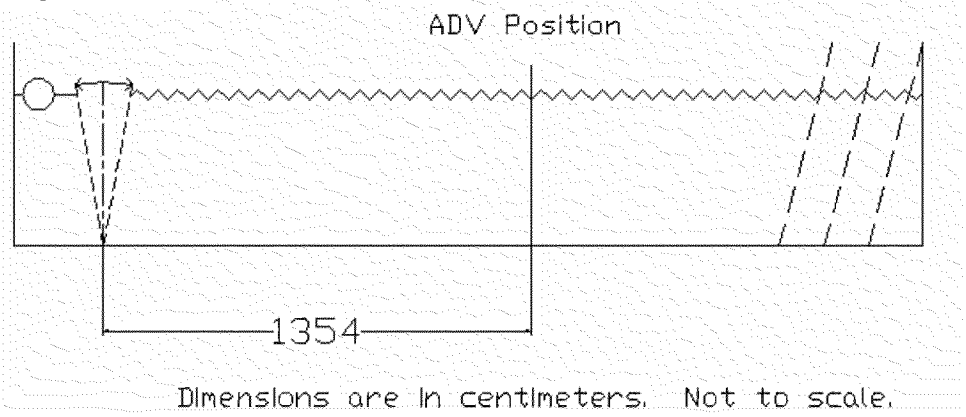

Figure 1: (a) Photograph of wave tank; (b) Wave absorber position; and (c) ADV position.

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The water level was measured using a wave gauge with an accuracy of 1.0 mm. The wave gauge is based on capacitance measurement, which varies in response to the submerged portion of the rod. The output from the transmitter is voltage. The wave gauge was calibrated by raising and lowering the gauge to levels of 125 cm, 150 cm and 175 cm. At each of these levels a voltage reading was recorded. Hence, a three point calibration curve was obtained. Drift was noted in the reading at latter times. Moisture buildup on locations (out of water) of the sensor likely caused the drift. Complete drying of the sensor would remedy the problem. The readings were logged to Labview data collection software (www.labview.com), and the recorded voltage was converted to water level based on the calibration curve. The data were logged at a frequency of 50 Hz (i.e., one data point every 0.02 seconds).

An ADV (Nortek Inc.) was used to provide three-directional velocity measurements. The probe is comprised of two components, the signal conditioning module and the acoustic sensor. The acoustic sensor of the ADV consists of four rods circling a transmitter. The receivers are oriented such that they will intersect the control volume. This control volume is defined by the shape of the transmit beam (approximated as cylindrical, though actually conical) with ends given by the length of the receive window for the probe. This control volume is approximately 5 cm from the acoustic sensor (thus non-intrusive) with a diameter and length of 1.8 mm and 7 mm, respectively. This gives a control volume of approximately 0.126 cm^3. The acoustic sensor is mounted to a stem that connects to the signal-conditioning module to be perpendicular to the major axis of the probe. The advantage of this arrangement is to allow velocity in the x-z plane to flow unobstructed. The ADV readings were output at 200 Hz. Thus, the measuring interval was 0.005 seconds. The probe of the ADV was placed centrally in the breaking zone (Figure 1). The ADV comes calibrated from the company.

3.2. Experimental procedures for oil dispersion in the batch mode

The chemical dispersant effectiveness was investigated for two dispersants (Corexit 9500, and SPC1000) plus water (as no-dispersant control) on two crude oils (Medium South American [MESA] and Alaska North Slope [ANS]) under three wave conditions (regular non-breaking wave, spilling breaking wave and plunging breaking wave) in the batch mode. MESA oil was weathered by evaporation (sparging with air for 130 h) to simulate the loss (approximately 14%) of volatile components at sea shortly after a spill. ANS oil was fresh and not weathered to test the dispersant effectiveness assuming an idea oil spill response scenario where dispersant application is available immediately available in the incident. The ANS oil was kindly provided by Dr. Jim Clark (Exxon Mobil Research and Engineering Co.), with Coding UN1267, PGI. The main fractions, namely saturates, aromatics, resins, and asphaltene, of the ANS oil were 32.0, 39.3, 24.4, and 4.3%, respectively, as characterized by using Iatroscan assay.

A three-factor mixed-level factorial experiment was designed to include 18 treatments with triplicate runs for each treatment, resulting in 54 runs for the entire design (Table 1). Treatments were applied in random order to minimize the impacts of confounding factors such as temperature, salinity and wind on the dispersant effectiveness of crude oil.

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Table 1: Dispersant effectiveness testing in the batch system

Treatment	Dispersants	Oils	Waves
1	Water	MESA	Regular non-breaking wave
2	Corexit 9500		
3	SPC 1000		
4	Water	ANS	
5	Corexit 9500		
6	SPC 1000		
7	Water	MESA	Spilling Breaker
8	Corexit 9500		
9	SPC 1000		
10	Water	ANS	
11	Corexit 9500		
12	SPC 1000		
13	Water	MESA	Plunger Breaker
14	Corexit 9500		
15	SPC 1000		
16	Water	ANS	
17	Corexit 9500		
18	SPC 1000		

For each experiment, seawater was pumped directly from the Bedford Basin through a double layer sock-filter (Atlantic Purification Ltd, Dartmouth, NS, Canada) with a pore size of 25 and 5 μm for the coarse and fine filters, respectively. The background temperature, salinity and fluorescence intensity and particle size distribution were recorded before the experiment started. For each experiment, 300 ml of crude oil was gently poured onto the surface of the water within a 40cm (inner diameter) tubular ring (constructed of NSF-51 reinforced clear PVC) 10 m from the wave generation paddle. Immediately after oil addition, 12 ml of dispersant (water for the control) was sprayed conically on top of the oil through a pressurized nozzle (60 psi; 0.635mm i.d.) at a dispersant-to-oil ratio (DOR) of 1:25. The ring was then lifted immediately prior to contact with the first wave. The desired wave conditions were operated continually during the 2h experiment. Samples were collected by using a set of 100ml syringes connected with a stainless steel manifold from four horizontal locations (8, 12, 16, and 20 m downstream from the wave maker), three depths (5, 75, and 140 cm from the average water surface), and four time points (5, 30, 60, 120 min). Sampling locations are shown in Figure 2. These samples were subdivided for oil chemical analysis using dichloromethane (DCM) extraction followed by ultraviolet spectrophotometry (UVS) (Venosa et al. 2002) (Venosa et al., 2008) and ultraviolet fluorescence analysis (Kepkay et al. 2002) (Kepkay et al. 2008) of dispersed oil concentration. After each experiment, the oil-containing seawater was completely drained with gas pumps, treated by filtration through an oleophilic oil absorbing material in a filtration column, and disposed of to the basin. The inner surfaces of the wave tank, including walls and floor, wave absorbers and wave generation paddle were thoroughly cleaned by power wash. The LISST was carefully washed with cleaning solution to remove oil, and thoroughly rinsed with tap water. The detection and emission windows were cleaned using a special lens-cleaning reagent.

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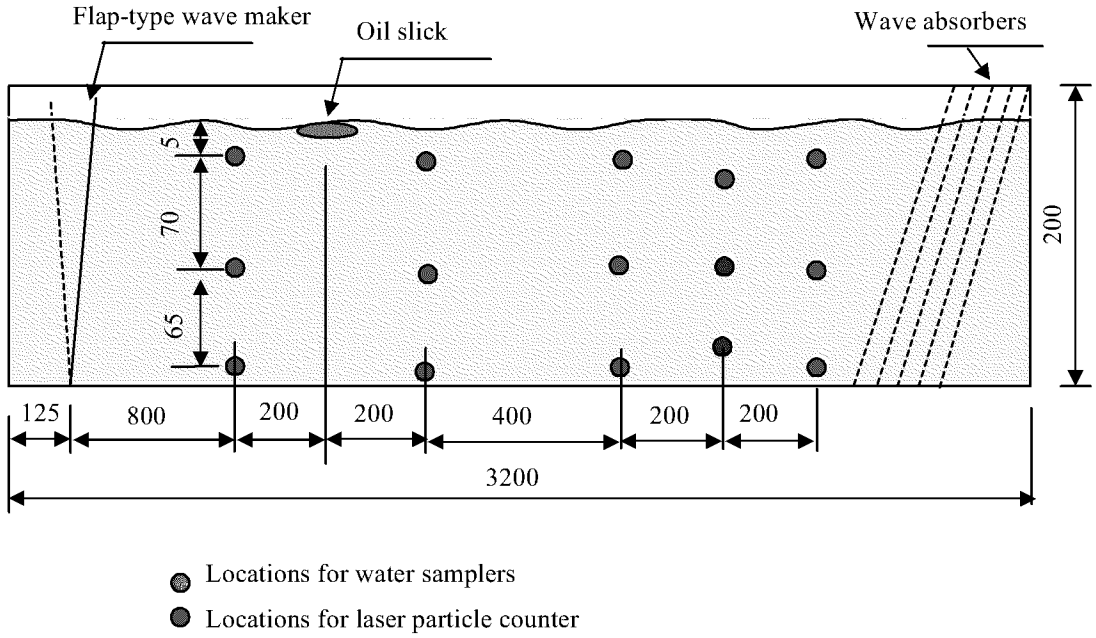

Figure 2: Schematic representation (all dimensions in cm, not to scale) of the wave tank

Dispersed oil droplet size distribution was measured using a laser *in-situ* scattering and transmissiometer (LISST-100X, Type C, Sequoia Scientific, Seattle, WA). For this instrument there were 32 particle size intervals logarithmically placed from 2.5 – 500 μm in diameter, with the upper size in each bin 1.18 times the lower. Particle size distribution was expressed as the average volumetric concentration of oil droplets within each interval of the size range. The data acquisition was conducted at real-time operation mode throughout each experiment, with an average of 10 measurements for each sample being measured every three seconds. The *in-situ* dispersed oil droplet size distribution was measured at three different depths (45, 80 and 125 cm from the average water surface) on one horizontal location (16 m downstream from the wave-maker) over four time periods (0-30, 30-60, 60-90, 90-120 min). Therefore for each measurement there were four 10-min continuous recordings with 30-min intervals throughout each experiment.

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3.3. Experimental procedures for oil dispersion in the flow-through mode

The chemical dispersant effectiveness was also investigated for the same dispersants and oil types under regular non-breaking wave and plunging breaking wave conditions in the flow-through mode to simulate current-driven dilution effect. The wave parameters for the flow-through system were the same as the batch system, except a current flow at 60 gallons per min (GPM) was introduced to the system to simulate the transport of waves in the open ocean. A three-factor mixed-level factorial experiment was designed to include 12 treatments with triplicate runs for each treatment, resulting in 36 runs for the entire design (Table 2). Treatments were applied in random order to minimize the impacts of confounding factors such as temperature, salinity and wind on the dispersant effectiveness of crude oil.

Table 2: Dispersant Effectiveness Testing in the Flow-through System

Treatment	Dispersants	Oils	Waves
1	Water	MESA	Regular non-breaking wave
2	Corexit 9500		
3	SPC 1000		
4	Water	ANS	
5	Corexit 9500		
6	SPC 1000		
7	Water	MESA	Plunging breaking
8	Corexit 9500		
9	SPC 1000		
10	Water	ANS	
11	Corexit 9500		
12	SPC 1000		

The same protocols were used for each experiment as those in the batch-mode experiments with the addition of measurements for background temperature, salinity, fluorescence intensity and particle size distribution that were recorded from the time the flow-through system was turned on prior to the initiation of the oil experiments; the desired wave conditions were operated continually for 1 hour (versus 2 hours for batch-mode); samples were taken at five time points (2, 5, 15, 30, 60 min), and; ultraviolet fluorescence analysis was not conducted following UVS analysis.

Dispersed oil droplet size distribution was measured using a laser *in-situ* scattering and transmissiometer (LISST-100X, Type C, Sequoia Scientific, Seattle, WA). The data acquisition was conducted at real time operation mode throughout each experiment, with an average of 10 measurements for each sample being measured every 3 seconds. The *in-situ* dispersed oil droplet size distribution was measured at one depth (60 cm from the average water surface) on one horizontal location (16 m downstream from the wave-maker) continuously over the entire 1 h experimental period.

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3.4. In-Situ Multiple Simultaneous Scattering and Fluorescence Sensor

Laboratory Calibration Phase: Alaska North Slope (ANS) crude oil was analyzed to determine the overall aromatic content for the laboratory calibration of the In-Situ Multiple Scattering and Fluorescence Sensor. The ANS oil was chosen for its relatively high dispersibility and its high aromatic (fluorescence) content. Oil extracts were analyzed for aromatic and alkylated-aromatic hydrocarbons, using modified EPA SW-846 method 8270 (US EPA), on a Hewlett-Packard 5890 gas chromatograph (GC) and 5971 mass spectrometer (MS) system. Data collected from the characterization analysis were used to build whole oil and individual component databases.

Response and Linearity Testing: A 100-L cylindrical tank was used during the laboratory dispersion testing to test the Response and Linearity of the instrument. The oil and dispersant were mixed using a variable-speed (20-200 rpm) Lightnin® Mixer with a stainless steel mixing impeller. Corexit 9500 was pre-mixed with the oil at a DOR of 1:25 for all experiments. Nominal oil concentrations of 10, 100, 1,000, and 10,000 ppb were tested during this experiment. The dynamic droplet size distribution and raw count data were measured from the light scattering and fluorescence sensors, respectively, for a period of five minutes. The test was performed three times over the nominal oil concentration range.

GC/MS Correlation Testing: The GC/MS correlation test was designed to relate fluorescence counts to the actual oil concentration (mg/L) within the test reactor and was performed concurrently with the concentration and linearity testing. During each test a 1-L sample was removed from the reactor and preserved in a glass sample bottle for analysis.

Turbidity Testing: The turbidity test (ASTM 2130) was performed to evaluate the multi-sensor's ability to accurately measure the concentration of dispersed oil within turbid seawater. This experiment was designed to evaluate the multi-sensor at surrogate turbidity concentrations of 100, 1,000, and 10,000 nephelometeric turbidity units (NTU) and nominal oil concentrations of 100, 1,000, and 10,000 □g/L. This experiment can determine a realistic operating range and demonstrate the multi-sensor's capacity to accurately measure oil concentration within a turbid environment. The test was performed three times over the nominal oil concentration and turbidity ranges.

The field testing of the in-situ multiple simultaneous scattering and fluorescence sensor was conducted by deploying the instrument in the wave tank facility at BIO. Experiments were performed to evaluate the multi-sensor at nominal ANS oil concentrations of 10, 100, 1,000, and 10,000 □g/L at a DOR of 1:25. The dynamic droplet size distributions and raw count data were recorded from the light scattering and fluorescence sensors, respectively, for a period of five min. Temperature, salinity, turbidity, and COD were recorded during the individual tests. Triplicate 1-L samples were collected during the testing, preserved through acidification, and returned to the LSU laboratory for GC/MS analysis.

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4.0 Results

4.1. Wave generation and hydrodynamic characterization

To generate regular waves in the tank, one needs simply to select the design wave period (or frequency) and set the motor to it for the intended duration. Due to the dissipative role of viscosity, the height of regular waves decreases as they propagate in the tank away from the wavemaker. Thus, to cause the wave height to increase and eventually break, one needs to "inject" momentum into the wave. This was done using the frequency sweep method discussed at length by Funke et al (1979). The method relies on the fact that waves propagate away from the wavemaker proportionally to their periods. Thus, if one generates a train of short-period (high frequency) waves followed by a train of long-period (low frequency) waves, the long-period waves would catch up to the short-period ones and inject momentum into them, especially at the crest of the long waves (Phillips 1977 p. 149).

Four settings of regular waves were investigated. They were for Low Frequency, LF, (T□2.1 s and 2.0 s for 7cm and 12 cm strokes, respectively) and High Frequency, HF, (T□1.18 s, for both strokes). The wavemaker ran for at least twenty minutes before the sampling began, which was approximately five minutes for the regular waves.

The plunging breaking waves were generated with a 12 cm stroke and periods T□2.0 sec and T□1.18 sec). Since the propagation speed of a wave in deep water is proportional to its period, the low frequency LF waves "catch up" to the high frequency HF waves resulting in breaking. Twenty minutes elapsed before the readings were made, which was for 30 minutes.

The dominant frequency of the waves was computed using spectral analysis of the time series of water level measurements. This was done for two reasons. First, an uncertainty exists in the set frequency on the dial because the gear box was not performing as accurately as expected. Second, it is possible that the motion of the flap was affected by the generated waves (splash from behind the flap and reflection). This unwanted effect would inadvertently alter the frequency that was set. These periods were then used in the frequency filtration discussed later.

Appendix A (1-4) shows the across-tank velocity, "v", of the regular waves for high and low frequency, and both strokes. Generally, the velocity decreased with depth, although for the deepest depths (1-4c), the velocity appeared very spiky, with magnitudes similar to the mid-depth (1-4b). Wave heights for the 7 cm stroke waves were about 8 cm and 10 cm for low and high frequency, respectively. The wave heights for the 12 cm stroke waves were around 15 cm and 20 cm for low and high frequency, respectively. The breaker occurred at approximately 13.54 m downstream of the wavemaker, essentially at mid-distance in the tank minimizing therefore the effects of standing waves that occur near the wavemaker (Dean and Dalrymple 1984 p. 175), and the wave absorber.

Appendix A (5) shows the time series of the across tank component v for plunging breaking waves. The series shows the kinematics of the wave in a period of 10 sec surrounding the breaker. The breaker occurred at about t = 2 sec. The velocity increases immediately after the breaker (5a). The breaker causes an increase in velocity around t = 7 sec (5b) and causes no

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noticeable increase in velocity at the deepest depth (5c). Wave height at breaking increased to about 25 cm. Breaking is induced when H/L ≥ 0.14 or 0.16 (Dean and Dalrymple 1984) when considering the breaking height with the actual period of 1 sec in the experiment for the high frequency waves.

Appendix A (6) reports the Fourier spectra for the plunging breaker experiment. In the figure the two peaks correspond to the high and low frequency waves. The energy in "u" and "w" was considerably larger than that for "v". This is from the higher velocity predominant in the "u" and "w" direction. Spectral peaks in the three components are also at higher frequencies than the noted in the figure. This is from harmonics of the dominant frequencies. The overall lower energy in the "v" component allow the frequency multiples to appear more dominant. The "v" spectrum closely follows the (-5/3) law (Eq. 11) more closely than the other two components. The flattening of the "u" and "w" components of the spectra are unlikely from noise, as noise would manifest itself equally in all components. It is possible that the harmonics dominated the higher frequencies for the "u" and "w" components. This property gives the "v" component as the suitable choice in computing the energy dissipation rate. Noise in the system does appear at frequencies greater than 50 Hz (≈ exp [3.9])

To calculate the energy dissipation rate, the values of the velocity fluctuations are needed. With Eq. 13 as a guideline, the velocity components consist of the mean flow and the fluctuations. An Infinite Impulse Response (IIR) "notch" filter separated the large scale flow from the small scale (Press et al. 1992). Spectral analysis dictated the removal of the frequencies. For the regular waves, the filter removed at the dominant frequencies and their harmonics. The goal was to leave the inertial sub-range undisturbed.

Appendix A (7) shows the filtered and unfiltered (original) "v" component for each of the type of regular wave used in the experiment. The filter removed the large-scale periodicity of the velocity, suggesting the effectiveness of the routine. The remaining (filtered) velocities are the fluctuations (v').

A combination of the high and low frequency wave filters were applied to the breaking wave (i.e. all filters applied to both high and low frequency waves were applied to the breaking waves). Appendix A (8) shows the affect of the filter on the plunging breaker. From Appendix A (5), we see that the breaker occurred at about t = 2 sec. The increase in velocity at around 3.8 sec is in both the filtered and unfiltered data. Turbulence from the breaker caused this local peak in the filtered velocity.

The autocorrelation function, R_E, (Eq. 16) was performed over the time series of the "v" velocity at each depth of the ADV. The Euler correlation time, τ_{Ei} , is the area below R_E from the vertical axis until the first zero crossing. Numerical integration gave time scales of around 0.1 sec for the regular wave experiments near the surface. The time scales for breaking increased to about 1 sec near the surface. Eq. (14) averages the velocity fluctuations over the time scale. This approach provides the average energy dissipation rate over the time scale, but does not provide information of the fine temporal scales of turbulence. For this reason, the following equation was used instead of Eq. (14):

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$$\varepsilon_j = A\frac{\left(v_j'\right)^2}{\tau_E} \qquad (17)$$

where the index j refers to time. Here, at any time t = j Δt (where Δt is equal to 0.02 sec), the ε is computed. The computed value of ε at each depth used its corresponding time scale. Appendix A (9-12) shows the ε calculated over time for the regular waves. These are at the same depths as the previously displayed velocity measurements. Qualitatively, the ε does not vary much over the whole series, with the exception of individual "spikes" every few seconds. The values generally decreased with depth.

Appendix A (13) displays ε for the plunging breaker at three depths. As expected, ε are higher near the surface. Breaking took place every 25 seconds. As such, the near surface plot has ε increase sharply during breaking and/or soon after the event. ε are elevated before the breaking events from the shear in the water when the low frequency waves overtake the high frequency waves. Deep in the column, the breaker does not clearly affect the ε.

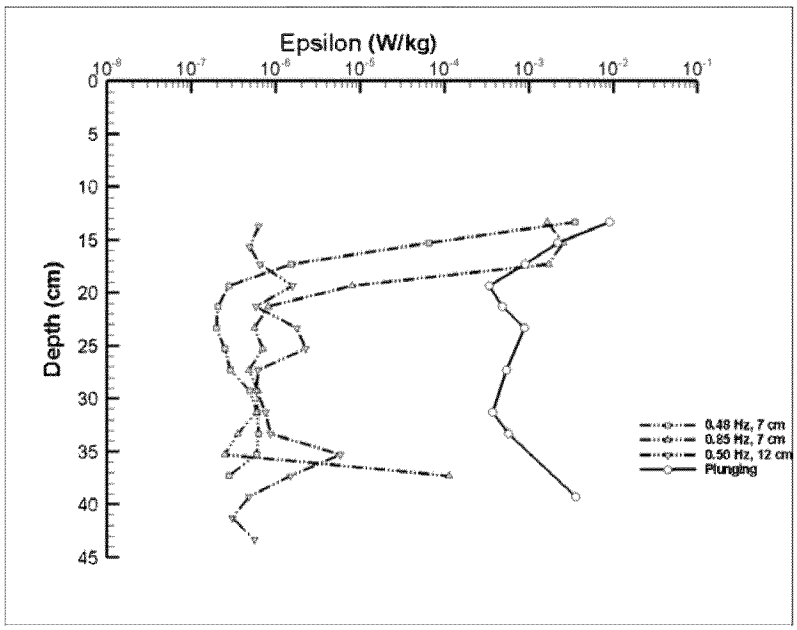

Figure 3: Average energy dissipation rates for regular and breaking waves. Note the effect of the breaker relative to the regular waves deep in the water column.

Figure 3 shows the average energy dissipation rates for the regular and breaking experiments for decreasing depths. The incorrect data from HF 12 cm experiment is not included in the plot. Here we see that the dissipation rates tend to decrease with depth and are much higher near the surface. The increase in dissipation at the deeper depths is likely caused by currents in the tank. The regular waves were averaged over the whole experiment, while the breaking waves had the top three values for each breaking packet averaged.

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4.2. Chemical Dispersant effectiveness testing in batch system

4.2.1 Effects of dispersant and wave conditions on oil distribution in the wave tank

To evaluate dispersant effectiveness, the fraction of added oil entrained in the water column of the wave tank must be determined. This can be accomplished either by measuring the amount of oil remaining on the surface after mixing in the presence of chemical dispersants or by measuring the oil concentration in the water column (NRC 2005, refs therein). The indirect method of measuring oil at the surface has been questioned because of incomplete recovery of oil fractions from compartments that cannot be explicitly measured, such as those evaporated into the atmosphere and irreversibly absorbed to the walls (Fingas and Ka'aihue 2004). In contrast, we collected a large number of samples with high resolution in space and time to directly measure the oil dispersed in the water column. The oil concentrations were determined by extraction of oil from the samples using dichloromethane, followed by reading absorbance at three wavelengths using ultraviolet spectrometry (Venosa et al., 2002). Figures 4 to 6 display representative contour plots of the MESA oil concentration in the wave tank. The ANS oil distributions in the wave tank (data not shown) were similar to those of MESA oil.

Figure 4A shows the control condition where only seawater was sprayed onto the oil slick under regular wave conditions. The added oil, which remained on the surface, was rapidly transported to the end of the tank due to the absence of dispersant that would reduce the oil-water interfacial tension and the lack of sufficient mixing energy to break up the slick. The ineffective natural dispersion of oil under regular wave conditions is clearly shown in Figure 4A, with high oil concentration on the surface near the wave absorbers, and the slow movement of dispersed oil upstream. In contrast, dispersion of MESA oil was significantly more effective over time after the slick was sprayed with either Corexit 9500 or SPC 1000, respectively (Figures 4B and 4C). Although the distribution of oil in the tank was similar to the control condition at five minutes, the oil became progressively more dispersed over time as its concentration steadily declined at the furthest downstream surface sampling, and the oil plume dispersed upstream and deeper into the water column. The overall dispersion was more evident after the addition of Corexit 9500 (Figure 4B) than SPC 1000 (Figure 4C).

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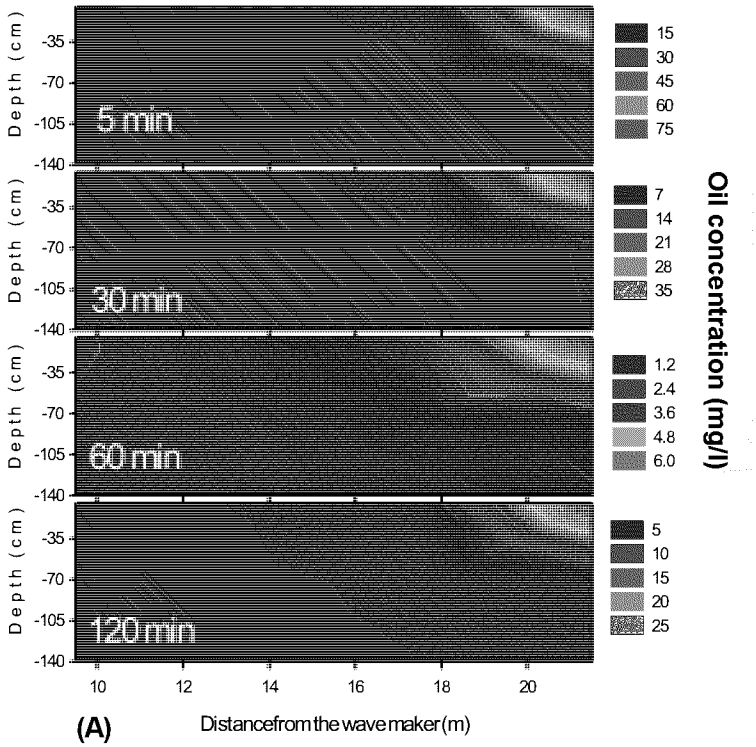

Figure 4a: Dispersed MESA oil concentration (mg/L) as a function of time and space under regular non-breaking waves with no dispersant.

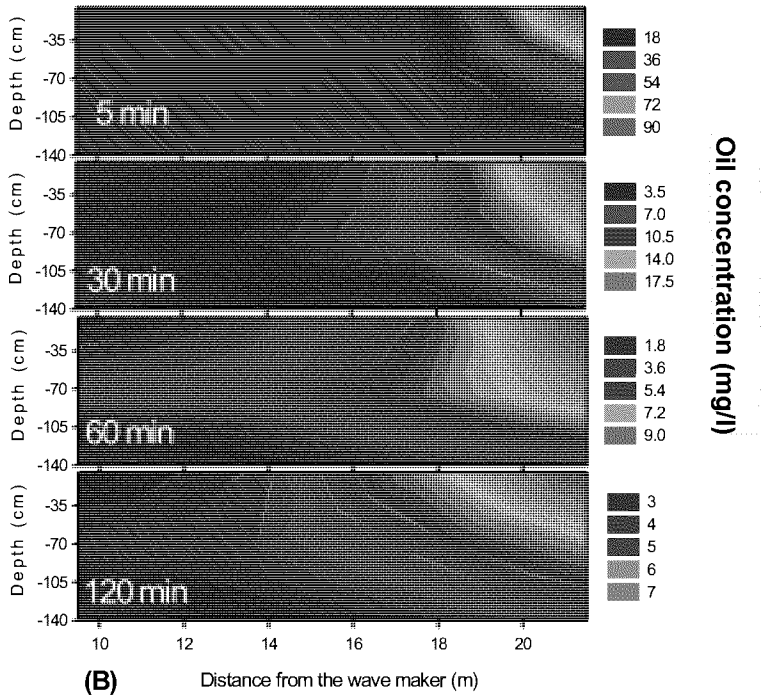

Figure 4b: Dispersed MESA oil concentration (mg/L) as a function of time and space under regular non-breaking waves with Corexit 9500.

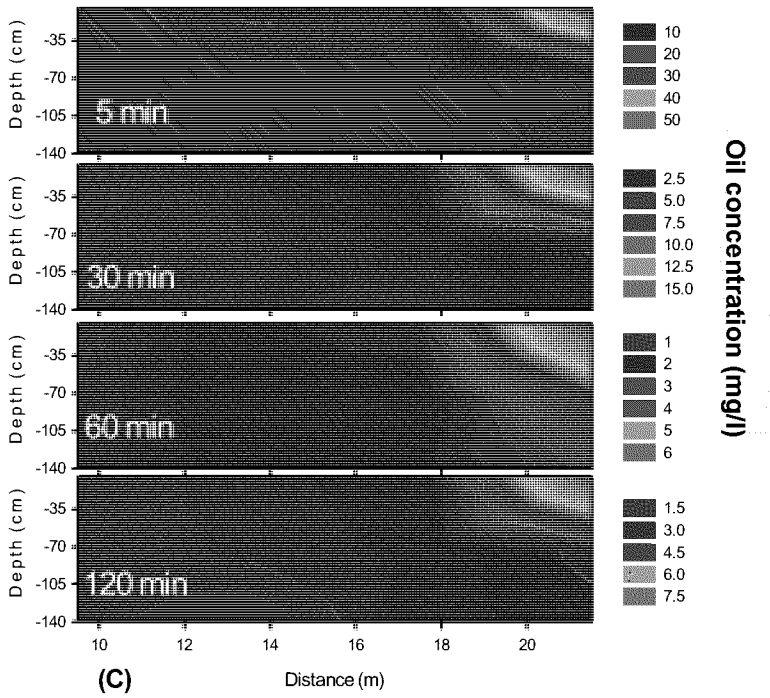

Figure 4c: Dispersed MESA oil concentration (mg/L) as a function of time and space under regular non-breaking waves with SPC 1000.

Under spilling breaking waves (Figure 5, next pages), the spreading of oil at the surface was enhanced under physical dispersion (Figure 5A) and chemical dispersion (Figures 5B and 5C). This was probably attributable to the dissipation of total kinetic energy as microscale turbulent eddies under the breaking waves, dampening the downstream drift velocity of the water and increasing the turbulent diffusion of dispersed oil droplets. Chemical dispersion by Corexit 9500 (Figure 3B) or SPC 1000 (Figure 5C) under spilling breaking waves increased oil dispersion significantly compared to the regular wave conditions (Figure 5A, B, C), as indicated by the movement of oil farther upstream. However, the depth of penetration of the oil plume was limited to the middle and upper half of the tank, similar to dispersion under regular wave conditions.

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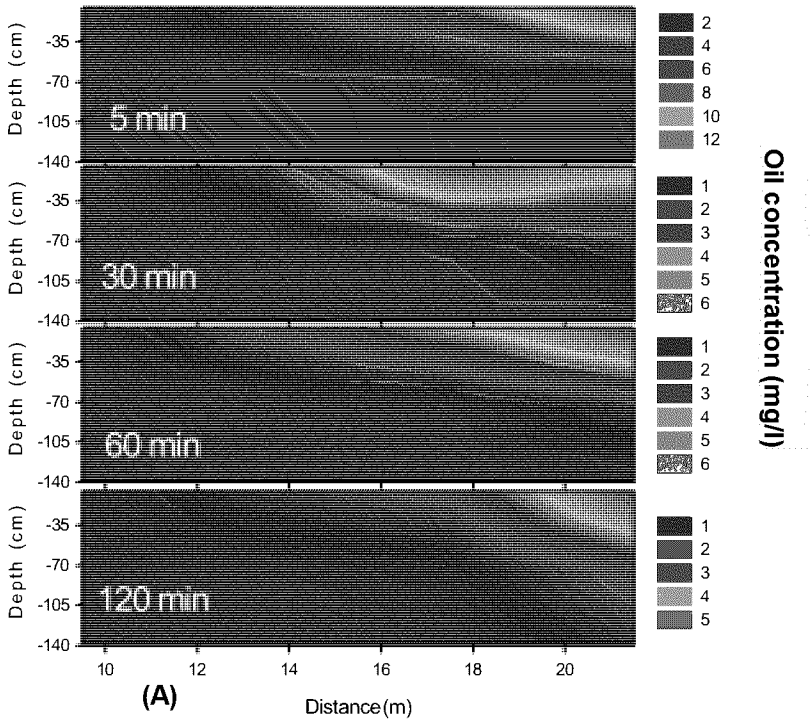

Figure 5a: Dispersed MESA oil concentration (mg/L) as a function of time and space under spilling breaking waves with no dispersant.

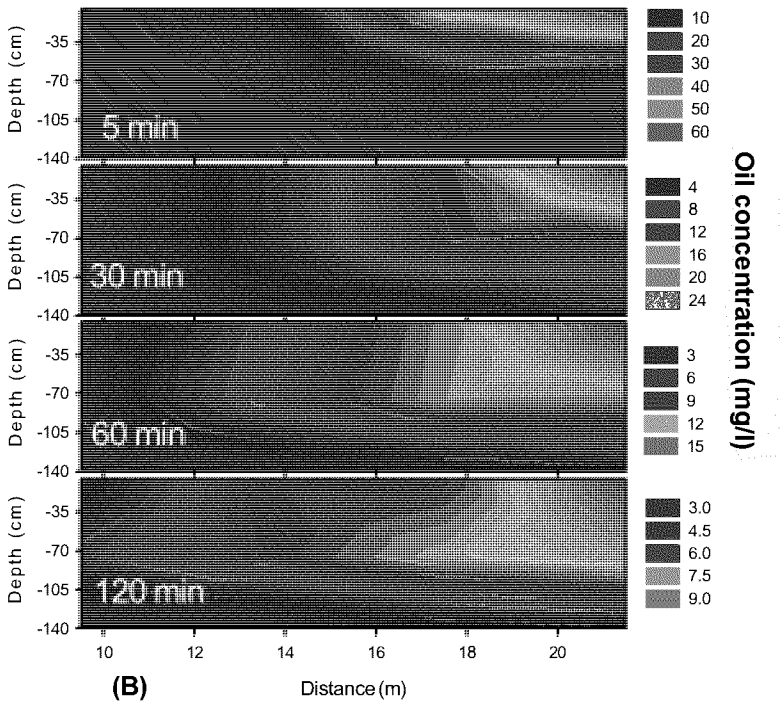

Figure 5b: Dispersed MESA oil concentration (mg/L) as a function of time and space under spilling breaking waves with Corexit 9500.

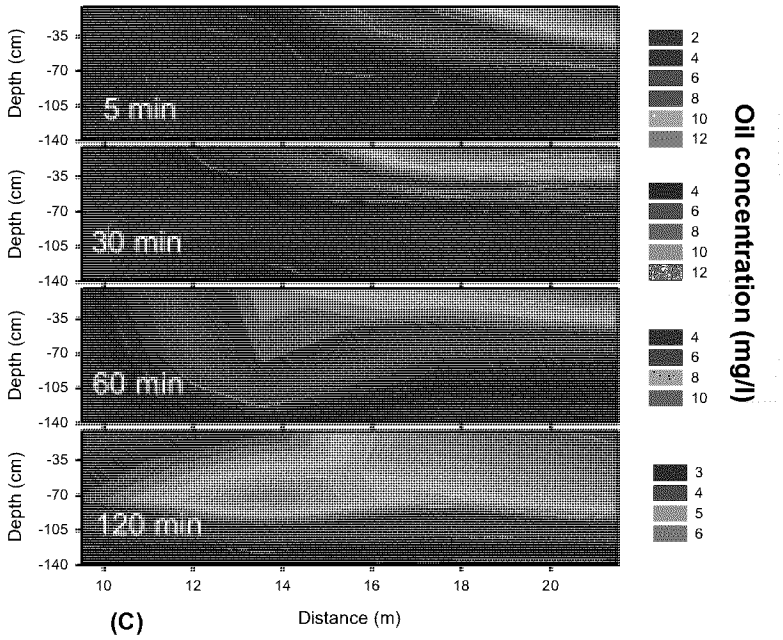

Figure 5c: Dispersed MESA oil concentration (mg/L) as a function of time and space under spilling breaking waves with SPC 1000.

Under plunging breaking waves (Figures 6A, B, C, next pages), spreading of the oil plume was even more pronounced compared to the non-breaking and spilling breaking waves. In the no-dispersant control condition, spreading at the surface was higher as shown by the reduced net drifting of oil at the surface (Figure 6A). In the presence of chemical dispersants, the oil plume appeared virtually homogenized in the wave tank at all depths due to the combined effect of more vigorous turbulent diffusion created by the plunging breaking waves and the presence of chemical dispersants (Figures 6B and 6C).

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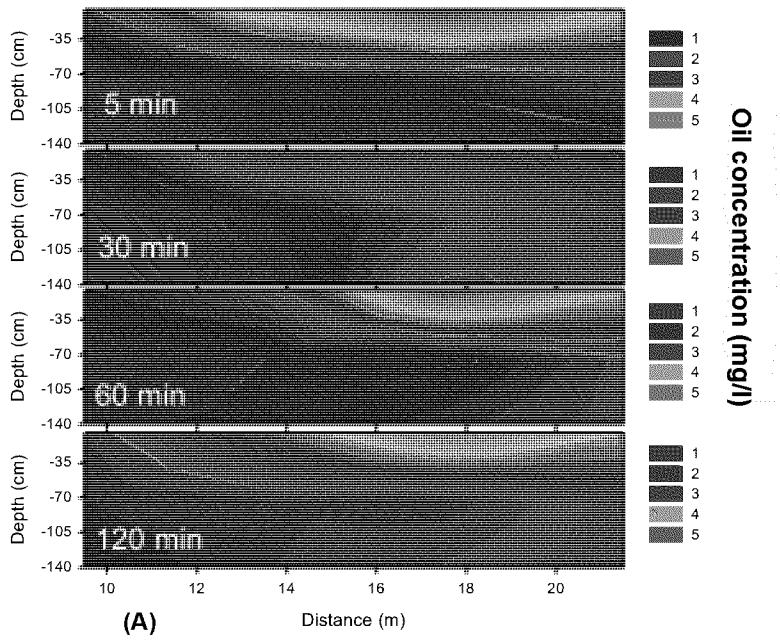

Figure 6a: Dispersed MESA oil concentration (mg/L) as a function of time and space under plunging breaking waves with no dispersant.

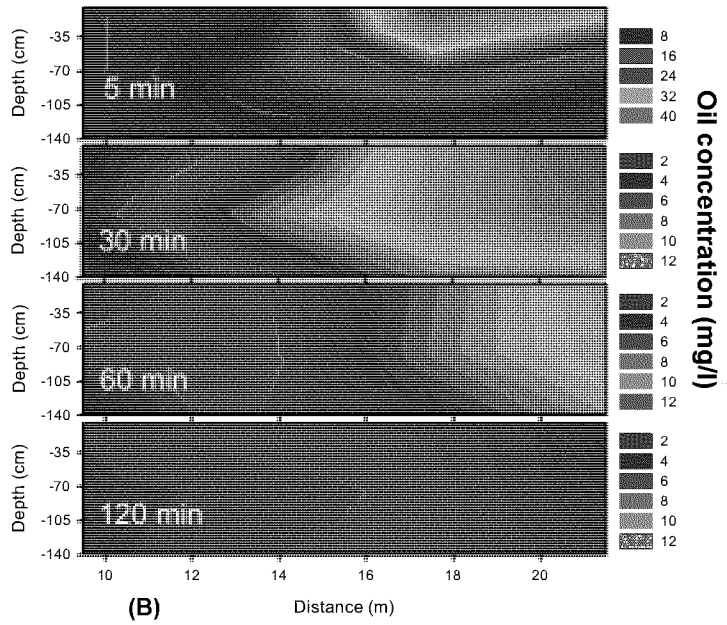

Figure 6b: Dispersed MESA oil concentration (mg/L) as a function of time and space under plunging breaking waves with Corexit 9500.

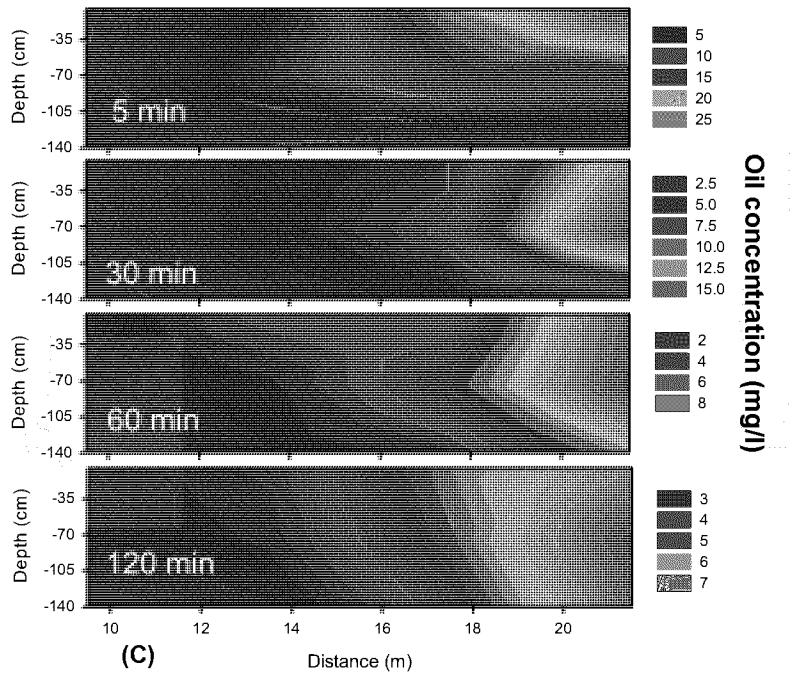

Figure 6c: Dispersed MESA oil concentration (mg/L) as a function of time and space under plunging breaking waves with SPC 1000.

The effect of breaking waves on the oil distribution (in particular the penetration depth of dispersed oil) is related to a number of contributing factors. As waves break, it is estimated that 30% to 50% of the dissipated wave energy entrains oil droplets into the water column (Lamarre and Melville 1991; Tkalich and Chan 2002), and effectively determines the first-order oil entrainment rate (Tkalich and Chan 2002). Breaking waves develop a mixing layer in the upper water column, and the penetration of oil results in a uniform mixing of the droplets, with the mixing layer proportional to the height of breaking waves (Delvigne and Sweeney 1988; Tkalich and Chan 2002). Moreover, breaking waves generate micro-scale turbulence with the smallest eddies having the greatest velocity gradients, leading to deformation, elongation and eventual breakup of larger droplets, forming a large number of small droplets that have lower buoyancy and more rapid diffusion efficiency (Delvigne et al. 1987; Li and Garrett 1998).

4.2.2 Dispersant effectiveness as a function of energy dissipation rate

To compare the effect of wave and dispersant on oil dispersion effectiveness, the average dispersed oil concentration in the bulk water column was calculated from the oil concentrations of the two lower depths and all four horizontal locations of water samples of the independent triplicate experiments for each treatment. Oil dispersion time (5, 30, 60, and 120 min) was treated separately to identify the time effect on the overall dispersion effectiveness for three dispersants on two oils under three different wave conditions. The higher values of the surface oil concentration, especially the one at the furthest downstream location, are the very indication of poor dispersion effectiveness, so it is more reasonable to exclude the surface measurements

from the calculation of the average dispersed oil concentration in the water column. Table 3 shows the calculated bulk water column average oil concentrations.

Table 3: Average water column dispersed oil concentrations (mg/l) as a function of time. Data reported as the average ± one standard deviation of independent triplicate runs.

Oil	Wave	Dispersant	5 min	30 min	60 min	120 min
MESA	Regular	Water	0.31 ± 0.02	0.44 ± 0.26	0.86 ± 0.65	1.05 ± 0.73
		Corexit	0.39 ± 0.28	3.39 ± 2.74	3.89 ± 1.85	4.05 ± 1.40
		SPC	0.69 ± 0.79	1.36 ± 1.09	2.00 ± 1.54	2.09 ± 1.51
	Spilling	Water	0.31 ± 0.09	0.39 ± 0.14	0.42 ± 0.22	0.71 ± 0.22
		Corexit	1.46 ± 1.57	5.04 ± 1.05	5.19 ± 1.46	4.79 ± 1.46
		SPC	2.40 ± 2.39	2.84 ± 2.71	3.61 ± 2.96	3.64 ± 2.83
	Plunging	Water	0.77 ± 0.27	1.55 ± 0.58	1.66 ± 0.43	2.07 ± 0.46
		Corexit	4.31 ± 0.95	7.09 ± 0.85	6.50 ± 0.29	5.43 ± 0.15
		SPC	3.39 ± 1.85	4.65 ± 1.62	4.31 ± 1.29	4.40 ± 0.70
ANS	Regular	Water	0.67 ± 0.77	0.81 ± 0.57	1.19 ± 0.57	1.37 ± 0.69
		Corexit	2.26 ± 2.17	3.32 ± 2.61	3.68 ± 1.03	3.93 ± 0.75
		SPC	1.49 ± 1.06	2.12 ± 1.60	2.21 ± 1.71	2.59 ± 1.93
	Spilling	Water	0.25 ± 0.08	0.25 ± 0.09	0.47 ± 0.47	0.55 ± 0.33
		Corexit	4.77 ± 1.00	8.58 ± 0.65	8.21 ± 1.05	6.55 ± 0.34
		SPC	1.97 ± 2.14	3.14 ± 3.64	2.92 ± 2.86	2.97 ± 2.21
	Plunging	Water	0.28 ± 0.15	1.01 ± 0.61	1.39 ± 0.65	1.61 ± 0.36
		Corexit	4.09 ± 3.65	8.37 ± 1.61	7.73 ± 0.75	6.91 ± 0.50
		SPC	2.91 ± 1.04	5.89 ± 3.06	5.69 ± 1.92	5.75 ± 1.06

Dispersant effectiveness (DE) was determined by estimating the average dispersed oil concentration in the water column for the two chemical dispersant treatments and the no-dispersant (physically dispersed) control as a function of □. This was performed by calculating the average oil concentrations of the eight samples recovered from the four horizontal locations and two lower depths of the water column in the wave tank. It is reasonable to exclude the surface samples from the calculation of the average dispersed oil concentration in the water column because the high oil concentrations on the surface of the water at the wave absorber end of the tank were largely controlled by surface drift, and would skew the calculations of DE. Intuitively, the extremely high oil concentration of the samples recovered from the surface in front of the wave absorbers under regular waves in the absence of dispersants is a clear indication of poor oil dispersion efficiency.

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Figures 7 and 8 present the estimated DE of the three dispersant types (including water as the control) on the two crude oils as a function of □. Different degrees of physical dispersion of the MESA and ANS crude were measured at each energy dissipation rate. The physical DE of MESA crude ranged from 4% to 9% at 5 min (Figure 5A), and then steadily increased with time, approaching 12% to 24% after 2 h (Figure 5D). Similarly, the physical DE of ANS crude was between 3.5% and 9% at 5 min (Figure 6A) and increased to between 10% and 19% at 2 h (Fig. 6D). Delvigne and Sweeney (1988) have reported that the physical dispersion of oil in a grid column generated droplets that were mostly larger than 50 μm in turbulence at energy dissipation rates of up to 3.5 $W \cdot kg^{-1}$, but they observed only a very small fraction of oil dispersed by breaking waves under a surface slick in their flume experiments. Lunel (1993, 1995) found that the dispersion of Forties crude oil with and without dispersant applied at sea generated a similar number of large oil droplets (> 70 μm), but dispersion of the oil with dispersant produced a much greater number of small droplets (< 70 μm). However, since none of these authors have reported physical DE explicitly, it is impossible to compare their results with our current work, beyond the consistency that physical dispersion of oil was expected. It was even more difficult to obtain physical DE of oil when bench-scale testing apparatus was used, due to coalescence and re-surfacing of oil from the relatively large water to oil ratio and wall effect of the confined space, (Chandrasekar et al. 2005; Chandrasekar et al. 2006).

Chemical dispersants were effective under all three wave conditions (Figures 7 and 8), with oil dispersion most effective under plunging breaking wave conditions and least effective under regular non-breaking wave conditions. The dispersant Corexit 9500 appeared twice as effective as SPC 1000 for the dispersion of MESA crude at the two lower energy dissipation rates, but the DE of the two dispersants was closer after oil was dispersed for 2 h at high energy dissipation rates. A similar trend was observed for the dispersion of ANS crude. At all three energy dissipation rates, though, the DE of Corexit 9500 was consistently higher than that of SPC 1000, and both were significantly higher than the control. The DE of the control was significantly increased as a function of time at high energy dissipation rates. The SPC 1000 was less effective at the two lower energy dissipation rates. In contrast, the Corexit 9500 appeared equally effective at the two higher energy dissipation rates but less effective at the low energy dissipation rate.

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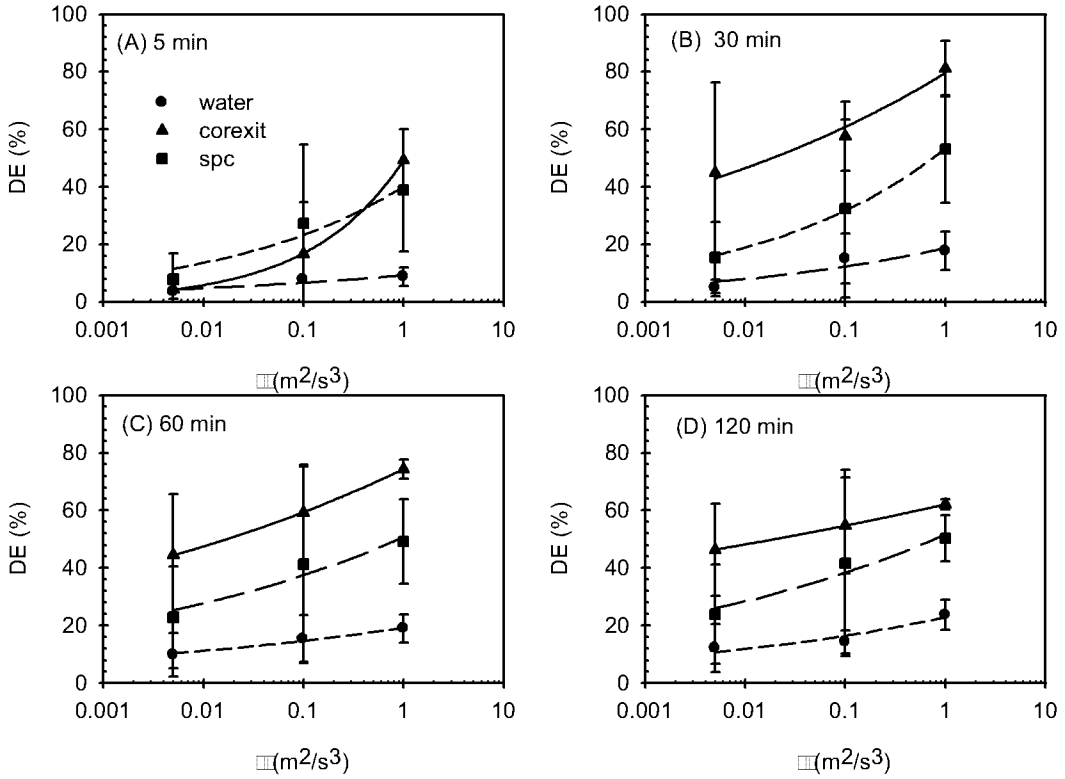

Figure 7: DE on MESA crude oil as a function of energy dissipation rate at: (A) 5 min, (B) 30 min, (C) 60 min, and (D) 120 min. Data shown are mean and one standard deviation of independent triplicate runs. Lines are best-fit regression of Equation 5.

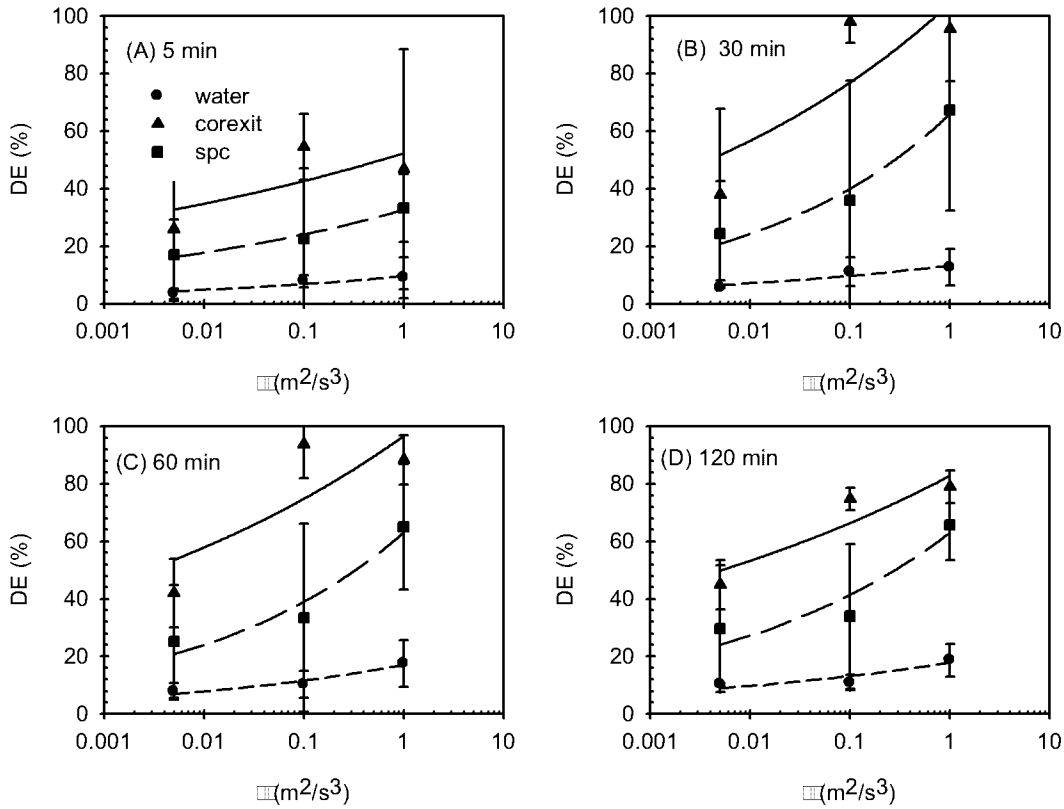

Figure 8: DE on ANS crude oil as a function of energy dissipation rate at: (A) 5 min, (B) 30 min, (C) 60 min, and (D) 120 min. Data shown are mean and one standard deviation of independent triplicate runs. Lines are best-fit regression of Equation 5.

To delineate the effect of each treatment factor on the oil dispersion, a four-way factorial analysis of variance (ANOVA) was conducted to determine the effects of main factors and multifactor interactions on the DE. The main factors tested included dispersant type (three levels), wave condition (three levels), oil type (two levels), and oil dispersion time (four levels). The oil dispersion time (5, 30, 60, and 120 min) was analyzed separately to identify the time required to achieve the maximum overall DE for the three dispersant conditions on the two oils under the three imposed wave conditions. The results of the ANOVA are summarized in Table 4. The ANOVA revealed that there was one significant three-factor interaction (dispersant by oil by wave, $p = 0.017$) and three significant two-factor interactions (dispersant by oil, $p = 0.016$; dispersant by wave, $p = 0.00001$; and dispersant by time, $p = 0.00385$). Interactions of these factors indicate that they had opposite effects on the DE. There was no two-way time-by-wave interaction. All four main factors showed very strong significant effects on the DE (oil, $P = 0.0074$; wave, dispersant type, and dispersion time, $P < 0.0000001$).

Table 4: Four-way factorial ANOVA of the main factor and multi-factor interaction effects on the dispersant effectiveness. Significant factors are flagged (*).

	Degree of freedom	Sum of square	Mean square	F value	Pr (F)
Dispersant (Disp)	2	627.8180	313.9090	140.2928	0.0000000 *
Wave	2	163.0560	81.5280	36.4366	0.0000000 *
Time	3	100.6297	33.5432	14.9912	0.0000000 *
Oil	1	16.5033	16.5033	7.3757	0.0074208 *
Disp/Oil	2	19.0702	9.5351	4.2614	0.0159212 *
Disp/Wave	4	69.9299	17.4825	7.8133	0.0000100 *
Oil/Wave	2	1.9648	0.9824	0.4391	0.6455039
Disp/Time	6	45.2753	7.5459	3.3724	0.0038509 *
Oil/Time	3	0.4255	0.1418	0.0634	0.9790765
Wave/Time	6	7.1573	1.1929	0.5331	0.7824024
Disp/Oil/Wave	4	28.0072	7.0018	3.1293	0.0167294 *
Disp/Oil/Time	6	1.9656	0.3276	0.1464	0.9895068
Disp/Wave/Time	12	6.7733	0.5644	0.2523	0.9948054
Oil/Wave/Time	6	8.4322	1.4054	0.6281	0.7075827
Disp/Wave/Oil/Time	12	5.4511	0.4543	0.2030	0.9981657
Residuals	144	322.2041	2.2375		

The Tukey's paired comparison method was used to compare the effects of different levels of the main factors that have been identified to significantly affect the DE; the results are listed in Table 5. The two tested dispersants both have significantly higher DE than the water control (increasing DE by an average margin of 48% and 26%, respectively, for Corexit 9500 and SPC 1000); Corexit 9500 was more effective than SPC 1000 by a 22% higher DE. As for the effect of the wave condition, spilling breaking waves significantly increased DE by 12% compared to the regular non-breaking waves; plunging breaking waves significantly increased the DE by an additional 13% compared to the spilling breaking waves. With regard to dispersion time, the extent of oil dispersion increased significantly from 5 min to 30 min, and leveled off thereafter.

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Table 5: Tukey's paired comparison of the different effects between treatment levels on DE (%) in the water column. Significant differences are flagged by * based on 95% simultaneous confidence intervals for specified linear combinations.

Treatment	Level	Estimates	Standard error	Lower limit	Upper limit
Dispersant	Corexit - SPC	21.6 *	2.98	14.6	28.7
	Corexit - Water	47.7 *	2.98	40.6	54.7
	SPC - Water	26.1 *	2.98	19.0	33.0
Wave	Plunging - Regular	24.3 *	2.98	17.3	31.4
	Plunging - Spilling	12.3 *	2.98	5.5	19.5
	Spilling - Regular	11.8 *	2.98	4.7	18.9
Time	30 min – 5 min	17.8 *	3.29	9.3	26.4
	60 min – 5 min	18.5 *	3.29	10.0	27.1
	120 min – 5 min	17.6 *	3.29	9.1	26.2
	60 min – 30 min	0.73	3.29	-7.8	9.3
	120 min – 30 min	-0.19	3.29	-8.7	8.4

4.2.3 Physically and chemically dispersed oil droplet size distributions

Figures 9 to 11 display representative dispersed MESA crude oil droplet size distributions measured near the surface of the wave tank for physical and chemical dispersion of oil under three different wave conditions. Table 6 summarizes the droplet size distribution statistics. Similar droplet size distributions were obtained in the middle and near the bottom of the wave tank (data not shown). The dispersed oil droplet size distribution data were also recorded for ANS crude from all three depths under different experimental conditions (data not shown). These data were similar to those for MESA. Physical dispersion (i.e., dispersion in absence of a chemical dispersant) of MESA oil created mono-modal lognormal droplet size distributions under regular wave conditions throughout the entire experiment (Fig. 9A, B). Bi- or tri-modal lognormal distributions were generated initially (first 10 min), which were further dispersed to mono-modal distributions, under spilling and plunging breakers (Fig. 10A,B; 11A,B). In the presence of chemical dispersants, however, multi-modal lognormal size distributions were produced under all three wave conditions throughout the entire duration of the dispersion experiment (Fig. 9C, E - 11C, E). A large number of oil droplets with droplet size less than 10 μm were created in the presence of chemical dispersants, especially by dispersant Corexit 9500. Application of dispersants expanded the range of size distributions as indicated by larger geometric standard deviations (GSD) associated with chemical dispersants (Table 6). Chemical dispersants also caused much higher dispersed phase volume concentrations (areas under the droplet size distributions) than physical dispersion (Figures 9-11). However, the droplet size distribution patterns of the chemically dispersed oil droplets were essentially the same after 30 min under all three wave conditions, as indicated by the percentage cumulative droplet size distributions (Fig. 9D,F; 10D,F; 11D,F).

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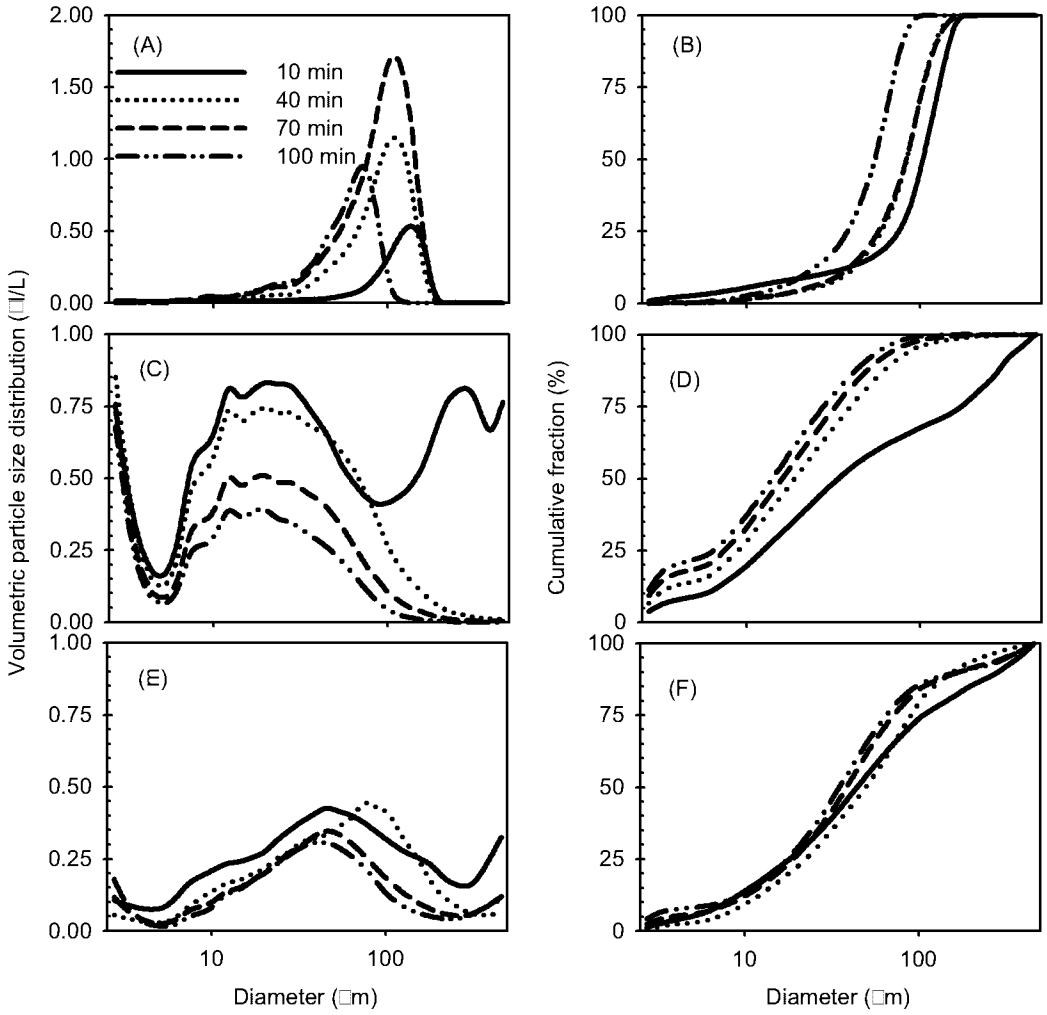

Figure 9: Volumetric (left) and cumulative (right) MESA oil droplet size distributions dispersed by water (A&B), Corexit 9500 (C&D), and SPC 1000 (E&F) under regular wave conditions.

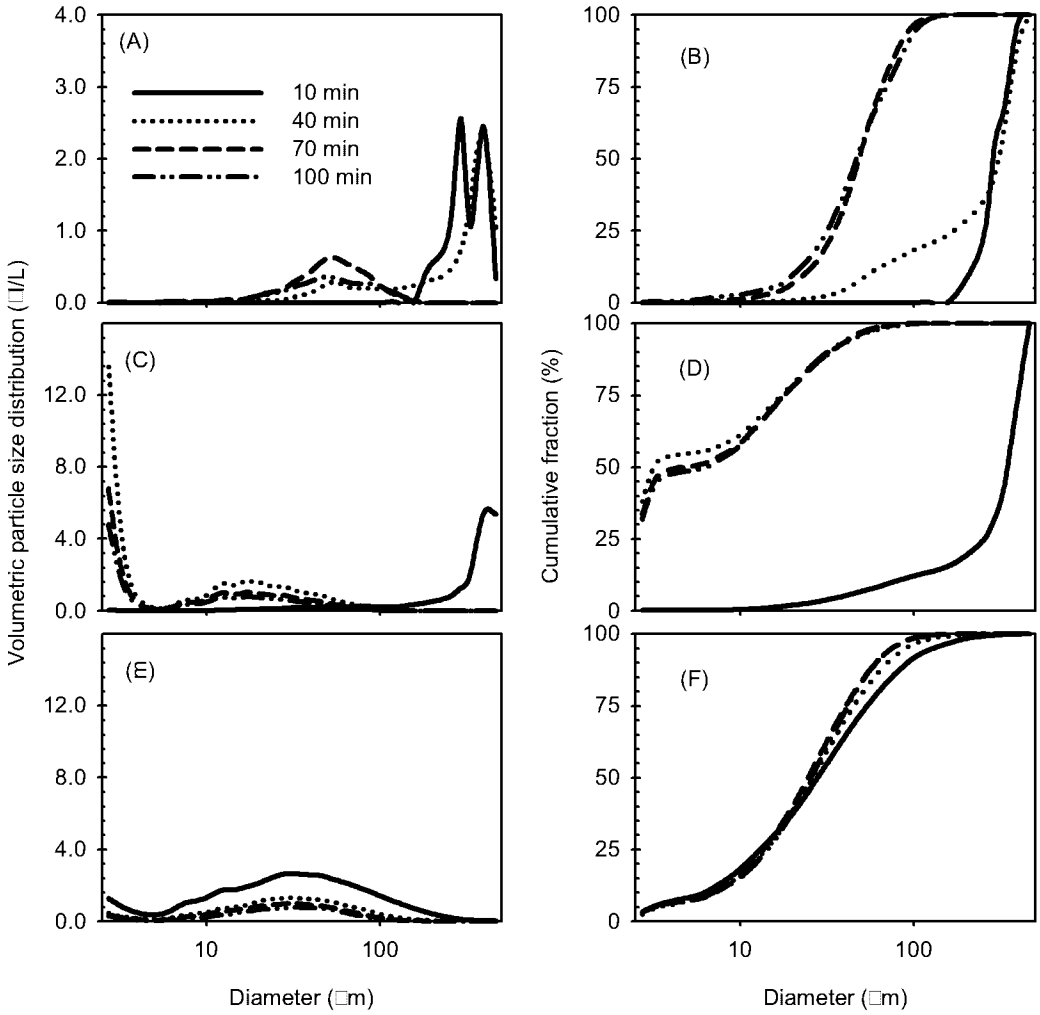

Figure 10: Volumetric (left) and cumulative (right) MESA oil droplet size distributions dispersed by water (A&B), Corexit 9500 (C&D), and SPC 1000 (E&F) under spilling breaking wave conditions.

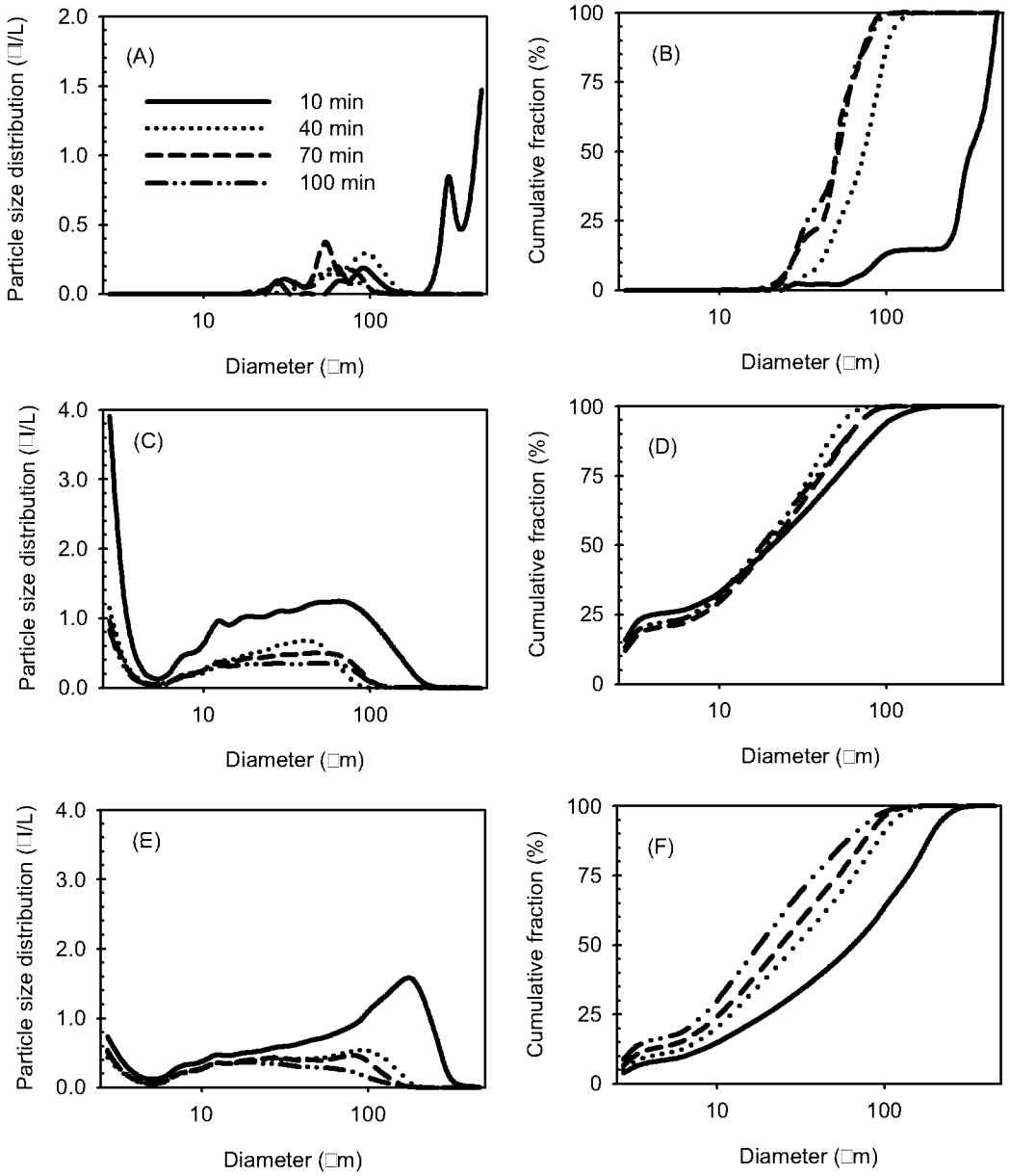

Figure 11: Volumetric (left) and cumulative (right) MESA oil droplet size distributions dispersed by water (A&B), Corexit 9500 (C&D), and SPC 1000 (E&F) under plunging breaking wave conditions.

Table 6: Droplet size distribution statistics

Wave	Dispersant	Time (min)	d16 [a]	d50 [a]	d84 [a]	GSD [b]	Modes	% < 70 µm
Regular	Water	10	53	104	143	1.64	1	22%
		40	46	80	116	1.59	1	34%
		70	45	80	114	1.59	1	35%
		100	28	55	74	1.63	1	75%
	Corexit	10	8	33	250	> 3.16	4	62%
		40	6	19	55	3.03	2	90%
		70	3.5	16	45	3.59	2	94%
		100	3	14	38	3.56	2	96%
	SPC	10	11	45	186	4.11	3	65%
		40	15	50	120	2.83	3	65%
		70	13	39	100	2.77	3	72%
		100	12	35	90	2.74	3	77%
Spilling	Water	10	230	280	360	1.25	2	0%
		40	85	310	380	2.11	2	13%
		70	29	50	75	1.61	1	78%
		100	25	48	80	1.79	1	75%
	Corexit	10	160	350	430	1.64	1	95%
		40	2.5	3	25	3.16	2	99%
		70	2.5	5	25	3.16	2	99%
		100	2.5	7	25	3.16	2	99%
	SPC	10	9	28	74	2.87	2	82%
		40	10	27	58	2.41	2	90%
		70	10	25	50	2.24	2	93%
		100	10.5	24	50	2.18	2	93%
Plunging	Water	10	225	330	430	1.38	4	5%
		40	45	70	96	1.46	2	45%
		70	31	50	70	1.50	2	82%
		100	29	48	68	1.53	2	92%
	Corexit	10	2.8	22	70	5.00	2	88%
		40	3	19	43	3.79	2	100%
		70	3	20	52	4.16	2	98%
		100	3	18	53	4.20	2	98%
	SPC	10	11	64	170	3.93	2	50%
		40	8	30	80	3.16	2	77%
		70	7	24	70	3.16	2	84%
		100	4	18	52	3.61	2	92%

[a] $d_{16\%}$, $d_{50\%}$, $d_{84\%}$ represent the 16%, 50%, or 84% of total mass of the droplets that are smaller than this diameter (µm); $d_{50\%}$ is the mass median diameter.
[b] GSD stands for geometric standard deviation.

4.2.4 Significant factors determining the average dispersed oil droplet sizes

The full spectrum of particle size distribution at each sampling time was converted to volume mean diameter (VMD) to compare the influence of different treatment conditions, including wave conditions, dispersant type and oil type, on the average droplet size. The VMD from physical dispersion (absence of dispersants) under all wave conditions started with wide

fluctuations but generally decreased over time. The time-series VMD were in good agreement at all three depths under regular waves and plunging breaking waves, but were smaller at the bottom than in the middle and near the surface under spilling breaking wave conditions, probably caused by less penetration depth of the spilling breaking waves. The VMD from the chemical dispersants were larger near the bottom than near the surface and in the middle of the wave tank under regular waves, but had wider fluctuations in the middle of the wave tank than near the surface and the bottom of the wave tank under spilling and plunging breaking waves conditions.

Figures 12 and 13 illustrate the average dispersed oil droplet VMD at the surface of the wave tank as a function of time at the end of each measurement period for MESA and ANS crude, respectively. Similar trends of the time-series average VMD under different dispersant and wave conditions were observed at the other two depths (in the middle and near the bottom) of the wave tank (data not shown). After 10 min, physically dispersed oil droplets were large (VMD >160 μm) under all three wave conditions (Fig. 12, 13). In contrast, chemical dispersants (both Corexit 9500 and SPC 1000) created the largest oil droplets (VMD_{MESA} > 140 μm, VMD_{ANS} > 200 μm) under regular non-breaking waves and the smallest droplets (VMD_{MESA} < 80μm VMD_{ANS} < 120 μm) under plunging breaking waves, with the average VMD more dependent on dispersant and oil type under spilling breaking wave conditions. As oil dispersion progressed, the average VMD declined at a rate dependent on dispersant type and wave conditions. Physical dispersion of both crude oils appears to have required the longest time (100 min) to reach the ultimate stable VMD under regular non-breaking wave conditions and the shortest time (40 min) under plunging breaking wave conditions. Chemical dispersants obviously facilitated better dispersion at lower energy dissipation rates under regular non-breaking and spilling breaking wave conditions. Corexit 9500 reduced the average VMD for both MESA and ANS under all three wave conditions at all four time points (Fig. 12A-C). SPC1000, however, decreased the average VMD markedly under spilling and plunging breaking waves for MESA, but reduced the average VMD even more dramatically under regular wave and spilling breaking waves for ANS. The effect of dispersant was clearly illustrated by the ultimate VMD for each combination of dispersant, wave, and oil: physically dispersed MESA and ANS oil droplets had VMD > 100 μm under all three wave conditions; SPC 1000 dispersed MESA to 150 μm under regular non-breaking waves and less than 70 μm under spilling and plunging breaking wave conditions, but it dispersed ANS crude to around 100 μm under all three wave conditions. Corexit 9500, however, dispersed both MESA and ANS to small sizes (< 70 μm) under all three wave conditions.

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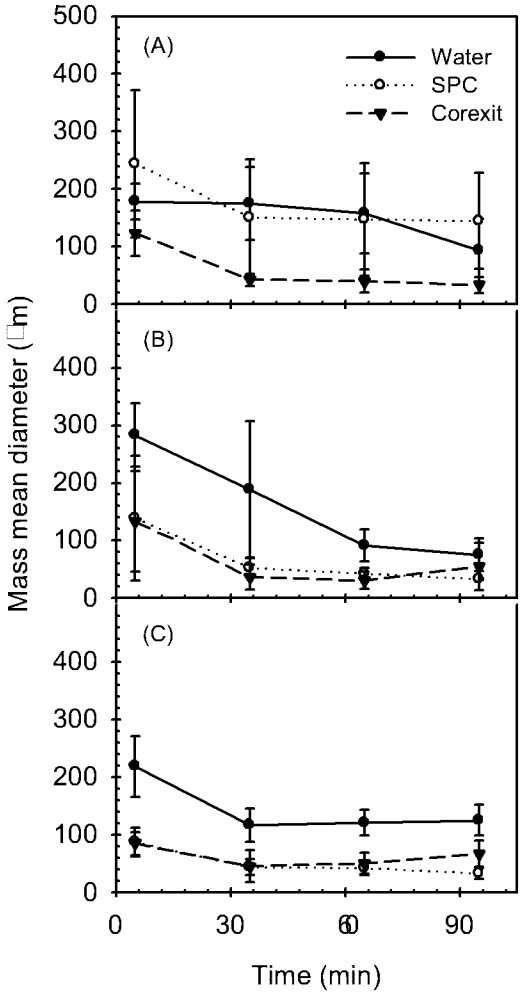

Figure 12: Dispersed MESA oil droplet size (volume mean diameter) as a function of time under: (A) regular non-breaking, (B) spilling breaking, and (C) plunging breaking wave conditions.

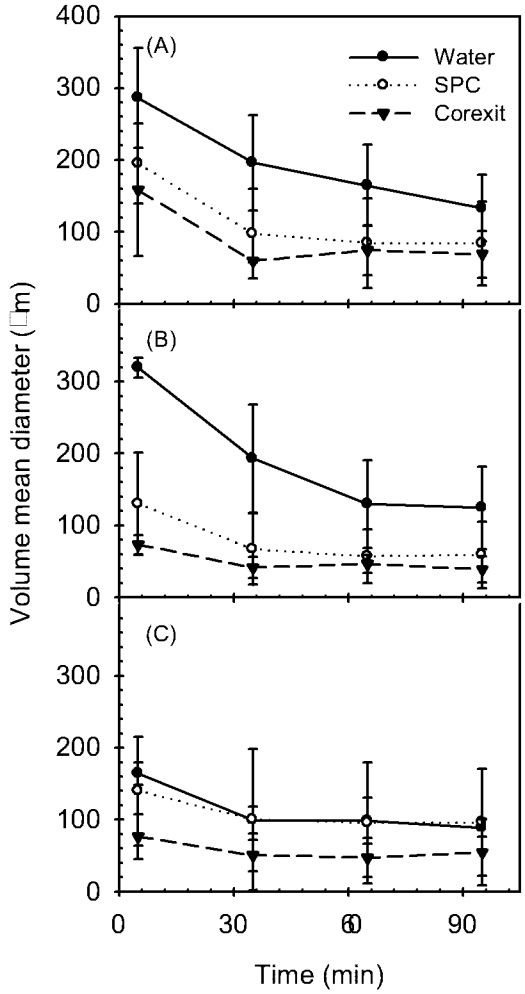

Figure 13: Dispersed ANS oil droplet size (volume mean diameter) as a function of time under: (A) regular non-breaking, (B) spilling breaking, and (C) plunging breaking wave conditions.

A five-way analysis of variance (ANOVA) was performed to test the factorial effects on the average VMD by: (1) wave condition, (2) dispersant type, (3) oil type, (4) dispersion time, and (5) measuring depth. Among these factors, testing of dispersion time allows for the identification of a minimum duration that is required for dispersion of oil into relatively stable average droplet sizes. The effect of water depth was tested to evaluate the spatial variation in the dispersed droplet sizes. The ANOVA results are presented in Table 7. As expected, the high-order interactions (all four- and five-factor and all but one three-factor interactions) are insignificant ($p > 0.25$). There was one significant three-factor interaction (dispersant*oil*wave, $p = 0.000$) and four significant two-factor interactions (depth*time, $p = 0.041$; oil*wave, $p = 0.027$; dispersant*wave, $p = 0.000$; and dispersant*oil, $p = 0.000$), indicating that average dispersed oil droplet size was affected non-uniformly by changes in the interacting variable. Besides the significant multi-factor interactions, three of the five main factors (wave type, dispersant type, and dispersion time, $p < 0.0000001$) were identified to have strong, statistically significant effects on the average dispersed oil droplet sizes. Two other tested main factors did not affect

average droplet sizes significantly: oil (p = 0.917) and sampling depth (p = 0.865). The significant effects of various factors were further compared at each treatment level with the Tukey's paired comparison test. The results are summarized in Table 8. The two dispersants significantly reduced the dispersed oil droplet size, with the average VMD being reduced by 91.5 μm by Corexit 9500 and 36.6 μm by SPC 1000. The plunging wave conditions significantly reduced the average dispersed droplet size by 35.7 μm. The average dispersed oil droplet sizes declined significantly by 42 μm between the first and second dispersion period. The differences in the average dispersed oil droplet sizes after 30 min were statistically insignificant (p > 0.05).

Table 7: Factorial analysis of variance of the effects on the average water column dispersed oil droplet sizes. Statistically significant factors are flagged with *.

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Dispersant	2	915,915	45,7957.5	118.6329	0.0000 *
Oil	1	42	42.0	0.0109	0.9169
Wave	2	185,989	92,994.7	24.0901	0.0000 *
Depth	2	1,124	561.8	0.1455	0.8650
Time	3	338,033	112,677.7	29.1889	0.0000 *
Dispersant:Oil	2	75,480	37,740.2	9.7765	0.0001 *
Dispersant:Wave	4	84,215	21,053.8	5.4539	0.0003 *
Oil:Wave	2	28,265	14,132.4	3.6610	0.0265 *
Dispersant:Depth	4	12,944	3,235.9	0.8383	0.5014
Oil:Depth	2	5,011	2,505.5	0.6491	0.5231
Wave:Depth	4	18,572	4,643.0	1.2028	0.3089
Dispersant:Time	6	47,433	7,905.6	2.0479	0.0582
Oil:Time	3	1,777	592.5	0.1535	0.9274
Wave:Time	6	47,863	7,977.1	2.0665	0.0560
Depth:Time	6	51,246	8,541.0	2.2125	0.0409 *
Dispersant:Oil:Wave	4	306,795	76,698.9	19.8687	0.0000 *
Dispersant:Oil:Depth	4	20,321	5,080.3	1.3160	0.2631
Dispersant:Wave:Depth	8	25,722	3,215.3	0.8329	0.5739
Oil:Wave:Depth	4	10,791	2,697.8	0.6989	0.5931
Dispersant:Oil:Time	6	10,436	1,739.3	0.4506	0.8446
Dispersant:Wave:Time	12	29,459	2,455.0	0.6359	0.8117
Oil:Wave:Time	6	1,642	273.7	0.0709	0.9986
Dispersant:Depth:Time	12	15,634	1,302.8	0.3375	0.9820
Oil:Depth:Time	6	3,360	559.9	0.1450	0.9900
Wave:Depth:Time	12	9,548	795.7	0.2061	0.9982
Dispersant:Oil:Wave:Depth	8	11,042	1,380.3	0.3576	0.9422
Dispersant:Oil:Wave:Time	12	19,691	1,640.9	0.4251	0.9535
Dispersant:Oil:Depth:Time	12	6,975	581.3	0.1506	0.9996
Dispersant:Wave:Depth:Time	24	45,060	1,877.5	0.4864	0.9820
Oil:Wave:Depth:Time	12	17,553	1,462.8	0.3789	0.9707
Dispersant:Oil:Wave:Depth:Time	24	20,595	858.1	0.2223	1.0000
Residuals	432	1,667,645	3,860.3		

Table 8: Tukey's paired comparison of the different effects between treatment levels on the average dispersed oil droplet size in the water column. Significant differences are flagged by * based on 95% simultaneous confidence intervals for specified linear combinations.

Factor	Level mean (µm)	Difference estimates	Standard error	Lower limit	Upper limit
Dispersant	Water 152.9	Corexit-SPC = -54.9 *	5.98	-69.0	-40.9
	Corexit 61.4	Corexit-Water = -91.5 *	5.98	-106.0	-77.4
	SPC 116.3	SPC – Water = -36.6 *	5.98	-50.6	-22.5
Wave	Regular 121.9	Plunger-Regular = -35.7 *	5.98	-49.7	-21.6
	Spiller 122.4	Plunger-Spiller = -36.2 *	5.98	-50.3	-22.2
	Plunger 86.2	Spiller – Regular = 0.566	5.98	-14.6	13.5
Time [a]	P1 148.5	P2 – P1 = -41.9 *	6.9	-59.7	-24.1
	P2 106.6	P3 – P1 = -53.5 *	6.9	-71.3	-35.7
	P3 94.9	P4 – P1 = -57.7 *	6.9	-75.5	-39.9
	P4 90.8	P3 – P2 = -11.7	6.9	-29.5	6.2
		P4 – P2 = -15.8	6.9	-33.6	2.0
		P4 – P3 = -4.13	6.9	-21.9	13.7
Depth	Surface 112.0	Middle-Surface = -3.00	5.98	-17.1	11.1
	Middle 109.0	Bottom-Surface = -2.53	5.98	-16.6	11.5
	Bottom 109.5	Bottom-Middle = 0.47	5.98	-13.6	14.5
Oil	MESA 109.9 ANS 110.4	ANS-MESA = 0.51	4.88	-9.1	10.1

[a] Time factor is expressed as P1, P2, P3, or P4 to denote the first, second, third and fourth half-an-hour of measurement period. Within the same time period, the measurements in the middle and the bottom of the tank are 10 and 20 min later than those at the surface, respectively.

4.3. Chemical dispersant effectiveness testing in the flow-through wave tank

4.3.1 Effects of dispersant and wave conditions on oil dispersion effectiveness

The effectiveness of dispersants under different wave conditions with currents was evaluated by monitoring spatial and temporal oil distribution in the flow-through wave tank. Figures 14 and 15 show the representative dispersed MESA and ANS oil concentrations, respectively, as a function of time in the middle depth (75 cm below the surface) at a location 10 m downstream from the initial slick. The dispersed oil concentration at mid-depth increased rapidly (within 5-10 min) and then decreased steadily due to the dilution effect of the current. The effects of wave

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conditions and dispersants are also clearly evident: dispersants increased oil concentrations several-fold under both regular and breaking wave conditions, with the breaking waves creating much higher oil concentrations than regular non-breaking waves. Similar oil distribution profiles were observed and recorded for the other sampling locations and depths within the test facility, with variability in oil concentrations and the time for the peak oil concentrations to occur (data not shown). To compare the effects of dispersant type and wave conditions on oil dispersion in this dynamic environment, the time-series oil concentrations at each sampling position (horizontal location and depth) were converted to an equivalent oil concentration that had the same flux of oil as the time-dependent oil concentrations over the experimental period (one hour).

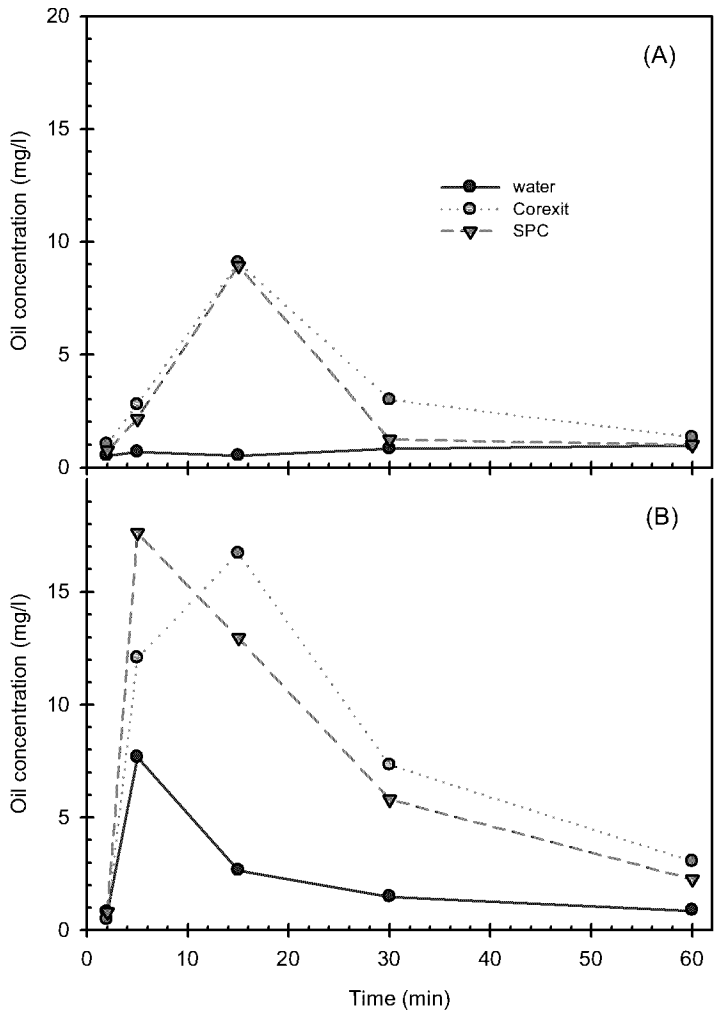

Figure 14: Dispersed MESA oil concentration as a function of time in the middle of the tank 10m downstream under: (A) regular wave, and (B) breaking wave conditions

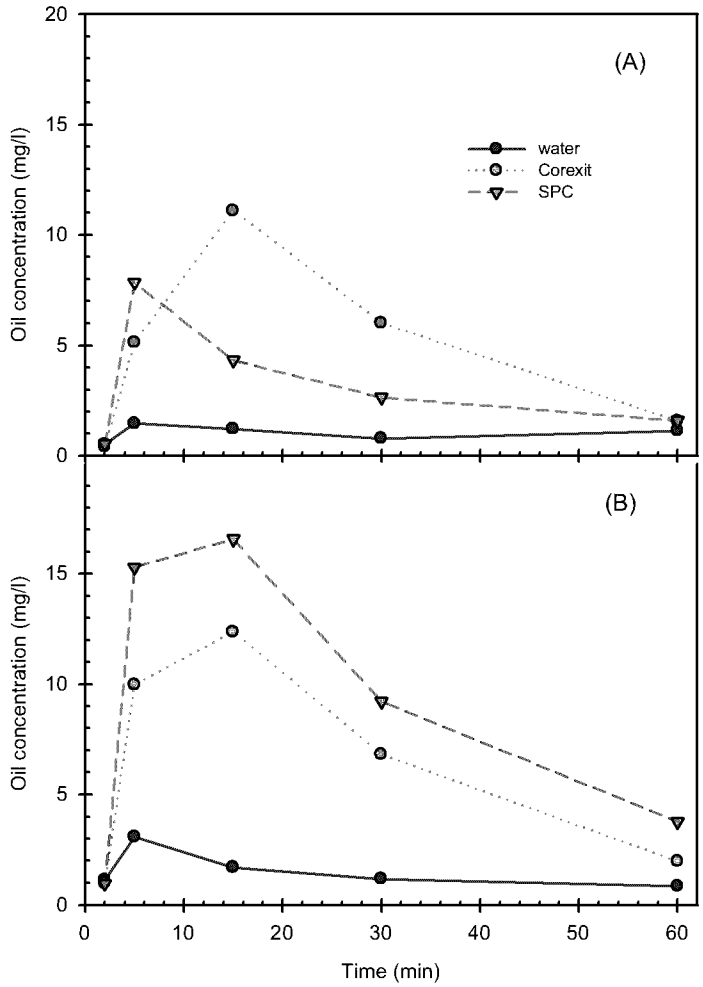

Figure 15: Dispersed ANS oil concentration as a function of time in the middle of the tank 10m downstream under: (A) regular wave, and (B) breaking wave conditions.

Figures 16 to 18 summarize the equivalent oil concentration at different horizontal locations and depths. The upstream (2m from the oil addition) location had consistently low oil (MESA or ANS) concentrations (about 1 mg/l) at all three depths for all dispersant types and wave conditions (Figures 16-18, A), where the effects of wave conditions and dispersants were insignificant for the dispersed oil concentrations ($p > 0.05$). Low oil concentrations (about 1 to 2 mg/l) were also observed at the bottom of the wave tank at three downstream locations (Figure 18, B-D), and the effects of wave conditions and dispersant type on oil concentrations at these spots were also insignificant ($p > 0.05$). The insignificant effects of dispersant type and wave conditions were likely due to the strong current flow, which counteracted turbulent diffusion of oil, resulting in lower water column oil concentrations at all depths upstream and the bottom of the downstream locations.

Dramatic effects of dispersants on oil distribution are evident from oil concentrations at the

surface and in the middle of the wave tank at the downstream locations (Figures 16C-16D and 17C-17D). Dispersants significantly ($p < 0.05$) increased oil concentration in the middle of the wave tank (Figure 17C-17D), indicating that dispersants enhanced penetration of oil into the water column. Dispersants also increased ($p = 0.05$) the surface oil concentration at 6m downstream location (Figure 16C), indicating that dispersants stimulated horizontal spreading of oil. These effects are observed under both regular non-breaking and breaking wave conditions, but the extent appeared stronger under breaking waves. This is consistent with the batch system wave tank experimental results, showing that Corexit 9500 was effective in low, moderate and higher energy conditions, whereas SPC 1000 worked better in moderate and higher energy conditions (Venosa et al. 2008). Although the effectiveness of the two dispersants was significantly different in the batch system, the difference was insignificant ($p > 0.05$) in the flow-through system (Figures 16 to 18). This may be due to the fast dilution of dispersed oil in the flow-through system to prevent re-coalescence of the dispersed oil droplets, particularly for the water-soluble dispersant SPC 1000.

The effect of wave conditions on oil distribution is clearly demonstrated by the measured oil concentrations at the surface of the 10 m downstream location (Figure 16D). The measured oil concentrations under regular waves were substantially higher than under plunging breaking wave conditions, indicating that breaking waves are more effective in transferring oil from the surface deeper into the water column. The effect of breaking waves is related to a series of contributing factors. During the breaking of waves, it has been estimated that 30% to 50% of the dissipated wave energy entrains the oil droplets in the water column (Lamarre and Melville 1991; Tkalich and Chan 2002). This energy determines the first-order oil entrainment rate (Tkalich and Chan 2002). Breaking waves develop a mixing layer in the upper part of the water column, and the penetration of oil results in a uniform mixing of the droplets, with the mixing layer proportional to the height of breaking waves (Delvigne and Sweeney 1988; Tkalich and Chan 2002). Moreover, breaking waves generate micro-scale turbulence with the smallest eddies that have the greatest velocity gradients, resulting in deformation, elongation and eventually breakup of larger droplets (Delvigne et al. 1987; Li and Garrett 1998).

When the oil slick was dispersed into small droplets and conveyed into the water column, the plume was consequently carried away from the mixing zone through current movement and dilution in the water column. In the field, the dispersed oil droplets are eventually removed via accelerated biodegradation and other routes of natural attenuation. The rapid dilution of oil from the central mixing zone is desired for minimizing exposure of pelagic species, for their biological effects from exposure to petroleum hydrocarbon compounds are proportional to the intensity and the duration of exposure time. The effects of dispersants and wave conditions on the dynamic dispersion effectiveness (DDE) of the dispersed oil within the experimental duration can be evaluated by computing the fraction of dispersed oil flowing out of the wave tank with the effluent current plume and the residual dispersed oil in the water column of the water tank at the end of each experiment. In this regard, the flow-through wave tank can be viewed as a vessel in which mixing by the surface regular non-breaking waves or irregular breaking waves is coexistent with the plug flow of the uniform currents. Mixing by waves caused the deviation of the flow pattern from an ideal plug flow of currents.

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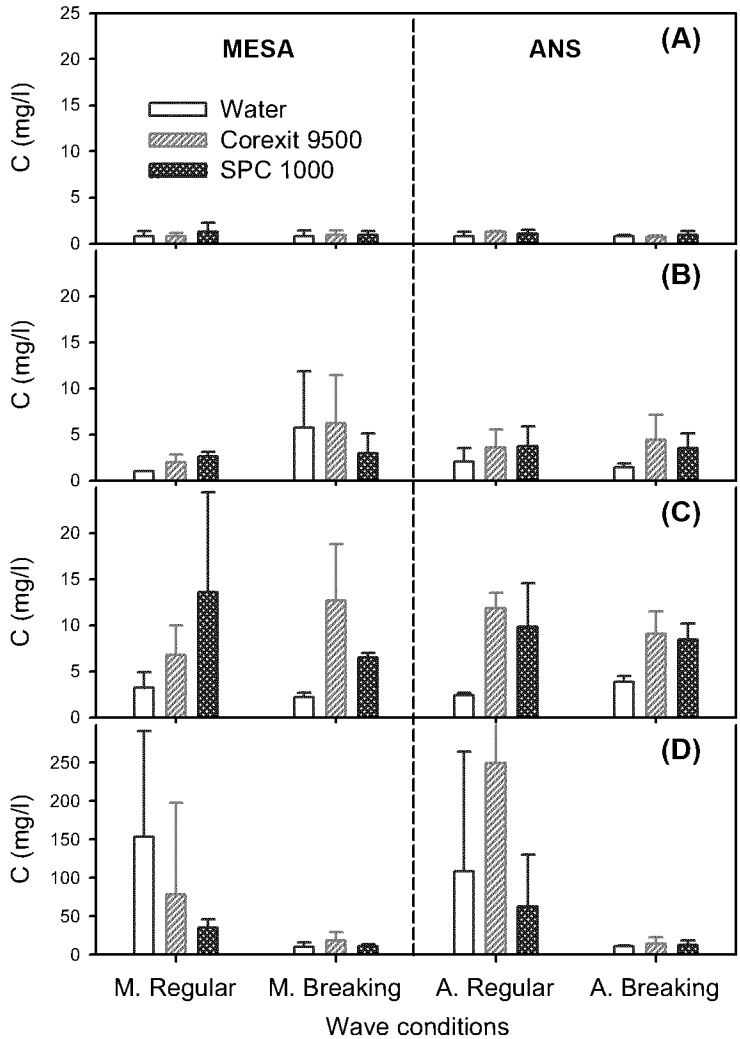

Figure 16: Equivalent dispersed oil concentrations at the surface of the wave tank at four different horizontal locations for the two tested crude oils: (A) 2m upstream; (B) 2 m; (C) 6 m; and (D) 10 m downstream. Note the different Y-axis scale for (D).

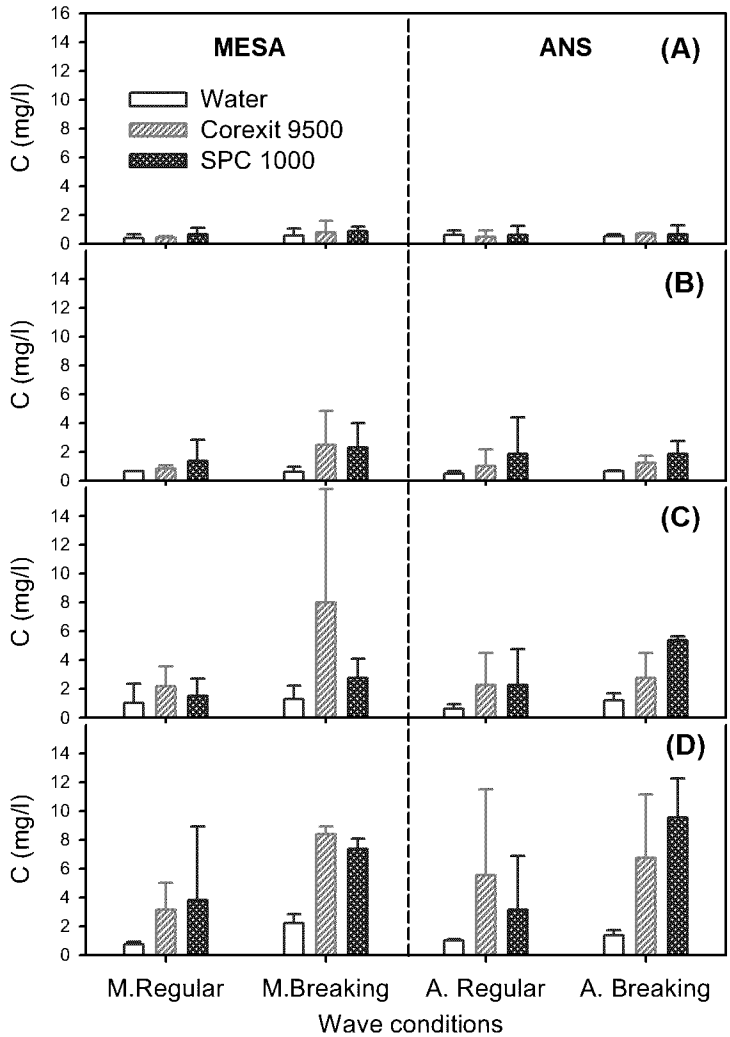

Figure 17: Equivalent dispersed oil concentrations in the middle of the wave tank at four different horizontal locations for the two tested crude oils: (A) 2m upstream; (B) 2 m downstream; (C) 6 m downstream; and (D) 10 m downstream.

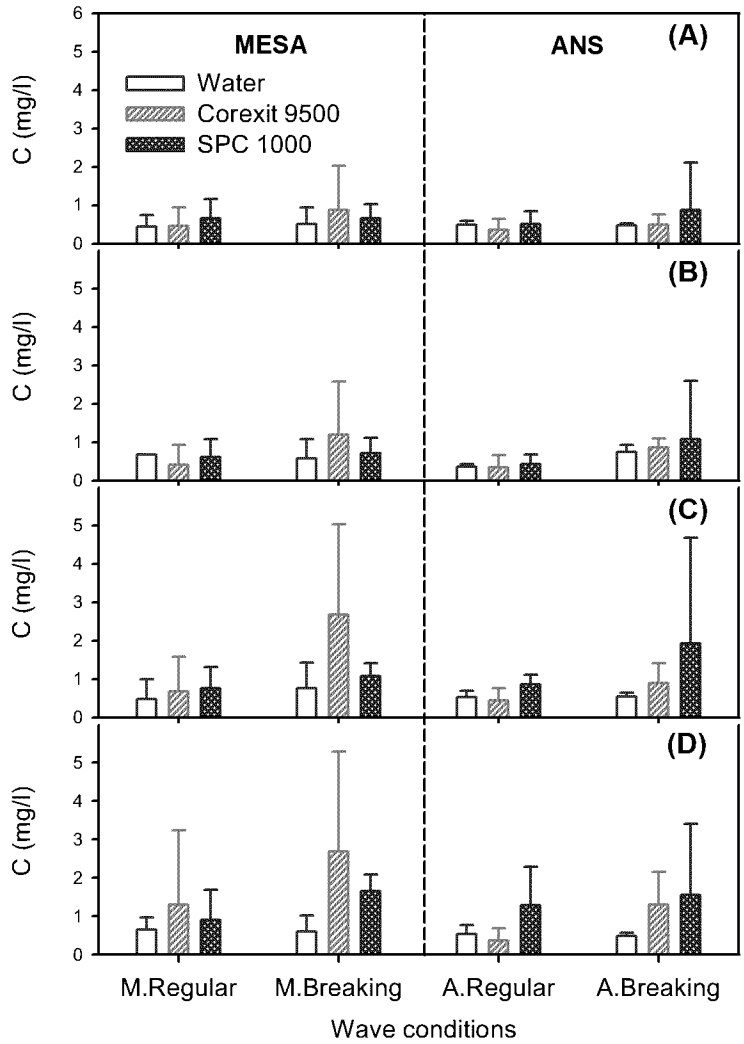

Figure 18: Equivalent dispersed oil concentrations at the bottom of the wave tank at four different horizontal locations for the two tested crude oils: (A) 2m upstream; (B) 2 m downstream; (C) 6 m downstream; and (D) 10 m downstream.

Figure 19 presents the estimated DDE of the MESA and ANS oils as a result of physical and chemical dispersion under the two wave conditions. For physical dispersion of MESA (Fig. 19A) under regular wave conditions, the DDE in the water column was 8% under regular waves but increased to 19% under breaking waves. The application of Corexit 9500 or SPC 1000 increased the DDE to 22% and 30% respectively under regular wave conditions. The combination of chemical dispersants and breaking wave conditions increased DDE to more than 56% and 46%, respectively, with Corexit 9500 and SPC 1000. Statistical ANOVA indicated both chemical dispersants ($p = 0.02$) and breaking waves ($p = 0.01$) significantly increased the DDE of MESA dispersion, but there was no significant difference between Corexit 9500 and SPC 1000 ($p = 0.96$). Similarly, dispersants ($p = 0.02$) significantly increased the DDE of ANS in the water

column (Fig. 19B) but no significant difference was found between Corexit 9500 and SPC 1000 ($p = 0.76$). Physical dispersion of ANS under regular wave and breaking wave conditions resulted in DDE in the water column to be 10% and 12%, respectively. Chemical dispersion by Corexit 9500 significantly increased DDE to 36% under regular wave conditions, and to 42% under breaking wave conditions. Dispersion by SPC 1000 increased the DDE to 25% under regular wave conditions and to 62% under plunging breaking wave conditions. Although breaking wave conditions were always associated with higher DDE of ANS, ANOVA indicated that the wave effect was insignificant ($p = 0.13$), due primarily to the relatively large error bars of triplicate runs but could also be attributed to the higher dispersibility of fresh ANS versus weathered MESA crude oil. The inhibition of dispersant effectiveness by increased weathering status of crude oil was reported in many studies (Chandrasekar et al. 2005; Moles et al. 2002; Nordvik 1995; White et al. 2002).

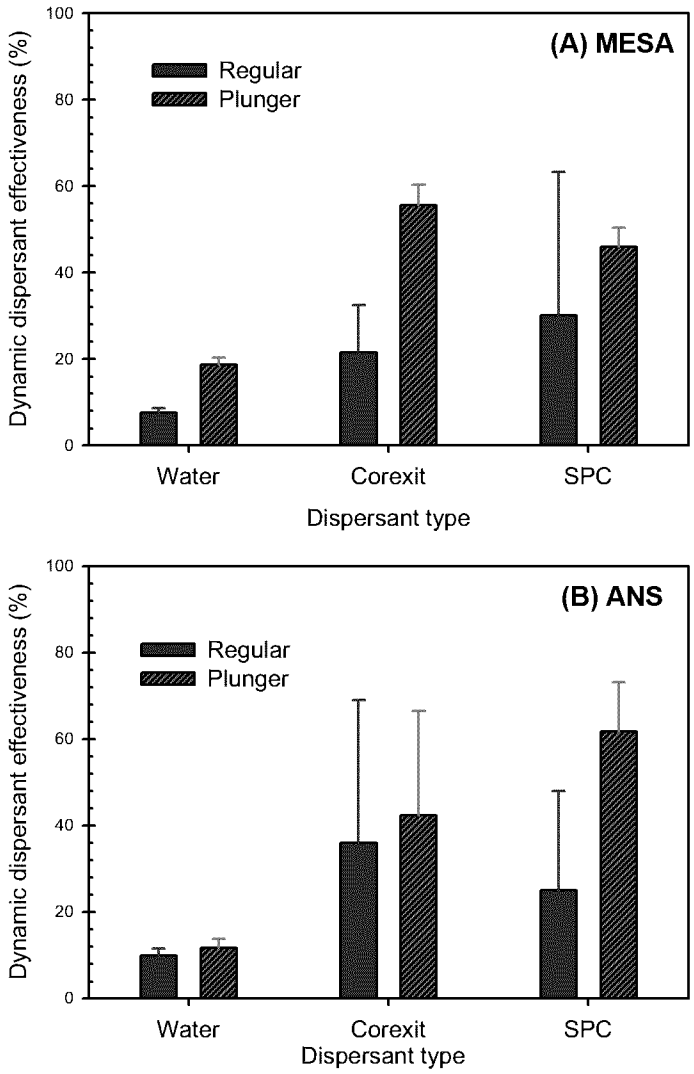

Figure 19: Dispersant effectiveness as a function wave conditions on: (A) MESA; (B) ANS. Data shown are average with one standard deviation of three independent replicate runs.

4.3.2 Effects of dispersant and wave conditions on droplet size distribution

Dispersant effectiveness is ultimately determined by the dispersed oil droplet size distribution (Darling et al. 1990; Lewis et al. 1985). Small droplets with sizes of tens of microns have small rise speeds and tend to remain suspended in the water column and become widely dispersed in the water column by turbulent diffusion and can be potentially removed more rapidly by biodegradation (Li and Garrett 1998). Conversely, large oil drops with radii of hundreds of microns tend to re-coalesce and resurface unless very strong mixing energy exists to overcome their buoyancy. Therefore, smaller droplets are much more favorable from the prospective of oil spill mitigation. Laboratory and field measurements suggest that for an effective dispersion of oil in which the dispersed oil droplets remain suspended in the water column, average droplet sizes have to be less than 50 to 70 um (Lunel 1993; Lunel 1995).

In this work, the dispersed oil droplet size distribution was measured by a laser particle counter (LISST-100X) that was suspended in the water column at the end of the flow through wave tank. The dispersed oil droplet size distribution was recorded continuously as a function of time in real-time mode. The recorded size distribution at each snapshot was in the mono-modal logarithmic normal distribution for the physically dispersed oil and multi-modal log-normal distribution for the chemically dispersed oil (data not shown). These oil distribution patterns are consistent with the dispersed particle size distributions that were observed in the batch system wave tank experiments on chemical dispersant effectiveness testing (Li et al. 2008b). To compare the effects of wave conditions and dispersant type on the average dispersed oil droplet size distribution in the water column, we calculated the volumetric mean diameter (VMD) of the dispersed oil.

Figures 20 and 21 summarize the effect of dispersant type and wave energy on the average dispersed oil droplet VMD for MESA and ANS, respectively. The droplets started at the same VMD level regardless of dispersant and wave conditions. In the absence of chemical dispersant (Fig. 20A, 21A), the oil droplet sizes remained large and highly variable (VMD ~ 150-400 μm) under the regular wave condition, but were rapidly reduced in size and variability (VMD ~ 150-200 μm) under breaking wave conditions. In the presence of chemical dispersant Corexit 9500 (Fig. 20B, 21B), the dispersed oil droplet sizes remained large but considerably reduced in variability (VMD ~300 μm) under regular wave conditions; these sizes were dramatically reduced (VMD ~50 μm) under breaking wave conditions within 10 min, and maintained at this small size for the rest of the experiment. SPC 1000 rapidly dispersed oil droplets (VMD of approximately 75-100-μm) under both regular and breaking wave conditions (Fig. 20C, 21C). The sizes persisted or slightly increased afterwards under regular wave conditions, probably due to re-coalescence and resurfacing after the depletion of water soluble SPC 1000 surfactants by current flow over time. Depletion of surfactants with prolonged mixing of oil in water emulsion stabilized by surfactants was reported in mixing tank system (Sanchez et al. 2001). However, the VMD continually decreased to about 50 μm under breaking wave conditions due to the high energy dissipation rate and turbulent diffusion.

The average size of the physically and chemically dispersed oil agree well with the results of our previous batch experimental studies (Li et al. 2008a; Li et al. 2008b) and those of the literature (Byford et al. 1984; Darling et al. 1990; Lunel 1995). The introduction of current in the flow-

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through wave tank, however, did not further reduce oil droplet size from what had been observed in the batch system (Li et al. 2008b). This can be attributed to the similarity of micro-scale turbulence, particularly energy dissipation rates measured during the hydrodynamic characterization of the batch system (Wickley-Olsen et al. 2008) and the flow-through system (unpublished data). The flow pattern, however, was clearly different when the wave tank was changed from the batch to the flow-through mode. In particular, the backflow near the bottom of the wave tank in the batch system was overcome by the forward current in the flow-through system, which purged the smaller dispersed oil droplets that were suspended in the water column out of the wave tank. This reduced the inter-drop collision frequency that would cause re-coalescence and resurfacing of the smaller dispersed oil droplets, while retaining the larger oil droplets floating at the surface to maintain high drop-eddy collision frequency for the breakage of droplets into small particles (Tsouris and Tavlarides 1994). Under breaking waves, however, although the larger droplets surfaced, they were continually broken into smaller droplets because of the high energy dissipation rate, and therefore these droplets were eventually purged downstream.

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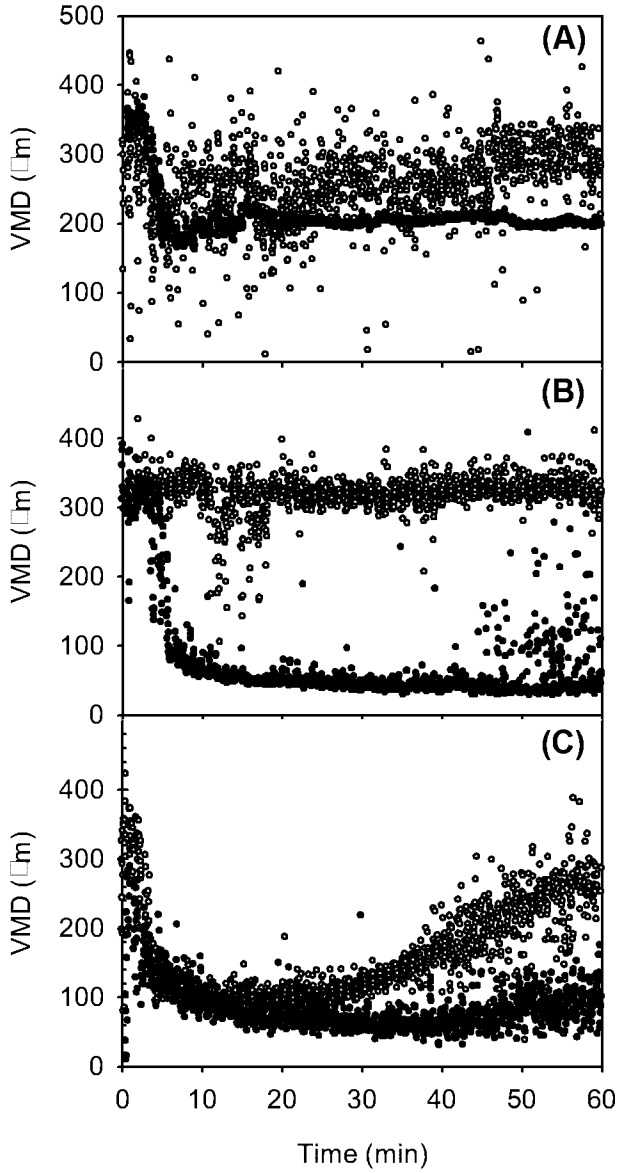

Figure 20: Effect of dispersant type [(A) water; (B) Corexit 9500; and (C) SPC 1000] and wave conditions [regular (open circles) and breaking (solid dots)] on average dispersed MESA oil droplet size.

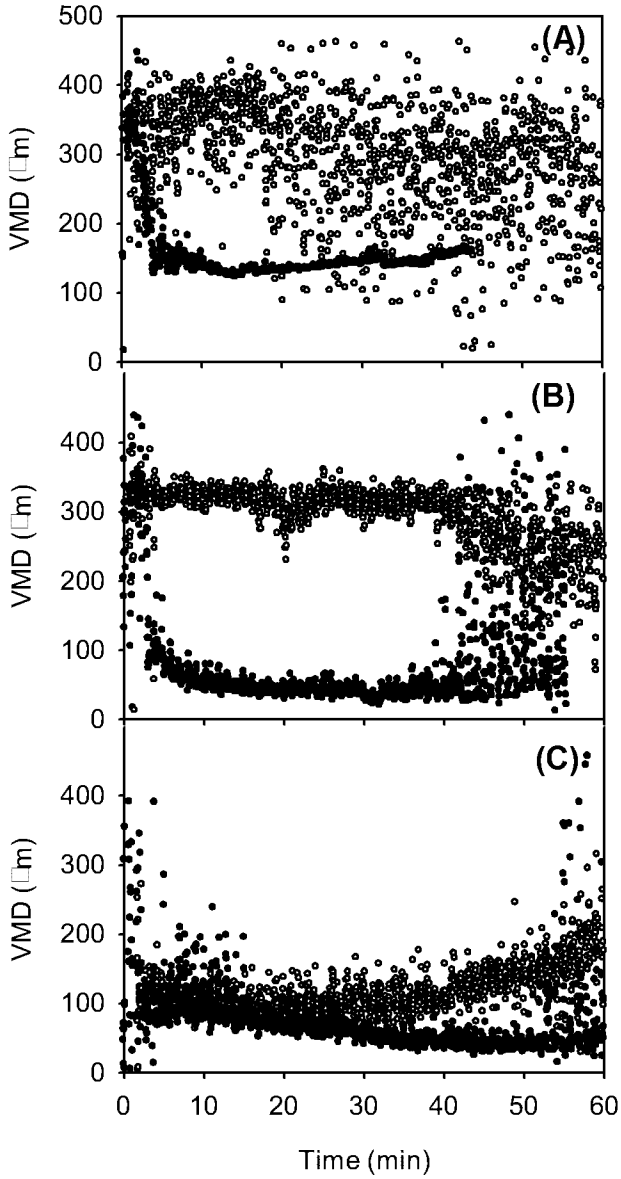

Figure 21: Effect of dispersant type [(A) water; (B) Corexit 9500; and (C) SPC 1000] and wave conditions [regular (open circles) and breaking (solid dots)] on average dispersed ANS oil droplet size.

4.4. In-Situ multiple simultaneous scattering and fluorescence sensor

To overcome the disadvantages of current Special Monitoring of Applied Response Technologies (SMART) such as single wavelength, pump and detection system requirements, large power source requirements, analog readout, limited depth (4m) and outdated software, a novel Wet Labs Environmental Characterization Optics (ECO) triplet sensor (Figure 22) was developed. This device has a suite of advantages, including:

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- Small footprint battery
- Performs free space measurement and requires no pump, small footprint, internal battery
- Accommodates a variety of deployment options
- Two (2) fluorescence sensors & one (1) scattering light sensor
- Can operate at depths to 600m
- PC-compatible software package

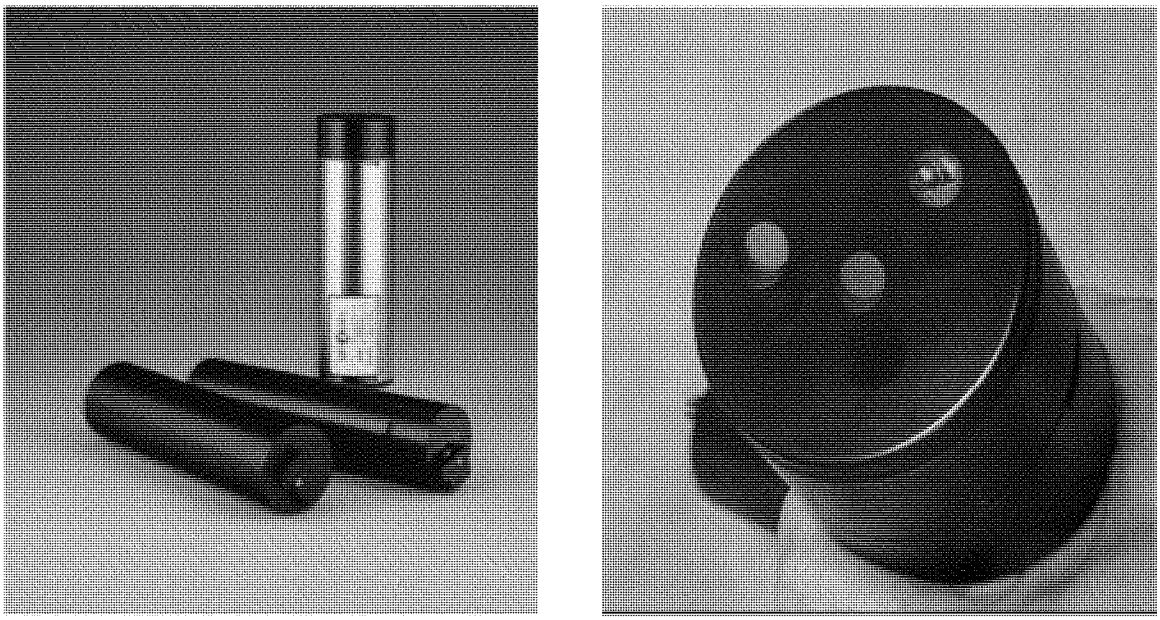

Figure 22: Wet Labs Environmental Characterization Optics (ECO) triplet sensor.

Fluorescence is a property of some materials in which light is absorbed at specific wavelengths and subsequently emitted at a longer wavelength. The excitation wavelength is the characteristic wavelength that results in an emission of light. WET Labs has pioneered the use of Light Emitting Diodes (LEDs) in fluorometers. Fluorescence Wavelength: Chlorophyll EX/EM 470/695 nm; CDOM EX/EM 370/460 nm. The volume scattering function (VSF) describes the directional dependence of this scattering. The VSF of particles depends on their size, shape, and internal index of refraction distribution. It has been determined that the backscattering coefficient is proportional to the light scattering at 117 degrees. Estimate of total turbidity Scattering Wavelength: 660 nm.

Weathered Alaskan North Slope crude oil was dispersed at various concentrations and monitored using the Wet Labs Environmental Characterization Optics (ECO) Triplet Sensor. Observation of potential interferences and instrument operational ranges were investigated in a modified standard jar test (40L). Oil was dispersed using a variable-speed (20-200 rpm) Lightnin® Mixer with a stainless steel mixing impeller. Wet Labs ECO 3 Triplet mounted directly in the reactor, at Scattering Wavelength: 660 nm; Fluorescence Wavelength: Chlorophyll EX/EM 470/695 nm, CDOM EX/EM 370/460 nm. Corexit ® 9500 was pre-mixed with the oil and applied at 20:1 ratio (v/v) using synthetic seawater (Instant Ocean) at 32ppt at 20ºC and the TPH oil concentrations of 3000, 5000, 12000, 22000, 48000, and 70000 ppb by adding specific amounts of stock solution to the reactor. The mixer was operated at 50-75 rpm (to reduce air bubbles). A

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sampling frequency of one reading per second was selected. The system was allowed to equilibrate for five minutes, and the raw count data from ECO 3 Triplet were collected using Windows Hyper-terminal software at each concentration at three separate events.

The results indicated that CDOM fluorescence was linear over the entire TPH concentration range (3,000-70,000 ug/L, R^2=0.9896). Chlorophyll fluorescence linearity covered a narrow TPH concentration range (3,000-20,000 ug/L, R^2=0.9686). Backscattering (660 nm) was linear over the entire TPH concentration range (3,000-70,000 ug/L, R^2=0.9654). CDOM fluorescence and backscattering (660 nm) proved to be most effective over broad concentration range. Results also showed good correlation between fluorescence and GC-MS (TPH) values, indicating that the unit is a useful tool for measuring chemically dispersed oil in nearshore marine environments. The in-situ fluorometer is capable of accurate detection of oil plumes in natural environments, and its ease of use (i.e. solid state, no field calibration) and simplified and fast deployment is a benefit to spill response community.

5.0 Discussion and Importance to Oil Spill Response/Restoration

The data presented here have demonstrated the significant effects of dispersant type, wave type and dispersion time on chemical dispersant effectiveness. Testing chemical dispersant effectiveness in wave tanks must have a careful control of hydrodynamic conditions, oil type and dispersion time to ensure the results are comparable. These quantitative data also suggest that interpretation of laboratory and wave tank chemical dispersant effectiveness testing data in the field must consider field operational conditions and environmental factors. This study demonstrated the quantitative relationship between chemical dispersant effectiveness and energy dissipation rate when the effects of two dispersants on two crude oils were evaluated under three different wave conditions in an experimental wave tank. The mixing energies of these wave conditions were close to those encountered in the field when oil spills are treated with chemical dispersants. The data reported here support the importance of breaking wave conditions in facilitating chemical dispersant effectiveness (Delvigne and Sweeney 1988; Li et al. 2008a; Nilson et al. 1985; Shaw 2003; Tkalich and Chan 2002). The oil-based dispersant, Corexit 9500, was more effective than the water-soluble dispersant, SPC 1000, in dispersing the two crude oils under all three wave types and energy levels. More studies are needed to evaluate dilution effects on the performance of these dispersants. These results together with the oil droplet size distribution data (Li et al. 2008b) will be used in developing better operational guidelines (document in preparation by Lee and Merlin for IMO) for dispersant use and improved predictive models of dispersant effectiveness for the field.

In-situ dispersed oil droplet size distribution is governed by a number of factors, including mixing energy, dispersant application and dispersant type, oil type and weathering status, and seawater temperature and salinity. Among these factors, breaking waves have been documented to play a crucial role in dispersion of oil slicks by generating velocity shear to break up and transport oil in turbulent flow (Li and Garrett 1998; Shaw 2003; Tkalich and Chan 2002). The effects of mixing energy on dispersed oil droplet size distributions and consequently dispersant effectiveness have been reported in laboratory tests (Byford et al. 1984; Chandrasekar et al. 2005; Lewis et al. 1985; Ma et al. 2008; Sorial et al. 2004a) and in field trials under low and high

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energy regimes caused by various wind effects (Lunel 1993; Lunel 1995). In this study, the effect of wave-generated mixing energy on the dispersed oil droplet size distribution was examined under three wave conditions with different energy dissipation rates. The average energy dissipation rates were estimated to be approximately 0.005, 0.1, and 1 $W \cdot kg^{-1}$ near the surface at the mixing zone for regular non-breaking waves, spilling breaking waves and plunging breaking waves, respectively. The energy dissipation rates declined exponentially to approximately 0.001 $W \cdot kg^{-1}$ for the two breaking wave conditions at a depth of 30 cm and decreased linearly under regular non-breaking wave conditions (Wickley-Olsen et al. 2008). The energy dissipation rate of plunging breaking waves was similar to those measured for breaking waves in the field (Delvigne and Sweeney 1988; Drennan et al. 1996; Terray et al. 1996). Regular non-breaking wave energy was also similar to that reported on the sea surface by Delvigne and Sweeney (1988), and the energy level of spilling breakers was in between. These wave conditions were identified to have significant effects on the droplet size distributions and average droplet size. As a result, dispersant effectiveness for different oil and chemical dispersant combinations was found to be directly correlated to the energy dissipation rate of the three different wave conditions. Even in the absence of dispersants, physical dispersion under plunging breaking wave conditions over an extended period of time generated a large amount of oil droplets suspended in the water column, leading to physical dispersion efficacy of MESA and ANS crude to be approximately 20%. Correspondingly, the observed median droplet size was about 48 μm and more than 90% oil droplets were < 70 μm, a size which Lunel (1995) suggested would remain permanently dispersed in the water column at sea.

The data presented here demonstrated that the application of chemical dispersants substantially altered the dispersed oil droplet size distributions in the wave tank by creating wider range multi-modal size distributions including a large number of small droplets < 10 □m in diameter and significantly reduced the average VMD. Dispersants tested in our system also significantly stimulated the initial oil break up kinetic rate and extent. The influence of chemical dispersants in increasing the number of small droplets in the water column was reported in laboratory tests (Byford et al. 1984; Jasper et al. 1978; Lewis et al. 1985) and field trials (Lunel 1993; Lunel 1995). Jasper et al. (1978) observed that the VMD of dispersed oil was reduced by 30-40% by the presence of a chemical dispersant. Lunel (1995) reported that dispersants increased the number of small droplets (<50 μm) by 5- to 30-fold in a sea trial, but the number of larger droplets (>50 μm) between the dispersant-treated and untreated oil were the same.

A significant difference in the average dispersed droplet sizes was identified between the two tested chemical dispersants, Corexit 9500, an oil-based chemical dispersant, and SPC 1000, a water-based dispersant. The apparent superiority of the oil-based dispersant is probably due to its stronger affiliation with oil in the course of oil dispersion, whereas the water-based dispersant tends to be washed away from the surface of oil droplets over a longer period of time, resulting in re-coalescence and resurfacing of the dispersed oil droplets in less vigorously mixed areas. The rearrangement of surfactant-stabilized oil-in-water emulsions has been reported and was explained as a result of the development of a surfactant depletion-flocculation process (Sanchez et al. 2001).

The significant factors affecting average VMD are in good agreement with those having significant effects on DE that has been evaluated by measurement of the dispersed oil

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concentration in the water column. For instance, the effects of Corexit 9500 and SPC 1000 on reducing the average VMD from 153 to 61 (or by 92) and 116 (or by 37) μm, respectively, were correspondingly correlated with their significant effects on increasing the DE by 48% and 26%, respectively. The significant effect of the plunging breaking wave conditions on reducing the average VMD from 122 to 86 (or by 36) μm matched the significant effect of increasing the DE by 25%. In addition, dispersion time was found to significantly decrease the average VMD from 148 to 106 (or by 42) μm and increase the DE by 18% during the first 30 min of dispersion. Such good correlation can be explained by the enhanced DE by dispersants and breaking waves through increasing the fraction of droplets that are more "permanently" dispersed (e.g., < 70 μm) in the water column. While reduction of oil-water interfacial tension by chemical dispersants allows for turbulent shears to form droplets on the order of 10 □m, the plunging breaking waves are associated with elevated energy dissipation rates and a lower Kolmogorov scale that reduces the droplet sizes.

Not surprisingly, oil dispersion time is a significant factor in dispersion of crude oils in the wave tank. Initial breakup kinetic rates suggested that the presence of dispersants clearly accelerated the breakup process (Table 4). As a result, chemical dispersion broke up oil into relatively stable droplet size distributions within a short period (~ 30 min), whereas physical dispersion took much longer to reach the ultimate droplet size distributions (Figures 9-13, Tables 6-8). The length of time required to disperse oil into relatively stable droplet size distributions, either in the presence or absence chemical dispersants, is dependent on the system hydrodynamics, especially the intensity and frequency of occurrence of breaking waves. A previous wave tank study conducted with less frequently occurring plunging breaking waves with lower wave energies (Li et al. 2008a) showed that active breakup of oil into smaller droplets continued beyond one hour.

Understanding *in-situ* dispersed oil droplet size distribution has significant implications in optimizing DE testing protocols in systems ranging from small-scale laboratory testing apparatuses to large-scale field trials. Clearly, due to the limitation of the scales, it would be unrealistic to extrapolate the observed droplet size distribution from a bench-scale testing apparatus to the field. To maintain the amount of oil and dispersant that can be precisely measured during standardized laboratory operations, the oil-to-water ratio would have to be much higher than what would be expected in the field, leading to higher oil loading and arbitrarily increased likelihood of re-coalescence and resurfacing of physically and/or chemically dispersed oil droplets (Fingas 2005; Fingas et al. 2002). Wave tank testing of chemical dispersant effectiveness significantly improved development of a testing protocol in regard to more realistic wave-generated mixing energy, which is scalable to the field given careful hydrodynamic characterization. In addition, the oil-to-water ratio is similar to that encountered in the field, resulting in a dispersed phase loading lower than the threshold concentration by which significant re-coalescence of small oil droplets may occur.

From an oil spill response operational point of view, formation of small oil droplets is favorable for mitigation of oil spills on water. The generation of a large number of small dispersed oil droplets is a clear indication of highly effective oil dispersion (Lunel 1993; Lunel 1995). Oil droplets with radii of tens of □m tend to gain sufficient energy to overcome the buoyancy and therefore penetrate deeper into the water column, spread more rapidly (Basheva et al. 1999), and are subject to accelerated biodegradation due to the increased oil-water interfacial area where

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most of the microbial oil degradation occurs (Macnaughton et al. 2003; Swannell and Daniel 1999). However, chemical dispersion of oil into smaller droplets may also be more effective at increasing exposure of pelagic and benthic species to chronically toxic concentrations of polycyclic aromatic hydrocarbon compounds (Couillard et al. 2005; Ramachandran et al. 2004). Further research is warranted to evaluate the environmental and ecological risks of using chemical dispersants as an oil spill response at sea, particularly chronic and sublethal impacts of dispersants and chemically dispersed oil on sensitive species.

The effectiveness of two chemical dispersants in dispersing crude oil into the water column as a function of low and high energy waves within an experimental wave tank operated under dynamic flow-through conditions was also evaluated in this study. The data presented demonstrated that the presence of a chemical dispersant under moderately high wave energy conditions significantly increased oil concentration in the water column, reduced dispersed oil droplet size distribution, and accelerated dilution rate of the dispersed oil facilitated by current activity. While breaking wave conditions contribute to the breakup of oil into small droplets due to high energy dissipation rates and enhanced droplet-eddy collision frequency, dispersants may increase the oil breakage efficiency under both regular and breaking wave conditions. We observed initial breakup of the oil slick into small droplets, penetration of the droplets into the water column, and the consequent dilution effect of the current flow during the quantification of dynamic dispersant effectiveness in the water column of the flow-through wave tank. Therefore, the concept of dynamic dispersant effectiveness (DDE) reported here reflects both dispersion of oil into water column and transport and dilution of the dispersed oil droplets through the water column. The DDE reported here might be different from the dispersant effectiveness (DE) obtained in bench-scale jar tests where only the contact efficiency between oil and dispersants is measured in small enclosed surroundings and unlimited collision frequency between oil droplets and eddies may occur, or batch wave tank tests where recirculation of the flow and dispersed oil droplets less rigorous mixing zone may induce re-coalescence and resurfacing of the dispersed oil droplets. Indeed, evaluating the dispersant effectiveness under dynamic flow-through conditions provides a more realistic setting that may be encountered in the field. The established experimental protocol under flow-through conditions in this study will prove useful for evaluating dispersant effectiveness of different chemical dispersant formulations for different oil types under specified wave energy conditions. The obtained data of dispersant effectiveness and particle size distribution as a function of energy dissipation rate provide useful information for developing better operational guidelines for dispersant use and improved predictive models on dispersant effectiveness in the field. The flow-through wave tank system can also be used to conduct environmentally relevant exposure studies on the toxicity of dispersed oil on sensitive marine species.

In summary, the data presented herein clearly demonstrate the importance of the presence of a chemical dispersant in driving surface oil into the water column. The following conclusions of this research will have practical importance to the oil spill response community:

- Dispersant use in deep water environments under moderately energetic wave conditions is a promising countermeasure technology for driving floating oil into the water column and away from water fowl exposure.
- Natural dispersion of oil from the surface into the water column occurs much more readily at high energy dissipation rates compared to low energy dissipation rates. Regular, non-

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breaking waves primarily move the oil downstream and the oil remains on the surface of the water.

- Chemical dispersant Corexit 9500 has been shown to be effective in all low, moderate and high energy conditions, whereas SPC 1000 can also be very useful in moderate to high energy conditions. The physical and chemical characteristics of the two dispersants (including surfactant and solvent) may explain the differences between these two dispersants (Corexit 9500 is oil-soluble, whereas SPC 1000 is water-soluble). More basic research is needed to gain a better understanding of the differences in performance.
- Efficacy of oil dispersion in forming small droplets is dependent on wave energy and the presence of a chemical dispersant. If either of those two factors is missing, dispersion can only take place in very high energy sea states.
- Even under high energy breaking wave conditions, use of chemical dispersants drastically reduces the length of time required for thorough dispersion of oil into small oil droplets in the water column, in comparison to natural dispersion by the action of breaking waves alone.
- When the window of opportunity for oil spill response operation is narrow, such as in the event of fast approaching oil patches and/or plumes that pose an imminent threat to shorelines and other sensitive ecosystems, rapid response with chemical dispersants may be deemed necessary even under high energy conditions because of the way in which they accelerate the dispersion of oil into the water column and therefore facilitate faster removal of oil via biodegradation.

6.0 Technology Transfer and Communications

Numerous scientific presentations were made at workshops and conferences attended by members of the oils spill response industry, scientists, academics and environmental regulators. In addition to future in-house applications, the data from this research is being transferred to other research groups involved in the development of predictive numerical models on oil dispersant efficacy. The overall goal of the project is improvement of operational guidelines. In this regard, one of the project PIs (Dr. Kenneth Lee) has agreed to co-chair an international workshop with Francois Merlin (Cedre, France) under the auspices of the International Maritime Organization (IMO) to revise its Operational Guideline for Oil Dispersant Use that is used by the oil spill response community on a global scale.

Furthermore, now that we have validated the application of the wave tank system for studies on oil dispersants, we have created demand for its use in future studies. This includes its use in studies by industry to evaluate the effectiveness of oil dispersants on specific waxy-crude oils found on the Grand Banks of Newfoundland, studies to understand the processes controlling oil-mineral aggregate (OMA) formation funded by MMS, and studies on the toxicity of chemical oil dispersants and oil on various age classes of fish including herring, salmon and cod funded by PWSRCAC and PERD.

This project has supported the development of instrumentation by Drs. P. Kepkay and M.S. Miles for in situ quantification and characterization of oil dispersed in seawater using fluorescence signatures. In particular, Dr. Kepkay's work on the development of UVFS probes has attracted considerable interest from the USCG's SMART Protocol development team.

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Our wave tank studies have attracted local (newspapers, etc.), national (DFO website) and international media attention (recent episode of Planet Earth – Discovery Channel).

Presentations include:

Boufadel, M.C., Wickley-Olsen, E., King, T., Li, Z., Lee, K., and Venosa, A.D., 2008. Theoretical Foundation for predicting dispersion effectiveness due to waves. In: *International Oil Spill Conference.* May 4-8, 2008 Savannah, GA.

Boufadel, M.C.*, Li, Z., Lee, K., and Venosa, A.D. 2006. Hydrodynamic characterization of a wave tank facility for the evaluation of oil dispersant effectiveness. Presented at: the *13th Annual International Petroleum Environmental Conference.* October 17-20, San Antonio, TX.

Chen, Z., Zhan, C.S., Lee, K., Li, Z., and Boufadel, M.C. 2006. Modeling of oil droplet kinetics under breaking waves. Presented at: the *3rd NATO/CCMS Workshop on Oil Spill Response.* October 11-13, Dartmouth, NS.

Kepkay, P., Yeung, C.W., Bugden, J.B.C., Li, Z., and Lee, K. 2008. Ultraviolet Fluorescence Spectroscopy (UVFS): A New Means of Determining the Effect of Chemical Dispersants on Oil Spills. In: *International Oil Spill Conference.* May 4-8, 2008, Savannah, GA.

Lee, K., Li, Z., Kepkay, P., Boufadel, M.C., and Venosa, A.D. 2008. Effects of chemical dispersants on oil-mineral-aggregation in a wave tank. In: *International Oil Spill Conference.* May 4-8, 2008. Savannah, GA.

Lee, K., Li, Z., King, T., Boufadel, M., and Venosa, A.D. (Accepted). Evaluating chemical dispersant efficacy in a flow-through wave tank under regular and breaking wave conditions. Accepted for presentation in the *Interspill'09 Conference and Exhibition*, May 12-14, 2009 Marseille, France

Lee, K., Li, Z., Kepkay, P., Boufadel, M.C., and Venosa, A.D. 2007. Effects of chemical dispersants on oil-mineral aggregation in a wave tank. Presented at the 30th AMOP Technical Seminar (June 5-7, 2007, Edmonton, AB, Canada), Environment Canada, Ottawa, ON, Canada

Lee, K., Boufadel, M.C., and Venosa, A.D. Li, Z., 2006. Wave tank studies for evaluation of dispersant effectiveness and toxicity. Presented at: the *3rd NATO/CCMS Workshop on Oil Spill Response.* October 11-13, Dartmouth, NS.

Lee, K.*, Li, Z., Kepkay, P., Boufadel, M.C., and Venosa, A.D. 2006. Formation and transport of oil-mineral aggregates in a wave tank. Presented at: the *13th Annual International Petroleum Environmental Conference.* October 17-20, San Antonio, TX.

Li, Z., Lee, K., Kepkay, P., Boufadel, M.C., and Venosa, A.D., 2007. Chemical dispersant effectiveness: oil concentration and droplet size distribution in a wave tank under regular non-breaking and breaking wave conditions. Presented at the 30th AMOP Technical Seminar (June 5-7, 2007, Edmonton, AB, Canada), Environment Canada, Ottawa, ON, Canada

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Li, Z., Lee, K., King, T., Boufadel, M.C., and Venosa, A.D., 2007. Wave tank studies on chemical dispersant effectiveness as a function of wave: Implication in spatial and temporal toxicity response. Presented at the 34th Annual Aquatic Toxicity Workshop, September 30 – October 3, 2007 Halifax, NS, Canada).

Li, Z., Lee, K., Kepkay, P., King, T., Boufadel, M.C., and Venosa, A.D. 2006. The application of in-situ laser particle size analysis to monitor the efficacy of chemical oil dispersants. Presented at: the *3rd NATO/CCMS Workshop on Oil Spill Response.* October 11-13, Dartmouth, NS.

Li, Z.*, Lee, K., Kepkay, P., Boufadel, M.C., and Venosa, A.D. 2006. Wave tank studies on dispersant effectiveness as a function of droplet size distribution. Presented at: the *13th Annual International Petroleum Environmental Conference.* October 17-20, San Antonio, TX.

Li, Z., Lee, K., Kepkay, P., Boufadel, M.C., and Venosa, A.D. 2008. Chemical dispersant effectiveness: droplet size distribution as a function of energy dissipation rate. In: *International Oil Spill Conference.* May 4-8, 2008 Savannah, GA.

Miles, S.S., 2006. Real-time Quantitative Measurement of Dispersed and Non-Dispersed Oils Using an In-Situ Multiple Simultaneous Scattering and Fluorescence Sensor. Presented at: the *3rd NATO/CCMS Workshop on Oil Spill Response.* October 11-13, Dartmouth, NS.

Venosa, A.D., Li, Z., Lee, K., Kepkay, P., and Boufadel, M.C., 2006. Wave tank studies on dispersant effectiveness as a function of energy dissipation rate. Presented at: the *3rd NATO/CCMS Workshop on Oil Spill Response.* October 11-13, Dartmouth, NS.

Venosa, A.D., Li, Z., Lee, K., Kepkay, P., and Boufadel, M.C., 2006. Wave tank studies on dispersant effectiveness as a function of energy dissipation rate. Presented at: the *13th Annual International Petroleum Environmental Conference.* October 17-20, San Antonio, TX.

Venosa, A.D., Lee, K., Boufadel, M.C., and Li, Z., 2008. Dispersant effectiveness as a function of energy dissipation rate in a wave tank. In: *International Oil Spill Conference.* May 4-8, 2008 Savannah, GA.

Wickley-Olsen, E., Boufadel, M.C., King, T., Li, Z., Lee, K., and Venosa, A.D., 2008. Regular and breaking waves in wave tank for dispersion effectiveness testing. In: *International Oil Spill Conference.* May 4-8, 2008 Savannah, GA.

Wickley-Olsen, E., Boufadel, M.C., King, T., Li, Z., Lee, K., and Venosa, A.D., 2007. Regular and breaking waves in wave tank for dispersion effectiveness testing. Presented at the 30th AMOP Technical Seminar (June 5-7, 2007, Edmonton, AB, Canada), Environment Canada, Ottawa, ON, Canada

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7.0 Achievement and Dissemination

A number of primary publications have directly resulted from this research program:

Botrus, D., M.C. Boufadel, E. Wickley-Olsen, J.W. Weaver, R. Weggel, K. Lee and A.D. Venosa (2008) Wave tank to simulate the movement of oil under breaking waves. Proceedings of the 31st Arctic and Marine Oil Spill Program (AMOP) Technical Seminar on Environmental Contamination and Response. Edmonton Alberta, Canada, June 2-5, 2008. pp. 53-68.

Boufadel, M.C., E. Wickley-Olsen, T. King, T., Z. Li, K. Lee and A.D. Venosa (2008) Theoretical foundation for predicting dispersion effectiveness due to waves. Proceedings of the 2008 International Oil Spill Conference, Savannah, Georgia, USA, May 4-8, 2008. pp. 509-514.

Bugden, J. B. C., C. W. Yeung, P. E. Kepkay, and K. Lee. 2008. Application of Ultraviolet Fluorometry and Excitation-Emission Matrix Spectroscopy (EEMS) to Fingerprint Oil and Chemically Dispersed Oil in Seawater. *Marine Pollution Bulletin*, 56, 677-685

Cole, M. G., King, T. L., and Lee, K. (2007). "Analytical technique for extracting hydrocarbons from water using sample container as extraction vessel in combination with a roller apparatus. Can. Tech. Rep. Fish. Aquat. Sci. 2733: vi + 12p."

Kepkay, P.E., C.W. Yeung, J.B.C. Bugden, Z. Li and K. Lee (2008), Ultraviolet Fluorescence Spectroscopy (UVFS): A new means of determining the effect of chemical dispersants on oil spills. Proceedings of the 2008 International Oil Spill Conference, Savannah, Georgia, USA, May 4-8, 2008. pp. 639-644.

Lee, K., Z. Li, P. Kepkay, M.C. Boufadel and A.D. Venosa (2008) Effects of chemical dispersants on oil-mineral-aggregation in a wave tank. Proceedings of the 2008 International Oil Spill Conference, Savannah, Georgia, USA, May 4-8, 2008. pp. 633-638

Lee, K., Z. Li, P. Kepkay, M.C. Boufadel and A.D. Venosa (2008) Wave tank studies on formation and transport of OMA from the chemically dispersed oil. In: Oil Spill Response: A Global Perspective, Davidson, W.F., K. Lee and A. Cogswell, A. (eds), NATO Science for Peace and Security Series – C: Environmental Security, Springer Publishing Company. pp. 159-177.

Li, Z., Kepkay, P., Lee, K., King, T., Boufadel, M. C., and Venosa, A. D., (2007), Effects of chemical dispersants and mineral fines on oil dispersion in a wave tank under breaking waves. Marine Pollution Bulletin, 54(7): 983-993.

Li, Z., P. Kepkay, M.C. Boufadel, A.D. Venosa and K. Lee (2008). Oil droplet size distribution as a function of energy dissipation rate in an experimental wavetank. Proceedings of the 2008 International Oil Spill Conference, Savannah, Georgia, USA, May 4-8, 2008. pp. 621-626.

Li, Z., Lee, K., Kepkay, P., Boufadel, M.C., and Venosa, A.D. 2008. Chemical dispersant effectiveness: droplet size distribution as a function of energy dissipation rate. In: *International Oil Spill Conference.* May 4-8, 2008 Savannah, GA.

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Li, Z., K. Lee, P. Kepkay, T. King, W. Yeung, M.C. Boufadel and A.D. Venosa (2008) Wave tank studies on chemical dispersant effectiveness: Dispersed oil droplet size distribution. In: Oil Spill Response: A Global Perspective, Davidson, W.F., K. Lee and A. Cogswell, A. (eds), NATO Science for Peace and Security Series – C: Environmental Security, Springer Publishing Company. pp. 143-157.

Li, Z., Lee, K., King, T., Boufadel, M.C., and Venosa, A.D. 2008. Assessment of chemical dispersant effectiveness in a wave tank under regular non-breaking and breaking wave conditions. *Marine Pollution Bulletin*, 56, 903-912

Li, Z., Lee, K., King, T., Boufadel, M. C., and Venosa, A. D. (2009). "Evaluating crude oil chemical dispersion efficacy in a flow-through wave tank under regular non-breaking wave and breaking wave conditions." *Marine Pollution Bulletin*, 58, 735-744

Li, Z., Lee, K., King, T., Boufadel, M.C., Venosa, A.D. (In press). "Evaluating oil spill chemical dispersant efficacy in an experimental wave tank: 2, Significant factors determining *in-situ* droplet size distributions." *Environmental Engineering Science*

Li, Z., Lee, K., King, T., Kepkay, P.E., Boufadel, M.C., Venosa, A.D. (In press). "Evaluating oil spill chemical dispersant efficacy in an experimental wave tank: 1, Dispersant effectiveness as a function of energy dissipation rate." *Environmental Engineering Science*

Ma, X., A. Cogswell, K. Lee, Z. Li (2008) Particle size analysis of dispersed oil and oil-mineral aggregates with an automated epi-fluorescence microscopy system. Environmental Technology, 29, 737-748.

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Wickley-Olsen, E., Boufadel, M.C., King, T., Li, Z., Lee, K., and Venosa, A.D., (2007), Regular and breaking waves in wave tank for dispersion effectiveness testing. Proceedings of: the 30th Arctic and Marine Oilspill Programs (AMOP) Technical Seminar, Edmonton, AB, Canada, 161-187

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The following publications received indirect benefits (e.g. application of methods/expertise developed) from funding associated with this program:

Chen, Z., C.S. Zhan, K. Lee, Z. Li and M.C. Boufadel (2008). Modeling of oil droplet kinetics under breaking waves. In: Oil Spill Response: A Global Perspective, Davidson, W.F., K. Lee

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and A. Cogswell, A. (eds), NATO Science for Peace and Security Series – C: Environmental Security., Springer Publishing Company. pp. 221-236

Davidson, W.F., K. Lee and A. Cogswell, A. (2008), Oil Spill Response: A Global Perspective. NATO Science for Peace and Security Series – C: Environmental Security., Springer Publishing Company. 365 pp.

Hodson, P. V., Khan, C. W., Saravanabhavan, G., Clarke, L., Brown, R. S., Hollebone, B., Wang, Z., Short, J., Lee, K., and King, T. (2007) Alkyl PAH in crude oil cause chronic toxicity to early life stages of fish. Proceedings of the 30th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Edmonton, AL, June 4-7, 2007, Environment Canada, pp. 291-299.

Ramachandran, S.D., M.J. Sweezey, P.V. Hodson, M. Boudreau, S. Courtenay, T. King, J.A. Dixon and K. Lee (2006) Influence of salinity and fish species on PAH uptake from dispersed MESA crude oil. Marine Pollution Bulletin 52:1182-1189

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8.0 Technical Training

This project has provided support and training opportunities to students ranging from high school to graduate students in Canada, the United States of America, and Europe:

Table 9: Student and postdoctoral trainee of this project

Name	Affiliation	Grade Level
Dan Belliveau	Dalhousie University	Undergraduate student
Jennifer Beer	Nova Scotia Community College	Undergraduate student
Venessa Page	Dalhousie University	Undergraduate student
John Niven	Dartmouth High School	High school student
Wolfe Mollin	FRANCE	Undergraduate student
Eric Whitley-Olsen	Temple University	Graduate student
Buffy Ashton	Louisiana State University	Graduate student
William Yeung	DFO/NRC/ McGill University	Doctoral student
Matt Asenault	Dalhousie University	Undergraduate student
Peter Flamming	Dalhousie University /Nova Scotia Community College	Undergraduate student
Jamie Joudrey	Dalhousie University	Undergraduate student
Amanda Hill	Nova Scotia Community College	Undergraduate student

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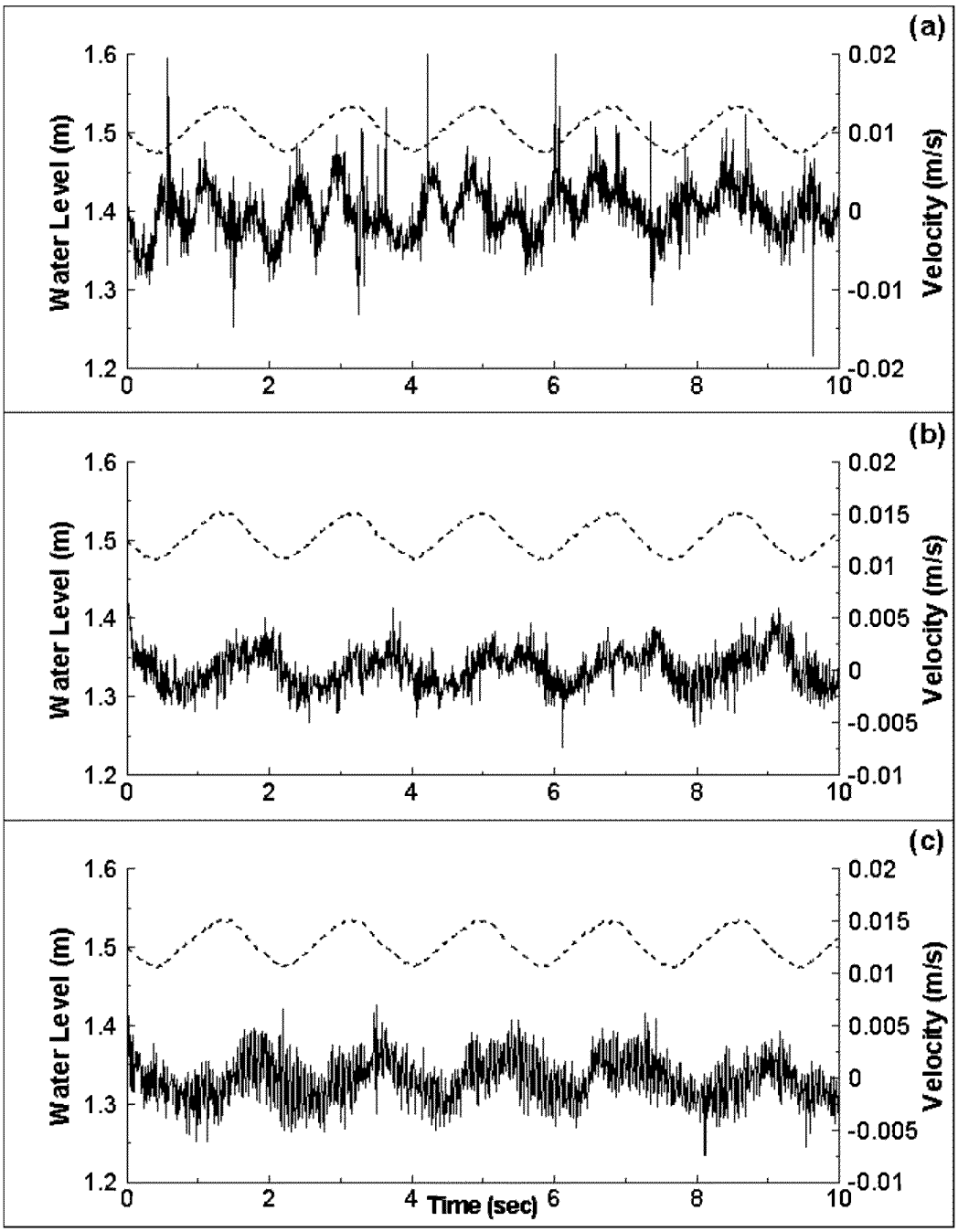
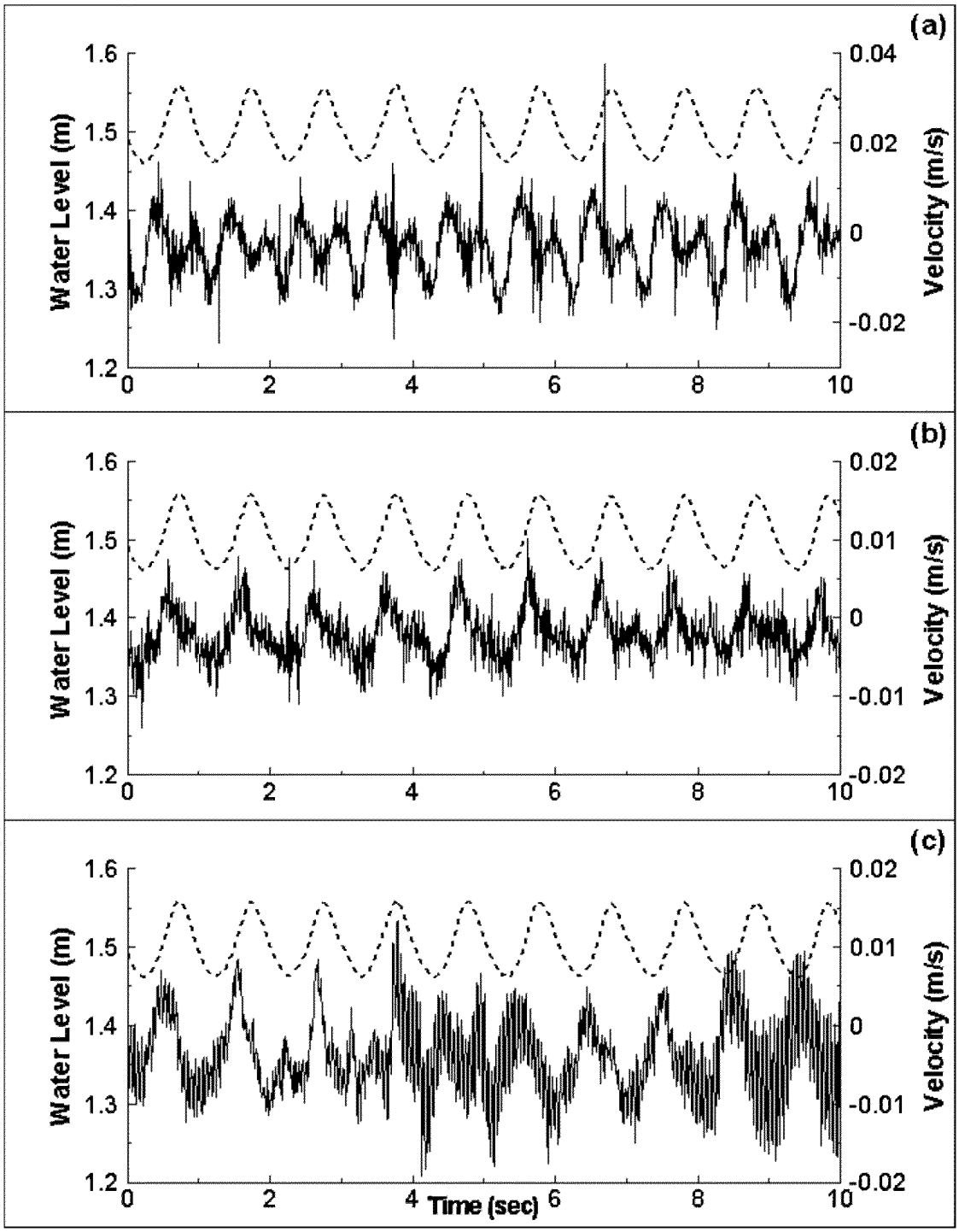
Appendices

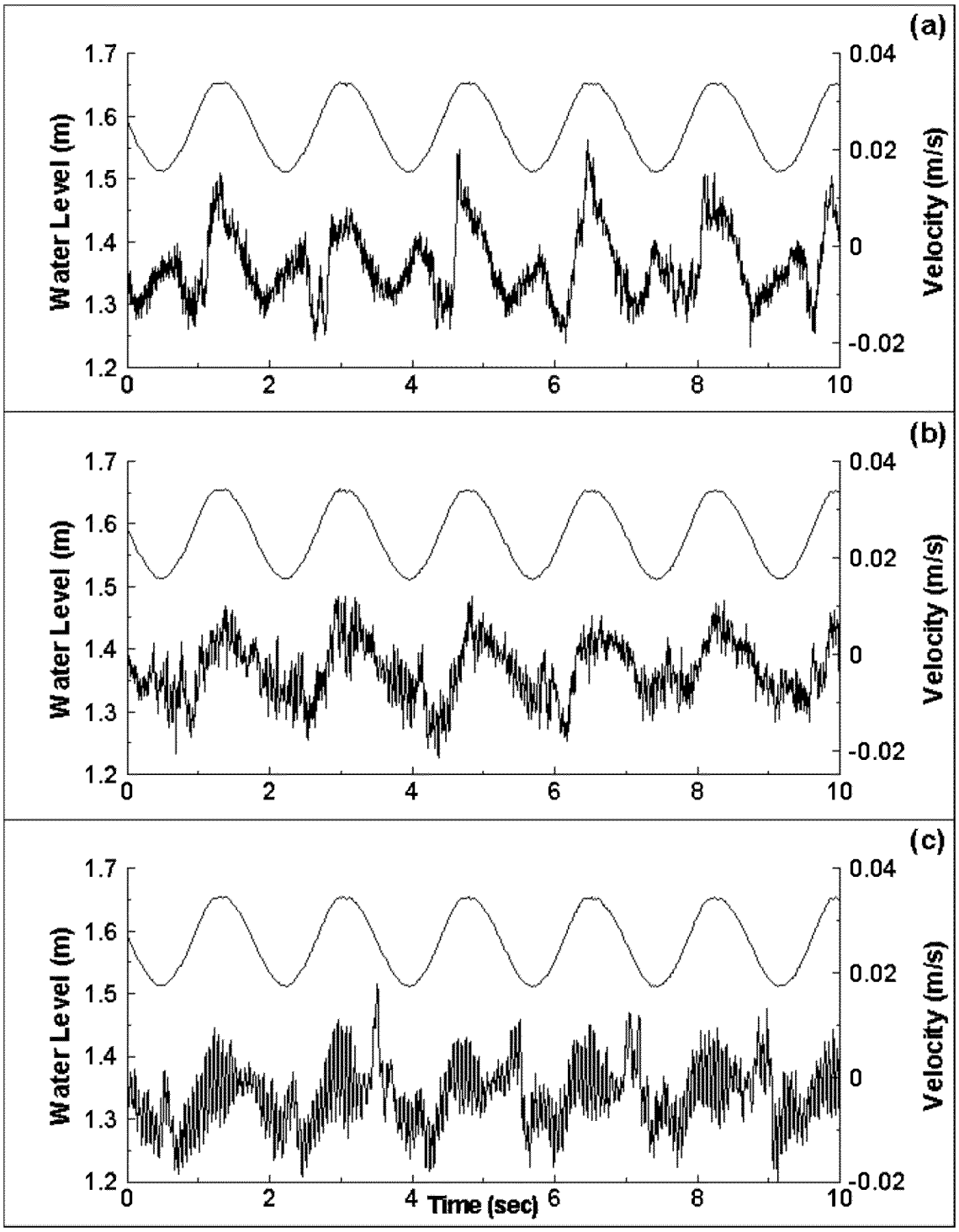
Appendix A1: Velocity series for across tank component "v" of low frequency waves generated with a 7 cm stroke at depths of (a) 10.7 cm, (b) 23.3 cm, and (c) 33.3 cm. Also shown by the dashed line is the water level for each series.



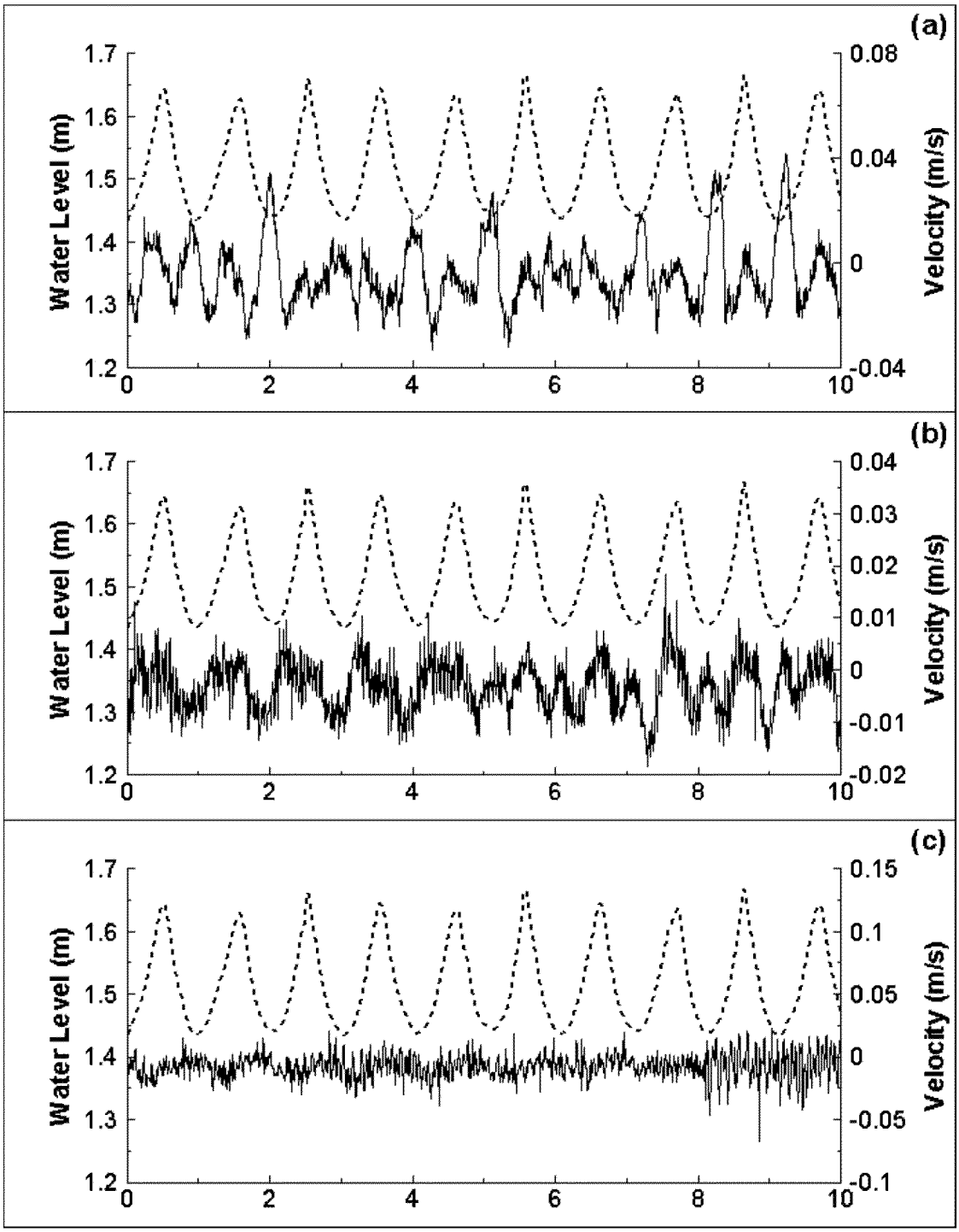
Appendix A2: Velocity series for across tank component "v" of high frequency waves generated with a 7 cm stroke at depths of (a) 10.7 cm, (b) 23.3 cm, and (c) 33.3 cm. Also shown by the dashed line is the water level for each series.



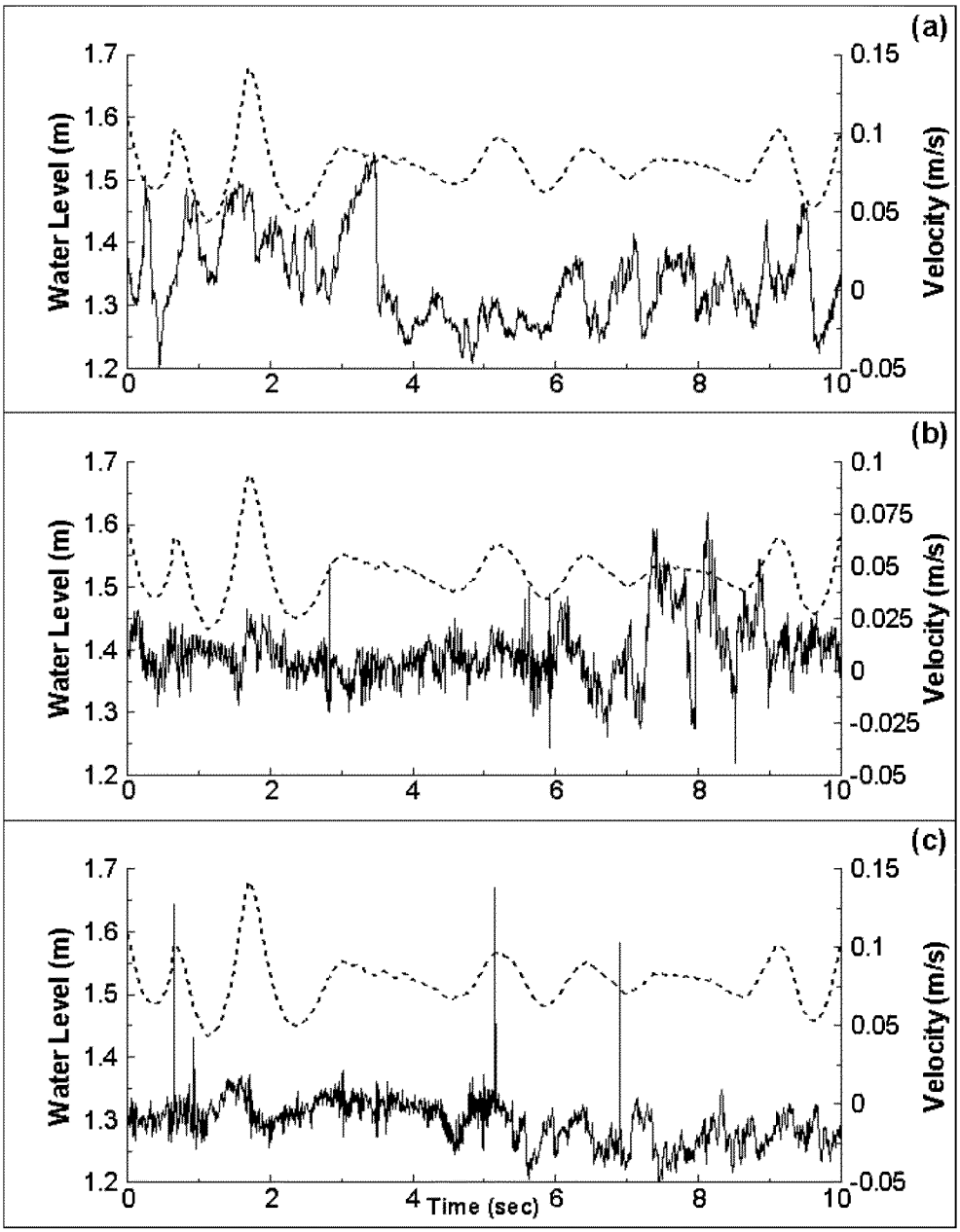
Appendix A3: Velocity series for across tank component "v" of low frequency waves generated with a 12 cm stroke at depths of (a) 13.3 cm, (b) 27.3 cm, and (c) 39.3 cm. Also shown by the dashed line is the water level for each series.



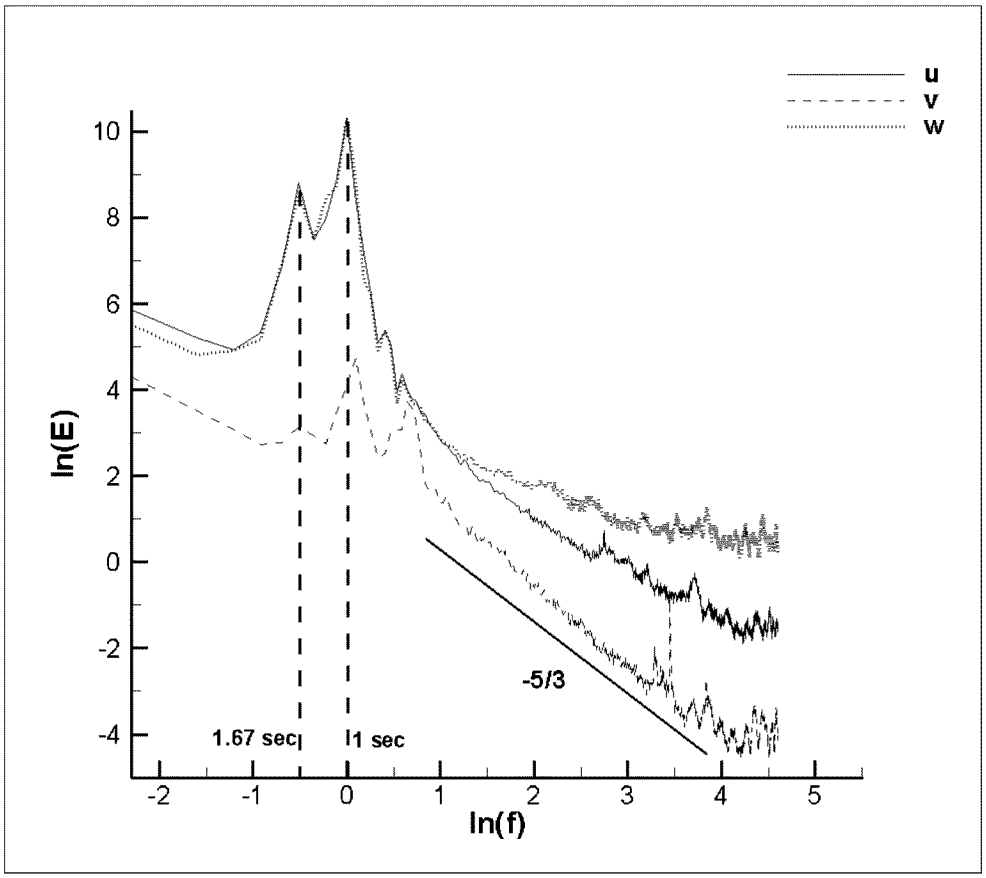
Appendix A4: Velocity series for across tank component "v" of high frequency waves generated with a 12 cm stroke at depths of (a) 13.3 cm, (b) 27.3 cm, and (c) 39.3 cm. Also shown by the dashed line is the water level for each series.



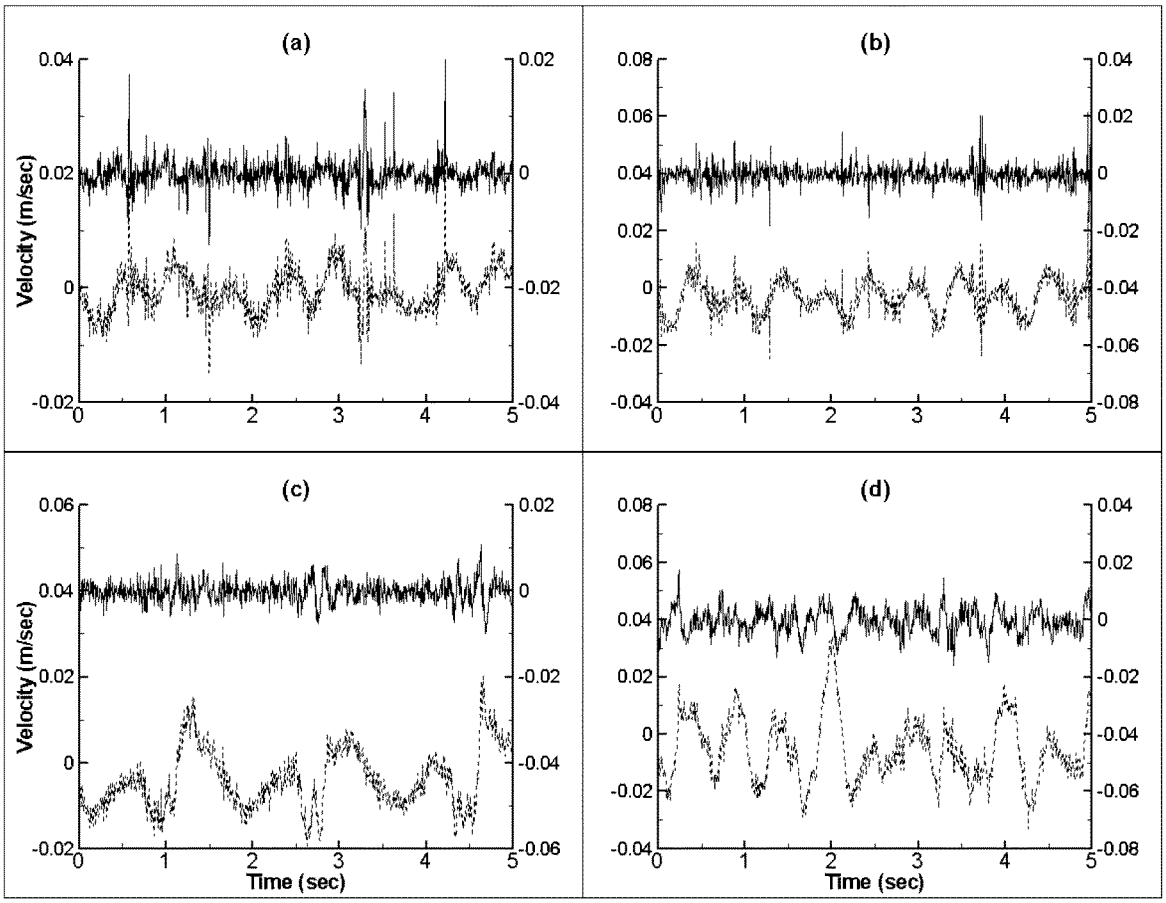
Appendix A5: Velocity series for across tank component "v" plunging breaking waves generated with a 12 cm stroke at depths of (a) 13.3 cm, (b) 27.3 cm and (c) 39.3 cm. Also shown by the dashed line is the water level for each series. The breaker occurred at 13.54 m from the flap.



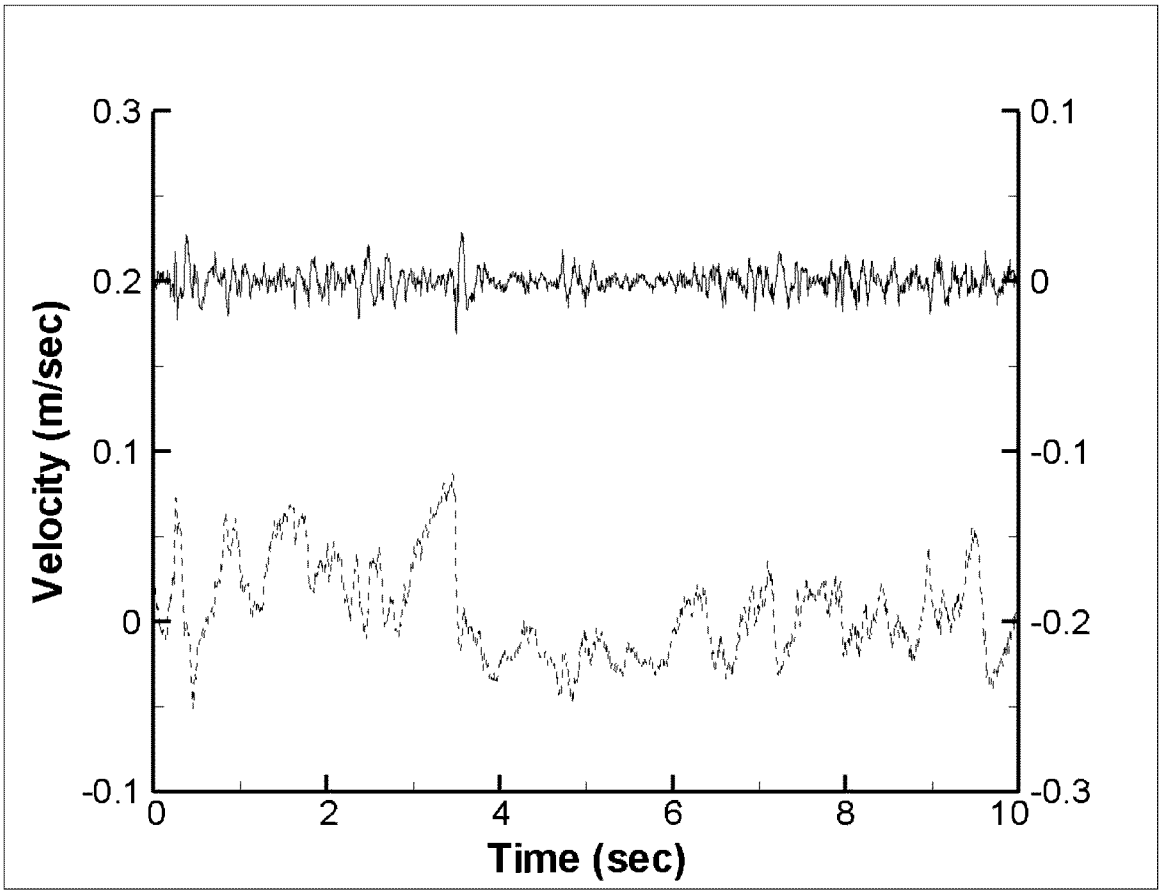
Appendix A6: Three component velocity spectra for the plunging breaking waves at a depth of 13.3 cm. The dominant frequencies of the system (= 1/Δt) are displayed. The Nyquist (f/2) frequency for the ADV sensor is (200 Hz / 2) = 100 Hz.



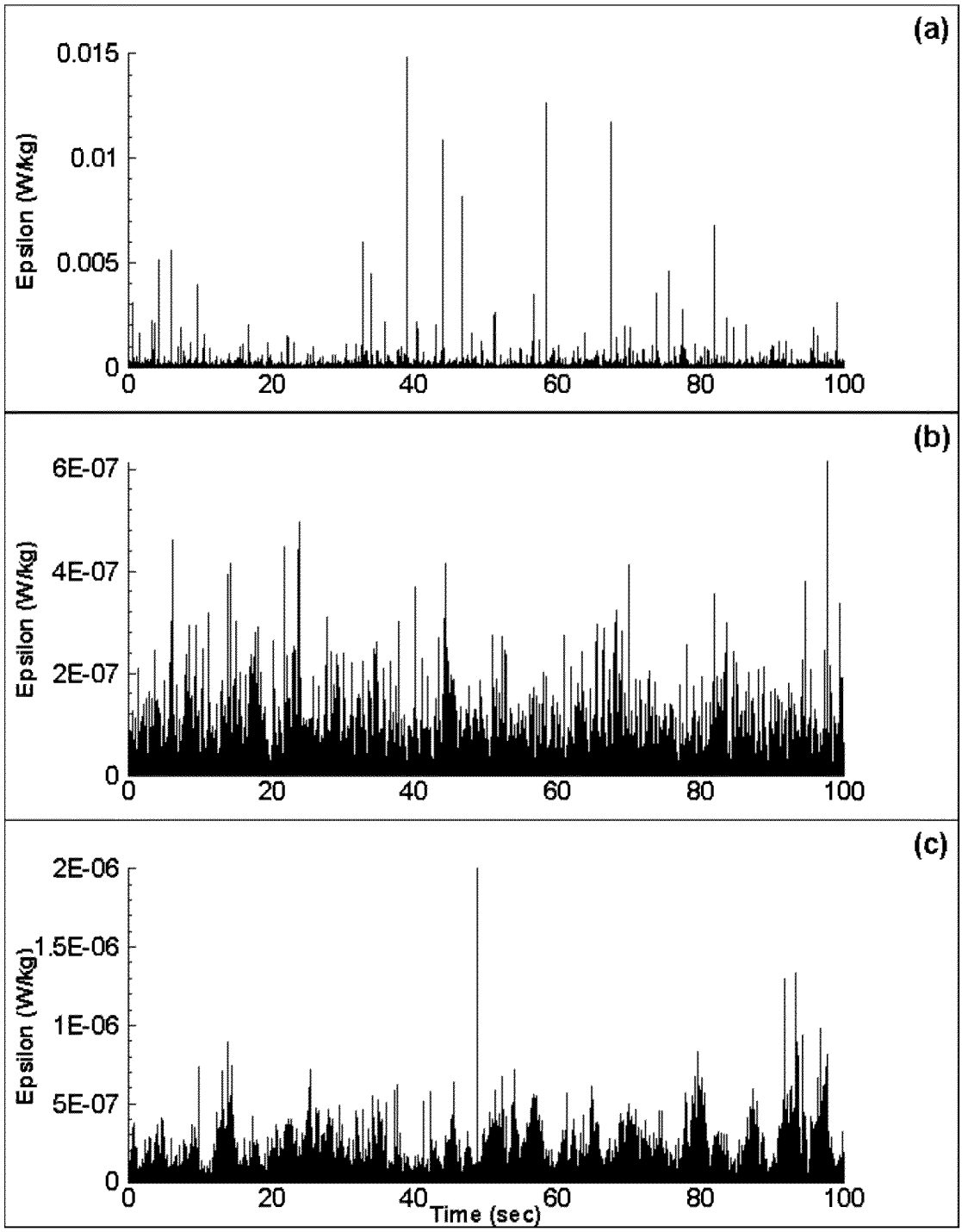
Appendix A7: Series for filtered across tank velocity "v" for (a) LF 7 cm stroke, (b) HF 7 cm stroke, (c) LF 12 cm stroke and (d) HF 12 cm stroke. Also shown (dashed) is the original velocity. Series are centered on their respective zeros.



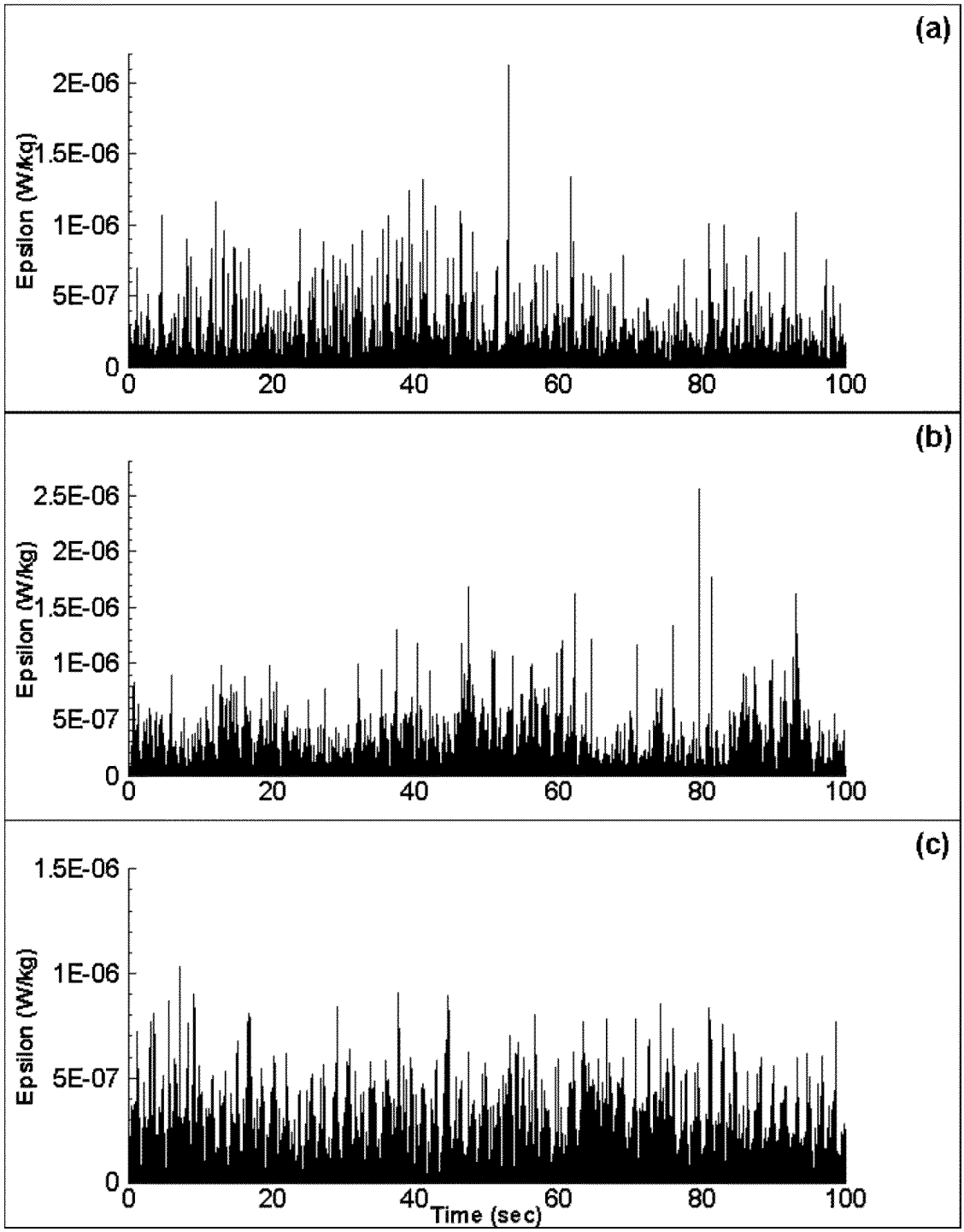
Appendix A8: Series for filtered across tank velocity "v" for the plunging breaker. Also shown (dashed) is the original velocity. Series are centered around their respective zeros.



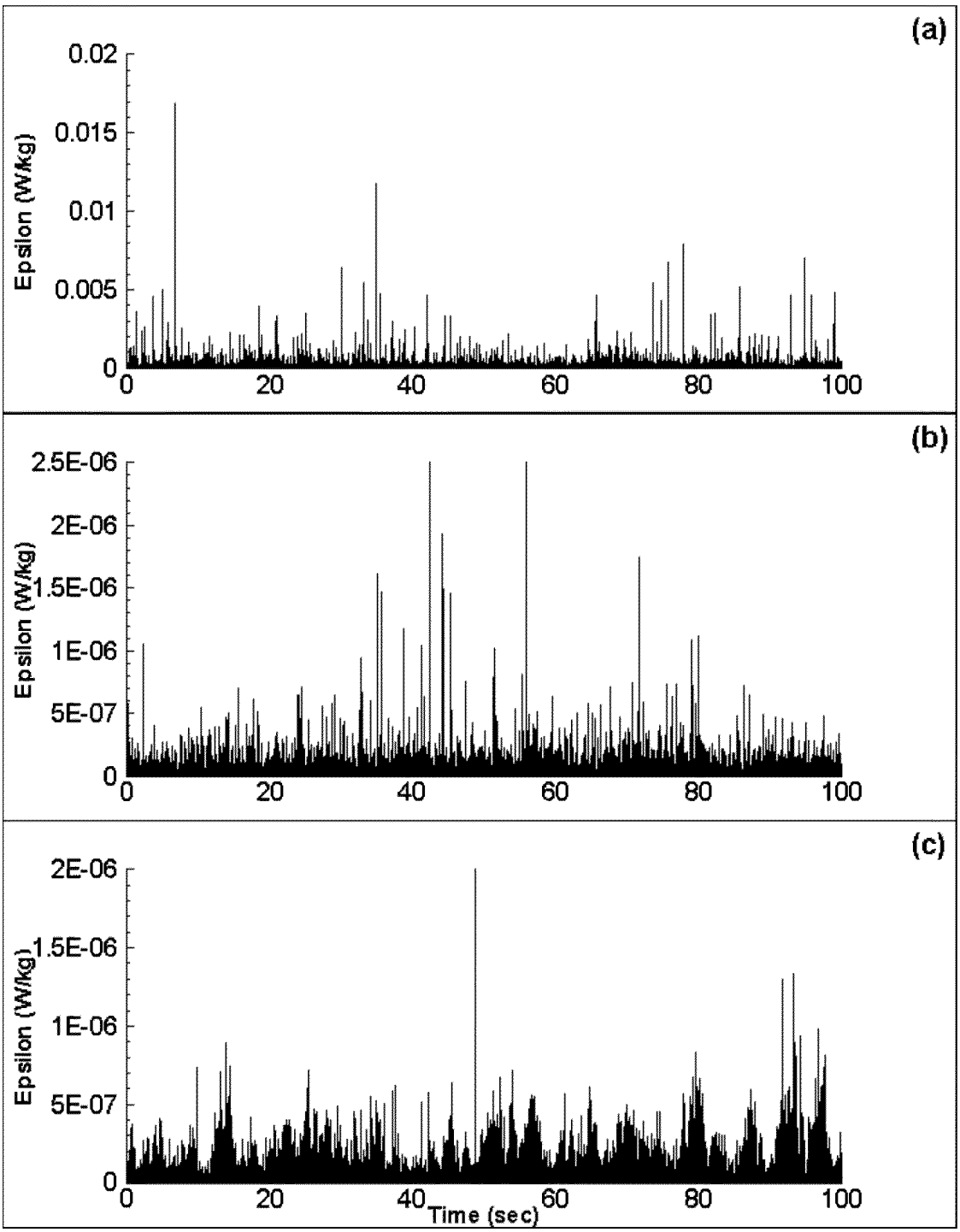
Appendix A9: Energy dissipation rates calculated over the regular wave low frequency (LF) 7 cm stroke data set for depth of (a) 10.7 cm, (b) 23.3 cm and (c) 33.3 cm.



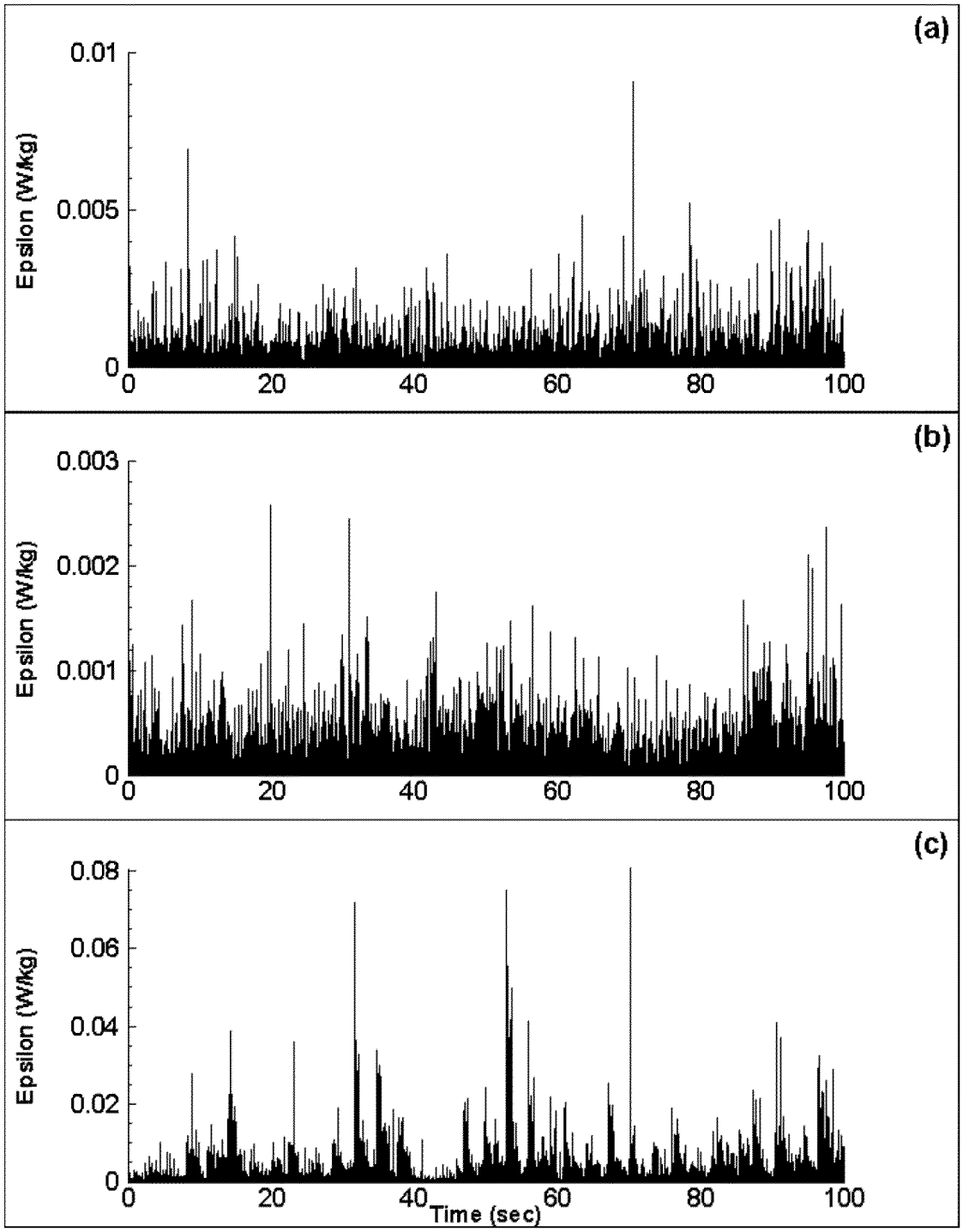
Appendix A10: Energy dissipation rates calculated over the regular wave low frequency (LF) 12 cm stroke data set for depths of (a) 13.3 cm, (b) 27.3 cm, and (c) 39.3 cm.



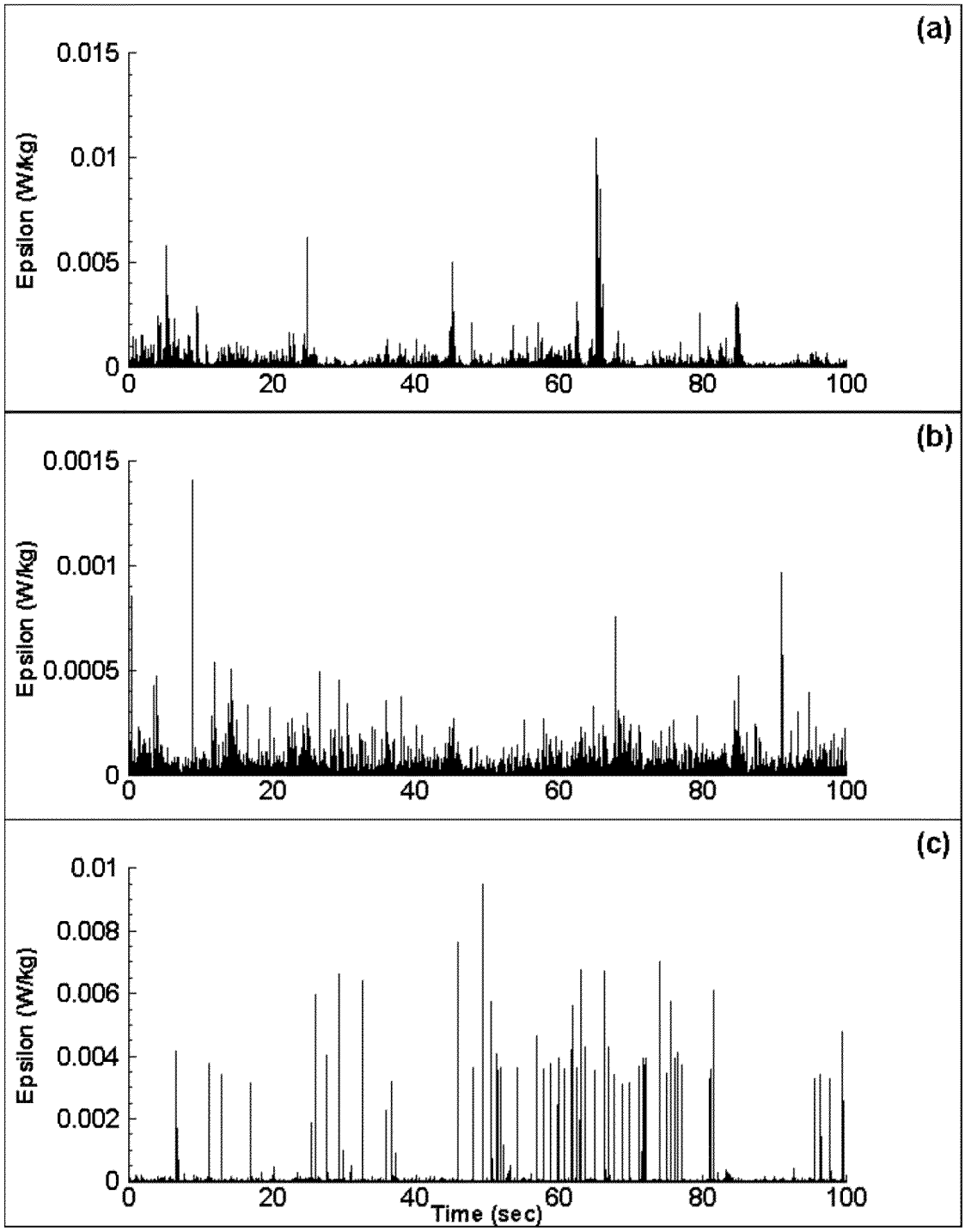
Appendix A11: Energy dissipation rates calculated over the regular wave high frequency (HF) 7 cm stroke data set for depth of (a) 10.7 cm, (b) 23.3 cm and (c) 33.3 cm.



Appendix A12: Energy dissipation rates calculated over the regular wave high frequency (HF) 12 cm stroke data set for depths of (a) 13.3 cm, (b) 27.3 cm, and (c) 39.3 cm.



Appendix A13: Energy dissipation rates calculated over the plunging breaker, 12 cm stroke data set for depth of (a) 6 cm, (b) 21.21 cm and (c) 41.49 cm.



Appendix A14: Average temperature-response fluorometer results of ANS crude oil

Light Scattering (660nm)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
21°C	1000 ppb	48	40	58	49	9.0	19
	2500 ppb	88	97	102	96	7.1	7.4
	5000 ppb	208	198	215	207	8.6	4.1
	10000 ppb	401	433	474	436	36	8.3
	50000 ppb	1527	1537	1619	1561	50	3.2
12°C	1000 ppb	60	61	54	58	3.8	6.5
	2500 ppb	85	94	89	89	4.5	5.0
	5000 ppb	201	218	204	208	9.1	4.4
	10000 ppb	436	474	466	459	20	4.4
	50000 ppb	1678	1658	1645	1660	17	1.0
5°C	1000 ppb	43	42	52	46	5.4	12
	2500 ppb	92	82	92	89	5.8	6.5
	5000 ppb	198	186	201	195	7.9	4.0
	10000 ppb	423	407	432	421	13	3.0
	50000 ppb	1625	1700	1673	1666	38	2.3

Chlorophyll (ex470/em695)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
21°C	1000 ppb	24	26	20	23	3.1	13
	2500 ppb	119	124	118	120	3.2	2.7
	5000 ppb	305	298	280	294	13	4.4
	10000 ppb	570	579	581	577	5.9	1.0
	50000 ppb	3440	3526	3530	3499	51	1.5
12°C	1000 ppb	28	30	21	26	4.7	18
	2500 ppb	168	187	182	179	10	5.5
	5000 ppb	381	403	394	393	11	2.8
	10000 ppb	766	759	763	763	3.5	0.5
	50000 ppb	3702	3787	3779	3756	47	1.2
5°C	1000 ppb	35	27	38	33	5.7	17
	2500 ppb	187	176	174	179	7.0	3.9
	5000 ppb	350	407	422	393	38	10
	10000 ppb	723	758	758	746	20	2.7
	50000 ppb	3786	3813	3836	3812	25	0.7

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CDOM (ex370/em460)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
21°C	1000 ppb	24	20	27	24	3.5	15
	2500 ppb	134	127	148	136	11	7.8
	5000 ppb	274	274	289	279	8.6	3.1
	10000 ppb	476	476	497	483	12	2.5
	50000 ppb	1508	1481	1525	1505	22	1.5
12°C	1000 ppb	20	24	20	21	2.3	11
	2500 ppb	162	162	160	161	1.2	0.7
	5000 ppb	279	285	284	283	3.2	1.1
	10000 ppb	467	456	461	461	5.5	1.2
	50000 ppb	1669	1650	1714	1678	33	2.0
5°C	1000 ppb	23	18	24	22	3.2	15
	2500 ppb	191	168	201	187	17	9.1
	5000 ppb	272	248	280	267	17	6.3
	10000 ppb	445	424	458	442	17	3.9
	50000 ppb	1661	1708	1691	1687	24	1.4

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Appendix A15: Average temperature-response fluoremeter results of MESA crude oil

Light Scattering (660nm)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
21°C	1000 ppb	18	25	22	22	3.5	16
	2500 ppb	65	75	71	70	5.0	7.2
	5000 ppb	157	154	155	155	1.5	1.0
	10000 ppb	325	306	332	321	13	4.2
	50000 ppb	1442	1421	1321	1395	65	4.6
12°C	1000 ppb	30	29	27	29	1.5	5.3
	2500 ppb	75	86	82	81	5.6	6.9
	5000 ppb	155	128	143	142	14	9.5
	10000 ppb	322	329	308	320	11	3.3
	50000 ppb	1558	1588	1571	1572	15	1.0
5°C	1000 ppb	31	31	24	29	3.9	14
	2500 ppb	68	62	61	64	3.7	5.8
	5000 ppb	114	126	128	123	7.5	6.1
	10000 ppb	333	346	346	342	7.3	2.1
	50000 ppb	1573	1522	1503	1533	36	2.3

Chlorophyll (ex470/em695)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
21°C	1000 ppb	25	22	28	25	3.0	12
	2500 ppb	79	102	87	89	12	13
	5000 ppb	254	245	248	249	4.6	1.8
	10000 ppb	513	501	489	501	12	2.4
	50000 ppb	3384	3331	3307	3341	39	1.2
12°C	1000 ppb	30	41	32	34	5.9	17
	2500 ppb	135	109	134	126	15	12
	5000 ppb	240	295	266	267	28	10
	10000 ppb	578	609	590	592	16	2.6
	50000 ppb	3503	3620	3588	3570	60	1.7
5°C	1000 ppb	38	28	39	35	6.1	17
	2500 ppb	125	128	118	124	5.1	4.1
	5000 ppb	247	245	250	247	2.5	1.0
	10000 ppb	610	588	593	597	12	1.9
	50000 ppb	3601	3662	3399	3554	138	3.9

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CDOM (ex370/em460)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
21°C	1000 ppm	89	71	81	80	9.1	11
	2500 ppm	158	149	176	161	14	8.6
	5000 ppm	212	181	235	209	27	13
	10000 ppm	322	282	351	318	35	11
	50000 ppm	1394	1506	1436	1445	57	3.9
12°C	1000 ppm	103	107	119	110	8.3	7.6
	2500 ppm	162	192	207	187	23	12
	5000 ppm	249	236	255	247	9.7	3.9
	10000 ppm	458	447	453	453	5.5	1.2
	50000 ppm	1460	1441	1506	1469	33	2.3
5°C	1000 ppm	140	145	141	142	2.7	1.9
	2500 ppm	224	217	232	224	7.5	3.3
	5000 ppm	312	310	310	311	1.1	0.4
	10000 ppm	473	589	530	531	58	11
	50000 ppm	1421	1480	1520	1474	50	3.4

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Appendix A16: Average background-subtracted turbidity-response fluorometer results of ANS Crude Oil

Light Scattering (660nm)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
< 2 NTU	1000 ppb	48	43	50	47	3.6	7.7
	2500 ppb	82	77	87	82	5.0	6.1
	5000 ppb	162	145	178	162	17	10
	10000 ppb	351	334	367	351	17	4.7
	50000 ppb	1308	1274	1325	1302	26	2.0
40 NTU	1000 ppb	15	13	18	15	2.5	16
	2500 ppb	30	26	35	30	4.5	15
	5000 ppb	64	52	71	62	10	15
	10000 ppb	194	177	205	192	14	7.3
	50000 ppb	369	349	386	368	19	5.0
200 NTU	1000 ppb	12	10	14	12	2.0	17
	2500 ppb	24	20	26	23	3.1	13
	5000 ppb	50	39	58	49	10	19
	10000 ppb	209	189	221	206	16	7.8
	50000 ppb	420	396	433	416	19	4.5

Chlorophyll (ex470/em695)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
< 2 NTU	1000 ppb	20	20	16	19	2.3	12
	2500 ppb	90	75	91	85	9.0	11
	5000 ppb	260	193	221	225	34	15
	10000 ppb	606	552	629	596	40	6.6
	50000 ppb	3670	3579	3697	3649	62	1.7
40 NTU	1000 ppb	21	25	29	25	4.0	16
	2500 ppb	121	105	103	110	9.9	9.0
	5000 ppb	221	199	201	207	12	5.9
	10000 ppb	346	319	409	358	46	13
	50000 ppb	1620	1635	1729	1661	59	3.6
200 NTU	1000 ppb	21	17	22	20	2.6	13
	2500 ppb	86	95	103	95	8.5	9.0
	5000 ppb	189	168	212	190	22	12
	10000 ppb	356	365	411	377	30	7.8
	50000 ppb	1531	1503	1453	1496	40	2.6

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CDOM (ex370/em460)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
< 2 NTU	1000 ppb	36	34	47	39	7.0	18
	2500 ppb	70	65	85	73	10	14
	5000 ppb	200	182	223	202	21	10
	10000 ppb	391	378	441	403	33	8.2
	50000 ppb	1163	1088	1194	1148	55	4.7
40 NTU	1000 ppb	17	12	16	15	2.6	18
	2500 ppb	40	30	40	37	5.8	16
	5000 ppb	77	64	80	74	8.5	12
	10000 ppb	200	180	213	198	17	8.4
	50000 ppb	455	418	473	449	28	6.2
200 NTU	1000 ppb	6	7	8	7	1.0	14
	2500 ppb	17	16	20	18	2.1	12
	5000 ppb	42	38	53	44	7.8	18
	10000 ppb	97	88	111	99	12	12
	50000 ppb	320	295	348	321	27	8.3

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Appendix A17: Average background-subtracted turbidity-response fluorometer results of MESA Crude Oil

Light Scattering (660nm)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
< 2 NTU	1000 ppb	43	53	50	49	5.1	11
	2500 ppb	73	78	70	74	4.0	5.5
	5000 ppb	146	154	159	153	6.6	4.3
	10000 ppb	413	407	415	412	4.2	1.0
	50000 ppb	1389	1409	1484	1427	50	3.5
40 NTU	1000 ppb	21	24	24	23	1.7	7.5
	2500 ppb	36	35	30	34	3.2	10
	5000 ppb	65	71	75	70	5.0	7.2
	10000 ppb	187	179	194	187	7.5	4.0
	50000 ppb	333	313	344	330	16	4.8
200 NTU	1000 ppb	23	32	28	28	4.5	16
	2500 ppb	34	39	39	37	2.9	7.7
	5000 ppb	66	63	61	63	2.5	4.0
	10000 ppb	204	196	219	206	12	5.7
	50000 ppb	414	399	446	420	24	5.7

Chlorophyll (ex470/em695)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
< 2 NTU	1000 ppb	62	62	61	62	0.6	0.9
	2500 ppb	151	164	183	166	16	9.7
	5000 ppb	358	315	348	340	23	6.6
	10000 ppb	650	617	640	636	17	2.7
	50000 ppb	3296	3221	3133	3217	82	2.5
40 NTU	1000 ppb	73	57	83	71	13	18
	2500 ppb	96	75	107	93	16	18
	5000 ppb	133	109	147	130	19	15
	10000 ppb	256	225	280	254	28	11
	50000 ppb	1511	1463	1540	1505	39	2.6
200 NTU	1000 ppb	25	21	31	26	5.0	20
	2500 ppb	46	34	44	41	6.4	16
	5000 ppb	71	62	72	68	5.5	8.1
	10000 ppb	186	189	230	202	25	12
	50000 ppb	1349	1299	1367	1338	35	2.6

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CDOM (ex370/em460)

Description		Run #1	Run #2	Run #3	Average	Std. Dev.	% RSD
< 2 NTU	1000 ppb	97	107	122	109	13	12
	2500 ppb	185	195	216	199	16	8.0
	5000 ppb	278	299	320	299	21	7.0
	10000 ppb	494	523	548	522	27	5.2
	50000 ppb	1514	1401	1400	1438	66	4.6
40 NTU	1000 ppb	27	31	36	31	4.5	14
	2500 ppb	54	42	45	47	6.2	13
	5000 ppb	88	77	82	82	5.5	6.7
	10000 ppb	204	192	217	204	13	6.1
	50000 ppb	428	385	414	409	22	5.4
200 NTU	1000 ppb	41	39	41	40	1.2	2.9
	2500 ppb	60	68	77	68	8.5	12
	5000 ppb	79	92	88	86	6.7	7.7
	10000 ppb	128	138	152	139	12	8.7
	50000 ppb	331	350	360	347	15	4.2

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Monitoring Dispersed Oil Droplet Size Distribution at the Gulf of Mexico Deepwater Horizon Spill Site

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ABSTRACT

In response to the Deepwater Horizon oil spill in the Gulf of Mexico, at-sea monitoring of dispersed oil was conducted to support the spill response operation, particularly for the verification and tracking of any sub-sea plumes identified by model prediction. This paper describes the methodology that has been developed for the analysis of small particle concentrations (SPC) in the field associated with dispersed oil. The dispersed oil droplet size distribution from the field samples was analyzed by using a laser *in situ* scattering and transmissometry system (LISST-100X, Sequoia Scientific Inc. Seattle, WA) system set up in the laboratory on the research vessels. The samples collected from the surface and water column were transferred into a full-path mixing chamber of the LISST-100X to perform particle size distribution analysis. Small particle ($d \leq 70\mu m$) concentrations were monitored to verify the surface and subsurface presence of dispersed oil, and to track the size and movement of the subsurface plume. Previous controlled experiments conducted in the laboratory and an experimental wave tank facility has shown that effective oil dispersion is correlated with the presence of large number of small particles and high volume concentration of small particles. The particle size and distribution data obtained from the field monitoring program can be used to support operational decisions during the emergency oil spill response operations. Together with other field monitoring components, including UV fluorescence intensity, and hydrocarbon chemical analysis, during the Deepwater Horizon oil spill response operation, LISST data was used in environmental impact assessments and to support fate and transport modeling of dispersed oil.

INTRODUCTION

The Deepwater Horizon (DWH) blowout at the MC252 Macondo well site lasted nearly three months. To reduce the impact of the surface oil reaching sensitive coastal environments, chemical dispersant was applied through surface application and subsurface direct injection into the wellhead.

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The use of dispersant in the DWH oil spill response, particularly its direct injection into the leaking wellhead, was controversial (www.oilspillcommission.gov/) and treated with caution by the regulatory authorities. As a requirement of subsea dispersant use, the U.S. EPA and the U.S. Coast Guard issued dispersant monitoring and assessment directive for subsurface dispersant application (USEPA 2010), which provided a plume monitoring and assessment plan for subsurface dispersant application. The plan defined two criteria to determine operational shut-down of subsurface dispersant applications: (1) If there is significant reduction in dissolved oxygen from background to below 2 mg/l; or (2) The Rototox toxicity test reveals excessive exertion of a toxic response. To meet these requirements, it was essential to conduct real-time data acquisition and report to the Unified Command Centre. For a timely evaluation of toxicity intensity (LC_{50}) and the impact scale, it became crucial to detect, track and quantify the presence of a potential subsurface oil plume with or without the injection of oil dispersants as predicted by numerical models (Mezic et al., 2010). The resultant plume could also change subject to other operational conditions, such as containment, the daily fluctuation of leak rate of the oil and gas flow, and the underwater currents.

The current protocol for monitoring oil in water behavior during dispersant operation is described in the Special Monitoring of Applied Response Technologies (SMART) document (USCG et al. 2006). The SMART protocol consists of Tier I monitoring via visual observation, Tier II monitoring with measurement of oil concentration of the dispersed oil generated in the upper water column under dispersant treated slicks, and Tier III monitoring using advanced, state-of-the-art techniques. In the case of the Deepwater Horizon oil spill in the Gulf of Mexico, where oil dispersants were injected at the wellhead at a depth exceeding 1500 m, subsurface plume monitoring was required, but no established protocol was available that could be directly applied for the field monitoring process.

At the request of the U.S. government and BP, a research team from the Centre for Offshore Oil, Gas and Energy Research (COOGER), Fisheries and Oceans Canada participated within a multi-agency at-sea monitoring operation coordinated by the Unified Command. As part of the larger coordinated spill response operations, our primary objectives were: (1) To conduct LISST particle analysis at various intervals from surface to seafloor, (2) To use UV-fluorometry method to delineate dispersion of hydrocarbons, (3) To perform ongoing sampling and analysis to track the subsurface oil plume emanating from the blown-out Deepwater Horizon wellhead, and (4) To provide data promptly to verify plume modeling outputs by NOAA, and SINTEF, and others. This paper presents the methodology of LISST-100X particle analysis in the monitoring program to support the task of oil plume model verification.

Materials and Methods

Instruments

The dispersed oil droplet size distribution was conducted at s ea using L aser *In Situ* Scattering and Transmissometry instruments (LISST -100X, Type C , Sequoia Scientific Inc., Seattle, WA). The LISST-100X particle size analyzer is an optical device

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that measures light scattering intensity over a series of 32 detector rings. The light scattering pattern from the 32 detector rings is subsequently processed with manufacturer-provided inversion algorithm to automatically calculate volume concentrations (in µl/l) for 32 logarithmically spaced size bins from 2.5 to 500 µm, along with output of 10 other parameters including laser transmitted power, laser reference power in calibrated units, pressure, temperature, optical transmission, and beam - attenuation. The 32 particle size bins measured by the LISST100X are logarithmicall y spaced with the upper size of each bin 1.18 times the lower.
For bench -top measurement on board of a research vessel , a full -path small mixing chamber (Sequoia Scientific Inc., Seattle, WA) was installed in line with the optics of the standard path (5 cm) of LISST-100X. The chamber has a volume of 1 20 ml, with built-in magnetic stirrer, a djustable speed controller , power supply , and drainage port . The mixing chamber allowed the submersible LISST-100X to be used as a laboratory particle size analyzer.

Laboratory baffled flask testing

Source oil from the MC252 was used to conduct laboratory tests using the baffled flask test (BFT), a proposed replacement standard for U.S. dispersant effectiveness tests (Sorial et al. 2004a; Sorial et al. 2004b; Venosa et al. 2002) . The hydrodynamics of the baffled flask has been characterized (Kaku et al. 2006a; Kaku et al. 2006b) . The method has been used in numerous dispersa nt effectiveness testing (Chandrasekar et al. 2005; Clark et al. 2005; Ma et al. 2008; Sorial et al. 2004a; Sorial et al. 2004b; Venosa et al. 2002).

Three lab tests were conducted with the BFT to validate the feasibility of using the bench-top LISST-100X method in the field. The first test was performed using the standard BFT (Sorial et al. 2004b; Venosa et al. 2002) to compare the dispersed oil droplet size distributions of the MC252 source oil dispersion with and without use of chemical dispersant. The high o il-to-water ratio in this standard test was selected to investigate the behaviour of oil immediately around the wellhead. Due to the restriction of the upper detection limit of the LISST -100X in terms of the total number of particles and total volume conc entrations, the testing solution was first diluted by 5% before transfer into the full-path small mixing chamber for size distribution analysis.

The dispersed oil droplet size distribution for the standard BFT at three different dispersant-to-oil ratios (DOR) were performed for the MC252 source oil at standard oil - to-water ratio (0.1 ml oil in 120 ml of filtered seawater). For the two tests involving dispersant, the dispersant and oil were premixed by adding the required amount of dispersant to oil in glass vials sealed with Teflon-lined cap. The vial was then vigorously mixed by hand-shaking to ensure thorough homogenization of dispersant and oil. During the baffled flask testing, the oil or dispersant -in-oil mixture was added into filtered seawater, and the mixture was placed at the rotary shaker to shake at 150 rpm for 10 minutes. After shaking, the contents were allowed to stand on the bench top for 10 minutes. After a 10 -minute standing time, a few ml of the mixture was first discarded through the stopcock valve of the flask, and then 30 ml of the mixture was dispensed to a clean 50 ml beaker, from which 5 ml of the solution was transferred with a glass pipette

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to another clean baffled flask containing 95 ml filtered seawater. This step was taken to ensure that the suspended total particle concentration was within the detection range of the LISST-100X. The contents of this second flask were swirled gently to homogenize the droplets in solution. Caution was exercised to avoid further breaking up of oil in the homogenization process.

The second experiment was designed to evaluate the dispersion of oil at a much lower oil-to-water ratio that would be more likely to be encountered in the field due to magnitude of dilution expected during the at-sea operations. The nominal oil concentration used in this test was 50 μL/L. After shaking for 10 minutes in the baffled flasks, the contents were transferred to the mixing chamber to perform particle size distribution analysis. Dispersed oil droplet size distributions were compared for oil with and without chemical dispersants at two mixing energy levels, 150 rpm and 200 rpm, simulating those that may be encountered in the field.

The last baffled flask test was conducted to disperse oil in the presence and absence of chemical dispersant at the same low concentration level as was used in the second test. After dispersion of oil in the baffled flask at 150 rpm for 10 minutes, the dispersed oil-in-water solution was used in various dilutions for bench-top LISST-100X particle size distribution analysis. The standard curves of the measured total particle concentrations calculated in the total particle size distribution range (2.5 - 500 μm) and the small particle size distribution range (2.5 - 70 μm) were compared for dispersion with and without dispersant, respectively. This was used to validate the method that has been used in the field for small particle concentration analysis.

Field measurement and monitoring procedures

Two LISST-100X's were used on board the vessel; one in the lab and one *in situ*. The LISST-100X in the lab was equipped with a full-path small mixing chamber (120 ml) and was used to conduct bench-top particle size analysis in the lab on board research vessels. The samples were collected from the surface with a bucket and from different depths in the water column with Rosette Niskin bottles at each station. These samples were transferred into the small mixing chamber of LISST-100X for particle size distribution analysis. The small particle concentrations (SPC) were calculated based on the sum of the volume concentrations of the first 20 bins of the LISST-100X, corresponding to size range from 2.5 to 68.8 μm. The SPC were tracked as a surrogate for oil particle concentrations. The second LISST-100X was deployed in water beside the vessel approximately 3m below the surface for *in situ* monitoring of the dispersed oil from the surface waves and currents. The bench-top measurement was reported in this paper, and the *in situ* deployment data are reported elsewhere (JAG final report, in preparation).

Results and Discussion

Laboratory baffled flask tests

Figure 1 presents the dispersed oil droplet volume frequency and cumulative size distribution for the three DOR ratios applied in the first baffled flask test with higher oil concentration. At a high DOR of 1:25, the frequency distribution was presented as bimodal distribution, and the majority of the dispersed oil droplets are in the small and

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very small size ranges (Fig. 1A). The median diameter of the dispersed oil droplets was less than 3 μm. At a low DOR of 1:100, the frequency distribution (Fig. 1B) had a shape similar to that at high DOR, with some shift of the frequency distribution from very small sizes to small sizes. In the absence of dispersant (Fig. 1C), the frequency distribution indicates that the dispersed oil sizes were distributed throughout the entire size distribution range, with significant amount of large and very large droplets.

Figure 2 compares the total dispersed oil concentrations and the volume mean diameters of the dispersed oil droplets at three DORs generated by the baffled flask methods. The total dispersed oil concentrations were calculated using two different size ranges: the total particle concentration (TPC), which uses all LISST measurements from 2.5 to 500 μm, or only the first 20 intervals of small particle concentrations (SPC) which uses data from 2.5 to 70 μm. Althou gh in the absence of dispersant, the values for TPC was three times higher than that for SPC (Fig. 2A), the absolute value of TPC without dispersant (2%) were orders of magnitude lower than those dispersed in the presence of chemical dispersants (61%) (Fig. 2A).

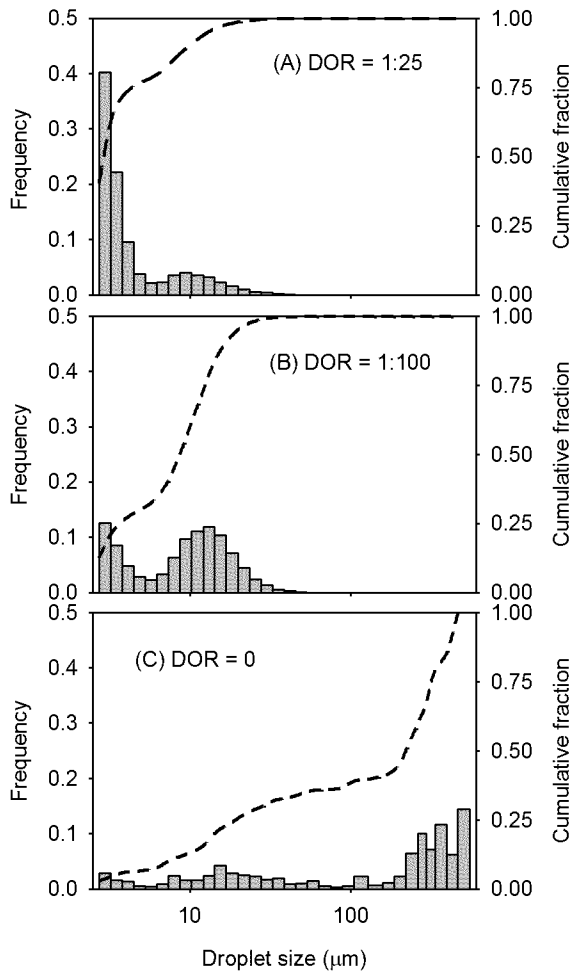

Figure 1: Dispersed oil droplet size distribution at three DORs: (A) 1:25; (B) 1:100; and (C) 0 (no dispersant control). Bars are volume size distribution frequency. Dashed lines denote cumulative volume size distribution.

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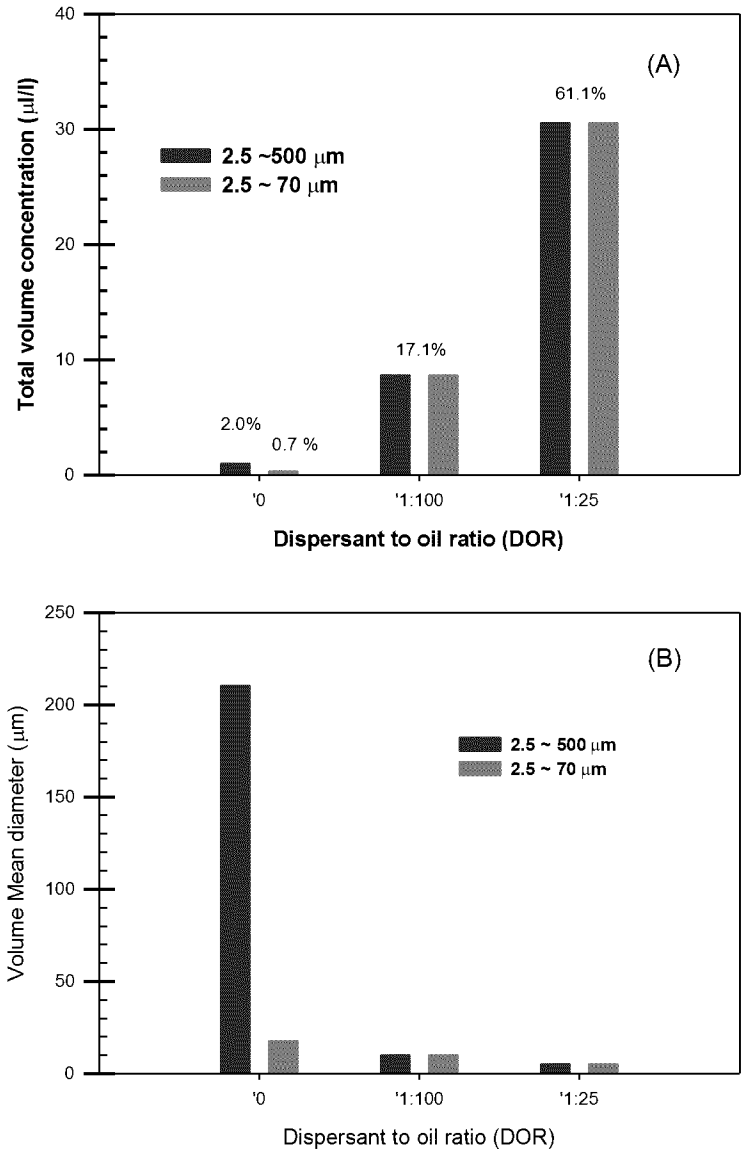

Figure 2: The total dispersed oil concentrations (A) and volume mean diameters (B) of the particle size distribution measured by using LISST-100X in the full particle size range (2.5 ~ 500) μm and in the small particle size range (2.5 ~ 70 μm).

Unlike physical dispersion alone, physical and chemical dispersion resulted in the same TPC and SPC because the majority of the chemically dispersed oil droplets were within the small particle size range as indicated by the steep rise of the cumulative fraction (dashed lines) in Figure 1A and 1B. It is worth noting that given the similar shape of droplet size distribution frequency (Fig. 1A, 1B), there was still a remarkable difference in the dispersed oil concentrations for low (17%) and high (61%) levels of DOR (Fig. 2A).

Figure 2 also presents the volume mean diameter of the dispersed oil droplet size distribution when the full particle size and the small size ranges were considered. For physical d ispersion only, because of the presence of relatively high amount of larger

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particles than the smaller ones, the VMD was greater than 200 μm when the full size range was compared. For chemical dispersion, however, the VMD was consistently lower than 20 μm in all conditions. Dispersion of oil at higher oil -to-water ratios may go through higher break -up and re -coalescence rates than dispersion at low oil concentrations. This is because the total amount of droplets is much higher at higher oil -to-water ratio than in the diluted low concentration system.

To investigate the effect of dispersant on dispersion of oil at low oil concentration in a diluted environment, a second group of BFTs was conducted to compare dispersed droplet size distribution at two DO Rs (no dispersant versus DOR of 1:25) and at two different mixing energy levels (150 and 200 rpm). Figure 3 presents the droplet size volume frequency distribution for the dispersion of oil at diluted low concentrations. At low concentration, the dispersi on of oil in the presence and absence of dispersant was carried out quite differently from the dispersion of oil at higher oil concentration, which is frequently used in the standard dispersant effectiveness test (EPA 1996; Sorial et al. 2004b; Venosa et al. 2002) . At a low mixing energy of 150 rpm, the dispersed droplet size frequency and cumulative distributions were similar in the presence and absence of chemical dispersant, both displaying a bimodal, log -normal distribution. The frequency of very small particles measured in the presence of dispersant (Fig. 3B) was higher than in its absence (Fig. 3A). At a high mixing energy of 200 rpm, however, the droplet size distribution of physical dispersion and chemical dispersion were remarkably different. Without dispersant, high mixing energy actually increased the relative portion of the large particles, suggesting that more rapid mixing may increase the collision frequency of dispersed oil droplets so that coalescence of small particles into larger ones occurs. With chemical dispersant, how ever, almost all the dispersed droplets fell within the first three size bins, indicating that chemical dispersion of low concentration oil at high mixing energy is very efficient in generating stable, exceptionally small particles of less than 10 μm.

Figure 4 summarizes the total volume concentration in the total particle concentration (TPC) and small particle concentration (SPC) range (Fig. 4A), and the volume mean diameter of the dispersed oil droplet size. These data show that for the dispersion of oil at low concentration, mixing energy played very important role in the overall dispersion efficiency. At 200 rpm, physical dispersion alone resulted in dispersion of oil at nearly 50%; together with chemical dispersant, the dispersion efficiency of oil reached almost 90%. At this low concentration level, calculation of the dispersed oil using the TPC and SPC resulted in very close values, indicating that the SPC can be used as a reliable surrogate of the total dispersed oil concentration in diluted system. This is also reflected by the volume mean diameter data shown in Figure 4B. All volume mean diameters (VMD) were less than 35 μm in the diluted system, regardless of whether the TPC or SPC were considered. In the presence of dispersant, i n particular, there was no difference in VMD calculation between TPC and SPC.

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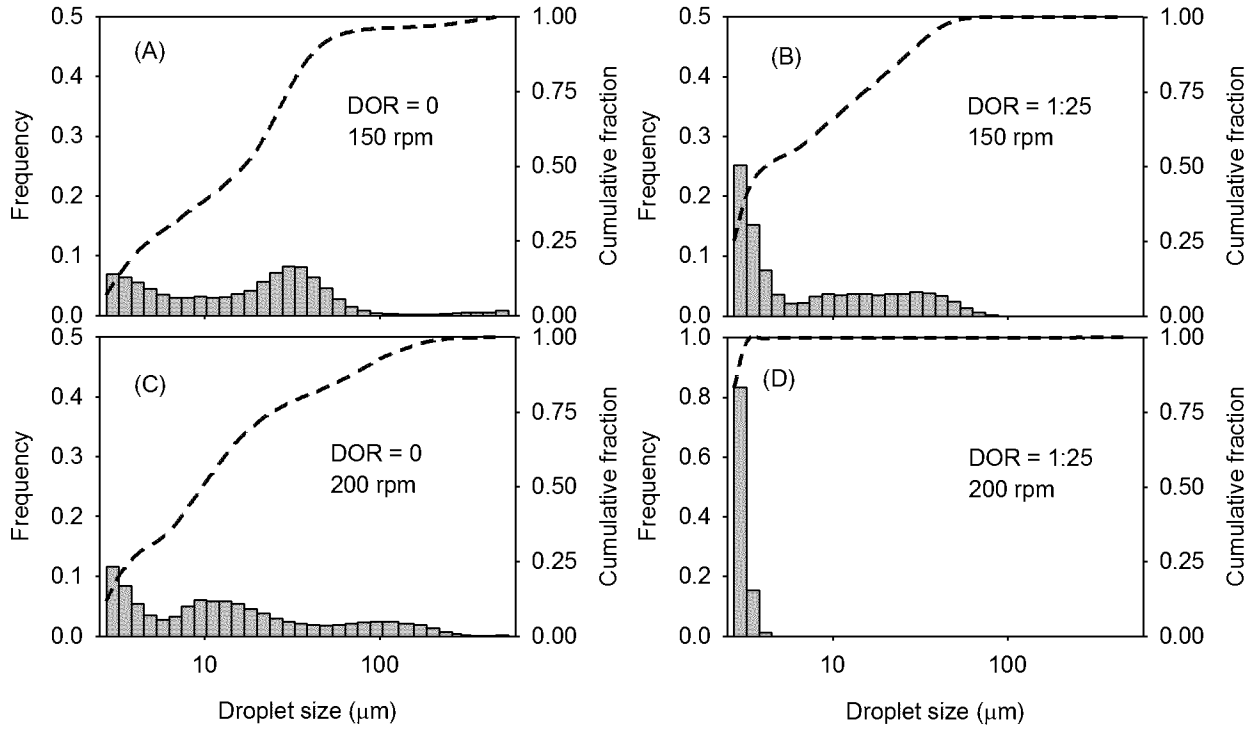

Figure 3: Dispersed oil droplet size distribution at two DORs and two mixing energy levels. Bars represent volume size distribution fr equency. Dashed lines denote cumulative volume size distribution.

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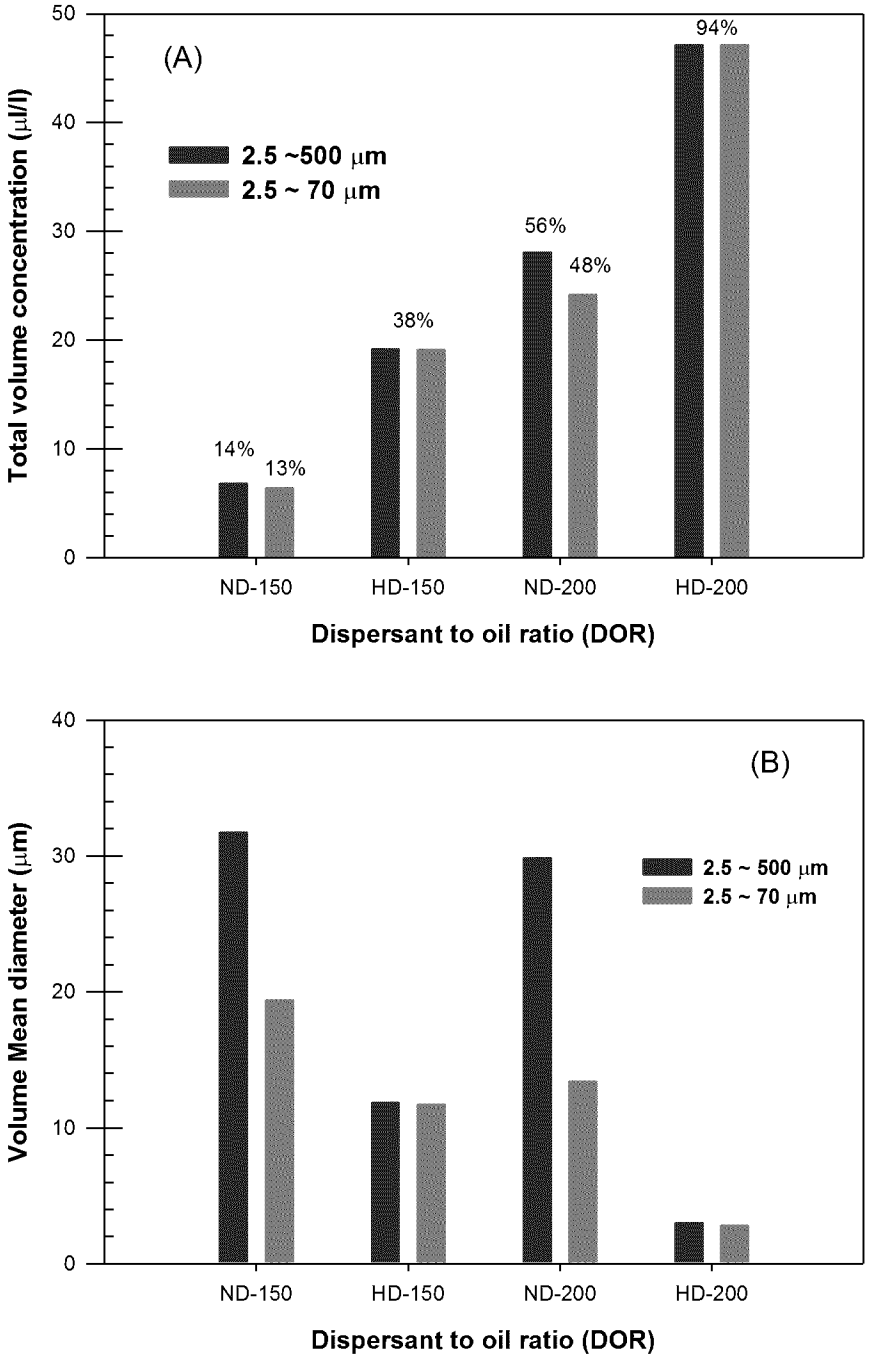

Figure 4: The total dispersed oil concentrations (A) and volume mean diameters (B) calculated from the particle size distributions measured by using LISST-100X in the full particle size range (2.5 ~ 500 μm) and in the small particle size (2.5 ~ 70 μm) at two DOR and two mixing energy levels (150 and 200 rpm). ND, no dispersant; HD with dispersant at DOR = 1:25.

To verify the LISST -100X bench -top mea surement of total dispersed oil concentration within a diluted system, we conducted another set of BFTs to generate calibration curves of the measured versus the nominal concentration of oil (determined by

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the amount of oil added to the seawater sample and the degree of dilution), and dispersed in the presence and absence of dispersant. Figure 5 illustrates the measured TPC and SPC for the diluted concentrations that were expected from our field measurements (see below). The graph shows that pretty good linear responses were reached for both dispersion conditions, and the response in terms of SPC was a very good indication of the TPC. This justifies our field monitoring protocol to focus on small particle concentrations in our daily report (see below).

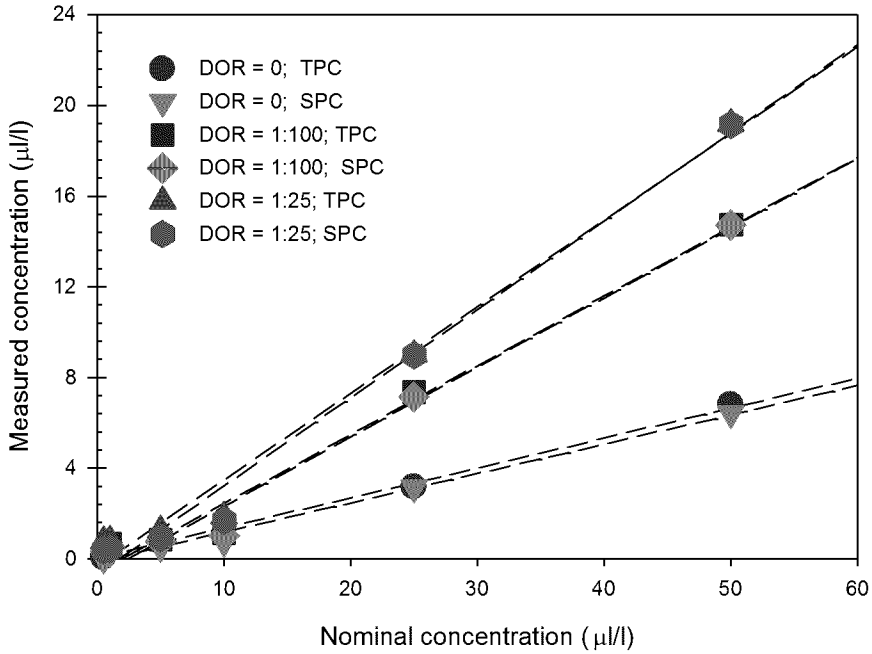

Figure 5: Evaluation of the bench -top LISST-100X measurements of dispersed oil concentrations in diluted environment in the presence and absence of dispersant. TPC denotes the total particle concentration; SPC repres ents small particle concentration.

Field monitoring

During nearly 4 month field operation, we have collected a total of 3,152 unique water samples from the surface to the seabed at 380 stations. Small particles (d < 70 µm) are considered more permanentl y dispersed oil in the water column, and SPC as a surrogate dispersed oil particle in the water were measured throughout the depth at each sampling station and reported each day.

There were two reasons why the bench -top LISST-100X analysis was chosen in the monitoring program, instead of conducting droplet size measurement by *in situ* deployment of the LISST -100X: (1) at an early stage in the oil spill response, the cable on the winch of our primary research vessel (R/V Brooks McCall) could only extend to a depth of 550 m, which was only one third the depth for reaching the seabed at the DWH site; (2) the LISST -100X instrument currently available on the market has a deployment limit of 300 m.

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The SPC were used to track the oil plume at subsurface for th ree reasons. First, dispersed oil droplets of size less than or equal to 70 μm were considered more permanently dispersed oil droplets in the water (Lunel 1993; Lunel 1995). Our wave tank dispersant effectiveness tests have repeatedly shown that most of the chemically dispersed crude oils have droplet sizes less than 70 μm (Li et al. 2008; Li et al. 2009). Physical dispersion of oil in our studies, however, constantly produced droplets larger than 70 μm. Second, the LISST -100X is an optical instrument. The particle size distribution is measured based on light intensity passing the emission and detection windows and is calculated using an inverse algorithm provided by the manufacturer. When used for ben ch-top analysis, the disagreement between water and air temperature can cause stratification of the water inside the small chamber, resulting in false representation of larger particles. Third, proper alignment of the instrument is critical for the reading of the inner ring, which reflects to the analysis of large particles. Even slight misalignment would result in false readings of several of the large particle intervals. To remove the artificially created readings that may be displayed from any slight misalignment caused by extended operation of the instrument at sea, we chose to focus on the small particle size ranges, which had less likelihood of false readings, regardless of the operational challenges.

Figure 6 summarizes the measured small parti cle concentrations for samples collected from the R/V Brooks McCall at 191 sites that extended from the wellhead out to a distance of 80 km. About 80% of the measured SPC values are below the method detection limit (MDL, 0.30 μl/l), suggesting the vast majority of the collected samples were near background levels. Among all the samples detected to be above the MDL, about 51% are from the surface samples (<10 m), 37% are from the plume samples (> 700 m), and the other 12% are samples from the middle layer (10 – 700 m).

The measured SPC decreased rapidly as a function of distance from the source at all three depths and reached to the MDL at 15 to 20 km from the wellhead (data not shown), indicating rapid dilution of the dispe rsed oil and possible removal of oil through biodegradation in the water column. Other spill response operations at the surface, including mechanical recoveries, and *in situ* burning, also contributed to some degree the mitigating of the spread of the surface oil slicks from the DWH spill site.

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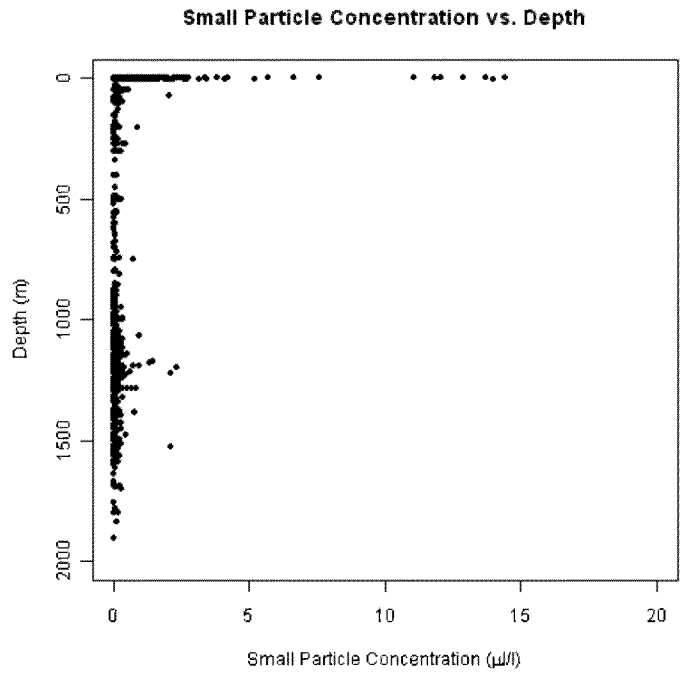

Figure 6: SPC from all samples collected from the R/V Brooks McCall

The SPC plotted as a function of time (data not shown) indicated the values were consistently low in the middle layer (10 – 700 m) all th e time. The SPC at the plume layer (> 700 m) were relatively higher around late May and early June. At the surface (0 – 10 m), the trend was not clear other than several peaks occurring in early May, late May to mid June, mid July, and mid August.

CONCLUSIONS

This paper describes a method for using the LISST-100X in a bench-top setup to measure dispersed oil concentration and the dispersed droplet size distribution. The small particle concentration (SPC) was used as a surrogate measurement of the dispersed total particle concentrations (TPC) that may be encountered in field monitoring of the dispersed oil concentration, especially from the subsurface dispersed oil plume.

The method was evaluated through conducting several laboratory baffled flask tests by using the DWH source oil and Corexit 9500 dispersant. In the oil dispersion experiment conducted using standard baffled flask test protocol at relatively high oil to water ratio, adding dispersant at different DORs proved to have drastic effects on the dispersed oil droplet size distribution and the total dispersed oil concentration. Chemical dispersion at DOR of 1:25 produced the highest number of small particles, and relatively high overall dispersion efficacy. Adding dispersant at a DOR of 1:100 also produced significant amounts of small particles, and resulted in moderate dispersion efficiency that was much lower than that at DOR of 1:25. Very low dispersion effectiveness was achieved for the no-dispersant control of the standard baffled flask tests.

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The BFT was also used to investigate the dispersion of the source oil under diluted low concentration conditions that are more likely to be encountered in the field. This set of experiments indicates that dispersion of the diluted oil in seawater was largely dependent on the mixing energy. High mixing energy at 200 rpm was associated with relatively high dispersion efficiency of oil for both physical and chemical dispersion. Lower mixing energy at 150 rpm resulted in much lower dispersion efficacy of oil. The baffled flask testing results demonstrate that the SPC was a good surrogate of the total dispersed oil concentration in the water at diluted, low concentrations in the environment.

Preliminary analysis of the field data obtained using SPC as a surrogate of dispersed oil concentration was presented to illustrate the application of the developed method. The SPC was analyzed to measure the dispersed oil concentrations at the surface and in the subsurface water column in the field. The positive correlation of SPC and UV fluorescence intensity suggests that the measured SPC can be attributed to hydrocarbons in seawater. Field measurement of SPC can provide prompt information that is required in guiding emergency oil spill response operations. The post-event evaluation of the data may also support fate and transport modeling of the dispersed oil, and the evaluation of the chemical dispersant effectiveness in field applications.

ACKNOWLEDGEMENTS

The authors wish to thank Scott Ryan for analyzing the massive field data, Xiaowei Ma for conducting laboratory baffled flask experiments for evaluating the method, and all the staff of COOGER who diligently participated in the field sampling and monitoring program during the Deepwater Horizon oil spill emergency response. We acknowledge tremendous support provided by the captains and all crew members of the Research Vessels *Brooks McCall* and *Ocean Veritas*. This field monitoring program during the emergency oil spill response operation was sponsored by BP and the U.S. Environmental Protection Agency.

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To: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Fri 7/15/2016 6:40:00 PM
Subject: FW: Two Interesting Papers from AMOP
Countermeasures AMOP 2016.pdf
Canada Dilbit Training AMOP 2016.pdf

The first one is the paper Kurt had mentioned last week I had asked to send our way.

-----Original Message-----
From: Hansen, Kurt A CIV [mailto:Kurt.A.Hansen@uscg.mil]
Sent: Friday, July 15, 2016 2:33 PM
To: steve.lehmann@noaa.gov; ed.levine@NOAA.gov; Conmy, Robyn <Conmy.Robyn@epa.gov>; scott.lundgren@noaa.gov; Principe, Vanessa <Principe.Vanessa@epa.gov>
Subject: Two Interesting Papers from AMOP

I may be sending more out as I relook over the proceedings.

Kurt A. Hansen, P.E.
U.S. Coast Guard Acquisition Directorate Research & Development Center
(860) 271-2865

MARINE WELL CONTAINMENT COMPANY

April 21, 2015

Mr. Carmine Dulisse
Health Safety Environment Officer
Marine Well Containment Company
400 N. Sam Houston Parkway, East
Houston, Texas 77060

U.S. Environmental Protection Agency
EPA Docket Center (EPA/DC)
1200 Pennsylvania Avenue NW 20460

RE: Docket ID No. EPA-HQ-OPA-2006-0090

Dear Dr. Gregory Wilson:

Thank you for the opportunity to provide comments to the Environmental Protection Agency's (EPA or the Agency) proposed rulemaking that would amend Subpart J of National Oil and Hazardous Substances Contingency Plan.

Marine Well Containment Company (MWCC) is an independent company with headquarters in Houston, Texas. Founded in 2011, MWCC is a leader in well containment response and provides well containment equipment and technology in the deepwater U.S. Gulf of Mexico. The company's mission is to be continuously ready to respond to a deepwater well control incident in the U.S. Gulf of Mexico. MWCC has ten member companies and represents unprecedented industry collaboration. On behalf of its members, MWCC maintains a stockpile of 200,000 gallons of dispersant (Corexit 9500A) for subsea use, subsea dispersant injection equipment and a dispersant application monitoring kit.

MWCC supports the comments submitted by API and its members relative to the use of dispersants as a tool for oil spill response. Below, MWCC has outlined its concerns broadly as it relates to the proposed rule as additional considerations.

MWCC recommends that the Agency consider these comments as they relate to safe, timely and effective response.

Subsea Dispersant Use

Dispersant is a critical tool in a well containment response. For offshore responses, subsea dispersant is used to provide operational safety at the incident site in addition to its potential role in minimizing environmental damages. Application of subsea dispersant allows responders to position themselves above the well to perform the work of clearing debris, assessing the damage, and capping the well. Without vertical access to the well the job of stopping the flow of oil can become significantly more complicated and consume much more time, resulting in significantly more harm to the environment. Application of dispersant during Deepwater Horizon was effective in minimizing oil at the surface in the vicinity of well containment operations, allowing work to be safely conducted with minimal exposures to personnel from Volatile Organic Compounds (VOC's) and from risk of fire or explosion from hydrocarbons in the atmosphere.

As written, this proposed rulemaking could make MWCC's current stockpile of dispersant unavailable, along with all major dispersant inventories. Any rulemaking must ensure an adequate inventory of dispersant is maintained as a tool available to responders, otherwise there may be significant negative environmental impacts and a negative impact to the ability to contain an uncontrolled offshore well. To illustrate the potential implications, consider this hypothetical scenario as a comparison point.

Most wells drilled today are designed to be capped using a capping stack. It is possible to have a cap at the site ready for installation in less than a week and provided the site is clear of debris with clean access to one of three previously identified connection points – it can be installed in 1-2 days after arrival. If one uses a hypothetical case of 40,000 barrels of oil per day, the total oil released if the well is capped in 2 weeks would be on the order of 560,000 barrels. Provided the application of dispersant is an option in the response scenario, a large portion of that 560,000 barrels of oil could be treated with dispersant, minimizing the potential impact on the safety of surface operations and the significant potential value it holds as a tool in a Net Environmental Benefit Analysis (NEBA).

If dispersant is not applied during this same well control event, the scenario can be impacted in one of two ways:

1. Delays resulting from VOC and LEL (Lower Explosive Limit) thresholds being reached can be expected to lengthen response times. The amount of delay cannot be forecasted as it will be dependent on a variety of factors such as the type of oil, depth of water, currents, and local weather.

2. If VOC's and LEL problems are too significant to allow capping operations to be carried out in proximity to the well, the only remaining option may be to drill a relief well which could take months to complete.

In this scenario both of these alternative methodologies result in delays to capping the well with an impact of an additional 40,000 barrels of oil per day. None of that oil

would be treated with dispersant, which has been proven to be effective in making the oil available to bacteria to speed the natural degradation processes. Consequently, oil will persist in the environment for a longer period of time, representing a safety risk to operational personnel at the surface trying to stop the flow of oil and creating greater personnel risk that must be managed for those responders involved in the spill response side of operations.

Hypothetical impacts of delays

Totals at 40,000 barrels per day	
14 Days	560,000
60 Days	2,400,000 Barrels

Dispersant Formula, Testing and Storage

MWCC opposes any rules that could effectively remove Corexit 9500A from the NCP Product Schedule. While we are not opposed to evolving the science surrounding dispersants and their application, the testing protocols as written could make all major stockpiles of dispersant unavailable for use in a response. We believe any changes to the approved list of dispersants on the NCP Product Schedule should have language that ensures an appropriate replacement is available, capable of meeting standards of safety and effectiveness, and able to be produced in sufficient quantities to meet industry needs. We also believe that sufficient time (grandfathering) must be provided to allow replacement of existing stockpiles.

Testing and storage requirements as written fail to recognize that stockpiles of dispersants today have been maintained appropriately and do not require a maximum shelf life as long as manufacturers testing and maintenance instructions are followed. Any requirement here should only be to follow the guidance provided by the manufacturer in testing and maintenance of the dispersant. The role of the regulator should be to see that industry is following that. Stipulating shelf life or prescriptive maintenance and testing protocols for a variety of different dispersants and future formulations only places the federal government in the position of writing regulations that are prescriptive and quickly become outdated as technology advances.

Response Coordination

Dispersants are applied when response decision-makers consider it required/beneficial to the overall response. The Net Environment Benefit Analysis (NEBA) process provides

a structured framework for collaboration from which response decision-makers can consider response scenario specifics and the trade-offs associated with environmental actions. MWCC maintains that new rules should not discourage, nor impede the FOSC's ability to make an informed, timely decision through the NEBA process.

With regard to authorization for agent use (Section § 300.910), MWCC believes that agency cooperation and decision-making flexibility are critical in a response. Preauthorization planning should not limit the option to use dispersants by response leadership. Setting arbitrary limits on the quantity and duration of use of dispersant limits the FOSC's ability to take into account specifics of the response scenario, necessarily inhibiting or impeding field commanders from making good sound decisions on the front lines because of prescriptive rules. Good tactical decision-making requires field commanders to have flexibility. MWCC supports the FOSC's ability to use their judgement in these situations.

Dispersant Monitoring

The Proposed Rule has additional dispersant effectiveness monitoring requirements beyond what is required in current practice. In principle, any additional requirements for response monitoring should delineate between near-term operational assessment and long-term Natural Resource Damage Assessments. Operational assessment is primarily concerned with providing information about how response options are mitigating the spill's effects on the health and safety of response personnel and the environment. For maximum effectiveness during a response, decision-making should be streamlined. Guidelines that are intended to incorporate both situations will likely bog down decision-making.

MWCC maintains a dispersant monitoring kit with the objective of informing operational decision making. MWCC utilized API Technical Report 1152, *Industry Recommended Subsea Dispersant Monitoring Plan – Version 1.0* as the basis for the approach for operational monitoring. The additional monitoring requirements imposed by this rule do not improve real-time operational decision making.

Cost of Proposed Rule

The Agency's estimated increase in cost to implement the Proposed Rule ($668,000) is greatly underestimated. MWCC purchased a stockpile of Corexit 9500A to meet the expectations of the Bureau of Safety and Environmental Enforcement (BSEE) that industry have dispersant equipment and a dispersant stockpile. The Agency's analysis fails to consider the replacement costs of existing stockpiles, such as MWCC's. If Corexit is removed from the NCP Product Schedule, MWCC estimates it would incur a loss of more than $8 million in the first year for its existing stockpile. The 200,000 gallon

stockpile could potentially become a waste with a disposal cost associated with it, and a replacement stockpile would have to be developed, and purchased at a cost expected to be greater than the current stockpile cost. In addition, any shelf life rules have to be factored into the cost equation. This example is for one company.

We thank you for the opportunity to comment and encourage more dialogue on these issues before a final decision is made. We are always available to educate on how well containment is conducted and the role dispersants would play in a response.

To: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Mon 2/8/2016 6:55:48 PM
Subject: Transmital to R10 - ARRT Preauthorization Plan Comments/Summary
Latest Comments on
ACTION - For Review and Transmital to R10 - ARRT Preauthorization Plan Comments/Summary

The two emails I found. One from me sending "OEM5" version to Craig, and the second from Craig to R10 with the comments, and his renaming of the file "OEM6" (he might have changed/added some comments).

To: Matthiessen, Craig[Matthiessen.Craig@epa.gov]
Cc: Wilson, Gregory[Wilson.Gregory@epa.gov]; Jennings, Kim[Jennings.Kim@epa.gov]
From: Principe, Vanessa
Sent: Tue 9/10/2013 7:21:56 PM
Subject: ACTION - For Review and Transmital to R10 - ARRT Preauthorization Plan Comments/Summary
ARRT Authorization OEM Comment Summary.docx
ARRT Dispersant Authorization Plan_Draft 8-27-13_OEM5.doc

Craig:

Attached are the revised Preauthorization Plan draft with comments, and a revised summary of comments that we think should also be sent to R10.

We have provided significant comments in the past that have highlighted our concerns of the broader implications of the approach the ARRT is taking. We believe the message should be sent that while OEM agreed to support their approach in establishing their preauthorization in this manner, our comments and edits on this version need to be incorporated and/or addressed in order for that agreement to stand. We should reserve the right to revisit our support if we feel uncomfortable that our comments have been addressed, especially since these comments have serious policy and legal implications beyond Alaska.

Further, we did not make a distinction between our and OGC comments. We checked with Jim and he was ok in saying that these were OEM/OGC comments, We believe there is a better chance they take the comments if they are presented to USCG in that manner.

Lastly, it should be emphasized that while they have sought input from HQ, this preauthorization approach is their responsibility.

We believer these are important points to be made to the EPA ARRT representatives.

Thanks for listening, G & V

To: Field, Chris[Field.Chris@epa.gov]
Cc: Jennings, Kim[Jennings.Kim@epa.gov]; Wilson, Gregory[Wilson.Gregory@epa.gov]; Principe, Vanessa[Principe.Vanessa@epa.gov]; Runge, Roberta[Runge.Roberta@epa.gov]; Tulis, Dana[Tulis.Dana@epa.gov]; Stanton, Larry[Stanton.Larry@epa.gov]
From: Matthiessen, Craig
Sent: Tue 9/17/2013 3:25:32 PM
Subject: Latest Comments on
ARRT Authorization OEM Comment Summary.docx
ARRT Dispersant Authorization Plan_Draft 8-27-13_OEM6.docx

Chris;

My apologies for the delay in getting this to you. Here are our comments on the latest version with a companion summary that lifts up some perspectives for situational awareness. Regards - Craig

ANNEX F

APPENDIX I: ALASKA REGIONAL RESPONSE TEAM OIL DISPERSANT AUTHORIZATION PLAN

This document is also available on the Alaska Regional Response Team website at:

http://alaskarrt.org/

or at the Alaska Department of Environmental Conservation website at:

http://dec.alaska.gov/spar/perp/plans/uc/Annex%20F%20(Jan%2010).pdf

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Alaska Regional Response Team

Oil Dispersant Authorization Plan

Revision 1

(Photo: M/V Golden Seas being towed to a Place of Refuge, December 2010)

Insert month/year here and substitute a photo of dispersant use during the Exxon Valdez Oil Spill

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1.0 BACKGROUND AND OVERVIEW

1.1 Introduction

The purpose of the Alaska Regional Response Team (ARRT) Oil Dispersant Authorization Plan is to outline the process to be used following an oil discharge in Alaska when dispersant use is being considered in a Preauthorization Area or in an Undesignated Area. In addition, this plan streamlines and facilitates the dispersant use authorization process and establishes a Preauthorization Area for Alaska, and provides a framework to further identify areas where dispersant use should be avoided.

The previous statewide guidelines and guidelines specific to Cook Inlet were approved by the ARRT in April 1986. Specific guidelines for Prince William Sound were approved by the ARRT on March 6, 1989. This plan, which was approved by the ARRT on _____, supersedes all previous statewide and area-specific dispersant guidelines/plans. In effect for all marine waters in Alaska[1], this plan is subject to periodic review and update by the ARRT.

1.2 Background

The capability to respond to an oil discharge in Alaska can be hampered by great distances, underdeveloped transportation networks, limited labor force, finite mechanical spill cleanup technology, severe weather, and other conditions. The use of dispersants may provide a response tool in addition to mechanical recovery and *in-situ* burning. See Figure 1 for a conceptual marine spill response decision chart.

Dispersants are chemical agents consisting of surfactants, solvents, and other compounds specifically designed to enhance dispersion of oil into water by generating larger numbers of small droplets of oil that are entrained into the water column by wave or tidal action. These small submerged oil droplets are then subject to natural processes, such as dissolution, volatilization, biodegradation, and sedimentation. Oil spill dispersants do not actually reduce the total amount of oil in the environment. Rather, they may change the inherent characteristics of the dispersed oil, thereby changing the oil's transport, fate, and potential effects.

As noted by the National Academy of Sciences[2] review of ongoing research on the use of dispersants as an oil spill response technique and the impact of dispersed oil on marine and coastal ecosystems, there are many uncertainties regarding the efficacy [effectiveness] and toxicity of dispersant use. Decisions to use dispersants involve trade-offs between decreasing the potential risk to water surface and shoreline habitats while increasing the potential risk to organisms in the water column. This trade-off reflects the complex interplay of many variables,

[1] For the purposes of this document, "marine waters in Alaska" is defined to include all waters beginning at the mean lower low tide along the Alaska shoreline outward to the 200 mile Exclusive Economic Zone.

[2] Oil Spill Dispersants Efficacy and Effects. 2005. National Academy of Sciences, available at: http://dels.nas.edu/resources/static-assets/materials-based-on-reports/special-products/oil_spill_dispersants_key_findings_final.pdf

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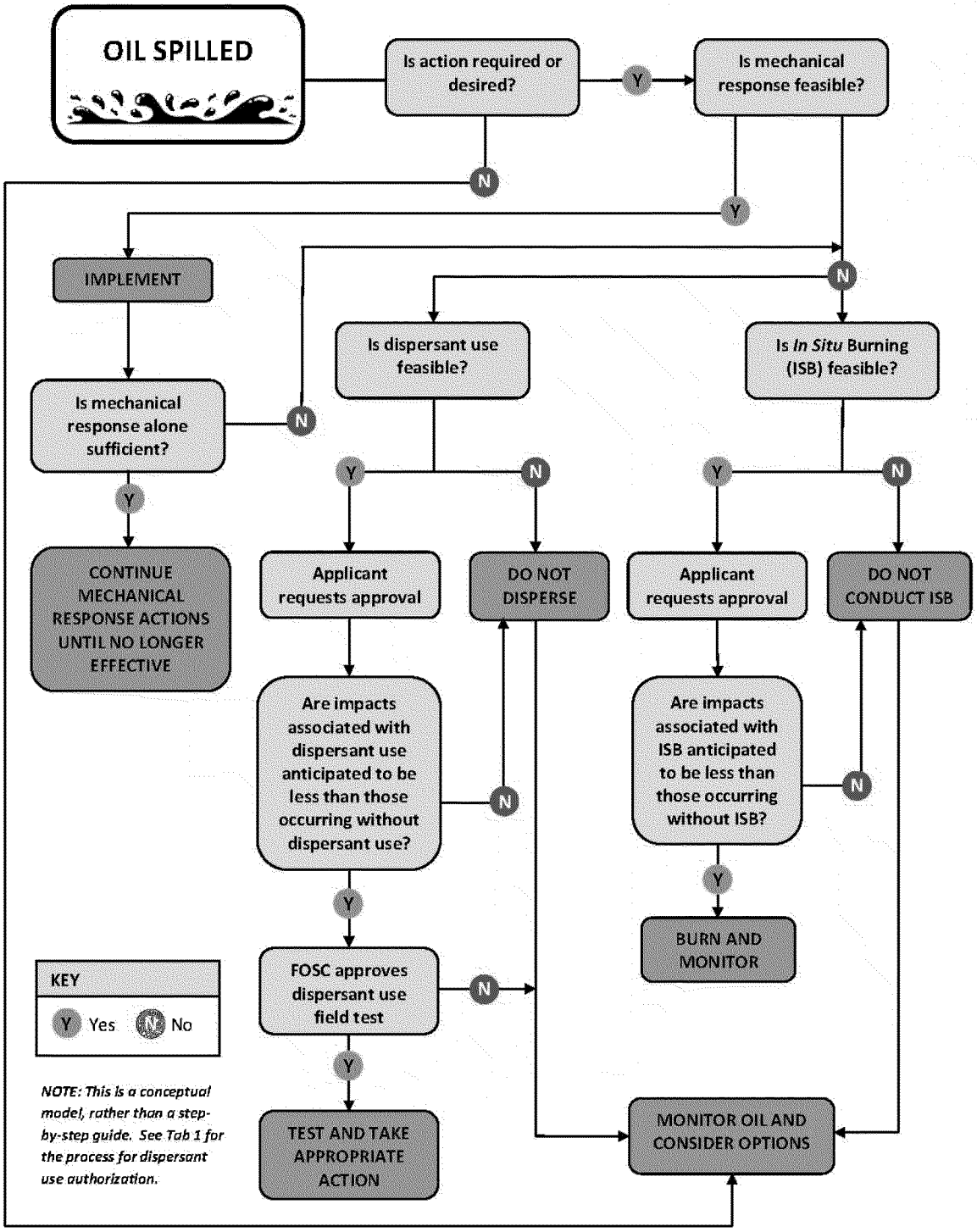
Figure 1. Conceptual Marine Spill Response Decision-Making



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including, but not limited to, the type of oil spilled; the volume of the spill; sea state and weather; water depth; water temperature; water salinity; degree of turbulence; presence, relative abundance, and life stages of potentially-affected wildlife and marine organisms; and the use of those resources. Prior to authorizing dispersant use in marine waters in Alaska, the FOSC needs to consider factors including, but not limited to, valuable commercial, subsistence, and recreational fisheries, as well as large and important populations of birds and marine mammals, including threatened and endangered species.

Key questions to consider during the dispersant use decision-making process include:

- Will the selected dispersant work effectively on the oil discharged and in the given circumstances?
- Can the dispersant be effectively applied to the oil?
- What are the environmental trade-offs of dispersant use and do they support the use of the dispersant in a given circumstance?

As stated in a May 2012 Government Accountability Office report, "Every oil spill is different, and the conditions—such as weather, oil type and volume, currents, and location—surrounding any unanticipated release of oil into the ocean are highly variable. Given this variability, no one study can account for all the potential permutations."[3]

1.3 Dispersant Use Authorizations

This document constitutes a dispersant use preauthorization plan and a case-by-case dispersant use authorization process in accordance with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) - Subpart J (Section 300.910). This plan is included in Annex F of *The Alaska Federal/State Preparedness Plan for Response to Oil and Hazardous Substance Discharges/Releases (Unified Plan)*.

Subpart J Section 300.910 of the NCP addresses the concurrence and consultation requirements for dispersant use authorizations. Specifically, it addresses dispersant use decision-making in the following circumstances:

- In accordance with the NCP - Subpart J (Section 300.910(a)), the [Federal] On-Scene Coordinator (OSC) may authorize the use of certain products without obtaining spill-specific concurrences under specified circumstances described in the preauthorization plan where the U.S. Environmental Protection Agency (EPA) Regional Response Team (RRT) representative, the state with jurisdiction over the waters of the area to which a preauthorization plan applies, and the U.S. Department of the Interior (DOI) and U.S. Department of Commerce (DOC) natural resource trustees approve the preauthorization plan in advance[4].

[3] Oil Dispersants: Additional Research Needed, Particularly on Subsurface and Arctic Applications. 2012. U.S. Government Accountability Office. A Report to Congressional Requestors. GAO-12-585.

[4] In Alaska, the natural resource trustee authorities are vested in the DOI and DOC ARRT representatives; state authorities for oil spil response are vested in the Alaska Department of Environmental Conservation ARRT representative.

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- In accordance with the NCP - Subpart J (Section 300.910(b)), for spill situations that are not addressed by the preauthorization plan, the [Federal] OSC, with concurrence of the EPA representative to the RRT and, as appropriate, the concurrence of the RRT representative from the state with jurisdiction over the navigable waters threatened by the release or discharge, and in consultation with the DOI and DOC natural resource trustees, when practicable, may authorize the use of dispersants on oil discharges provided that the products are listed on the NCP Product Schedule[5].

- In accordance with the NCP – Subpart J (Section 300.910(d), the [Federal] OSC may authorize the use of any dispersant without obtaining the concurrence of the EPA representative to the RRT and, as appropriate, the RRT representative from the state with jurisdiction over the navigable waters threatened by the release or discharge, when, in the judgment of the [Federal] OSC, the use of the product is necessary to prevent or substantially reduce a hazard to human life. In that case, the [Federal] OSC is to inform (as soon as possible) the EPA RRT representative and, as appropriate, the RRT representative from the affected state and, when practicable, the DOI and DOC natural resource trustees[6] of the use of a product, including products not on the NCP Product Schedule. Once the threat to human life has subsided, the continued use of dispersant must follow the approval process described in Section 300.910(a) or (b).

1.4 Dispersant Areas

Preauthorization Area

The Preauthorization Area for Alaska is shown on Figure 2 and is described as follows: Commencing at Cape Suckling in position 59-59.35N 143-53.49W, then proceeding south to 200 nautical miles offshore to position 56-18.00N 144-00.00W, then proceeding westerly along the 200 nautical mile EEZ line until it intersects with the maritime boundary line (MBL) in position 51-21.49N 167-40.44W, then proceeding northeast along the MBL to position 54-54.00N 171-58.50W, then proceeding easterly remaining 100 nautical miles offshore to position 55-45.00N 167-00.00W, then proceeding southeasterly to Cape Sarichef in position 54-35.90N 164-55.65W, then proceeding northwesterly directly to 24 nautical miles offshore to position 54-52.43N 165-26.00W, then proceeding westerly remaining 24 nautical miles offshore following along the entire Aleutian Islands chain rounding Attu Island counter clockwise and entering the North Pacific Ocean, then proceeding eastward along the southern coast of the Aleutian Islands and south of the Shumagin Islands into the Gulf of Alaska and along the eastern coast of the Kodiak Archipelago, then proceeding south of the Kenai Peninsula and Prince William Sound until reaching position 59-29.00N 144-03.00W, and then proceeding north connecting to Cape Suckling in position 59-59.35N 143-53.49W. The Preauthorization Area excludes any avoidance areas identified in their respective SCPs.

[5] In Alaska, the natural resource trustee authorities are vested in the DOI and DOC ARRT representatives; state authorities for oil spill response are vested in the State On-Scene Coordinator.

[6] In Alaska, the natural resource trustee authorities are vested in the DOI and DOC ARRT representatives

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This Preauthorization Area ensures that the USCG can require certain vessel and facility response plan holders in Alaska to maintain a minimum dispersant use capability in accordance with a USCG August 31, 2009 rulemaking, 33 CFR Parts 154 and 155 "Vessel and Facility Response Plans for Oil: 2003 Removal Equipment Requirements and Alternative Technology Revisions; Final Rule (Final Rule)." This includes tank vessels that carry crude oil and stop at one or more U.S. ports at some point during their transit.

The boundaries of the Preauthorization Area were based on the location of common shipping routes followed by crude oil vessels regulated under the Final Rule, with a buffer zone of 24 nautical miles offshore. The 24 nautical mile boundary corresponds to the U.S. contiguous zone (a feature commonly depicted on nautical charts), excludes nearshore sensitive areas from the Preauthorization Area. The boundaries reflect the findings from the Endangered Species Act (ESA) Section 7 consultation(s) with U.S. Fish and Wildlife Service and/or National Marine Fisheries Service (NMFS) representatives conducted prior to the approval of this plan in accordance with the ESA Memorandum of Agreement (see Annex G of the Unified Plan)

This Preauthorization Area overlaps offshore areas included in several subarea contingency plans (SCPs), i.e., the Prince William Sound, Cook Inlet, Kodiak Island, Bristol Bay, and Aleutian Islands SCPs. Following approval of this plan by the ARRT, the appropriate USCG Federal On-Scene Coordinator (FOSC), EPA FOSC, and Alaska Department of Environmental Conservation (ADEC) State On-Scene Coordinator shall engage federal and state natural resource trustees, federally-recognized tribes, and stakeholders in a process to identify locations where dispersant use should be avoided within the Preauthorization Area where the Preauthorization Area overlaps their respective SCP. Any identified locations shall be included in Section I (Dispersant Use Avoidance Areas) of each SCP and posted online (see http://alaskarrt.org/Documents.aspx?f=175). This process shall be completed within 24 months following ARRT approval of this plan. Any avoidance area identified in the identified subarea contingency plans shall no longer be considered part of the Preauthorization Area for dispersant use and shall be automatically reclassified as an Undesignated Area that follows the Case-by-Case process outlined in Tab 1, Part 1B.

Undesignated Areas

Undesignated Areas include all marine waters in Alaska outside of the Preauthorization Area. These Undesignated Areas overlap offshore areas included in several SCPs as noted above. Following approval of this plan by the ARRT, the appropriate USCG FOSC, EPA FOSC, and ADEC SOSC shall engage federal and state natural resource trustees, federally-recognized tribes, and stakeholders in a process to identify locations where dispersant use should be avoided within the Undesignated Areas where the Undesignated Areas overlap their respective SCP. Any identified locations shall be included in Section I (Dispersant Use Avoidance Areas) of each SCP and posted online (see http://alaskarrt.org/Documents.aspx?f=175).

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Figure 2. Preauthorization Area

[Insert figure here]

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2.0 DISPERSANT USE POLICIES, CRITERIA, AND CONDITIONS/STIPULATIONS

2.1 Policies

The following policies shall be followed whenever dispersant use is considered and/or authorized:

- The primary method for response up oil will be the mechanical removal of oil.
- The use of dispersants may provide an alternative response tool when conditions prevent using mechanical recovery and/or *in-situ* burning.
- Dispersant delivery in a mechanical recovery area will not displace or interfere with mechanical or other response operations.
- All requests for dispersant use, including the appropriate process in Tab 1.
- Prolonged applications of dispersants that exceed 96 hours, or subsea applications are not preauthorized.
- All input related to dispersant use authorizations will be provided to the FOSC within the timeframe requested by the FOSC. The FOSC will provide sufficient time for relevant input related to dispersant use authorization.
- The preauthorization of dispersant use (inside the Preauthorization Area) only applies to crude oil. Requests for dispersant use for any other type of oil (e.g., diesel fuel, jet fuel, intermediate fuel oils, bunker oils) will be considered using the Process for Case-by-Case Dispersant Use Authorization in Tab 1, Part 1B.
- Decisions regarding the use of dispersants will be based on an incident-specific evaluation of whether the selected dispersant will work effectively on the oil discharged, if the dispersant can be effectively applied to the oil, and the trade-offs associated with the potential impacts of dispersants, dispersed oil, and non-dispersed oil on the environment and human-use areas, including when compared to other response options. The evaluation of trade-offs will consider the criteria identified below in Section 2.2. All decisions will be documented including the methods used.
- One or more dispersant application field tests to determine the effectiveness of oil dispersion under existing site-specific environmental conditions will be conducted. The resulting information will be analyzed to determine whether full-scale dispersant application(s) will begin. A dispersant application field test is defined as one aircraft sortie or one vessel-based application swath.
- Any prolonged use of dispersants (i.e., full scale dispersant application ongoing for, or expected to exceed or exceeding, 96 hours following initial dispersant application or any use of dispersants subsea (i.e., below the water surface), whether in a Preauthorization Area or in an Undesignated Area, will only be considered using the Process for Case-by-Case Dispersant Use Authorization in Tab 1, Part 1B.
- All dispersant applications (including field tests) will include effectiveness monitoring as outlined in the Special Monitoring of Applied Response Technologies (SMART) Tier 1, Tier 2, and Tier 3 protocols (see Tab 4, Part 1). In the event SMART Tier 2 and Tier 3

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monitoring is not operationally feasible in the Preauthorization Area, the request for dispersant use or continued use will be considered via the Process for Case-by-Case Dispersant Use Authorization in Tab 1, Part 1B.

  - Monitoring for effectiveness of dispersant use and any other factors (or "key indicators") established by the FOSC in consultation with the EPA, DOI, and DOC ARRT representatives and, when appropriate, the State On-Scene Coordinator (SOSC), will be conducted by a qualified third party (who is acceptable to the Unified Command and the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC) or by the USCG Strike Team/SMART Team. All SMART Tier 1, 2, and 3 monitoring will be performed in accordance with procedures in the most current SMART protocols (see Tab 4, Part 1).

- For every dispersant application, the FOSC will ensure that all required monitoring is conducted. The resulting information will be analyzed and used on a daily basis to determine whether dispersant application(s) will continue, be postponed, or cease and whether any modification(s) need to be made.
- Environmental monitoring for atypical dispersant application (e.g., prolonged [>96 hours] surface, subsea) will be guided by the NRT "Environmental Monitoring for Atypical Dispersant Operations" (see Tab 4, Part 2).
- All monitoring that includes sampling will be conducted in accordance with a Quality Assurance Project Plan that addresses sample collection methodology, handling, chain of custody, and decontamination procedures (see Tab 4, Part 2, Section 4).

2.2 Criteria

The following criteria will be considered in dispersant use decision-making within marine waters in Alaska:

- Bathymetry - it is generally recognized that adequate mixing and dilution of dispersants should occur if applied in waters deeper than 10 fathoms (or 60 feet) depth provided there is sufficient energy for mixing. The 10 fathom contour is a standard depth contour line included on National Oceanic and Atmospheric Administration marine charts.
- Distance from shore - an adequate buffer needs to be established to reduce the chances of applying dispersants to sensitive shorelines/nearshore areas and to ensure that drifting dispersant and/or dispersed oil mixtures do not adversely affect intertidal and benthic biota.
- Wind and currents - areas where there is generally little movement of water would not provide sufficient mixing energy for effective dispersant use. With higher wind speeds (beginning at 12-14 meters per second (26.8 to 31.3 miles per hour)), the benefits of dispersant application start to diminish compared to natural dispersion.
- Salinity - most dispersants are made for use in saltwater and are not effective in fresh water or waters with a salinity of less than 15 parts per thousand.
- Temperature - dispersant effectiveness will be affected by ambient water temperatures, with more complete dispersion in warmer waters.

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- Response equipment - the availability and time to mobilize response equipment may affect whether dispersants can be used.
- Shoreline types - certain shoreline types (e.g., gravel, mixed sand and gravel, coarse-grained sand beaches, and marshes) may trap oil for long periods. The amount of wave energy (e.g., protected inlets vs. high-energy exposed beaches) will also affect oil retention and persistence.
- Sensitive habitats - certain habitats where biota breed, rear young, feed, or congregate (e.g., eelgrass beds, kelp beds, saltwater marshes, and designated critical habitats for threatened or endangered species) may be adversely affected by oil and/or dispersed oil.
- Sensitive species – including threatened or endangered species – these species may be adversely affected by oil and/or dispersed oil.
- Other areas designated for special use or protection - these areas (e.g., national and state parks, national wildlife refuges, and wildness areas) may be adversely affected by oil and/or dispersed oil.
- Historic properties - these resources (e.g. archeological and historic resources) may be adversely affected by oil and/or dispersed oil.
- Human use activities - these activities (e.g., subsistence, fishing, and boating activities) may be adversely affected by oil and/or dispersed oil.
- Public and private facilities – these facilities (e.g., fish hatcheries, aquaculture and mariculture facilities, public water intakes, and docks) may be adversely affected by oil and/or dispersed oil).

2.3 Conditions/Stipulations

The following conditions and stipulations shall be included in any dispersant application field test and in any subsequent authorization of full-scale dispersant application(s):

- All dispersant application field tests will be conducted on a representative portion of the oil slick.
- All dispersant applications will be conducted in accordance with the conditions and procedures identified in Tab 1. Dispersant application effectiveness and potential trade-offs associated with its use will be evaluated on a daily basis, informing the FOSC's decision to continue, postpone, modify, or cease dispersant application based on that day's monitoring information.
- Dispersant applications will only be carried out in daylight conditions.
- Dispersants will only be applied in areas where the water depth is ≥ 10 fathoms (60 feet) and at sufficient distances from shore to ensure that sensitive near-shore and benthic habitats are not affected by dispersants and/or dispersed oil.
- Dispersants applications will maintain a minimum 500 meters (1,640 feet) horizontal separation from swarming fish, rafting flocks of birds, marine mammals in the water, and/or marine mammal haul-outs.

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- To avoid disturbances at walrus haul-outs, any dispersant-related aircraft will comply with any Federal Aviation Administration Temporary Flight Restriction(s) and Notice to Airmen and/or aviation restrictions issued by the U.S. Fish and Wildlife Service (FWS). In addition, any dispersant-related vessel(s) will comply with any USCG Notice to Mariners and/or FWS restrictions for walrus haul-outs.
- Any monitoring required by FWS and/or National Marine Fisheries Service for Endangered Species Act Section 7 compliance will be conducted.
- DOI and/or DOC will provide a specialist in aerial surveying of marine mammals and pelagic birds to accompany a Tier 1 monitoring team to help ensure compliance with the above requirements. If DOI and/or DOC cannot provide the appropriate specialist(s), a third party acceptable to the DOI and/or DOC will be identified to accompany the monitoring team.
- Any atypical dispersant application (e.g., prolonged [> 96 hours] surface and subsea) will be guided by the NRT "Environmental Monitoring for Atypical Dispersant Operations" (see Tab 4, Part 2).
- Other incident-specific conditions/stipulations: _____

  _____

  _____

  _____

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TAB 1. PROCESS FOR DISPERSANT USE AUTHORIZATION

Part 1A: Process for Dispersant Use in the Preauthorization Area

The following information outlines the procedure that shall be followed when the Federal On-Scene Coordinator (FOSC) has made a decision to authorize the use dispersants on a crude oil discharge within the dispersant Preauthorization Area under the preauthorized conditions[7]:

1. The FOSC directs the Responsible Party (RP) to mobilize resources for dispersant use, while the RP and the Environmental Unit (EU) of the Incident Command immediately begin to complete the checklists contained in Parts 2-3. This checklist information will be used to inform the decision to authorize dispersant use and establish the parameters of the incident-specific authorization, as appropriate. If there is no RP identified, the FOSC, serving as the "Requestor," may direct mobilization of resources for dispersant use as noted above.
2. The FOSC immediately notifies the following entities of the decision to authorized the use dispersants:
   - U.S. Environmental Protection Agency (EPA) Alaska Regional Response Team (ARRT) representative
   - U.S. Department of the Interior (DOI) ARRT representative
   - U.S. Department of the Commerce (DOC) ARRT representative
   - State On-Scene Coordinator (SOSC)
   - Representative for each appropriate federally-recognized tribe
   - Representative for each appropriate stakeholder group (e.g., local government(s), Native corporation(s), regional citizens' advisory council(s))
3. The FOSC directs appropriate entities (i.e., previously-agreed upon third party (or parties) and/or USCG Strike Team/Special Monitoring of Applied Response Technologies [SMART] Team) to mobilize Tier 1, 2, and 3 monitoring capabilities.
4. The FOSC initiates, as appropriate, Endangered Species Act (ESA) Section 7 consultation(s) with U.S. Fish and Wildlife Service and/or National Marine Fisheries Service (NMFS) representatives in accordance with the ESA Memorandum of Agreement (see Annex G of the *Unified Plan*).
5. The FOSC initiates, as appropriate, Essential Fish Habitat consultation with a NMFS representative.
6. The National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator (SSC) and EU, in coordination with the Operations Section, provide any necessary supporting information (e.g., ADIOS model runs, currents, water temperature, salinity, and fish and wildlife observations) required in Parts 2-3. The completed Parts 2-3 are submitted by the EU Leader to the FOSC. The FOSC completes Questions 1-17 in Part 4. The completed Parts 2-4 are provided to other members of the Unified Command (UC)

[7] These steps assume that the FOSC will be working within a Unified Command structure and that all input related to dispersant use authorization(s) will be provided to the FOSC within the timeframe required by the FOSC.

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and representatives identified in Step 2 above.

Part 1A: Process for Dispersant Use in Preauthorization Areas, Cont.

7. An individual representing the FOSC holds a teleconference (at a time determined by the FOSC) with individuals identified in Step 2 above, appropriate members of the EU, and the UC for the purpose of informing the FOSC's decision to use dispersants.
8. The FOSC completes Questions 18-20 in Part 4, documents any changes to Parts 2-4, and completes Part 5 prior to proceeding with a dispersant application field test (following Steps 9-15 below, as appropriate) or postponing or cancelling the field test.
9. The Dispersant Field Task Force (DFTF)[8] advises the FOSC that dispersant application and monitoring personnel, equipment, and supplies are staged and ready to deploy for a dispersant application field test.
10. The DFTF, under the supervision of the FOSC, conducts a dispersant application field test and all required monitoring.
11. The NOAA SSC, using the results of the SMART Tier 1, 2, and 3 monitoring, determines whether the dispersant is effectively dispersing the oil, documents the basis for that determination, and provides the information to the EU.
12. The EU provides to the FOSC, other members of the UC, and individuals identified in Step 2 above, a recommendation on whether full-scale dispersant application(s) should commence with any modification(s) and/or any additional monitoring requirements.
13. An individual representing the FOSC holds a teleconference (at a time determined by the FOSC) with individuals identified in Step 2 above, appropriate members of the EU, and the UC for the purpose of informing the FOSC's decision to authorize any full-scale dispersant application(s) or to postpone or cancel authorization of dispersant application(s). [The frequency of teleconferences following any first full-scale dispersant application will be determined on an incident-specific basis by the FOSC, the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC. Those teleconferences will inform the FOSC's decision to continue, postpone, modify or cease authorization of full-scale dispersant application(s).]
14. The FOSC determines whether to authorize full-scale dispersant application(s) with any modification(s) and/or any additional monitoring requirements will begin, be postponed, or cancelled; documents any revisions to Parts 2-5; and provides the information to the rest of the UC and individuals identified in Step 2 above. Following any prolonged use of dispersants (i.e., full scale dispersant application ongoing for, or expected to exceed or exceeding 96 hours following initial dispersant application and/or subsea dispersant application, any additional authorization dispersant use will be considered via the Process for Case-by-Case Dispersant Use Authorization in Tab 1, Part 1B.
15. After the response for this incident has been completed, the FOSC will complete a Dispersant Use After-Action Report (see Tab 3) for submittal to other members of the UC, all ARRT members, other individuals identified in Step 2 above, and the National Response Team. The FOSC will provide an opportunity for signatories in Part 5 to provide

[8] The DFTF includes all dispersant application and dispersant monitoring teams.

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comment prior to finalization of the report. The final report will be posted on the ARRT public website.

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Part 1B: Process for Case-by-Case Dispersant Use Authorization

The following information outlines the procedure that shall be followed when the application of dispersants into marine waters in Alaska is being proposed as a response option for discharges of any oil in Undesignated Areas and/or discharges of oil, other than crude oil, in a Preauthorization Area outside the preauthorized conditions[9].

1. The Responsible Party (RP), serving as the Requestor, notifies the Federal On-Scene Coordinator (FOSC) of their intention to prepare and submit a Dispersant Use Request (see Part 2). Depending on the timing and need to move quickly, the FOSC may direct the RP to begin mobilizing equipment, materials, and personnel in preparation to implement the dispersant use plan to be proposed. [If there is no RP identified, the FOSC may serve as the Requestor.]
2. The FOSC immediately notifies the following entities of the RP's intent to submit a Dispersant Use Request:
   - U.S. Environmental Protection Agency (EPA) Alaska Regional Response Team (ARRT) representative
   - U.S. Department of the Interior (DOI) ARRT representative
   - U.S. Department of Commerce (DOC) ARRT representative
   - State On-Scene Coordinator (SOSC)
   - Representative for each appropriate federally-recognized tribe
   - Representative for each appropriate stakeholder group (e.g., local government(s), Native corporation(s), regional citizens' advisory council(s))
3. Depending on the timing and need to move quickly, the FOSC directs appropriate entities (i.e., previously-agreed upon third party (or parties) and/or USCG Strike Team/Special Monitoring of Applied Response Technologies [SMART] Team) to mobilize Tier 1, 2, and 3 monitoring capabilities.
4. The FOSC initiates, as appropriate, Endangered Species Act (ESA) Section 7 consultation(s) with U.S. Fish and Wildlife Service and/or National Marine Fisheries Service (NMFS) representatives in accordance with the ESA Memorandum of Agreement (see Annex G of the *Unified Plan*).
5. The FOSC initiates, as appropriate, Essential Fish Habitat consultation with a NMFS representative.
6. The National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator (SSC) and Environmental Unit (EU), in coordination with the Operations Section, provide any necessary supporting information (e.g., ADIOS model runs, currents, water temperature, salinity, and fish and wildlife observations) required in Parts 2-3. The completed Parts 2-3 are submitted by the EU Leader to the FOSC. The FOSC completes Questions 1-17 in Part 4.
7. An individual representing the FOSC holds a teleconference (see procedure listed below) with individuals identified in Step 2 above, the Unified Command (UC), and appropriate

[9] These steps assume that the FOSC will be working within a Unified Command structure and that all input related to dispersant use authorization(s) will be provided to the FOSC within the timeframe requested by the FOSC.

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members of the EU for the purpose of the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, to take action on the Dispersant Use Request.

Teleconference Procedure for Dispersant Application Field Test

Individual representing the FOSC:

- Confirms when the FOSC requires input from all parties identified in Step 2 above.
- Provides to all parties identified in Step 2 above, information on the teleconference time and call-in number, and copies of Parts 2-4.
- Chairs the teleconference and: (1) conducts roll call, recording name, title, and affiliation of teleconference participants; (2) requests (from the Requestor) a brief summary/overview of the plan for the proposed dispersant application field test (field test); (3) directs questions to the appropriate UC or EU representative(s); (4) requests input from the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC; (5) requests input from federally-recognized tribes and stakeholders; (6) facilitates development of a consensus recommendation (if possible) by the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, on the proposed field test, including any special considerations, constraints, permit requirements, and/or special authorizations; (7) queries the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, for their summary input on the proposed field test; and (9) verbally summarizes input received.
- Prepares and provides as soon as possible to the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, a draft written summary of the teleconference results along with the names, titles, and affiliations of teleconference participants. Incorporates as soon as possible any corrections to the summary provided by the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, and immediately provides the final summary to the UC with a copy to each teleconference participant.

Part 1B: Process for Case-by-Case Dispersant Use Authorization, Cont.

8. The FOSC completes Questions 18-20 in Part 4 and documents any changes to Parts 2-4; the FOSC, the EPA, DOI and DOC ARRT representatives and, when appropriate, the SOSC, complete Part 5, prior to proceeding with a dispersant application field test (following Steps 9-15 below, as appropriate) or postponing or cancelling the field test as determined in the above procedure.
9. The Dispersant Field Task Force (DFTF)[10] advises the FOSC that dispersant application and monitoring personnel, equipment, and supplies are staged and ready to deploy for a dispersant application field test.
10. The DFTFs, under the supervision of the FOSC, conducts a dispersant application field test and all required monitoring.
11. The NOAA SSC, using the results of the SMART Tier 1, 2, and 3 monitoring, determines whether the dispersant is effectively dispersing the oil, documents the basis for that determination, and provides the information to the EU.

[10] The DFTF includes all dispersant application and dispersant monitoring teams.

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Part 1B: Process for Case-by-Case Dispersant Use Authorization, Cont.

12. The EU provides to the UC and individuals identified in Step 2 above, a recommendation on whether full-scale dispersant application(s) should commence with any modification(s) and/or any additional monitoring requirements.
13. An individual representing the FOSC holds a teleconference (see procedure listed below) with individuals identified in Step 2 above, the UC, and appropriate members of the EU for the purpose of the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, to take action on a request for full-scale dispersant application(s). [The frequency of teleconferences following any first full-scale dispersant application will be determined on an incident-specific basis by the FOSC, the EPA, DOI, DOC ARRT representatives and, when appropriate, the SOSC. Those teleconferences will reconsider the decision to continue, postpone, or cease full-scale dispersant application(s). Following any prolonged use of dispersants (i.e., full scale dispersant application ongoing for, or expected to exceed or exceeding 96 hours following initial dispersant application), or request for any subsea dispersant application, a teleconference will be held to reconsider the decision to continue dispersant application(s).

Teleconference Procedure for Full-Scale Dispersant Application

Individual representing the FOSC:

- Confirms when the FOSC requires input from all parties identified in Step 2 above.
- Provides to all parties identified in Step 2 above, information on the teleconference time and call-in number and any revisions to Parts 2-4 made following any dispersant application field test(s) and/or the EU's recommendation regarding whether full-scale dispersant application(s) should commence with any modification(s) and/or any additional monitoring requirements.
- Chairs the teleconference and: (1) conducts roll call, recording name, title, and affiliation of teleconference participants; (2) requests (from the Requestor) a brief summary/overview of the plan for the proposed full-scale dispersant application (full-scale application); (3) directs questions to the appropriate UC or EU representative(s); (4) requests input from the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC; (5) requests input from appropriate federally-recognized tribes and stakeholders; (6) facilitates development of a consensus recommendation (if possible) by the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, on the proposed full scale application, including any special considerations, constraints, permit requirements, and/or special authorizations; (7) queries the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, for their summary input on the proposed full-scale application; and (9) verbally summarizes input received.
- Prepares and provides as soon as possible to the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, a draft written summary of the teleconference results along with the names, titles, and affiliations of teleconference participants. Incorporates as soon as possible any corrections to the summary provided by the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC,

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and immediately provides the final summary to the UC with a copy to each teleconference participant.

Part 1B: Process for Case-by-Case Dispersant Use Authorization, Cont.

14. The FOSC documents any changes to Parts 2-4. In addition, the FOSC, the EPA, DOI and DOC ARRT representatives and, when appropriate, the SOSC complete Part 5 prior to commencing, postponing, or cancelling full-scale dispersant application(s) as determined through the above procedure. Any revisions to Parts 2-5 will be provided to the rest of the UC and individuals identified in Step 2 above.
15. After the response for this incident has been completed, the FOSC will complete a Dispersant Use After-Action Report (see Tab 3) for submittal to other members of the UC, all ARRT members, other individuals identified in Step 2 above, and the National Response Team. The FOSC will provide an opportunity for signatories in Part 5 to provide comment prior to finalization of the report. The final report will be posted on the ARRT public website.

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Part 2: Dispersant Use Request

INCIDENT NAME		Date Prepared:	
		Time Prepared:	
INCIDENT LOCATION		**REQUESTOR INFORMATION**	
Latitude:		Name:	
Longitude:		Affiliation:	
Description:		Address:	
		Phone:	
		Cell Phone:	
Incident Date:		Fax:	
Incident Time:		Email:	

Areas dispersants to be applied in: ☐ Preauthorization Area
☐ Undesignated Area

BASIC DATA

Type of incident (check one):
- ☐ Grounding
- ☐ Transfer operations
- ☐ Explosion
- ☐ Collision
- ☐ Allision
- ☐ Blowout
- ☐ Other _____

Oil discharged: API:
- ☐ North Slope Crude _____
- ☐ Cook Inlet Crude _____
- ☐ Residuals _____
- ☐ Diesel #2 _____
- ☐ JP4 _____
- ☐ Other: _____

Estimated volume of oil discharged/discharge rate:
_____ gallons; _____ gallons per _____

Potential oil discharge volume estimate:
_____ gallons

Oil discharge status (check one):
- ☐ Continuous
- ☐ Intermittent
- ☐ One time only, now stopped

Did source burn? ☐ Yes ☐ No
Is source still burning? ☐ Yes ☐ No
Is oil easily emulsified? ☐ Yes ☐ No

RESPONSE CONSIDERATIONS

Why is mechanical recovery ineffective and/or inadequate?
Is the mechanical recovery insufficient? If so, why?
_____
_____
_____
_____

Will *in-situ* burning (ISB) also be used? ☐ Yes ☐ No
Will mechanical recovery also be used? ☐ Yes ☐ No
Will dispersant use impede mechanical recovery? ☐ Yes ☐ No

If yes, explain how this will be resolved:
_____
_____
_____

ADIOS MODEL

Has ADIOS been run by a qualified person? ☐ Yes ☐ No
Identify individual and affiliation: _____
If yes, please fill out the following ADIOS input parameters:
Wind speed _____ Water temp. _____
ADIOS output parameters to be specified:
- Percentage evaporation

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Current estimate of water surface covered by oil as of: Date/Time: _____ Area: _____ sq. mi.	• Viscosity change • Water percentage or emulsification over a 5-day period

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Part 2: Dispersant Use Request, Cont.

WEATHER AND SEA CONDITIONS

Check boxes and enter wind values in the following table:

	Present Condition	12-hour Forecast	24-hour Forecast
Clear			
Partly cloudy			
Overcast			
Rain			
Snow			
Fog			
Wind speed (knots/mph)			
Wind direction (from)			

Visibility (miles): _____

Tidal state at _____ o'clock (check one):

☐ Slack tide ☐ Incoming (flood) ☐ Outgoing (ebb)

✓ **Attachment 1:** Graph with tidal information for 3 tidal cycles.

Dominant current (net drift):

Speed (knots): _____ Direction (to): _____

Sea state: present condition (check one)

☐ Calm ☐ Choppy ☐ Swell

Sea state: 24-hour forecast (check one)

☐ Calm ☐ Choppy ☐ Swell

Waves (height estimate), present condition: _____ feet

Waves (height estimate), 24-hr forecast: _____ feet

Depth of water at slick: _____ feet

Water temperature: _____ degrees C and F

Water salinity: _____ parts/thousand

If ice is present, describe: _____

_____

_____

Next sunrise: _____ Next sunset: _____

WILDLIFE INFORMATION

Have fish swarms, birds, and/or marine mammals been observed near the oil slick?

☐ Yes ☐ No If yes, please answer the following:

Type observed (e.g., birds, sea otters, seals, whales, fish)	Estimated Number

DISPERSANT USE PLAN

Proposed date and time for application of dispersants:

Date: _____ Time: _____

Distance to nearest staging area (airport/facility):

_____ mi

What is the dispersant proposed for use?

☐ Corexit 9500 ☐ Corexit 9527

☐ Other: _____

Material Safety Data Sheet (MSDS) attached? ☐Yes ☐No

What is the proposed dispersant to oil ratio?

_____:_____

How much total dispersant per acre is proposed?

_____ gallons

What is the estimated percentage of spill slick area to be treated? _____ percent

Who will apply the dispersants?

Individual/Affiliation: _____

Application Method	Estimated Dispersant Capacity Per Sortie	Estimated Number of Sorties
☐ Boat	_____	_____
☐ C-130	_____	_____
☐ CASA	_____	_____
☐ Helicopter	_____	_____
☐ Other:	_____	_____

Distance from source: _____ miles

Distance from nearest shoreline: _____ miles

✓ **Attachment 2:** Provide a chart with a distance scale. Chart must include: 1) estimated spill trajectory and landfalls with time; 2) location and distance of proposed dispersant application relative to zone boundaries, proposed dispersant application field test location, and other response activities including ISB; 3) dispersant tactic summary and how it will augment the mechanical response, if used; and 4) fish and wildlife locations relative to the oil slick.

DISPERSANT USE HEALTH AND SAFETY PLAN

Does the site-specific health and safety plan cover the dispersant use plan? ☐ Yes ☐ No

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*(Include in the chart being submitted as **Attachment 2** the proximity of the above observed fish and wildlife)*	✓ **Attachment 3**: Relevant portion of health and safety plan, including MSDS.

Part 2: Dispersant Use Request, Cont.

DISPERSANT SYSTEM APPLICATION

Application system design:

- Designed specifically for this purpose? ☐ Yes ☐ No
- Used previously for this purpose? ☐ Yes ☐ No
- Tested to be effective and safe? ☐ Yes ☐ No
- Meet manufacturer's recommendations? ☐ Yes ☐ No

Application personnel are trained and/or experienced in the use of dispersants and this application system? ☐ Yes ☐ No

Aerial application system:

- A qualified Dispersant Controller will be in a separate aircraft over the spray area(s)? ☐ Yes ☐ No
- Dispersant Controller will be able to direct operations and avoidance of fish and wildlife? ☐ Yes ☐ No

Boat application system:

- A qualified Dispersant Controller will oversee operations? ☐ Yes ☐ No
- System components meet relevant ASTM standards? ☐ Yes ☐ No

✓ **Attachment 4**: Description of dispersant application system and application team personnel name(s), title(s), affiliation(s), and qualifications.

COMMUNICATIONS PLAN

Describe the communications plan to be used for communications between and among the Unified Command, Dispersant Controller, SMART Team, and dispersant applications platform(s):

DISPERSANT MONITORING

Indicate the SMART monitoring to be used:

- Tier 1: ☐ Yes ☐ No
- Tier 2: ☐ Yes ☐ No
- Tier 3: ☐ Yes ☐ No

Describe other monitoring to be used:

Describe monitoring platform(s) that will be used:

Identify name, title, affiliation, and qualification of each monitoring team member:

SIGNATURES

Requestor:

_____
Requester's Printed Name and Signature

Requester contact cell phone: _____

Date and time submitted to FOSC and, when appropriate, the SOSC:

_____ _____
Date Time

Received by:

_____ _____
FOSC Printed Name and Signature Date/Time

_____ _____
SOSC Printed Name and Signature Date/Time

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Part 3: Incident-Specific Resources at Risk

A. Information Considered

☐ Sensitive Areas information in the subarea contingency plan(s) (SCPs) for this incident, including any locations where dispersant use should be avoided

☐ Relevant Geographic Response Strategies in appropriate SCPs for this incident

☐ Incident-specific on-scene observations (e.g., by responders, local agency representatives, and local residents); identify name/affiliation: _____

☐ Others: _____

B. Biological Species (may not be a complete list of species present)

	Present/Absent/ or Unknown	Other Relevant Information	Used for Subsistence?
Endangered/Threatened/Candidate Species:			
Migratory birds (specify)			
Sea otters (southwest Distinct Population Segment)			
Polar bears			
Seals (specify)			
Toothed whales (specify)			
Baleen whales (specify)			
Sea Lions			
Other Species:			
Seabirds			
Diving birds (unlisted populations)			
Waterfowl (unlisted populations)			
Shorebirds			
Raptors (unlisted populations)			
Sea Otters (unlisted populations)			
Walruses			
Fur seals			
Other seals (unlisted populations)			
Toothed whales (unlisted populations)			
Baleen whales (unlisted populations)			
Ungulates			
Bears (brown and/or black)			
Furbearers			
Fish:			
Pelagic and larval			
Bottomfish			
Intertidal mollusks			
Crustacea			
Plankton (including larval species)			

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Part 3: Incident-Specific Resources at Risk, Cont.

C. Habitat Types

	Present/Absent/Unknown	Other Relevant Information
Salt/brackish-water marshes		
Eelgrass beds/kelp beds		
Tidal mudflats		
Sheltered rocky shores/shallow reefs		
Gravel beaches		
Mixed sand and gravel beaches		
Coarse-grained sand beaches		
Peat shorelines		
Inundated low-lying tundra		
Ice (seasonal, multi-year)		
Marine mammal haul-outs/rookeries		
Migratory bird nesting colonies		
Fish spawning grounds		
Others:		

D. Special Designations

	Present/Absent/Unknown	Other Relevant Information
ESA designated critical habitats		
Essential Fish Habitat		
Legislatively-designated areas		
Native allotments		
Others:		

E. Historic Properties

	Present/Absent/Unknown	Other Relevant Information
Historic Resources		
Archaeological Resources		
Others:		

F. Other Considerations

	Present/Absent/Unknown	Other Relevant Information
Commercial harvest areas		
Subsistence harvest areas		
Recreational use areas		
Mariculture facilities		
Commercial facilities/activities		
Public infrastructure		
Others:		

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Part 4: FOSC Dispersant Authorization Checklist*

	YES	NO	CONSIDERATIONS
1.	☐	☐	***Dispersant Use Request Received:*** The Requestor has submitted a completed Dispersant Use Request (Part 2).
			Notifications: The following entities have been notified of the potential dispersant use for this incident:
2a.	☐	☐	a. State On-Scene Coordinator (SOSC)
2b.	☐	☐	b. U.S. Environmental Protection Agency (EPA) Alaska Regional Response Team (ARRT) representative
2c.	☐	☐	c. U.S. Department of the Interior (DOI) ARRT representative
2d.	☐	☐	d. U.S. Department of Commerce (DOC) ARRT representative
2e.	☐	☐	e. Appropriate federally-recognized tribes (identify representative(s)): _____
2f.	☐	☐	f. Appropriate stakeholders (e.g., local governments, Native corporations, regional citizens' advisory councils) (identify representative(s)): _____
2g.	☐	☐	g. Agreed-upon monitoring team(s) and/or USCG Strike Team/Special Monitoring of Applied Response Technologies (SMART) Team.
3.	☐	☐	***Endangered Species Act (ESA) Consultations:*** The U.S. Fish and Wildlife Service (FWS) and/or National Marine Fisheries Service (NMFS) ESA contact(s) have been notified and, if appropriate, ESA Section 7 consultation(s) have begun in accordance with the ESA Memorandum of Agreement.
4.	☐	☐	***Essential Fish Habitat (EFH) Consultations:*** NMFS EFH contact has been notified and, if appropriate, EFH consultations have begun.
5.	☐	☐	***Dispersability:*** Available technical and scientific information, including results from the ADIOS model, suggests that the discharged oil is dispersible. The analysis delineates the conditions and timeframe in which the oil is no longer dispersable. Identify source(s) relied upon: _____
6.	☐	☐	***NCP Listed Dispersant:*** The dispersant to be used is listed on the current NCP Product Schedule, is considered appropriate for the existing environmental and physical conditions, and its use is consistent with the recommended application information provided in the NCP Product Schedule Technical Notebook. Identify source(s) relied upon: _____
			Response Considerations:
7a.	☐	☐	a) Has mechanical response been deemed to be ineffective and/or inadequate? If yes, specify reason(s) (e.g., availability, effectiveness, timeliness, sea state, spatial coverage, weather conditions): _____
7b.	☐	☐	b) Is dispersant application being used to supplement mechanical recovery?
7c.	☐	☐	c) Is *in-situ* burning being considered in conjunction with mechanical recovery and dispersant use?
7d.	☐	☐	d) Is a map illustrating timing, tactics, and proximity of each response option to each other attached?
			Dispersant Availability and Timeliness: Sufficient dispersant application and monitoring equipment has been confirmed to be available:
8a.	☐	☐	a) to meet the conditions of use in the Dispersant Use Plan (see Part 2), and
8b.	☐	☐	b) to be deployable within the conditions and time frame the oil will be dispersible.
9.	☐	☐	***Weather and Sea Conditions:*** Predicted weather and sea conditions are conducive to dispersant application by the chosen system or platform. (Generally, for aerial application, wind ≤ 25 kts (28.77 mph), visibility ≥ 3 nm (3.45 miles), and ceiling ≥1,000 ft. Generally for boat application, a sea state that will allow the vessel to be used to conduct an effective and safe spray operation.) Identify any updated conditions: _____
10.	☐	☐	***Personal Protective Equipment (PPE):*** PPE for all personnel involved in, or affected by, dispersant application conforms to the site-specific health and safety plan and has been confirmed to be available.
			General Adequacy of Dispersant Spray System and Personnel Competency: Note: The general criteria for evaluating the suitability for use of any dispersant system is the ability of the Requestor to demonstrate to the satisfaction of the FOSC, the following:

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			Has the application system been:
11a.	☐	☐	a) Specifically designed for its intended purpose, or
11b.	☐	☐	b) If not specifically designed for dispersant use, used previously and deemed to be effective and appropriate, and will be used again in a similar manner, or

Part 4: FOSC Dispersant Authorization Checklist, Cont.

	YES	NO	CONSIDERATIONS
11c.	☐	☐	c) If not specifically designed and not previously used for dispersant application, deemed to be effective and appropriate by some other specific means; if so, identify specific means: _____
11d.	☐	☐	d) Is the design and operation of the application system such that it can reasonably be expected to apply the chemical dispersant in a manner consistent with the dispersant manufacturer's recommendation, especially with regards to dosage rates, and concentrations?
11e.	☐	☐	e) Will the dispersant application be supervised by personnel that have experience, knowledge, specific training, and/or recognized competence with chemical dispersants and the type of system to be used?
			Aerial Application Operational and Technical Issues: In the case of aerial application of dispersants:
12a.	☐	☐	a) Is there a Dispersant Controller who will be over the spray area(s) in a separate aircraft from the dispersant aircraft while dispersants are being applied?
12b.	☐	☐	b) Is the Dispersant Controller qualified and able to direct the dispersant aircraft to maintain a 500 meter (1,640 feet) horizontal separation between the dispersant application andswarming fish, rafting flocks of birds, marine mammals in the water, and/or marine mammal haul-outs?
12c.	☐	☐	c) Is the aircraft spray system capable of producing dispersant droplet sizes that provide for optimal dispersant effectiveness (generally 250-500 µm), by following manufacturer and ASTM guidance?
			Boat Application Operational Technical Issues: If the system involves spray arms or booms that extend over the edge of a boat and has fan type nozzles that spray a fixed pattern of dispersant, has the Requestor confirmed that the dispersant application will comply with all of the following ASTM standards?
13a.	☐	☐	*a)* **ASTM F 1413-92** *Standard Guide for Oil Spill Dispersant Application Equipment: Boom and Nozzle Systems*
13b.	☐	☐	*b)* **ASTM F 1460-93** *Standard Practice for Calibrating Oil Spill Dispersant Application Equipment: Boom and Nozzle Systems*
13c.	☐	☐	*c)* **ASTM F 1737-96** *Standard Guide for Use of Oil Spill Dispersant Application Equipment during Spill Response: Boom and Nozzle Systems*
			Monitoring Protocols/Deployment:
14a.	☐	☐	a) Have the agreed-upon monitoring team(s) and/ or USCG Strike Team SMART Team been activated?
14b.	☐	☐	b) Are they prepared to fly over the response area to conduct Tier 1 visual monitoring during every dispersant application?
14c.	☐	☐	c) Are they prepared to implement the Tier 2 and Tier 3 water column monitoring component of the SMART monitoring protocols for every dispersant application?
14d.	☐	☐	d) Are wildlife observers prepared to accompany Tier 1 monitors to watch for swarming fish, rafting flocks of birds, marine mammals in the water, and marine mammal haul-outs?
14e.	☐	☐	e) Are there additional monitoring requirements? If so, identify:_____ and indicate if appropriate entities are prepared to implement any additional requirement?
15.	☐	☐	***Communications:*** Has a communications plan been developed that will allow communications between and among the Unified Command, Dispersant Controller, all monitoring team(s), and dispersant applications platform(s)?
16.	☐	☐	***Natural Resource Trustee Input:*** Has the FOSC received input from natural resource trustees on incident-specific resources at risk (see Part 3)?
			Conditions/Stipulations: Will the following application conditions and stipulations be included in any dispersant application?
17a.	☐	☐	a) All dispersant application field tests will be conducted on a representative portion of the slick.

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17b.	☐	☐	Dispersant application will be in accordance with the approved dispersant application plan.
17c.	☐	☐	c) Dispersants will only be applied in areas where the water depth is ≥ 10 fathoms (60 feet).
17d.	☐	☐	d) Dispersant applications will maintain a minimum 500 meters (1,640 feet) horizontal separation from swarming fish, rafting flocks of birds, marine mammals in the water, and marine mammal haul-outs.
17e.	☐	☐	e)

Part 4: FOSC Dispersant Authorization Checklist, Cont.

	YES	NO	CONSIDERATIONS
17f.	☐	☐	f) Federal Aviation Administration Temporary Flight Restrictions and Notice to Airmen and/or FWS flight and vessel restrictions to avoid disturbing walrus on haul-outs will be followed.
17g.	☐	☐	g) Dispersant applications will only be carried out in daylight conditions.
17h.	☐	☐	h) DOI and/or DOC (or a third party observer acceptable to DOI and/or DOC) will provide a specialist in aerial surveying of marine mammals and/or pelagic birds to accompany the SMART observer.
17i.	☐	☐	i) Monitoring protocols required by EPA, State, and/or DOI and DOC natural resource trustees (e.g., ESA compliance) will occur.
17j.	☐	☐	j) Prolonged dispersant application will be guided by recommendations in the NRT "Environmental Monitoring for Atypical Dispersant Operations."
17k.	☐	☐	k) SMART Tier 1, 2, and 3 monitoring will occur during any dispersant application.
18.	☐	☐	***SOSC, EPA, DOI, and DOC Input:*** Has the FOSC received input from the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC on the dispersant request?
19.	☐	☐	***Federally-Recognized Tribe Input:*** Has the FOSC received input from appropriate federally-recognized tribes?
20.	☐	☐	***Stakeholder Input:*** Has the FOSC received input from appropriate stakeholders on the dispersant request?

* If "no" is checked for any of the above questions, the FOSC will document reasons for making that determination and what, if anything, may be done to change the response to "yes."

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Part 5: Dispersant Use Authorization Document[11]

Incident: _____

U.S. Department of the Interior Consultation by DOI ARRT Representative (for case-by case authorization only):

- o _____Does not support the use of dispersants (reasons attached)
- o _____Agrees with dispersant use in the selected areas under attached conditions
- o _____Agrees with dispersant use as requested in the application form

_____	_____	_____
Signature	Printed Name	Time/Date

U.S. Department of Commerce Consultation by DOC ARRT Representative (for case-by-case authorization only):

- o _____Does not support the use of dispersants (reasons attached)
- o _____Agrees with dispersant use in the selected areas under attached conditions
- o _____Agrees with dispersant use as requested in the application form

_____	_____	_____
Signature	Printed Name	Time/Date

U.S. Environmental Protection Agency Concurrence by EPA ARRT Representative (for case-by-case authorization only):

- o _____No dispersants may be applied (reasons attached)
- o _____Dispersants may be used in the selected areas under attached conditions
- o _____Dispersants may be applied as requested in the application form

_____	_____	_____
Signature	Printed Name	Time/Date

State of Alaska Concurrence by State On-Scene Coordinator (for case-by-case authorization only):

- o _____No dispersants may be applied (reasons attached)
- o _____Dispersants may be used in the selected areas under attached conditions
- o _____Dispersants may be applied as requested in the application form

_____	_____	_____
Signature	Printed Name	Time/Date

Federal On-Scene Coordinator Decision

- o _____No dispersants may be applied (reasons attached)
- o _____Dispersant use is postponed (reasons attached)
- o _____Dispersants may be used in the selected areas under attached conditions
- o _____Dispersants may be applied as requested in the application form (reasons attached for the basis of determining that dispersant use would minimize overall environmental impacts)

_____	_____	_____
Signature	Printed Name	Time/Date

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[11] This document shall be completed, as appropriate, for both a dispersant application field test and any subsequent request for full-scale application. Where signatures cannot be immediately obtained in person or via email or fax, verbal input will suffice until signatures can be obtained.

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TAB 2. DISPERSANT USE AFTER-ACTION REPORT

Guidelines and Requirements

The Dispersant Application After-Action Report will focus on the following elements of the dispersant application:

- An overview of the incident (prepared by the Federal On-Scene Coordinator (FOSC))
- A description of how the dispersant application(s) were conducted (prepared by the Requestor)
- A description of how Tier 1 monitoring was conducted and the results (prepared by the Tier 1 Monitoring Team)
- A description of how Tier 2 and Tier 3 monitoring was conducted and the results (prepared by the Tier 2 and 3 Monitoring Team)
- Description of how other dispersant monitoring was conducted and the results, if applicable (prepared by the individuals/team conducting the monitoring)
- Description of any adverse environmental effects associated with the dispersant application, such as impacts to fish and/or wildlife (e.g. disturbance, unintentional over-spray)
- Other elements requested by the FOSC or the Alaska Regional Response Team (ARRT)

This report shall include the elements shown in the Report Outline below. In addition, the report shall be submitted within 30 days of completion of the dispersant operation(s) or a timeframe agreed upon by the ARRT, to all Unified Command (UC), ARRT, and National Response Team members and all individuals identified in Step 2 of Tab 1, Part 1A and/or Part 1B.

Report Outline
I. Incident Overview A. Background information 1. Cause or potential cause of spill, if known 2. Type and amount of oil spilled 3. Location of spill 4. Movement of oil slick, including any trajectories 5. Weathering and behavior of oil 6. Other pertinent information B. Response actions taken/effectiveness (e.g., mechanical recovery, protective booming, *in-situ* burning, dispersant use) C. Summary of decision-making process resulting in the authorization of a request for the use of dispersants, including the basis for the environmental trade-off determination II. Description and the Dispersant Application A. Description of dispersant application (including all dispersant application field test(s)) 1. Type and amount of dispersant applied 2. Type(s) of aircraft and/or vessel(s) used and dispersant system(s) used

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Report Outline, Cont.

3. Personnel directly involved in dispersant application (e.g., Dispersant Controller) and summary of their qualifications and experience
4. Location (shown on a map of appropriate scale), date, time, ratio of dispersant to oil, and total amount of dispersant applied for each dispersant application

5. Weather conditions at time(s) of each application, including sea state, water temperature, water salinity
7.
6. Staging area, distance to region of application, and specifics regarding logistics (including time) involved in supporting the dispersant application
7. Communications used
8. Interaction between UC and field units carrying out guidance received
9. Spotter aerial observations
10. Description of any adverse environmental effects associated with the dispersant application, such as impacts to fish and wildlife (e.g.,disturbance, unintentional over-spray)
11. Health and Safety Plan requirements (including Personal Protective Equipment)

B. Lessons learned
1. What worked well
2. What needed improvement
3. Recommendations

III. Description and Results of Tier 1 (Visual) Monitoring

A. How the monitoring was carried out (e.g., method, vehicle, monitors, etc.)
1. Specifics regarding equipment and suitability of vessel(s) used
2. Description of observations regarding the dispersal of oil
3. Communications used and any associated problems
4. Operational support from the staging area, etc.
5. Interaction between the Incident Management Team (IMT) and the field units carrying out guidance received from the IMT

B. Results of Tier 1 monitoring, including a copy of the National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator's (SSC) documentation on monitoring results and the Environmental Unit's (EU) recommendation to the FOSC

C. Lessons learned
1. What worked well
2. What needed improvement
3. Recommendations

IV. Description and Evaluation of Tier 2 and Tier 3 (Water Column) Monitoring

A. How the monitoring was carried out (e.g. method, vehicle, monitors, etc.)
1. Specifics regarding equipment and suitability of the vessel(s) used
2. Description of observations regarding the dispersal of oil
3. Communications used and any associated problems
4. Operational support from the staging area, etc.
5. Interaction between the IMT and the field units carrying out guidance received from the IMT

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Report Outline, Cont.
B. Results of Tier 2 and Tier 3 monitoring, including a copy of the NOAA SSC's documentation on monitoring results and the EU's recommendation to the FOSC C. Lessons learned 1. What worked well 2. What needed improvement 3. Recommendations V. Description and Evaluation of Additional Monitoring, if conducted A. How the monitoring was carried out (e.g. method, vehicle, monitors, etc.) 1. Specifics regarding equipment and suitability of the aircraft/vessel(s) used 2. Description of observations 3. Communications used and any associated problems 4. Operational support from the staging area, etc. 5. Interaction between the IMT and the field units carrying out guidance received from the IMT B. Results of monitoring C. Lessons learned 1. What worked well 2. What needed improvement 3. Recommendations VI. Additional Elements (as requested by the FOSC or ARRT)

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TAB 3. MONITORING PROTOCOLS

Part 1: Special Monitoring Of Applied Response Technologies (SMART)

(The latest SMART Protocols will be included in the final plan)

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Part 2: NRT Environmental Monitoring for Atypical Dispersant Operations

(This document will be included in the final plan)

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To: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Mon 2/8/2016 6:36:13 PM
Subject: ARRT Dispersant Authorization Plan_Draft 8-27-13_OEM5.doc
ARRT Dispersant Authorization Plan_Draft 8-27-13_OEM5.doc

This is the last comment version I found in my files. This has our added sentence under policies re 96 hrs/subsea.

The date the file was saved is 9/10/13.

ANNEX F

APPENDIX I: ALASKA REGIONAL RESPONSE TEAM OIL DISPERSANT AUTHORIZATION PLAN

This document is also available on the Alaska Regional Response Team website at:

http://alaskarrt.org/

or at the Alaska Department of Environmental Conservation website at:

http://dec.alaska.gov/spar/perp/plans/uc/Annex%20F%20(Jan%2010).pdf

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Alaska Regional Response Team

Oil Dispersant Authorization Plan

Revision 1

(Photo: M/V Golden Seas being towed to a Place of Refuge, December 2010)

Insert month/year here and substitute a photo of dispersant use during the Exxon Valdez Oil Spill

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1.0 BACKGROUND AND OVERVIEW

1.1 Introduction

The purpose of the Alaska Regional Response Team (ARRT) Oil Dispersant Authorization Plan is to outline the process to be used following an oil discharge in Alaska when dispersant use is being considered in a Preauthorization Area or in an Undesignated Area. In addition, this plan streamlines and facilitates the dispersant use authorization process and establishes a Preauthorization Area for Alaska, and provides a framework to further identify areas where dispersant use should be avoided.

The previous statewide guidelines and guidelines specific to Cook Inlet were approved by the ARRT in April 1986. Specific guidelines for Prince William Sound were approved by the ARRT on March 6, 1989. This plan, which was approved by the ARRT on _____, supersedes all previous statewide and area-specific dispersant guidelines/plans. In effect for all marine waters in Alaska[1], this plan is subject to periodic review and update by the ARRT.

1.2 Background

The capability to respond to an oil discharge in Alaska can be hampered by great distances, underdeveloped transportation networks, limited labor force, finite mechanical spill cleanup technology, severe weather, and other conditions. The use of dispersants may provide a response tool in addition to mechanical recovery and *in-situ* burning. See Figure 1 for a conceptual marine spill response decision chart.

Dispersants are chemical agents consisting of surfactants, solvents, and other compounds specifically designed to enhance dispersion of oil into water by generating larger numbers of small droplets of oil that are entrained into the water column by wave or tidal action. These small submerged oil droplets are then subject to natural processes, such as dissolution, volatilization, biodegradation, and sedimentation. Oil spill dispersants do not actually reduce the total amount of oil in the environment. Rather, they may change the inherent characteristics of the dispersed oil, thereby changing the oil's transport, fate, and potential effects.

As noted by the National Academy of Sciences[2] review of ongoing research on the use of dispersants as an oil spill response technique and the impact of dispersed oil on marine and coastal ecosystems, there are many uncertainties regarding the efficacy [effectiveness] and toxicity of dispersant use. Decisions to use dispersants involve trade-offs between decreasing the potential risk to water surface and shoreline habitats while increasing the potential risk to organisms in the water column. This trade-off reflects the complex interplay of many variables,

[1] For the purposes of this document, "marine waters in Alaska" is defined to include all waters beginning at the mean lower low tide along the Alaska shoreline outward to the 200 mile Exclusive Economic Zone.

[2] Oil Spill Dispersants Efficacy and Effects. 2005. National Academy of Sciences, available at: http://dels.nas.edu/resources/static-assets/materials-based-on-reports/special-products/oil_spill_dispersants_key_findings_final.pdf

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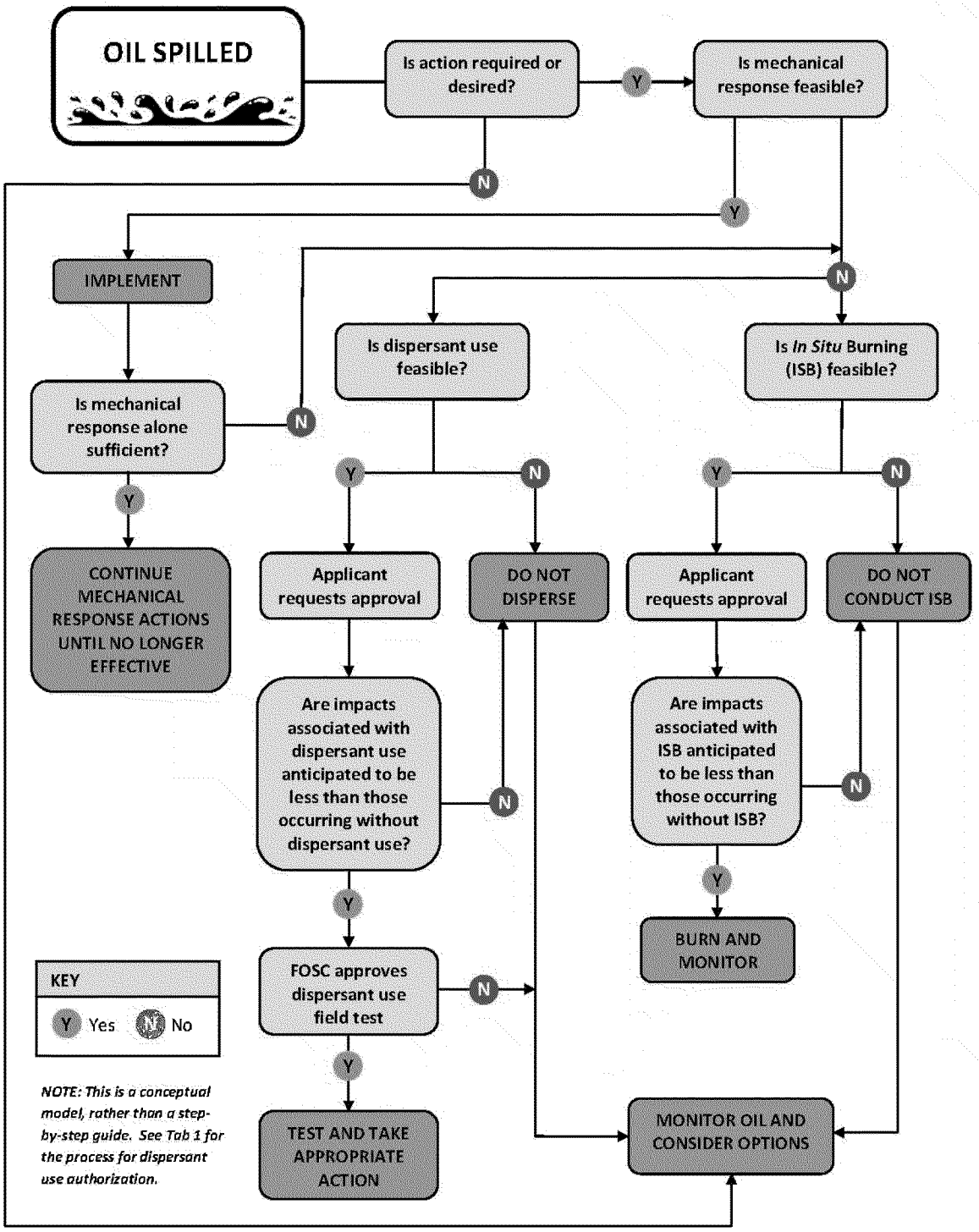
Figure 1. Conceptual Marine Spill Response Decision-Making



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including, but not limited to, the type of oil spilled; the volume of the spill; sea state and weather; water depth; water temperature; water salinity; degree of turbulence; presence, relative abundance, and life stages of potentially-affected wildlife and marine organisms; and the use of those resources. Prior to authorizing dispersant use in marine waters in Alaska, the FOSC needs to consider factors including, but not limited to, valuable commercial, subsistence, and recreational fisheries, as well as large and important populations of birds and marine mammals, including threatened and endangered species.

Key questions to consider during the dispersant use decision-making process include:

- Will the selected dispersant work effectively on the oil discharged and in the given circumstances?
- Can the dispersant be effectively applied to the oil?
- What are the environmental trade-offs of dispersant use and do they support the use of the dispersant in a given circumstance?

As stated in a May 2012 Government Accountability Office report, "Every oil spill is different, and the conditions—such as weather, oil type and volume, currents, and location—surrounding any unanticipated release of oil into the ocean are highly variable. Given this variability, no one study can account for all the potential permutations."[3]

1.3 Dispersant Use Authorizations

This document constitutes a dispersant use preauthorization plan and a case-by-case dispersant use authorization process in accordance with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) - Subpart J (Section 300.910). This plan is included in Annex F of *The Alaska Federal/State Preparedness Plan for Response to Oil and Hazardous Substance Discharges/Releases (Unified Plan)*.

Subpart J Section 300.910 of the NCP addresses the concurrence and consultation requirements for dispersant use authorizations. Specifically, it addresses dispersant use decision-making in the following circumstances:

- In accordance with the NCP - Subpart J (Section 300.910(a)), the [Federal] On-Scene Coordinator (OSC) may authorize the use of certain products without obtaining spill-specific concurrences under specified circumstances described in the preauthorization plan where the U.S. Environmental Protection Agency (EPA) Regional Response Team (RRT) representative, the state with jurisdiction over the waters of the area to which a preauthorization plan applies, and the U.S. Department of the Interior (DOI) and U.S. Department of Commerce (DOC) natural resource trustees approve the preauthorization plan in advance[4].

[3] Oil Dispersants: Additional Research Needed, Particularly on Subsurface and Arctic Applications. 2012. U.S. Government Accountability Office. A Report to Congressional Requestors. GAO-12-585.

[4] In Alaska, the natural resource trustee authorities are vested in the DOI and DOC ARRT representatives; state authorities for oil spil response are vested in the Alaska Department of Environmental Conservation ARRT representative.

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- In accordance with the NCP - Subpart J (Section 300.910(b)), for spill situations that are not addressed by the preauthorization plan, the [Federal] OSC, with concurrence of the EPA representative to the RRT and, as appropriate, the concurrence of the RRT representative from the state with jurisdiction over the navigable waters threatened by the release or discharge, and in consultation with the DOI and DOC natural resource trustees, when practicable, may authorize the use of dispersants on oil discharges provided that the products are listed on the NCP Product Schedule[5].

- In accordance with the NCP – Subpart J (Section 300.910(d), the [Federal] OSC may authorize the use of any dispersant without obtaining the concurrence of the EPA representative to the RRT and, as appropriate, the RRT representative from the state with jurisdiction over the navigable waters threatened by the release or discharge, when, in the judgment of the [Federal] OSC, the use of the product is necessary to prevent or substantially reduce a hazard to human life. In that case, the [Federal] OSC is to inform (as soon as possible) the EPA RRT representative and, as appropriate, the RRT representative from the affected state and, when practicable, the DOI and DOC natural resource trustees[6] of the use of a product, including products not on the NCP Product Schedule. Once the threat to human life has subsided, the continued use of dispersant must follow the approval process described in Section 300.910(a) or (b).

1.4 Dispersant Areas

Preauthorization Area

The Preauthorization Area for Alaska is shown on Figure 2 and is described as follows: Commencing at Cape Suckling in position 59-59.35N 143-53.49W, then proceeding south to 200 nautical miles offshore to position 56-18.00N 144-00.00W, then proceeding westerly along the 200 nautical mile EEZ line until it intersects with the maritime boundary line (MBL) in position 51-21.49N 167-40.44W, then proceeding northeast along the MBL to position 54-54.00N 171-58.50W, then proceeding easterly remaining 100 nautical miles offshore to position 55-45.00N 167-00.00W, then proceeding southeasterly to Cape Sarichef in position 54-35.90N 164-55.65W, then proceeding northwesterly directly to 24 nautical miles offshore to position 54-52.43N 165-26.00W, then proceeding westerly remaining 24 nautical miles offshore following along the entire Aleutian Islands chain rounding Attu Island counter clockwise and entering the North Pacific Ocean, then proceeding eastward along the southern coast of the Aleutian Islands and south of the Shumagin Islands into the Gulf of Alaska and along the eastern coast of the Kodiak Archipelago, then proceeding south of the Kenai Peninsula and Prince William Sound until reaching position 59-29.00N 144-03.00W, and then proceeding north connecting to Cape Suckling in position 59-59.35N 143-53.49W. The Preauthorization Area excludes any avoidance areas identified in their respective SCPs.

[5] In Alaska, the natural resource trustee authorities are vested in the DOI and DOC ARRT representatives; state authorities for oil spill response are vested in the State On-Scene Coordinator.

[6] In Alaska, the natural resource trustee authorities are vested in the DOI and DOC ARRT representatives

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This Preauthorization Area ensures that the USCG can require certain vessel and facility response plan holders in Alaska to maintain a minimum dispersant use capability in accordance with a USCG August 31, 2009 rulemaking, 33 CFR Parts 154 and 155 "Vessel and Facility Response Plans for Oil: 2003 Removal Equipment Requirements and Alternative Technology Revisions; Final Rule (Final Rule)." This includes tank vessels that carry crude oil and stop at one or more U.S. ports at some point during their transit.

The boundaries of the Preauthorization Area were based on the location of common shipping routes followed by crude oil vessels regulated under the Final Rule, with a buffer zone of 24 nautical miles offshore. The 24 nautical mile boundary corresponds to the U.S. contiguous zone (a feature commonly depicted on nautical charts), excludes nearshore sensitive areas from the Preauthorization Area. The boundaries reflect the findings from the Endangered Species Act (ESA) Section 7 consultation(s) with U.S. Fish and Wildlife Service and/or National Marine Fisheries Service (NMFS) representatives conducted prior to the approval of this plan in accordance with the ESA Memorandum of Agreement (see Annex G of the Unified Plan)

This Preauthorization Area overlaps offshore areas included in several subarea contingency plans (SCPs), i.e., the Prince William Sound, Cook Inlet, Kodiak Island, Bristol Bay, and Aleutian Islands SCPs. Following approval of this plan by the ARRT, the appropriate USCG Federal On-Scene Coordinator (FOSC), EPA FOSC, and Alaska Department of Environmental Conservation (ADEC) State On-Scene Coordinator shall engage federal and state natural resource trustees, federally-recognized tribes, and stakeholders in a process to identify locations where dispersant use should be avoided within the Preauthorization Area where the Preauthorization Area overlaps their respective SCP. Any identified locations shall be included in Section I (Dispersant Use Avoidance Areas) of each SCP and posted online (see http://alaskarrt.org/Documents.aspx?f=175). This process shall be completed within 24 months following ARRT approval of this plan. Any avoidance area identified in the identified subarea contingency plans shall no longer be considered part of the Preauthorization Area for dispersant use and shall be automatically reclassified as an Undesignated Area that follows the Case-by-Case process outlined in Tab 1, Part 1B.

Undesignated Areas

Undesignated Areas include all marine waters in Alaska outside of the Preauthorization Area. These Undesignated Areas overlap offshore areas included in several SCPs as noted above. Following approval of this plan by the ARRT, the appropriate USCG FOSC, EPA FOSC, and ADEC SOSC shall engage federal and state natural resource trustees, federally-recognized tribes, and stakeholders in a process to identify locations where dispersant use should be avoided within the Undesignated Areas where the Undesignated Areas overlap their respective SCP. Any identified locations shall be included in Section I (Dispersant Use Avoidance Areas) of each SCP and posted online (see http://alaskarrt.org/Documents.aspx?f=175).

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Figure 2. Preauthorization Area

[Insert figure here]

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2.0 DISPERSANT USE POLICIES, CRITERIA, AND CONDITIONS/STIPULATIONS

2.1 Policies

The following policies shall be followed whenever dispersant use is considered and/or authorized:

- The primary method for response up oil will be the mechanical removal of oil.
- The use of dispersants may provide an alternative response tool when conditions prevent using mechanical recovery and/or *in-situ* burning.
- Dispersant delivery in a mechanical recovery area will not displace or interfere with mechanical or other response operations.
- All requests for dispersant use, including the appropriate process in Tab 1.
- Prolonged applications of dispersants that exceed 96 hours, or subsea applications are not preauthorized.
- All input related to dispersant use authorizations will be provided to the FOSC within the timeframe requested by the FOSC. The FOSC will provide sufficient time for relevant input related to dispersant use authorization.
- The preauthorization of dispersant use (inside the Preauthorization Area) only applies to crude oil. Requests for dispersant use for any other type of oil (e.g., diesel fuel, jet fuel, intermediate fuel oils, bunker oils) will be considered using the Process for Case-by-Case Dispersant Use Authorization in Tab 1, Part 1B.
- Decisions regarding the use of dispersants will be based on an incident-specific evaluation of whether the selected dispersant will work effectively on the oil discharged, if the dispersant can be effectively applied to the oil, and the trade-offs associated with the potential impacts of dispersants, dispersed oil, and non-dispersed oil on the environment and human-use areas, including when compared to other response options. The evaluation of trade-offs will consider the criteria identified below in Section 2.2. All decisions will be documented including the methods used.
- One or more dispersant application field tests to determine the effectiveness of oil dispersion under existing site-specific environmental conditions will be conducted. The resulting information will be analyzed to determine whether full-scale dispersant application(s) will begin. A dispersant application field test is defined as one aircraft sortie or one vessel-based application swath.
- Any prolonged use of dispersants (i.e., full scale dispersant application ongoing for, or expected to exceed or exceeding, 96 hours following initial dispersant application or any use of dispersants subsea (i.e., below the water surface), whether in a Preauthorization Area or in an Undesignated Area, will only be considered using the Process for Case-by-Case Dispersant Use Authorization in Tab 1, Part 1B.
- All dispersant applications (including field tests) will include effectiveness monitoring as outlined in the Special Monitoring of Applied Response Technologies (SMART) Tier 1, Tier 2, and Tier 3 protocols (see Tab 4, Part 1). In the event SMART Tier 2 and Tier 3

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monitoring is not operationally feasible in the Preauthorization Area, the request for dispersant use or continued use will be considered via the Process for Case-by-Case Dispersant Use Authorization in Tab 1, Part 1B.

  - Monitoring for effectiveness of dispersant use and any other factors (or "key indicators") established by the FOSC in consultation with the EPA, DOI, and DOC ARRT representatives and, when appropriate, the State On-Scene Coordinator (SOSC), will be conducted by a qualified third party (who is acceptable to the Unified Command and the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC) or by the USCG Strike Team/SMART Team. All SMART Tier 1, 2, and 3 monitoring will be performed in accordance with procedures in the most current SMART protocols (see Tab 4, Part 1).

- For every dispersant application, the FOSC will ensure that all required monitoring is conducted. The resulting information will be analyzed and used on a daily basis to determine whether dispersant application(s) will continue, be postponed, or cease and whether any modification(s) need to be made.
- Environmental monitoring for atypical dispersant application (e.g., prolonged [>96 hours] surface, subsea) will be guided by the NRT "Environmental Monitoring for Atypical Dispersant Operations" (see Tab 4, Part 2).
- All monitoring that includes sampling will be conducted in accordance with a Quality Assurance Project Plan that addresses sample collection methodology, handling, chain of custody, and decontamination procedures (see Tab 4, Part 2, Section 4).

2.2 Criteria

The following criteria will be considered in dispersant use decision-making within marine waters in Alaska:

- Bathymetry - it is generally recognized that adequate mixing and dilution of dispersants should occur if applied in waters deeper than 10 fathoms (or 60 feet) depth provided there is sufficient energy for mixing. The 10 fathom contour is a standard depth contour line included on National Oceanic and Atmospheric Administration marine charts.
- Distance from shore - an adequate buffer needs to be established to reduce the chances of applying dispersants to sensitive shorelines/nearshore areas and to ensure that drifting dispersant and/or dispersed oil mixtures do not adversely affect intertidal and benthic biota.
- Wind and currents - areas where there is generally little movement of water would not provide sufficient mixing energy for effective dispersant use. With higher wind speeds (beginning at 12-14 meters per second (26.8 to 31.3 miles per hour)), the benefits of dispersant application start to diminish compared to natural dispersion.
- Salinity - most dispersants are made for use in saltwater and are not effective in fresh water or waters with a salinity of less than 15 parts per thousand.
- Temperature - dispersant effectiveness will be affected by ambient water temperatures, with more complete dispersion in warmer waters.

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- Response equipment - the availability and time to mobilize response equipment may affect whether dispersants can be used.
- Shoreline types - certain shoreline types (e.g., gravel, mixed sand and gravel, coarse-grained sand beaches, and marshes) may trap oil for long periods. The amount of wave energy (e.g., protected inlets vs. high-energy exposed beaches) will also affect oil retention and persistence.
- Sensitive habitats - certain habitats where biota breed, rear young, feed, or congregate (e.g., eelgrass beds, kelp beds, saltwater marshes, and designated critical habitats for threatened or endangered species) may be adversely affected by oil and/or dispersed oil.
- Sensitive species – including threatened or endangered species – these species may be adversely affected by oil and/or dispersed oil.
- Other areas designated for special use or protection - these areas (e.g., national and state parks, national wildlife refuges, and wildness areas) may be adversely affected by oil and/or dispersed oil.
- Historic properties - these resources (e.g. archeological and historic resources) may be adversely affected by oil and/or dispersed oil.
- Human use activities - these activities (e.g., subsistence, fishing, and boating activities) may be adversely affected by oil and/or dispersed oil.
- Public and private facilities – these facilities (e.g., fish hatcheries, aquaculture and mariculture facilities, public water intakes, and docks) may be adversely affected by oil and/or dispersed oil).

2.3 Conditions/Stipulations

The following conditions and stipulations shall be included in any dispersant application field test and in any subsequent authorization of full-scale dispersant application(s):

- All dispersant application field tests will be conducted on a representative portion of the oil slick.
- All dispersant applications will be conducted in accordance with the conditions and procedures identified in Tab 1. Dispersant application effectiveness and potential trade-offs associated with its use will be evaluated on a daily basis, informing the FOSC's decision to continue, postpone, modify, or cease dispersant application based on that day's monitoring information.
- Dispersant applications will only be carried out in daylight conditions.
- Dispersants will only be applied in areas where the water depth is ≥ 10 fathoms (60 feet) and at sufficient distances from shore to ensure that sensitive near-shore and benthic habitats are not affected by dispersants and/or dispersed oil.
- Dispersants applications will maintain a minimum 500 meters (1,640 feet) horizontal separation from swarming fish, rafting flocks of birds, marine mammals in the water, and/or marine mammal haul-outs.

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- To avoid disturbances at walrus haul-outs, any dispersant-related aircraft will comply with any Federal Aviation Administration Temporary Flight Restriction(s) and Notice to Airmen and/or aviation restrictions issued by the U.S. Fish and Wildlife Service (FWS). In addition, any dispersant-related vessel(s) will comply with any USCG Notice to Mariners and/or FWS restrictions for walrus haul-outs.
- Any monitoring required by FWS and/or National Marine Fisheries Service for Endangered Species Act Section 7 compliance will be conducted.
- DOI and/or DOC will provide a specialist in aerial surveying of marine mammals and pelagic birds to accompany a Tier 1 monitoring team to help ensure compliance with the above requirements. If DOI and/or DOC cannot provide the appropriate specialist(s), a third party acceptable to the DOI and/or DOC will be identified to accompany the monitoring team.
- Any atypical dispersant application (e.g., prolonged [> 96 hours] surface and subsea) will be guided by the NRT "Environmental Monitoring for Atypical Dispersant Operations" (see Tab 4, Part 2).
- Other incident-specific conditions/stipulations: _____

  _____

  _____

  _____

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TAB 1. PROCESS FOR DISPERSANT USE AUTHORIZATION

Part 1A: Process for Dispersant Use in the Preauthorization Area

The following information outlines the procedure that shall be followed when the Federal On-Scene Coordinator (FOSC) has made a decision to authorize the use dispersants on a crude oil discharge within the dispersant Preauthorization Area under the preauthorized conditions[7]:

1. The FOSC directs the Responsible Party (RP) to mobilize resources for dispersant use, while the RP and the Environmental Unit (EU) of the Incident Command immediately begin to complete the checklists contained in Parts 2-3. This checklist information will be used to inform the decision to authorize dispersant use and establish the parameters of the incident-specific authorization, as appropriate. If there is no RP identified, the FOSC, serving as the "Requestor," may direct mobilization of resources for dispersant use as noted above.
2. The FOSC immediately notifies the following entities of the decision to authorized the use dispersants:
   - U.S. Environmental Protection Agency (EPA) Alaska Regional Response Team (ARRT) representative
   - U.S. Department of the Interior (DOI) ARRT representative
   - U.S. Department of the Commerce (DOC) ARRT representative
   - State On-Scene Coordinator (SOSC)
   - Representative for each appropriate federally-recognized tribe
   - Representative for each appropriate stakeholder group (e.g., local government(s), Native corporation(s), regional citizens' advisory council(s))
3. The FOSC directs appropriate entities (i.e., previously-agreed upon third party (or parties) and/or USCG Strike Team/Special Monitoring of Applied Response Technologies [SMART] Team) to mobilize Tier 1, 2, and 3 monitoring capabilities.
4. The FOSC initiates, as appropriate, Endangered Species Act (ESA) Section 7 consultation(s) with U.S. Fish and Wildlife Service and/or National Marine Fisheries Service (NMFS) representatives in accordance with the ESA Memorandum of Agreement (see Annex G of the *Unified Plan*).
5. The FOSC initiates, as appropriate, Essential Fish Habitat consultation with a NMFS representative.
6. The National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator (SSC) and EU, in coordination with the Operations Section, provide any necessary supporting information (e.g., ADIOS model runs, currents, water temperature, salinity, and fish and wildlife observations) required in Parts 2-3. The completed Parts 2-3 are submitted by the EU Leader to the FOSC. The FOSC completes Questions 1-17 in Part

[7] These steps assume that the FOSC will be working within a Unified Command structure and that all input related to dispersant use authorization(s) will be provided to the FOSC within the timeframe required by the FOSC.

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4. The completed Parts 2-4 are provided to other members of the Unified Command (UC) and representatives identified in Step 2 above.

Part 1A: Process for Dispersant Use in Preauthorization Areas, Cont.

7. An individual representing the FOSC holds a teleconference (at a time determined by the FOSC) with individuals identified in Step 2 above, appropriate members of the EU, and the UC for the purpose of informing the FOSC's decision to use dispersants.
8. The FOSC completes Questions 18-20 in Part 4, documents any changes to Parts 2-4, and completes Part 5 prior to proceeding with a dispersant application field test (following Steps 9-15 below, as appropriate) or postponing or cancelling the field test.
9. The Dispersant Field Task Force (DFTF)[8] advises the FOSC that dispersant application and monitoring personnel, equipment, and supplies are staged and ready to deploy for a dispersant application field test.
10. The DFTF, under the supervision of the FOSC, conducts a dispersant application field test and all required monitoring.
11. The NOAA SSC, using the results of the SMART Tier 1, 2, and 3 monitoring, determines whether the dispersant is effectively dispersing the oil, documents the basis for that determination, and provides the information to the EU.
12. The EU provides to the FOSC, other members of the UC, and individuals identified in Step 2 above, a recommendation on whether full-scale dispersant application(s) should commence with any modification(s) and/or any additional monitoring requirements.
13. An individual representing the FOSC holds a teleconference (at a time determined by the FOSC) with individuals identified in Step 2 above, appropriate members of the EU, and the UC for the purpose of informing the FOSC's decision to authorize any full-scale dispersant application(s) or to postpone or cancel authorization of dispersant application(s). [The frequency of teleconferences following any first full-scale dispersant application will be determined on an incident-specific basis by the FOSC, the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC. Those teleconferences will inform the FOSC's decision to continue, postpone, modify or cease authorization of full-scale dispersant application(s).]
14. The FOSC determines whether to authorize full-scale dispersant application(s) with any modification(s) and/or any additional monitoring requirements will begin, be postponed, or cancelled; documents any revisions to Parts 2-5; and provides the information to the rest of the UC and individuals identified in Step 2 above. Following any prolonged use of dispersants (i.e., full scale dispersant application ongoing for, or expected to exceed or exceeding 96 hours following initial dispersant application and/or subsea dispersant application, any additional authorization dispersant use will be considered via the Process for Case-by-Case Dispersant Use Authorization in Tab 1, Part 1B.
15. After the response for this incident has been completed, the FOSC will complete a Dispersant Use After-Action Report (see Tab 3) for submittal to other members of the UC, all ARRT members, other individuals identified in Step 2 above, and the National

[8] The DFTF includes all dispersant application and dispersant monitoring teams.

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Response Team. The FOSC will provide an opportunity for signatories in Part 5 to provide comment prior to finalization of the report. The final report will be posted on the ARRT public website.

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Part 1B: Process for Case-by-Case Dispersant Use Authorization

The following information outlines the procedure that shall be followed when the application of dispersants into marine waters in Alaska is being proposed as a response option for discharges of any oil in Undesignated Areas and/or discharges of oil, other than crude oil, in a Preauthorization Area outside the preauthorized conditions[9].

1. The Responsible Party (RP), serving as the Requestor, notifies the Federal On-Scene Coordinator (FOSC) of their intention to prepare and submit a Dispersant Use Request (see Part 2). Depending on the timing and need to move quickly, the FOSC may direct the RP to begin mobilizing equipment, materials, and personnel in preparation to implement the dispersant use plan to be proposed. [If there is no RP identified, the FOSC may serve as the Requestor.]
2. The FOSC immediately notifies the following entities of the RP's intent to submit a Dispersant Use Request:
   - U.S. Environmental Protection Agency (EPA) Alaska Regional Response Team (ARRT) representative
   - U.S. Department of the Interior (DOI) ARRT representative
   - U.S. Department of Commerce (DOC) ARRT representative
   - State On-Scene Coordinator (SOSC)
   - Representative for each appropriate federally-recognized tribe
   - Representative for each appropriate stakeholder group (e.g., local government(s), Native corporation(s), regional citizens' advisory council(s))
3. Depending on the timing and need to move quickly, the FOSC directs appropriate entities (i.e., previously-agreed upon third party (or parties) and/or USCG Strike Team/Special Monitoring of Applied Response Technologies [SMART] Team) to mobilize Tier 1, 2, and 3 monitoring capabilities.
4. The FOSC initiates, as appropriate, Endangered Species Act (ESA) Section 7 consultation(s) with U.S. Fish and Wildlife Service and/or National Marine Fisheries Service (NMFS) representatives in accordance with the ESA Memorandum of Agreement (see Annex G of the *Unified Plan*).
5. The FOSC initiates, as appropriate, Essential Fish Habitat consultation with a NMFS representative.
6. The National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator (SSC) and Environmental Unit (EU), in coordination with the Operations Section, provide any necessary supporting information (e.g., ADIOS model runs, currents, water temperature, salinity, and fish and wildlife observations) required in Parts 2-3. The completed Parts 2-3 are submitted by the EU Leader to the FOSC. The FOSC completes Questions 1-17 in Part 4.
7. An individual representing the FOSC holds a teleconference (see procedure listed below) with individuals identified in Step 2 above, the Unified Command (UC), and appropriate

[9] These steps assume that the FOSC will be working within a Unified Command structure and that all input related to dispersant use authorization(s) will be provided to the FOSC within the timeframe requested by the FOSC.

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members of the EU for the purpose of the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, to take action on the Dispersant Use Request.

Teleconference Procedure for Dispersant Application Field Test

Individual representing the FOSC:

- Confirms when the FOSC requires input from all parties identified in Step 2 above.
- Provides to all parties identified in Step 2 above, information on the teleconference time and call-in number, and copies of Parts 2-4.
- Chairs the teleconference and: (1) conducts roll call, recording name, title, and affiliation of teleconference participants; (2) requests (from the Requestor) a brief summary/overview of the plan for the proposed dispersant application field test (field test); (3) directs questions to the appropriate UC or EU representative(s); (4) requests input from the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC; (5) requests input from federally-recognized tribes and stakeholders; (6) facilitates development of a consensus recommendation (if possible) by the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, on the proposed field test, including any special considerations, constraints, permit requirements, and/or special authorizations; (7) queries the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, for their summary input on the proposed field test; and (9) verbally summarizes input received.
- Prepares and provides as soon as possible to the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, a draft written summary of the teleconference results along with the names, titles, and affiliations of teleconference participants. Incorporates as soon as possible any corrections to the summary provided by the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, and immediately provides the final summary to the UC with a copy to each teleconference participant.

Part 1B: Process for Case-by-Case Dispersant Use Authorization, Cont.

8. The FOSC completes Questions 18-20 in Part 4 and documents any changes to Parts 2-4; the FOSC, the EPA, DOI and DOC ARRT representatives and, when appropriate, the SOSC, complete Part 5, prior to proceeding with a dispersant application field test (following Steps 9-15 below, as appropriate) or postponing or cancelling the field test as determined in the above procedure.
9. The Dispersant Field Task Force (DFTF)[10] advises the FOSC that dispersant application and monitoring personnel, equipment, and supplies are staged and ready to deploy for a dispersant application field test.
10. The DFTFs, under the supervision of the FOSC, conducts a dispersant application field test and all required monitoring.
11. The NOAA SSC, using the results of the SMART Tier 1, 2, and 3 monitoring, determines whether the dispersant is effectively dispersing the oil, documents the basis for that determination, and provides the information to the EU.

[10] The DFTF includes all dispersant application and dispersant monitoring teams.

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Part 1B: Process for Case-by-Case Dispersant Use Authorization, Cont.

12. The EU provides to the UC and individuals identified in Step 2 above, a recommendation on whether full-scale dispersant application(s) should commence with any modification(s) and/or any additional monitoring requirements.
13. An individual representing the FOSC holds a teleconference (see procedure listed below) with individuals identified in Step 2 above, the UC, and appropriate members of the EU for the purpose of the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, to take action on a request for full-scale dispersant application(s). [The frequency of teleconferences following any first full-scale dispersant application will be determined on an incident-specific basis by the FOSC, the EPA, DOI, DOC ARRT representatives and, when appropriate, the SOSC. Those teleconferences will reconsider the decision to continue, postpone, or cease full-scale dispersant application(s). Following any prolonged use of dispersants (i.e., full scale dispersant application ongoing for, or expected to exceed or exceeding 96 hours following initial dispersant application), or request for any subsea dispersant application, a teleconference will be held to reconsider the decision to continue dispersant application(s).

Teleconference Procedure for Full-Scale Dispersant Application

Individual representing the FOSC:

- Confirms when the FOSC requires input from all parties identified in Step 2 above.
- Provides to all parties identified in Step 2 above, information on the teleconference time and call-in number and any revisions to Parts 2-4 made following any dispersant application field test(s) and/or the EU's recommendation regarding whether full-scale dispersant application(s) should commence with any modification(s) and/or any additional monitoring requirements.
- Chairs the teleconference and: (1) conducts roll call, recording name, title, and affiliation of teleconference participants; (2) requests (from the Requestor) a brief summary/overview of the plan for the proposed full-scale dispersant application (full-scale application); (3) directs questions to the appropriate UC or EU representative(s); (4) requests input from the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC; (5) requests input from appropriate federally-recognized tribes and stakeholders; (6) facilitates development of a consensus recommendation (if possible) by the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, on the proposed full scale application, including any special considerations, constraints, permit requirements, and/or special authorizations; (7) queries the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, for their summary input on the proposed full-scale application; and (9) verbally summarizes input received.
- Prepares and provides as soon as possible to the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC, a draft written summary of the teleconference results along with the names, titles, and affiliations of teleconference participants. Incorporates as soon as possible any corrections to the summary provided by the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC,

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and immediately provides the final summary to the UC with a copy to each teleconference participant.

Part 1B: Process for Case-by-Case Dispersant Use Authorization, Cont.

14. The FOSC documents any changes to Parts 2-4. In addition, the FOSC, the EPA, DOI and DOC ARRT representatives and, when appropriate, the SOSC complete Part 5 prior to commencing, postponing, or cancelling full-scale dispersant application(s) as determined through the above procedure. Any revisions to Parts 2-5 will be provided to the rest of the UC and individuals identified in Step 2 above.
15. After the response for this incident has been completed, the FOSC will complete a Dispersant Use After-Action Report (see Tab 3) for submittal to other members of the UC, all ARRT members, other individuals identified in Step 2 above, and the National Response Team. The FOSC will provide an opportunity for signatories in Part 5 to provide comment prior to finalization of the report. The final report will be posted on the ARRT public website.

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Part 2: Dispersant Use Request

INCIDENT NAME		Date Prepared:	
		Time Prepared:	
INCIDENT LOCATION		**REQUESTOR INFORMATION**	
Latitude:		Name:	
Longitude:		Affiliation:	
Description:		Address:	
		Phone:	
		Cell Phone:	
Incident Date:		Fax:	
Incident Time:		Email:	

Areas dispersants to be applied in: ☐ Preauthorization Area
☐ Undesignated Area

BASIC DATA

Type of incident (check one):
- ☐ Grounding
- ☐ Transfer operations
- ☐ Explosion
- ☐ Collision
- ☐ Allision
- ☐ Blowout
- ☐ Other _____

Oil discharged: API:
- ☐ North Slope Crude _____
- ☐ Cook Inlet Crude _____
- ☐ Residuals _____
- ☐ Diesel #2 _____
- ☐ JP4 _____
- ☐ Other: _____

Estimated volume of oil discharged/discharge rate:
_____ gallons; _____ gallons per _____

Potential oil discharge volume estimate:
_____ gallons

Oil discharge status (check one):
- ☐ Continuous
- ☐ Intermittent
- ☐ One time only, now stopped

Did source burn? ☐ Yes ☐ No
Is source still burning? ☐ Yes ☐ No
Is oil easily emulsified? ☐ Yes ☐ No

RESPONSE CONSIDERATIONS

Why is mechanical recovery ineffective and/or inadequate?
Is the mechanical recovery insufficient? If so, why?
_____
_____
_____
_____

Will *in-situ* burning (ISB) also be used? ☐ Yes ☐ No
Will mechanical recovery also be used? ☐ Yes ☐ No
Will dispersant use impede mechanical recovery? ☐ Yes ☐ No

If yes, explain how this will be resolved:
_____
_____
_____

ADIOS MODEL

Has ADIOS been run by a qualified person? ☐ Yes ☐ No
Identify individual and affiliation: _____
If yes, please fill out the following ADIOS input parameters:
Wind speed _____ Water temp. _____
ADIOS output parameters to be specified:
- Percentage evaporation

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Current estimate of water surface covered by oil as of: Date/Time: _____ Area: _____ sq. mi.	• Viscosity change • Water percentage or emulsification over a 5-day period

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Part 2: Dispersant Use Request, Cont.

WEATHER AND SEA CONDITIONS

Check boxes and enter wind values in the following table:

	Present Condition	12-hour Forecast	24-hour Forecast
Clear			
Partly cloudy			
Overcast			
Rain			
Snow			
Fog			
Wind speed (knots/mph)			
Wind direction (from)			

Visibility (miles): _____

Tidal state at _____ o'clock (check one):

☐ Slack tide ☐ Incoming (flood) ☐ Outgoing (ebb)

✓ **Attachment 1:** Graph with tidal information for 3 tidal cycles.

Dominant current (net drift):

Speed (knots): _____ Direction (to): _____

Sea state: present condition (check one)

☐ Calm ☐ Choppy ☐ Swell

Sea state: 24-hour forecast (check one)

☐ Calm ☐ Choppy ☐ Swell

Waves (height estimate), present condition: _____ feet

Waves (height estimate), 24-hr forecast: _____ feet

Depth of water at slick: _____ feet

Water temperature: _____ degrees C and F

Water salinity: _____ parts/thousand

If ice is present, describe: _____

_____

_____

Next sunrise: _____ Next sunset: _____

WILDLIFE INFORMATION

Have fish swarms, birds, and/or marine mammals been observed near the oil slick?

☐ Yes ☐ No If yes, please answer the following:

Type observed (e.g., birds, sea otters, seals, whales, fish)	Estimated Number

DISPERSANT USE PLAN

Proposed date and time for application of dispersants:

Date: _____ Time: _____

Distance to nearest staging area (airport/facility):

_____ mi

What is the dispersant proposed for use?

☐ Corexit 9500 ☐ Corexit 9527

☐ Other: _____

Material Safety Data Sheet (MSDS) attached? ☐Yes ☐No

What is the proposed dispersant to oil ratio?

_____:_____

How much total dispersant per acre is proposed?

_____ gallons

What is the estimated percentage of spill slick area to be treated? _____ percent

Who will apply the dispersants?

Individual/Affiliation: _____

Application Method	Estimated Dispersant Capacity Per Sortie	Estimated Number of Sorties
☐ Boat	_____	_____
☐ C-130	_____	_____
☐ CASA	_____	_____
☐ Helicopter	_____	_____
☐ Other:	_____	_____

Distance from source: _____ miles

Distance from nearest shoreline: _____ miles

✓ **Attachment 2:** Provide a chart with a distance scale. Chart must include: 1) estimated spill trajectory and landfalls with time; 2) location and distance of proposed dispersant application relative to zone boundaries, proposed dispersant application field test location, and other response activities including ISB; 3) dispersant tactic summary and how it will augment the mechanical response, if used; and 4) fish and wildlife locations relative to the oil slick.

DISPERSANT USE HEALTH AND SAFETY PLAN

Does the site-specific health and safety plan cover the dispersant use plan? ☐ Yes ☐ No

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*(Include in the chart being submitted as **Attachment 2** the proximity of the above observed fish and wildlife)*	✓ **Attachment 3**: Relevant portion of health and safety plan, including MSDS.

Part 2: Dispersant Use Request, Cont.

DISPERSANT SYSTEM APPLICATION

Application system design:

- Designed specifically for this purpose? ☐ Yes ☐ No
- Used previously for this purpose? ☐ Yes ☐ No
- Tested to be effective and safe? ☐ Yes ☐ No
- Meet manufacturer's recommendations? ☐ Yes ☐ No

Application personnel are trained and/or experienced in the use of dispersants and this application system? ☐ Yes ☐ No

Aerial application system:

- A qualified Dispersant Controller will be in a separate aircraft over the spray area(s)? ☐ Yes ☐ No
- Dispersant Controller will be able to direct operations and avoidance of fish and wildlife? ☐ Yes ☐ No

Boat application system:

- A qualified Dispersant Controller will oversee operations? ☐ Yes ☐ No
- System components meet relevant ASTM standards? ☐ Yes ☐ No

✓ **Attachment 4**: Description of dispersant application system and application team personnel name(s), title(s), affiliation(s), and qualifications.

COMMUNICATIONS PLAN

Describe the communications plan to be used for communications between and among the Unified Command, Dispersant Controller, SMART Team, and dispersant applications platform(s):

DISPERSANT MONITORING

Indicate the SMART monitoring to be used:

- Tier 1: ☐ Yes ☐ No
- Tier 2: ☐ Yes ☐ No
- Tier 3: ☐ Yes ☐ No

Describe other monitoring to be used:

Describe monitoring platform(s) that will be used:

Identify name, title, affiliation, and qualification of each monitoring team member:

SIGNATURES

Requestor:

_____
Requester's Printed Name and Signature

Requester contact cell phone: _____

Date and time submitted to FOSC and, when appropriate, the SOSC:

_____ _____
Date Time

Received by:

_____ _____
FOSC Printed Name and Signature Date/Time

_____ _____
SOSC Printed Name and Signature Date/Time

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Part 3: Incident-Specific Resources at Risk

A. Information Considered

☐ Sensitive Areas information in the subarea contingency plan(s) (SCPs) for this incident, including any locations where dispersant use should be avoided

☐ Relevant Geographic Response Strategies in appropriate SCPs for this incident

☐ Incident-specific on-scene observations (e.g., by responders, local agency representatives, and local residents); identify name/affiliation: _____

☐ Others: _____

B. Biological Species (may not be a complete list of species present)

	Present/Absent/ or Unknown	Other Relevant Information	Used for Subsistence?
Endangered/Threatened/Candidate Species:			
Migratory birds (specify)			
Sea otters (southwest Distinct Population Segment)			
Polar bears			
Seals (specify)			
Toothed whales (specify)			
Baleen whales (specify)			
Sea Lions			
Other Species:			
Seabirds			
Diving birds (unlisted populations)			
Waterfowl (unlisted populations)			
Shorebirds			
Raptors (unlisted populations)			
Sea Otters (unlisted populations)			
Walruses			
Fur seals			
Other seals (unlisted populations)			
Toothed whales (unlisted populations)			
Baleen whales (unlisted populations)			
Ungulates			
Bears (brown and/or black)			
Furbearers			
Fish:			
Pelagic and larval			
Bottomfish			
Intertidal mollusks			
Crustacea			
Plankton (including larval species)			

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Part 3: Incident-Specific Resources at Risk, Cont.

C. Habitat Types

	Present/Absent/Unknown	Other Relevant Information
Salt/brackish-water marshes		
Eelgrass beds/kelp beds		
Tidal mudflats		
Sheltered rocky shores/shallow reefs		
Gravel beaches		
Mixed sand and gravel beaches		
Coarse-grained sand beaches		
Peat shorelines		
Inundated low-lying tundra		
Ice (seasonal, multi-year)		
Marine mammal haul-outs/rookeries		
Migratory bird nesting colonies		
Fish spawning grounds		
Others:		

D. Special Designations

	Present/Absent/Unknown	Other Relevant Information
ESA designated critical habitats		
Essential Fish Habitat		
Legislatively-designated areas		
Native allotments		
Others:		

E. Historic Properties

	Present/Absent/Unknown	Other Relevant Information
Historic Resources		
Archaeological Resources		
Others:		

F. Other Considerations

	Present/Absent/Unknown	Other Relevant Information
Commercial harvest areas		
Subsistence harvest areas		
Recreational use areas		
Mariculture facilities		
Commercial facilities/activities		
Public infrastructure		
Others:		

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Part 4: FOSC Dispersant Authorization Checklist*

	YES	NO	CONSIDERATIONS
1.	☐	☐	***Dispersant Use Request Received:*** The Requestor has submitted a completed Dispersant Use Request (Part 2).
			Notifications: The following entities have been notified of the potential dispersant use for this incident:
2a.	☐	☐	a. State On-Scene Coordinator (SOSC)
2b.	☐	☐	b. U.S. Environmental Protection Agency (EPA) Alaska Regional Response Team (ARRT) representative
2c.	☐	☐	c. U.S. Department of the Interior (DOI) ARRT representative
2d.	☐	☐	d. U.S. Department of Commerce (DOC) ARRT representative
2e.	☐	☐	e. Appropriate federally-recognized tribes (identify representative(s)): _____
2f.	☐	☐	f. Appropriate stakeholders (e.g., local governments, Native corporations, regional citizens' advisory councils) (identify representative(s)): _____
2g.	☐	☐	g. Agreed-upon monitoring team(s) and/or USCG Strike Team/Special Monitoring of Applied Response Technologies (SMART) Team.
3.	☐	☐	***Endangered Species Act (ESA) Consultations:*** The U.S. Fish and Wildlife Service (FWS) and/or National Marine Fisheries Service (NMFS) ESA contact(s) have been notified and, if appropriate, ESA Section 7 consultation(s) have begun in accordance with the ESA Memorandum of Agreement.
4.	☐	☐	***Essential Fish Habitat (EFH) Consultations:*** NMFS EFH contact has been notified and, if appropriate, EFH consultations have begun.
5.	☐	☐	***Dispersability:*** Available technical and scientific information, including results from the ADIOS model, suggests that the discharged oil is dispersible. The analysis delineates the conditions and timeframe in which the oil is no longer dispersable. Identify source(s) relied upon: _____
6.	☐	☐	***NCP Listed Dispersant:*** The dispersant to be used is listed on the current NCP Product Schedule, is considered appropriate for the existing environmental and physical conditions, and its use is consistent with the recommended application information provided in the NCP Product Schedule Technical Notebook. Identify source(s) relied upon: _____
			Response Considerations:
7a.	☐	☐	a) Has mechanical response been deemed to be ineffective and/or inadequate? If yes, specify reason(s) (e.g., availability, effectiveness, timeliness, sea state, spatial coverage, weather conditions): _____
7b.	☐	☐	b) Is dispersant application being used to supplement mechanical recovery?
7c.	☐	☐	c) Is *in-situ* burning being considered in conjunction with mechanical recovery and dispersant use?
7d.	☐	☐	d) Is a map illustrating timing, tactics, and proximity of each response option to each other attached?
			Dispersant Availability and Timeliness: Sufficient dispersant application and monitoring equipment has been confirmed to be available:
8a.	☐	☐	a) to meet the conditions of use in the Dispersant Use Plan (see Part 2), and
8b.	☐	☐	b) to be deployable within the conditions and time frame the oil will be dispersible.
9.	☐	☐	***Weather and Sea Conditions:*** Predicted weather and sea conditions are conducive to dispersant application by the chosen system or platform. (Generally, for aerial application, wind ≤ 25 kts (28.77 mph), visibility ≥ 3 nm (3.45 miles), and ceiling ≥1,000 ft. Generally for boat application, a sea state that will allow the vessel to be used to conduct an effective and safe spray operation.) Identify any updated conditions: _____
10.	☐	☐	***Personal Protective Equipment (PPE):*** PPE for all personnel involved in, or affected by, dispersant application conforms to the site-specific health and safety plan and has been confirmed to be available.
			General Adequacy of Dispersant Spray System and Personnel Competency: Note: The general criteria for evaluating the suitability for use of any dispersant system is the ability of the Requestor to demonstrate to the satisfaction of the FOSC, the following:

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			Has the application system been:
11a.	☐	☐	a) Specifically designed for its intended purpose, or
11b.	☐	☐	b) If not specifically designed for dispersant use, used previously and deemed to be effective and appropriate, and will be used again in a similar manner, or

Part 4: FOSC Dispersant Authorization Checklist, Cont.

	YES	NO	CONSIDERATIONS
11c.	☐	☐	c) If not specifically designed and not previously used for dispersant application, deemed to be effective and appropriate by some other specific means; if so, identify specific means: _____
11d.	☐	☐	d) Is the design and operation of the application system such that it can reasonably be expected to apply the chemical dispersant in a manner consistent with the dispersant manufacturer's recommendation, especially with regards to dosage rates, and concentrations?
11e.	☐	☐	e) Will the dispersant application be supervised by personnel that have experience, knowledge, specific training, and/or recognized competence with chemical dispersants and the type of system to be used?
			Aerial Application Operational and Technical Issues: In the case of aerial application of dispersants:
12a.	☐	☐	a) Is there a Dispersant Controller who will be over the spray area(s) in a separate aircraft from the dispersant aircraft while dispersants are being applied?
12b.	☐	☐	b) Is the Dispersant Controller qualified and able to direct the dispersant aircraft to maintain a 500 meter (1,640 feet) horizontal separation between the dispersant application andswarming fish, rafting flocks of birds, marine mammals in the water, and/or marine mammal haul-outs?
12c.	☐	☐	c) Is the aircraft spray system capable of producing dispersant droplet sizes that provide for optimal dispersant effectiveness (generally 250-500 µm), by following manufacturer and ASTM guidance?
			Boat Application Operational Technical Issues: If the system involves spray arms or booms that extend over the edge of a boat and has fan type nozzles that spray a fixed pattern of dispersant, has the Requestor confirmed that the dispersant application will comply with all of the following ASTM standards?
13a.	☐	☐	*a)* **ASTM F 1413-92** *Standard Guide for Oil Spill Dispersant Application Equipment: Boom and Nozzle Systems*
13b.	☐	☐	*b)* **ASTM F 1460-93** *Standard Practice for Calibrating Oil Spill Dispersant Application Equipment: Boom and Nozzle Systems*
13c.	☐	☐	*c)* **ASTM F 1737-96** *Standard Guide for Use of Oil Spill Dispersant Application Equipment during Spill Response: Boom and Nozzle Systems*
			Monitoring Protocols/Deployment:
14a.	☐	☐	a) Have the agreed-upon monitoring team(s) and/ or USCG Strike Team SMART Team been activated?
14b.	☐	☐	b) Are they prepared to fly over the response area to conduct Tier 1 visual monitoring during every dispersant application?
14c.	☐	☐	c) Are they prepared to implement the Tier 2 and Tier 3 water column monitoring component of the SMART monitoring protocols for every dispersant application?
14d.	☐	☐	d) Are wildlife observers prepared to accompany Tier 1 monitors to watch for swarming fish, rafting flocks of birds, marine mammals in the water, and marine mammal haul-outs?
14e.	☐	☐	e) Are there additional monitoring requirements? If so, identify:_____ and indicate if appropriate entities are prepared to implement any additional requirement?
15.	☐	☐	***Communications:*** Has a communications plan been developed that will allow communications between and among the Unified Command, Dispersant Controller, all monitoring team(s), and dispersant applications platform(s)?
16.	☐	☐	***Natural Resource Trustee Input:*** Has the FOSC received input from natural resource trustees on incident-specific resources at risk (see Part 3)?
			Conditions/Stipulations: Will the following application conditions and stipulations be included in any dispersant application?
17a.	☐	☐	a) All dispersant application field tests will be conducted on a representative portion of the slick.

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17b.	☐	☐	Dispersant application will be in accordance with the approved dispersant application plan.
17c.	☐	☐	c) Dispersants will only be applied in areas where the water depth is ≥ 10 fathoms (60 feet).
17d.	☐	☐	d) Dispersant applications will maintain a minimum 500 meters (1,640 feet) horizontal separation from swarming fish, rafting flocks of birds, marine mammals in the water, and marine mammal haul-outs.
17e.	☐	☐	e)

Part 4: FOSC Dispersant Authorization Checklist, Cont.

	YES	NO	CONSIDERATIONS
17f.	☐	☐	f) Federal Aviation Administration Temporary Flight Restrictions and Notice to Airmen and/or FWS flight and vessel restrictions to avoid disturbing walrus on haul-outs will be followed.
17g.	☐	☐	g) Dispersant applications will only be carried out in daylight conditions.
17h.	☐	☐	h) DOI and/or DOC (or a third party observer acceptable to DOI and/or DOC) will provide a specialist in aerial surveying of marine mammals and/or pelagic birds to accompany the SMART observer.
17i.	☐	☐	i) Monitoring protocols required by EPA, State, and/or DOI and DOC natural resource trustees (e.g., ESA compliance) will occur.
17j.	☐	☐	j) Prolonged dispersant application will be guided by recommendations in the NRT "Environmental Monitoring for Atypical Dispersant Operations."
17k.	☐	☐	k) SMART Tier 1, 2, and 3 monitoring will occur during any dispersant application.
18.	☐	☐	***SOSC, EPA, DOI, and DOC Input:*** Has the FOSC received input from the EPA, DOI, and DOC ARRT representatives and, when appropriate, the SOSC on the dispersant request?
19.	☐	☐	***Federally-Recognized Tribe Input:*** Has the FOSC received input from appropriate federally-recognized tribes?
20.	☐	☐	***Stakeholder Input:*** Has the FOSC received input from appropriate stakeholders on the dispersant request?

* If "no" is checked for any of the above questions, the FOSC will document reasons for making that determination and what, if anything, may be done to change the response to "yes."

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Part 5: Dispersant Use Authorization Document[11]

Incident: _____

U.S. Department of the Interior Consultation by DOI ARRT Representative (for case-by case authorization only):

- o _____Does not support the use of dispersants (reasons attached)
- o _____Agrees with dispersant use in the selected areas under attached conditions
- o _____Agrees with dispersant use as requested in the application form

_____	_____	_____
Signature	Printed Name	Time/Date

U.S. Department of Commerce Consultation by DOC ARRT Representative (for case-by-case authorization only):

- o _____Does not support the use of dispersants (reasons attached)
- o _____Agrees with dispersant use in the selected areas under attached conditions
- o _____Agrees with dispersant use as requested in the application form

_____	_____	_____
Signature	Printed Name	Time/Date

U.S. Environmental Protection Agency Concurrence by EPA ARRT Representative (for case-by-case authorization only):

- o _____No dispersants may be applied (reasons attached)
- o _____Dispersants may be used in the selected areas under attached conditions
- o _____Dispersants may be applied as requested in the application form

_____	_____	_____
Signature	Printed Name	Time/Date

State of Alaska Concurrence by State On-Scene Coordinator (for case-by-case authorization only):

- o _____No dispersants may be applied (reasons attached)
- o _____Dispersants may be used in the selected areas under attached conditions
- o _____Dispersants may be applied as requested in the application form

_____	_____	_____
Signature	Printed Name	Time/Date

Federal On-Scene Coordinator Decision

- o _____No dispersants may be applied (reasons attached)
- o _____Dispersant use is postponed (reasons attached)
- o _____Dispersants may be used in the selected areas under attached conditions
- o _____Dispersants may be applied as requested in the application form (reasons attached for the basis of determining that dispersant use would minimize overall environmental impacts)

_____	_____	_____
Signature	Printed Name	Time/Date

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[11] This document shall be completed, as appropriate, for both a dispersant application field test and any subsequent request for full-scale application. Where signatures cannot be immediately obtained in person or via email or fax, verbal input will suffice until signatures can be obtained.

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TAB 2. DISPERSANT USE AFTER-ACTION REPORT

Guidelines and Requirements

The Dispersant Application After-Action Report will focus on the following elements of the dispersant application:

- An overview of the incident (prepared by the Federal On-Scene Coordinator (FOSC))
- A description of how the dispersant application(s) were conducted (prepared by the Requestor)
- A description of how Tier 1 monitoring was conducted and the results (prepared by the Tier 1 Monitoring Team)
- A description of how Tier 2 and Tier 3 monitoring was conducted and the results (prepared by the Tier 2 and 3 Monitoring Team)
- Description of how other dispersant monitoring was conducted and the results, if applicable (prepared by the individuals/team conducting the monitoring)
- Description of any adverse environmental effects associated with the dispersant application, such as impacts to fish and/or wildlife (e.g. disturbance, unintentional over-spray)
- Other elements requested by the FOSC or the Alaska Regional Response Team (ARRT)

This report shall include the elements shown in the Report Outline below. In addition, the report shall be submitted within 30 days of completion of the dispersant operation(s) or a timeframe agreed upon by the ARRT, to all Unified Command (UC), ARRT, and National Response Team members and all individuals identified in Step 2 of Tab 1, Part 1A and/or Part 1B.

Report Outline
I. Incident Overview A. Background information 1. Cause or potential cause of spill, if known 2. Type and amount of oil spilled 3. Location of spill 4. Movement of oil slick, including any trajectories 5. Weathering and behavior of oil 6. Other pertinent information B. Response actions taken/effectiveness (e.g., mechanical recovery, protective booming, *in-situ* burning, dispersant use) C. Summary of decision-making process resulting in the authorization of a request for the use of dispersants, including the basis for the environmental trade-off determination II. Description and the Dispersant Application A. Description of dispersant application (including all dispersant application field test(s)) 1. Type and amount of dispersant applied 2. Type(s) of aircraft and/or vessel(s) used and dispersant system(s) used

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Report Outline, Cont.

3. Personnel directly involved in dispersant application (e.g., Dispersant Controller) and summary of their qualifications and experience
4. Location (shown on a map of appropriate scale), date, time, ratio of dispersant to oil, and total amount of dispersant applied for each dispersant application

5. Weather conditions at time(s) of each application, including sea state, water temperature, water salinity
7.
6. Staging area, distance to region of application, and specifics regarding logistics (including time) involved in supporting the dispersant application
7. Communications used
8. Interaction between UC and field units carrying out guidance received
9. Spotter aerial observations
10. Description of any adverse environmental effects associated with the dispersant application, such as impacts to fish and wildlife (e.g.,disturbance, unintentional over-spray)
11. Health and Safety Plan requirements (including Personal Protective Equipment)

B. Lessons learned
1. What worked well
2. What needed improvement
3. Recommendations

III. Description and Results of Tier 1 (Visual) Monitoring

A. How the monitoring was carried out (e.g., method, vehicle, monitors, etc.)
1. Specifics regarding equipment and suitability of vessel(s) used
2. Description of observations regarding the dispersal of oil
3. Communications used and any associated problems
4. Operational support from the staging area, etc.
5. Interaction between the Incident Management Team (IMT) and the field units carrying out guidance received from the IMT

B. Results of Tier 1 monitoring, including a copy of the National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator's (SSC) documentation on monitoring results and the Environmental Unit's (EU) recommendation to the FOSC

C. Lessons learned
1. What worked well
2. What needed improvement
3. Recommendations

IV. Description and Evaluation of Tier 2 and Tier 3 (Water Column) Monitoring

A. How the monitoring was carried out (e.g. method, vehicle, monitors, etc.)
1. Specifics regarding equipment and suitability of the vessel(s) used
2. Description of observations regarding the dispersal of oil
3. Communications used and any associated problems
4. Operational support from the staging area, etc.
5. Interaction between the IMT and the field units carrying out guidance received from the IMT

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Report Outline, Cont.
B. Results of Tier 2 and Tier 3 monitoring, including a copy of the NOAA SSC's documentation on monitoring results and the EU's recommendation to the FOSC C. Lessons learned 1. What worked well 2. What needed improvement 3. Recommendations V. Description and Evaluation of Additional Monitoring, if conducted A. How the monitoring was carried out (e.g. method, vehicle, monitors, etc.) 1. Specifics regarding equipment and suitability of the aircraft/vessel(s) used 2. Description of observations 3. Communications used and any associated problems 4. Operational support from the staging area, etc. 5. Interaction between the IMT and the field units carrying out guidance received from the IMT B. Results of monitoring C. Lessons learned 1. What worked well 2. What needed improvement 3. Recommendations VI. Additional Elements (as requested by the FOSC or ARRT)

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TAB 3. MONITORING PROTOCOLS

Part 1: Special Monitoring Of Applied Response Technologies (SMART)

(The latest SMART Protocols will be included in the final plan)

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Part 2: NRT Environmental Monitoring for Atypical Dispersant Operations

(This document will be included in the final plan)

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To: Principe, Caleb M. (GSFC-4010)[caleb.m.principe@nasa.gov]
From: Principe, Vanessa
Sent: Fri 11/20/2015 9:26:16 PM
Subject: Can you print this?
OilBudgetCalc_Full_HQ-Print_111110.pdf

Oil Budget Calculator

Deepwater Horizon

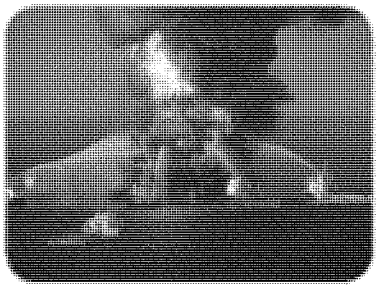
TECHNICAL DOCUMENTATION

November 2010

A Report by:

The Federal Interagency Solutions Group,
Oil Budget Calculator Science and Engineering Team

Oil Budget Calculator
Deepwater Horizon



TECHNICAL DOCUMENTATION

A Report to the National Incident Command

November 2010

This document is the product of several individuals who were consulted on particular aspects of the Oil Budget Calculator, provided field data, suggested formulas, analysis methods, and/or reviewed the algorithms used in the calculator.

LEADS:

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Bristol, Sky	U.S. Geological Survey (USGS)
Possolo, Antonio	National Institute of Standards and Technology (NIST)

MAJOR CONTRIBUTORS OR REVIEWERS: (See Appendix 9 for short biographies)

Expert	Affiliation	Major contribution
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French McCay, Debbie	[redacted]	Review
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Many others contributed directly or indirectly to the Calculator development but were not necessarily involved in the preparation of this document. Some are listed below:

Expert	Affiliation	Major contribution
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Galt, Jerry	[redacted]	Review
Hammond, Steve	[redacted]	Interface
Lacheras, Juan	[redacted]	Natural dispersion
Mabile, Nere	[redacted]	In-situ burning
Miller, Mark	[redacted]	Initial summary
Svekovsky, Jan	[redacted]	Remote sensing
Yapa, Pooji	[redacted]	Subsurface oil

The Coastal Response Research Center (CRRC), a partnership between the National Oceanic and Atmospheric Administration and the University of New Hampshire, provided logistical support with document preparation and the peer-review process. Particular thanks to Nancy Kinner, Zachary Magdol and Kathy Mandsager.

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EXECUTIVE SUMMARY

An oil budget (ICS Form 209) is normally prepared as part of the Incident Action Plan for ordinary oil spills. The Deepwater Horizon spill was anything but ordinary, and a special tool had to be developed to construct a workable oil budget useful to the unified command in making its response decisions. This report describes that tool.

The National Incident Command (NIC) assembled several interagency expert scientific teams to estimate the volume of BP Deepwater Horizon oil that has been released from the well and the short-term fate of that oil. The expertise of government scientists serving on these teams was complemented by non-governmental and governmental specialists providing data, offering suggestions, and reviewing the calculations and conclusions.

The Flow Rate Technical Group (FRTG) and the Department of Energy (DOE) developed estimates of the flow rate and of the total volume of oil released. A second interagency team, led by the U. S. Geological Survey (USGS) from the Department of the Interior, and the National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) from the Department of Commerce, developed a tool called the Oil Budget Calculator to determine what happened to the oil.

The Oil Budget Calculator was designed to assist the Situation Unit of the Incident Command System (ICS). Therefore, its sole purpose was to inform and advise the response, and it should not be used to assess environmental damage or any other purpose.

The Calculator became operational on June 22, 2010 but continues to undergo modification and refinement, not only best to characterize what happened to the oil in this case, but also to assist in the response to future, similar spills. The numbers in this report may change as new information becomes available. The calculator assumed as an input the estimated 4.9 million barrels of oil discharged in total from the well from April 20 until July 14, 2010, provided by FRTG/DOE, and used both direct and indirect measurements and the best scientific estimates available to determine what has happened to the oil.

This report discusses the methods used to estimate the portions of that volume that were recovered directly from the well head, dispersed either chemically or naturally, evaporated or dissolved, burned or skimmed, and the portion left over ("other" oil) that may still be amenable to response actions. The latest results, by and large, are consistent with early results, produced by an early version of the Calculator and announced in a NOAA press release of

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August 4, 2010: the early estimate of the percentage of "other" (or, "residual") oil was 26%; the current version of the Calculator estimates it at 23%, and qualifies this estimate with the belief that, with high confidence, the true percentage should be between 11% (best-case scenario) and 30% (worst-case scenario).

The report also describes the methods used to qualify such estimates with uncertainty assessments. Processes such as direct capture and burning, that were directly measured on-scene, have the smallest uncertainty. Processes such as dispersion that have to be estimated based upon limited data, theoretical considerations and expert knowledge from past incidents, have the greatest uncertainty. The emphasis was on getting a conservative answer so as not to underestimate cleanup requirements. In terms of response, this translates into using conservative estimates for cleanup efficiency, particularly with regard to skimmer efficiency and dispersant success.

The Calculator does not track the final fate of the spilled oil. Instead it estimates oil that may be amenable to response decisions as opposed to oil that is not (e.g. dissolved or evaporated oil). No attempt was made to estimate the amount of dispersed oil that reached the sediments; nor was degradation rate of any of the oil components evaluated quantitatively. The focus was on estimating the fraction of the spilled oil that might still be amenable to response actions, so that informed decisions could be made.

The Oil Budget Calculator is believed to be sufficiently accurate to meet the needs of the Deepwater Horizon spill response. Thus, while it may have underestimated dispersed oil, it predicted sufficient amounts of subsurface oil as to encourage a large-scale water-sampling program. Suggestions are provided at the end of the report that would allow improved budgets in future large-scale incidents.

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LIST OF ACRONYMS

ASA	Applied Science Associates
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
BOP	Blowout Preventer
DOE	Department of Energy
DOI	Department of the Interior
DOR	Dispersant to Oil Ratio
DWH	Deepwater Horizon
FRTG	Flow Rate Technical Group
ICS	Incident Command System
ITOPF	International Tanker Owners Pollution Federation Limited
LISST	Laser In Situ Scattering and Transmissometry
MNS	Mackay-Nadeau-Steelman Laboratory Test
NIC	National Incident Command
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOAA/ERD	NOAA's Emergency Response Division
NRC	National Research Council
ORR	Oil Recovery Rate
PAH	Polycyclic Aromatic Hydrocarbon
RE	Recovery Efficiency
ROV	Remotely Operated Vehicle
SMART	Special Monitoring of Applied Response Technologies
TE	Throughput Efficiency
USCG	United States Coast Guard
USGPA	United States Gallon per Acre
USGS	United States Geological Survey
WHOI	Woods Hole Oceanographic Institute

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1. INTRODUCTION

The Oil Budget Calculator grew out of a need to provide status of the spilled oil to the National Incident Command. Excel spreadsheets were first created to record volumes of skimmed oily water, of oil burned, and of dispersant applied. Later, the number of barrels that were directly captured was also recorded. However, there was no accounting for the fate of the remaining oil, and as the model became increasingly complex, the spreadsheets became difficult to interpret. Therefore, the U.S. Geological Survey (USGS), the U. S. Coast Guard, the National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) developed the Calculator, using data and supplementary expertise provided by non-government experts. The Calculator became operational, as a response tool, on June 22, 2010. However, it continues to undergo modification and refinement.

This document discusses the technical understanding that was captured in the model implemented in the Calculator — a simplified model that has evolved over time since it was first applied to produce results announced by NOAA on August 4, 2010 —, presents an assessment of the oil fate at the time of the well having been capped for good, and gives recommendations for future research. The aforementioned early results (published in a NOAA press release) included the estimate of 26% as the percentage of residual or "other" oil. The latest results presented in this report update this estimate to 23%, and assert that, with high confidence, the true percentage should be between 11% (best-case scenario) and 30% (worst-case scenario).

Because this matter has drawn the attention of scholars and other interested parties outside the oil spill science community, additional background material is included. However, in the end, this report is still only the technical documentation of a tool used for response, and it is neither a comprehensive review of the relevant technical literature, nor a research contribution intended for publication in a professional journal. Interested readers seeking more background on oil spill science are referred to Lehr (2001), NRC (2003), or Reed et al. (1999). Appendices describe the statistical approach used to qualify the Calculator's estimates with uncertainty assessments, the Calculator itself, the raw data used in the Calculator, and supporting findings of laboratory and field studies.

It is important to remember that the Deepwater Horizon incident was an emergency, not an experiment. In spill emergencies, decision makers need immediate information that

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sometimes requires estimates of unknown quantities without as much data as a scientific study normally would demand. Some of the processes governing the fate of the oil are poorly understood and knowledge about them mostly consists of the personal experience of skilled spill responders. In developing the Calculator, the team handled these poorly understood phenomena by constructing a simplified model that the participating experts could reach a consensus on, or by choosing compromise values (for rate or other constants, for example) if a consensus could not be reached.

The usefulness and accuracy of the Oil Budget Calculator needs to be assessed in light of its purpose, further discussed below. The answers that the Calculator provides to the response team only need to be accurate to the extent that they correctly inform cleanup decisions and do not lead to errors in response actions. Accuracy beyond that level, while desirable from a scientific viewpoint, is superfluous for the purpose for which the tool was designed. Hence, potentially large errors (e.g., in estimates of volumes of dispersed oil) likely would be inconsequential unless they would have led to misdirected response activities: we are not aware of instances of such misdirection in this case.

The reader is cautioned that the numerical values stated in this report are estimates based on the information available at the time that the estimates were produced, and are based on the simplified understanding that the time constraints of the response allowed: therefore, not only are they tentative, but most likely will change as new information becomes available. For this reason, the final mass balance calculation of the Deepwater Horizon Spill lies somewhere in the future, to be produced only after all the appropriate and necessary studies will have been completed.

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2. PURPOSE AND BRIEF DESCRIPTION OF THE OIL BUDGET CALCULATOR

Once spilled into the marine environment and moved from the source, the oil interacts with the environment in a number of processes collectively called weathering. Figure 1 shows some short-term processes that acted on this spilled oil. These processes change both the composition and properties of the oil, and can result in the amount of oil in the water environment being continually reduced. Other longer-term processes such as biodegradation, photo-oxidation, and sedimentation may have an impact on the environment but are less amenable to response decisions.

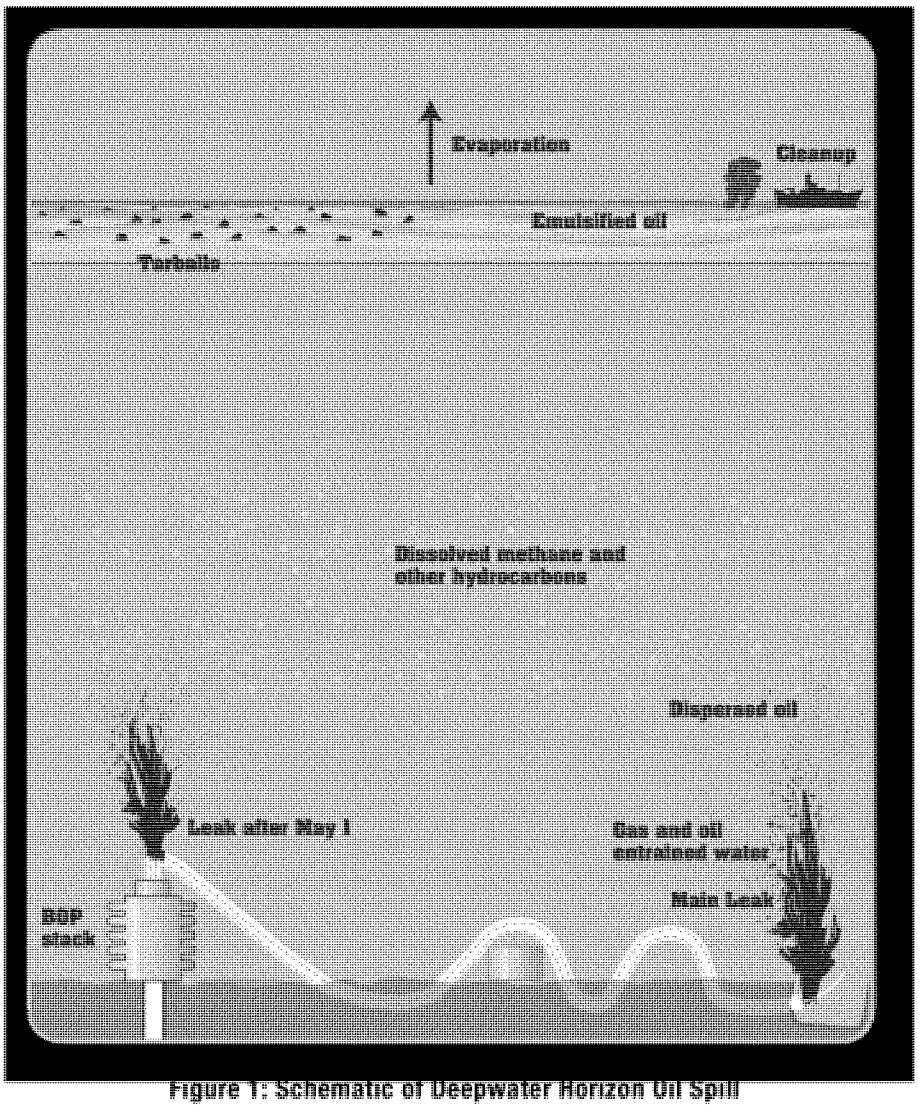

Figure 1: Schematic of Deepwater Horizon Oil Spill

The Oil Budget Calculator was designed to assist the Situation Unit of the Incident Command System (ICS). ICS was developed to provide federal, state, and local governments, as well as private and not-for-profit entities, with a consistent framework for the preparation for, response to, and recovery from any incident or event, regardless of the size, nature, duration, location, scope, or complexity. The ICS Form 209 provides the mass balance information that the unified command needs to assess the size of the threat and make informed response decisions. Preparing the mass balance tables for an ICS 209 form is usually a straightforward process. Vessel tanks are sounded, reports from the field estimate oil amount recovered or beached, and standard fate and behavior models, perhaps coupled with trained observer overflights, provide the remaining numbers for the tables. Such was not the case for the recent Deepwater Horizon Spill. Instead, the most sophisticated technology, involving expertise and apparatus never before used on oil spills, was necessary to construct even the most rudimentary mass balance table. The Oil Budget Calculator was a combined effort of several federal agencies, leading academics in the field of spill science, and practical response experts with years of actual spill experience. Its results are a product of field measurement, scientific analysis and practical cleanup expertise. The emphasis was on getting a conservative answer. In terms of response, this translates into using conservative estimates for cleanup efficiency, particularly with regard to skimmer efficiency and dispersant success.

The application of the tool defined its design requirements:

- Calculator must be operable by response personnel, not specialized staff, and use easily accessible input data.
- Calculator must generate output that provides information similar to the standard ICS 209 form along with some estimate of the confidence of the answers generated.
- Calculator must be able to deal with incomplete, uncertain, or missing data and still provide the best estimate available to the unified command.
- The Calculator should be conservative in its answers (i.e., it should err on overestimating oil that is still available to cleanup activities as opposed to oil that is outside of response capabilities).

It is important to understand what the Calculator is not designed to accomplish:

- The Calculator is not a spill research tool, although new research has been a product of its development. Simplifications were made to make it accessible to response personnel.
- The Calculator is not a damage assessment tool and is not applicable to determining environmental impact of the spilled oil. Other methods are required for this task.

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- The Calculator does not track the final fate of the spilled oil. Instead it estimates oil that may be amenable to response decisions as opposed to oil that is not (e.g. dissolved or evaporated oil).

The logical structure of the algorithm that drives the Calculator is straightforward. Mass is conserved as processes act upon the spilled oil. The chronological order that is assumed for the unfolding of these processes is based on observations from other spills and our understanding of the corresponding science. Oil that comes from the well either is directly captured or not. The portion that is not captured there, in turn either is dispersed naturally or chemically in the jet zone at the leakage points, or rises to the surface. Some of the dispersed oil dissolves into the water column. Some of the oil that floats to the sea surface either dissolves on the way up or quickly evaporates. Oil that remains on the surface can be burned or skimmed. Some of the surface oil disperses naturally or chemically into the water column. After all these processes, there will be some oil left. A brief description of the governing equations (listed in full in Appendix 1) is given below.

(1) *Subtract off direct recovery from the total amount escaping from the reservoir.* While this oil does not enter the Gulf waters, it was important to record this amount for the Unified Command since logistical assignments depend upon it. If $V_R(t)$ is the oil volume discharged on day t and $V_{DT}(t)$ is the amount of oil directly recovered, then the effective discharge, $V_{RE}(t)$, is given by

$$V_{RE}(t) = V_R(t) - V_{DT}(t) \tag{1}$$

(2) *Determine the lower water column chemical dispersion amount.* The amount of oil that is dispersed as a result of the injection of dispersants is calculated. To guarantee that mass balance is maintained, this amount cannot exceed the effective discharge. Some of the oil that is dispersed as small droplets will have a portion of the hydrocarbons dissolve into the surrounding water. Subtracting this gives $V_{DC}(t)$, the net chemically dispersed oil:

$$V_{DC}(t) = (1 - k_7)\min(90k_2V_{CB}(t), V_{RE}(t)) \tag{2}$$

Here, $V_{CB}(t)$ is the volume of dispersing chemicals injected into the subsurface jet. The rate constants k_2 and k_7 are defined in Appendix 1 along with the other rate constants.

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They are treated as random variables whose probability distributions describe our incomplete knowledge about their values, which is a consequence of our uncertainty about the exact attributes of the physical process the equations attempt to model.

(3) *Determine natural dispersion from the leaking jet.* From oil that is not chemically dispersed, compute the fraction that is naturally dispersed. Again, subtract oil that dissolves from the droplets.

$$V_{DN}(t) = (1 - k_7)\max(0, k_1(V_{RE}(t) - V_{DC}(t)/(1 - k_7))) \tag{3}$$

(4) *Calculate the dispersed oil near the bottom.* Add the amount that is chemically dispersed and naturally dispersed near the bottom. This oil is not available for evaporation, nor is the oil that dissolved near the bottom.

$$V_{DB}(t) = V_{DC}(t) + V_{DN}(t) \tag{4}$$

(5) *Compute skimmed oil as a fraction of oily water recovered.* Not all the liquid recovered by mechanical recovery, V_{OW}, is oil. The rate constant k_6 specifies that fraction. $V_{NW}(t) = k_6 V_{OW}(t)$ defines the net skimmed oil. Oil at all stages of weathering is skimmed. The model makes the assumption that the majority of the skimmed oil is 'older' oil. Hence, this oil is assumed to have already lost all oil that might evaporate.

(6) *Determine oil that evaporates or dissolves.* Compute oil that evaporates from surface oil during its first day on the surface or dissolves. Add evaporation from the second day on the surface plus oil that dissolves from dispersed oil. Let $Z = V_{RE}(t) - V_{DB}(t)/(1 - k_7)$ be the oil that makes it to the surface on day t. The oil that rose to the surface on day t-1 and is still left (neglecting natural surface dispersion and skimming) is $W(t-1) = (1 - k_4)Z(t-1) - V_{BU}(t-1)$. Since evaporation and dissolution are combined, dissolution from the bottom is added to V_E, the net evaporated or dissolved, where

$$V_E(t) = k_4 Z(t) + k_5 W(t-1) + \frac{k_7}{1 - k_7} V_{DB}(t) \tag{5}$$

Here V_{BU} is the volume of oil that is burned in-situ. The model uses reported values for daily volumes burned as one of its inputs. Since the burns involve oil that will have reached the

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surface at any prior point in time, occasionally the total volume burned on a particular day may exceed the amount of oil surfacing on that day.

(7) *Determine natural surface dispersion.* Surface dispersion, V_{NS}, is a competitive process with emulsification and the potential for dispersion decreases as the oil weathers on the surface. Disperse the surface oil that is available for surface dispersion, after subtracting evaporation and burning:

$$V_{NS}(t) = k_8 \max(0, W(t)) \tag{6}$$

(8) *Determine chemically dispersed oil near the surface.* Compute volume of chemically dispersed oil from surfactants sprayed on the surface slicks, $V_{DS}(t)$. Check that it does not exceed oil volume on the surface, based upon $V_S(t-1)$, which is the total volume of surface oil remaining from the day before.

$$V_{DS}(t) = \min(20 k_3 V_{CS}(t), V_S(t-1)) \tag{7}$$

Here, $V_{CS}(t)$ is the volume of dispersants used on day t. The remainder is then added to the "Other" oil category. For the purpose of the Calculator, this "Other" oil is treated as if it is all on the surface, when in fact some of it is not.

Appendix 1 lists all the equations used in the current version of the calculator, and explains how the uncertainty assessments for the estimates were produced. The corresponding results are described in Appendix 2, and are summarized in Figures 12 and 13.

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3. PREVIOUS EXPERIENCE THE IXTOC SPILL

The Deepwater Horizon incident is not the first large oil spill in the Gulf of Mexico. In June of 1979, the Ixtoc I exploratory well in the Bay of Campeche blew out, releasing oil for 290 days. It was the largest spill in history, at that time, totaling approximately 3.5 million barrels. The well was in much shallower water (165 ft) than the Deepwater Horizon.

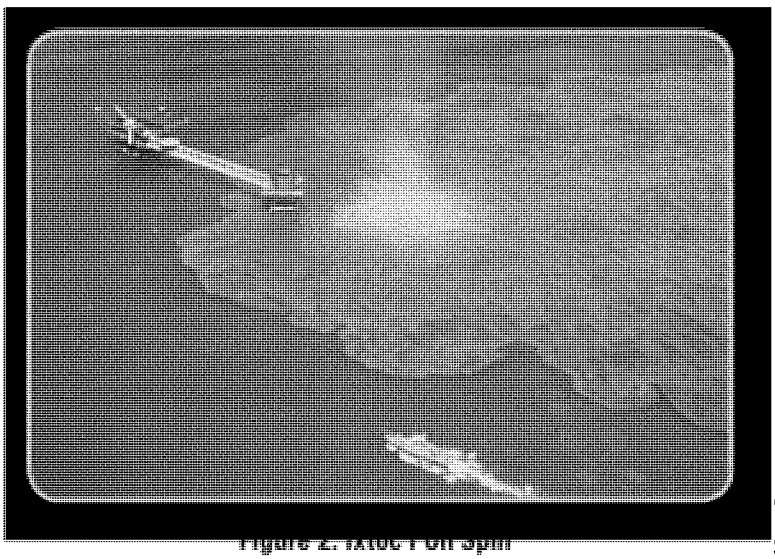

Figure 2. Ixtoc I oil spill

In many ways, the present Deepwater Horizon spill and response is similar to Ixtoc incident. For example, in both cases the oil released at the well was saturated with gas and formed an emulsion on the surface. In terms of the response, various devices were employed at the Ixtoc and Deepwater Horizon but were unsuccessful at stopping the flow of oil from the well. Again in both situations, eventually a relief well was employed to stem the flow. As for countermeasures, literature states mechanical recovery removed about 4-5% of the oil from the water surface during Ixtoc, which appears similar to the Deepwater Horizon incident. Large-scale dispersant operations were undertaken on oil on the water surface. In both events there was an impact on the fishing industry from the outright ban or local restrictions on fishing.

As much as the two incidents were similar, there are key differences. It is not the objective of this report to directly compare the two spills. However, as it relates to the subsequent discussion of the Oil Budget Calculator it is important to mention some pertinent detail.

Based on a limited literature review, the obvious difference is the depth of the oil release point where the Ixtoc I release point was approximately 165 ft (51m) below the water surface and the Deepwater Horizon release point was approximately 5000 ft. (1500m) below the water surface. Second, dispersants were used on the surface oil slick at the Ixtoc I but no subsurface application is noted (Jernelov and Linden, 1981). The loss to evaporation to the atmosphere of the Ixtoc I oil was reported as 50%. It is postulated that the circumstance of the Ixtoc I incident facilitated a larger mass of the oil reaching the water surface enabling greater overall mass loss to evaporation into the atmosphere in comparison to the conditions at the Deepwater Horizon incident.

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There appears to be some differences in the physical and chemical properties of the two oils. Literature (Jernelov and Linden, 1981, Linton and Koons, 1983) noted the Ixtoc oil was a light type with an API gravity of 32, heavier than the Deepwater Horizon oil. Detailed chemical analysis of the Ixtoc I well head oil was not available in the literature reviewed preparing for the Oil Budget Calculator report. The literature did report that the Ixtoc I oil formed a "chocolate mousse" emulsion on the water surface within kilometers of the wellhead (Overton, 1981). Empirical evidence shows that the Ixtoc I and Deepwater Horizon Macondo oils differed; this will have some bearing on the mass balance determination of the oil spills.

Finally, literature on the Ixtoc I oil spill reported that the change in the chemical properties of the spill oil along with the heavy sediment load in the water column caused a good fraction of the oil to settle on the bottom of the Gulf of Mexico. News reports published in September 2010 indicated that this might also be true for this spill. However, ongoing sampling programs have not confirmed the claim of extensive oil being present on the bottom of the Gulf from Deepwater Horizon.

Jernelov and Linden (1981) constructed the following mass balance table for the Ixtoc I oil spill which has been included here for the convenience of the readers. It should be noted the table prepared by Jenelov and Linden reports values based on information available at the time. Readers are referred to the literature for further details on the assumptions used and contradictory opinions.

Table 1: Mass Balance for Ixtoc 1

	Percent	M Tons
Burned at well site	**1**	
Mechanically removed	**5**	
Degraded biologically, photo, chemically	**12**	
Landed on Mexican beaches	**6**	
Landed on Texas beaches	**<1**	
Sank to bottom	**25**	
TOTAL	**100**	**476,000**

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4. LEAK RATE AND SUBSURFACE OIL BEHAVIOR

Oil was initially leaking from two major sources several hundred meters apart. After severing the riser in early June, oil only leaked from the single location at the blowout preventer (BOP). The leak rate varied both in the short-term and in the longer-term. The latter was due mainly to the drop in reservoir pressure. Figure 3 shows the estimated flow rate, based upon studies done by various teams of experts employing a variety of methods. Details on the measurements of the Flow Rate Technical Group (FRTG) Plume Team using image correlation velocimetry are available in the Plume Calculation Team Report (2010). At the time of this document preparation (August and September 2010), the report by the joint effort of the FRTG and Department of Energy (DOE) was still in draft form. The source estimates by FRTG/DOE were considered to be accurate to within ten percent. This uncertainty level is adopted by the Calculator, with three release rates (FRTG/DOE estimate minus ten percent, FRTG/DOE estimate, and FRTG/DOE estimate plus ten percent).

The leak was a combination of gas and oil. In fact, a key parameter in estimating flow was the average ratio of these two. The actual value seemed to vary over the time period of the spill. Increasing gas increased the velocity of the plume but decreased the mass flow. Analysis of available short movies of the riser flow showed the existence of periods when the flow oscillates from pure gas to seemingly pure oil. The DOE/FRTG consensus generally accepted an average value of 44% oil percentage by volume for the exiting flow, based upon measurements of Woods Hole Oceanographic Institute (WHOI, 2010).

The Deepwater Horizon spill was unique not only for its size but also its location at a mile beneath the water surface. In general, when oil and gas are released from a deep-water location, they are expected to break into bubbles or droplets of various sizes. These sizes can vary widely. In field trials off Norway (Chen and Yapa, 2003), they were generally between 1 mm and 10 mm. Leifer (2010) has suggested, however, that the gas bubbles for the Deepwater Horizon spill were smaller than the North Sea experiments.

The larger droplets have a relatively stronger buoyancy force to friction force than the smaller droplets (this ratio increases with diameter) and therefore move faster towards the surface than smaller droplets. If the simple form of Stokes' law is assumed (not valid for larger droplets), droplet rise/fall velocity, v_{rise}, is a function of the water viscosity, υ_w, relative density difference, $\Delta\rho$, and characteristic droplet size, d. The value of c_{stoke} varies, depending upon several factors. Figure 4 shows the rise velocity for this oil, according to Yapa et al. (2010).

$$v_{rise} = c_{stoke}\Delta\rho\frac{d^2}{\upsilon_w} \tag{8}$$

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All the droplets are subject to cross currents that will move them laterally while moving upwards. For this reason the larger droplets and the smaller droplets may not come to the surface at the same location, but quite a distance apart. If there are droplets of very fine scale, it may take weeks or even months for them to come to the surface (Galt, 2010). Galt concluded that even for the large droplets, the rise time was several hours, an answer consistent with Yapa (2010) estimates. Galt also concluded that droplets in the 100 to 200 micron diameter range would take such a long time to surface from a depth of one mile that they were effectively dispersed. This is considerably larger than the common maximum diameter size limit for dispersed oil droplets of around 60-80 microns (Lehr, 2001; NRC 2005). Spaulding et al. (2000) estimated that the rise time for 200 micron droplets with specific gravity of 0.81, less dense than this oil, would have a rise time from this depth on the order of a week.

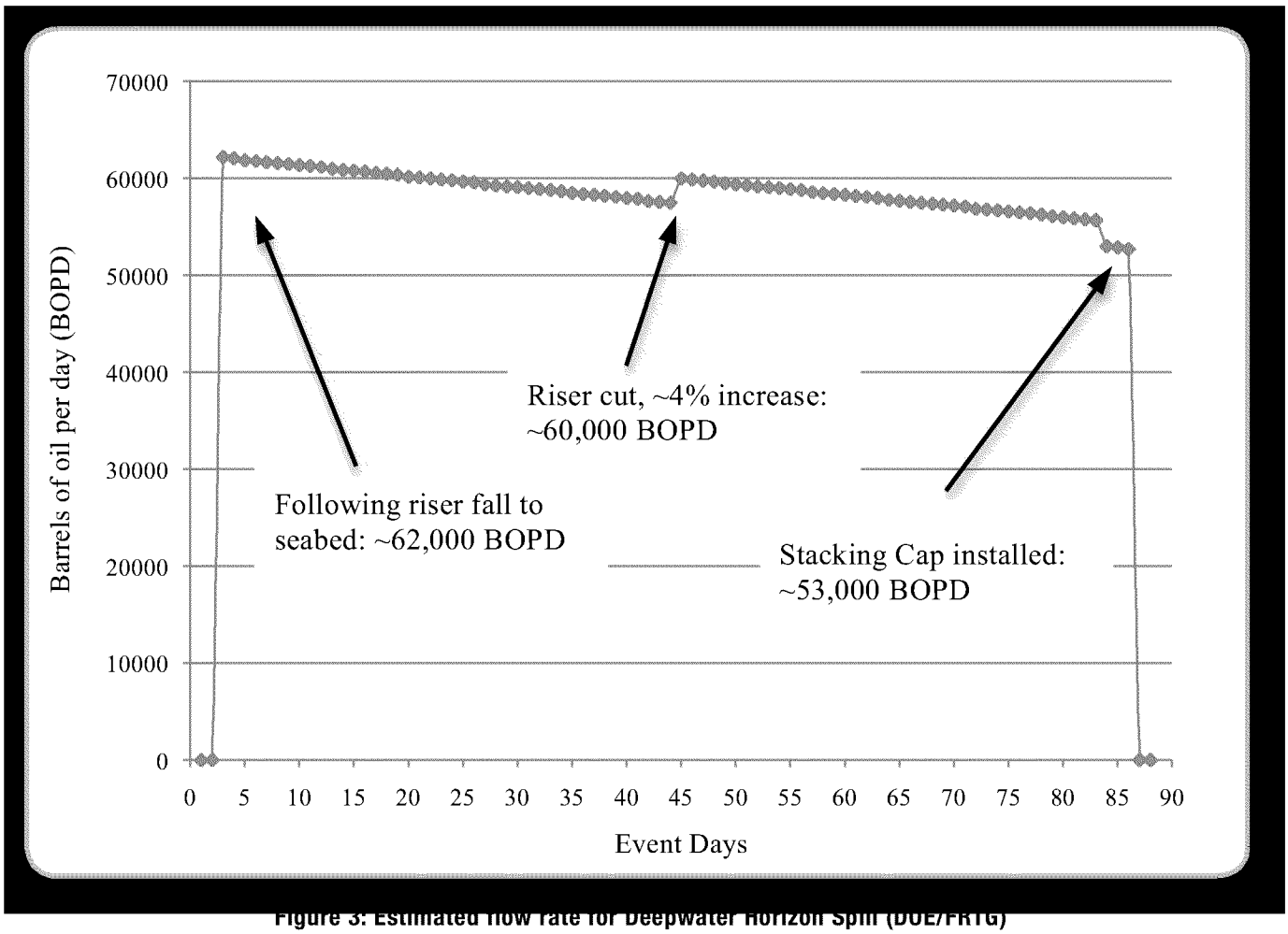

Figure 3: Estimated flow rate for Deepwater Horizon Spill (DOE/FRTG)

However, the large surface slicks showed that a good percentage of the released oil did make it to the surface. The remote sensing effort of the NASA ER/2 equipped with Airborne

Visible InfraRed Imaging Spectrometer (AVIRIS) surveyed about 30% of the core area of the surface spill on May 17, 2010. Extrapolating the examined area to the whole slick, Clark et al (2010) estimated that a minimum of floating oil of between 66,000 and 120,000 bbl. Limitations of the instruments do not allow measurement of very thick oil. The report suggested that if adjustments were made for this limitation, the surface oil could be as much as 500,000 bbl. According to the DOE-FRTG estimates, approximately 1.6 million bbl had been released from the well-head by that time. This suggests that somewhat less than a third of the oil had reached and remained on the surface if the report's hypothesis is correct. Since sub-surface recovery and dispersant applications were limited preceding this date, this estimate is not inconsistent with the later estimated values of remaining oil produced by the Oil Budget Calculator.

The plume also contained gas of many bubble sizes. For this incident, a large amount gas bubbles dissolved and may never have made it to the surface. Gas bubbles move faster than oil bubbles if they are the same size. Because of this, gases can separate from the main plume and start going in a slightly different direction (Chen and Yapa, 2004). Gases when released in deep-water, also have the potential to be converted into hydrates. Methane has a level of hydrate dissociation generally around 550 m of water depth as shown in Figure 5. This is not a fixed value. It depends on parameters like water temperature and gas type (Spaulding et al, 2000). Natural gas can get converted to hydrates at a much higher level. Therefore, gases can get converted into hydrates as they travel up. Hydrates are still buoyant with specific gravities of around 0.92 to 0.96. As hydrates travel towards the water surface they can get reconverted back into gas when they reach the lower pressure in the shallower regions (Leifer, 2010). Where the oil to gas ratio is sufficiently high, rather than an oily bubble, the aggregate is better described as a droplet with internal bubble. He concludes this effect could be very significant. For a primarily gas bubble (i.e., very low oil to gas ratio), in contrast, the effect of surface flow around the bubble pushing surface materials towards the downstream hemisphere could minimize any oil effect. This blowout occurred at far greater pressure than has been studied in the Deep Spill study (Johansen et al. 2000), or the lab (Masutani and Adams (2000), at depths where hydrate formation is far more rapid (Rehder et al. 2009). The oil budget calculator does not keep track of the gas bubbles, hydrates or dissolved gases.

5. DISSOLUTION

Unlike a typical spill, oil from the Deepwater Horizon spill entered the marine environment 5000 feet below the surface of the Gulf, and started weathering before it reached the air-water surface. Because of the nature of the material flowing from the riser, which was a miscible mixture of oil and natural gas, significant dispersion of the liquid oil occurred near the wellhead. Some of the oil droplets were so small, less than a 100 microns in diameter, that the turbulent diffusivity of the water was enough to overcome the oil's natural buoyancy, and caused the micro droplets to be dispersed at depth by ocean currents. Larger droplets floated to the surface, however the speed of the transit was determined by the size of the drops. Larger accumulations of droplets of oil rose fairly quickly while smaller droplets rose slowly and were dispersed further from the spill site by currents in the water column.

The important point about this movement of oil from the wellhead is that oil in tiny droplets is exposed to weathering processes both at depth as well as on its transit to the surface, and once on the surface, weathering continues. Another important point is that much of the oil moved through the marine environment as tiny drops, and these drops were continually exposed to uncontaminated Gulf water in their transit. This means that the dissolution of compounds from the tiny oil droplets was not controlled by equilibrium factors, and this resulted in an almost continuous molecular extraction from the oil droplets by the water column. The results of this continuous extraction are that even sparingly soluble compounds were extracted from the droplets and dissolution was a much more important factor in the weathering of Deepwater Horizon spilled oil than it is in more common surface oil spills.

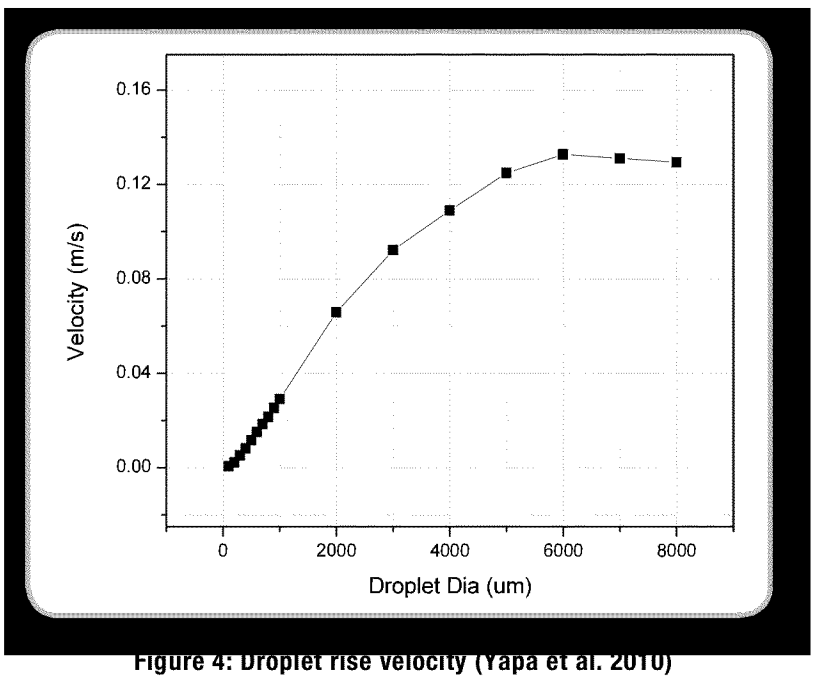

Figure 4: Droplet rise velocity (Yapa et al. 2010)

The proverb that oil and water do not mix is usually scientifically accurate when it relates to molecular dissolution of oil into the surrounding water from a surface spill. For the normal surface type spill, dissolution is less important for estimating the mass balance of the slick (NRC 2003). However, as described above, because of the nature and depth of the release, dissolution of oil into the water column was a significant weathering factor.

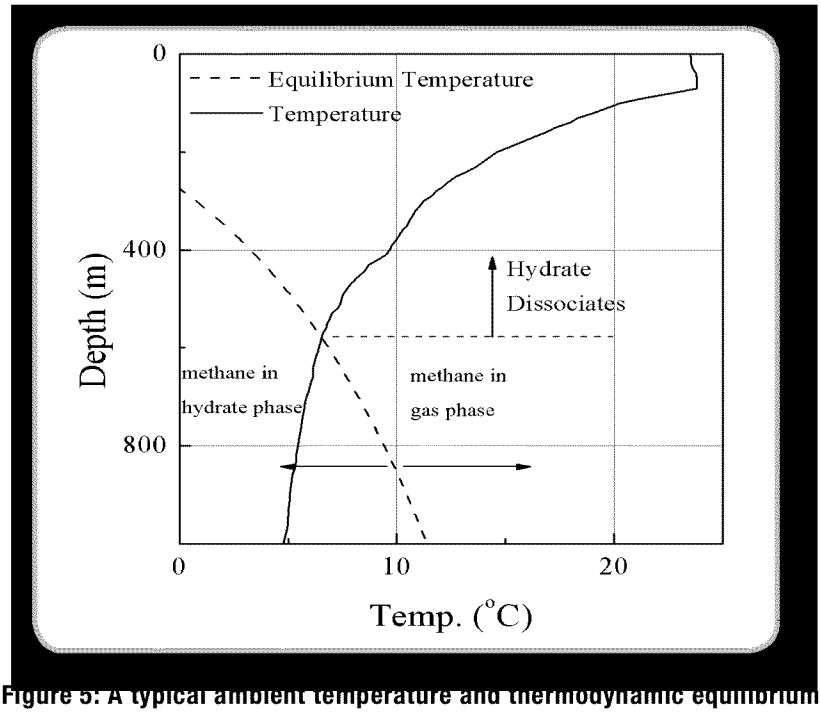

Figure 5: A typical ambient temperature and thermodynamic equilibrium curve for Methane (Chen and Yapa 2004)

The dissolution process is a very complex series of interactions between hydrocarbon molecules that are non-polar and surrounding water molecules that are polar. In general, polar molecules dissolve in polar solvents, seawater in this case, and non-polar molecules dissolve in non-polar solvents, the oil in this case. However, because of their molecular shapes, sizes, and chemical bonds, some non-polar compounds are slightly soluble in polar solvents. Such is the case when considering oil solubility in seawater. As a general rule, small mono-aromatic compounds, such as benzene and the alkyl benzenes, have significant seawater solubility compared to equivalently sized saturated compounds. This solubility extends to larger aromatic compounds, such as naphthalene and its alkyl homologues, and may also slightly extend to three-ringed aromatic compounds such as the phenanthrenes and the dibenzothiophenes. As a rule of thumb, saturate compounds are the least water soluble of the components of oil, probably because they have no significant interactions with solvent water molecules and do have significant interactions with similar non-polar compounds in the oil. The conclusions are consistent with experimental results obtained at SINTEF (Melbye at al. 1999) which showed that a component needs to have a water solubility of a

minimum 0.3 -1 mg/L in seawater (Figure 6) in order to have any significant potential to dissolve out from an oil droplet when rising to the surface. This means that n-alkanes up to maximum n-C8-9 may have a potential to dissolve but larger alkanes have very limited solubility potentials. However, the mono-aromatic benzene compounds (the BTEX's), C0-C3 Napthalenes, and the C0-C1-alkylated 3-rings PAH can be stripped out of oil droplets because of their water solubilities. The bottom line is that when tiny droplets of oil transit the water column to the surface, many of the low molecular weight one, two and maybe three-ringed aromatic compounds can be dissolved into the water column. This dissolution can affect both the toxicity and physical properties of surface oil from deepwater releases.

Few models or studies exist for oil dissolution at spills, mostly in dated work and older generation spill models. Mackay and Shiu (1975) measured the aqueous solubility of fresh and weathered crude oil. Payne et al. (1984) reported that studies of Prudhoe Bay crude found that truly dissolved components were almost exclusively alkyl-substituted lower weight mono-aromatic hydrocarbons with very little n-alkane dissolution. The dissolution rate depends directly upon surface area, which was proportionally larger per volume spilled for this spill incident compared to a normal surface spill by factors of 100 to 1000. Mackay and Leinonen (1977) concluded that, for droplets less than 100 microns in diameter, dissolution is very rapid for any component that will dissolve at all. Any remaining material in the droplet will consist of relatively insoluble saturate hydrocarbons, i.e. hydrocarbons with a carbon number greater than about 8, and larger multi-ringed aromatic PAHs. While the droplets that made it to the surface were larger than 100 microns, the extended time that it took for them to reach the surface suggests that dissolution of even marginally soluble compounds occurred.

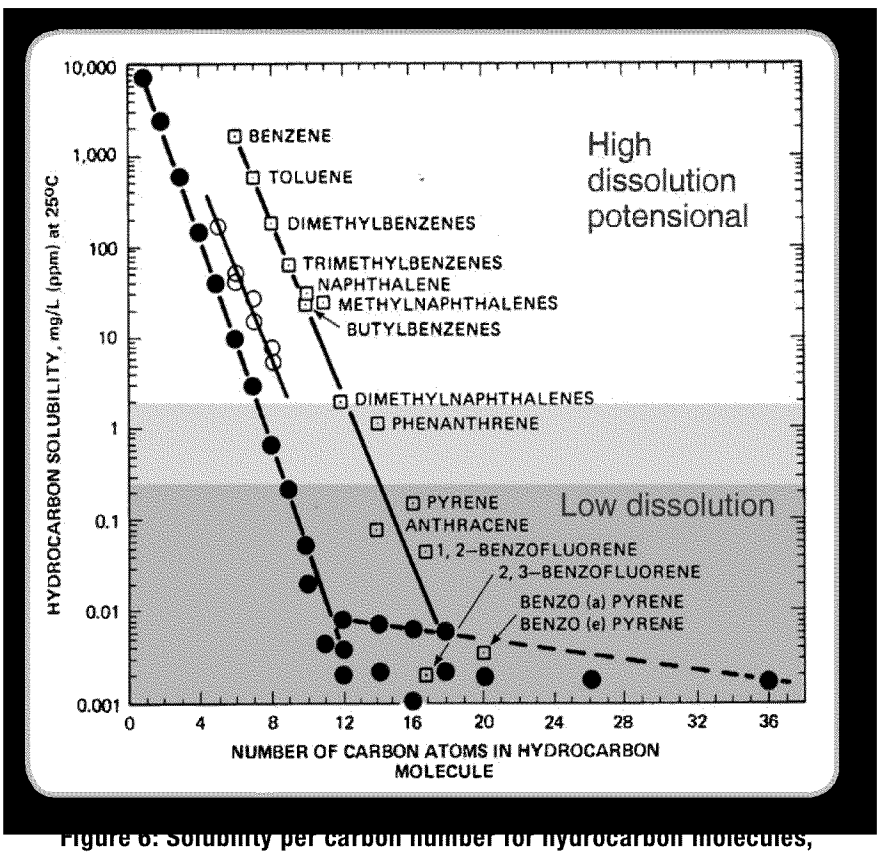

Figure 6: Solubility per carbon number for hydrocarbon molecules, (Modified from McAuliffe, 1987 IOSC - proc. Pp 275-288)

It should be pointed out that initial chemical analysis of some samples collected below the Gulf's surface indicates that significant dissolution did occur. One and two ringed aromatic compounds, and some of the three ringed sulfur heterocyclic aromatic compounds, appear to have been dissolved during transit from the wellhead. These compounds have carbon numbers above 10, and there is some evidence that normal alkanes were also slightly affected by the long transit that occurred as oil drops moved through the water column.

Based upon the chemistry of the oil and the above discussions, it was estimated that any oil exposed to conditions that could lead to dissolution would lose between 5-10% of its volume this way. Since many of these same molecules would evaporate, this process was included in the evaporative losses estimate for any oil that made it to the surface. However, dissolution is subtracted from oil dispersed near the bottom that never reaches the air-water interface. These estimates may change as further studies underway at SINTEF and elsewhere provide additional information. At a minimum, it may be possible to separate dissolved fraction from evaporative fraction. If, on final review, we find that water samples with oil droplets were collected just below the water surface, then by using GC-MS, it is possible to look at the changes in ratios between the more semi-volatile aromatics (e.g. 2-3 rings PAH's and their alkyl homologues) versus the corresponding n-alkanes with same boiling Points (similar vapor pressure, but with far less solubility). In that way, it would be possible to say more specifically how much of the depletion of the components in the range of C10 -C17 is due to dissolution, and how much is due to evaporation. Such information would be useful for impact assessment but, for the purpose of response, would be of limited value. The Oil Budget Calculator groups dissolution and evaporation.

6. EVAPORATION

Laboratory and field studies of oil weathering under wide ranging conditions and for a wide range of crude oils demonstrate that surface slicks quickly lose volatile components to evaporation. As the more volatile compounds are lost, the rate of evaporation slows. Evaporation is often the most significant loss mechanism from surface slicks during the first week following a spill. Generally, after a week at sea, evaporation is no longer a significant loss mechanism for surface oil. For light crude oils, such as this oil, the great majority of the evaporative loss occurs within a couple days of its exposure to the air.

Empirical methods were used to estimate the evaporation rate during this spill. Samples of weathered oil collected from the sea surface were analyzed using GC/MS. Laboratory weathering of the source oil provided an independent assessment of evaporative behavior. Estimations of evaporation rates were not based on model predictions; rather models were used in analyzing data from field measurements.

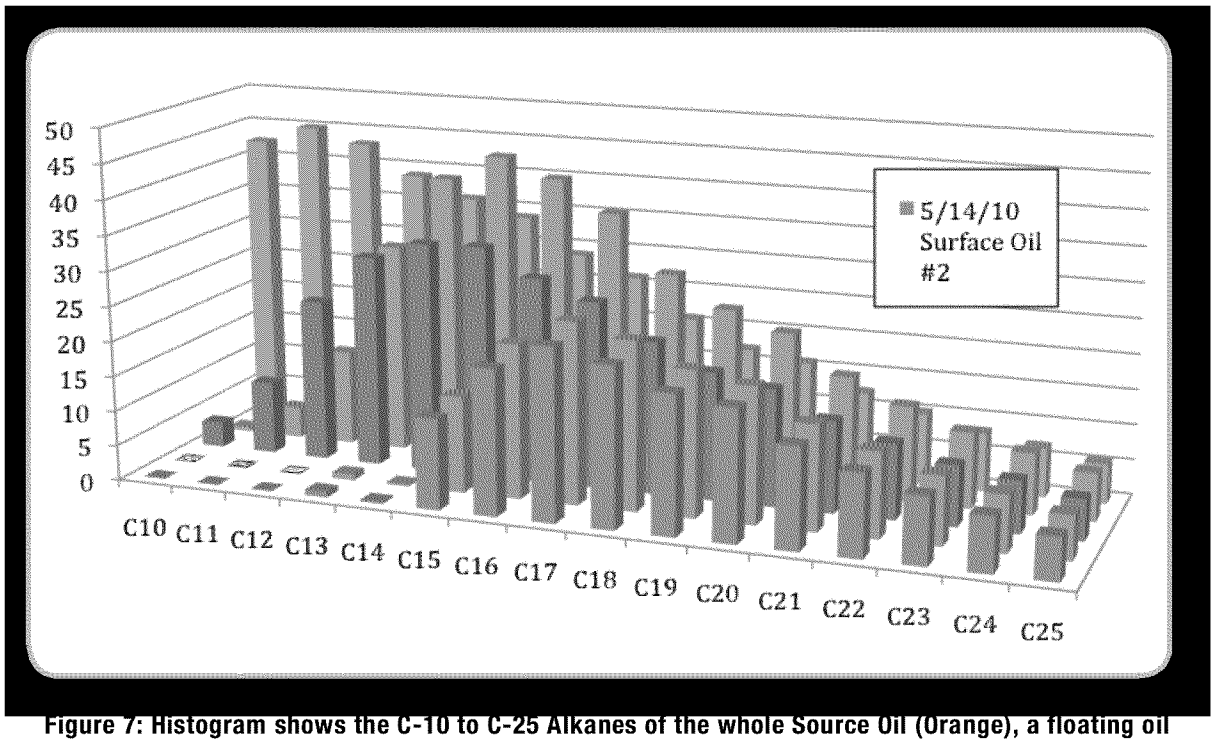

Figure 7: Histogram shows the C-10 to C-25 Alkanes of the whole Source Oil (Orange), a floating oil sample immediately adjacent to the source (red), and two floating oil samples at a relatively highly weathered oil further away from the source (green, purple). The highly weathered samples show that virtually all the alkanes below C-15 have been stripped from the original source oil. (Blue bar graph is sample from dispersant efficiency testing).

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Evaporation changes not only the volume of a surface oil slick, but changes the chemical composition of the oil as well. Because smaller chemical compounds are preferentially lost during evaporation, it affects the relative abundance of individual chemical compounds within the oil. These changes can be observed by comparing the composition of unweathered oil to that which has weathered on the surface. Other loss processes, such as dissolution, can also change the composition of the oil. While dissolution is usually not a dominant loss mechanism for surface spills it might be significant for releases in deep water. Without the appropriate samples, it was not practical to try to resolve the relative importance of dissolution and evaporation, so these two losses are grouped. Oil that never reached the sea surface is not susceptible to evaporative loss, so the measured estimates of fraction evaporated only applies to the oil that surfaced.

Pseudo-component models (Payne et al. 1984; Kirstein et al. 1984) were used to process measured data. These models approximate the oil as an ideal mixture of a relatively small number of components, each component representing a range of individual chemical compounds with similar vapor pressures. Each component is characterized by a mole fraction and a vapor pressure. The rate, per unit area, at which a component evaporates from the surface slick is proportional to the wind speed, the mole fraction of that component within the oil (which varies with time), and the vapor pressure of that component (which varies with the temperature of the oil, assumed to be the same as the water temperature). The rate equations for the components are solved simultaneously. The total evaporation rate is set equal to the sum of the rates of the individual components. This method has been adapted for an oil-weathering model, ADIOS2™, developed by NOAA (Jones 1997), the Type A model developed by ASA (French et al., 1996) and the OWM model developed by SINTEF (Reed, Singsaas et al. 2001).

NOAA's Emergency Response Division (NOAA/ERD) measured the composition of several oils (Figure 7). For the purpose of this discussion on evaporation, in Figure 7 we focus on the oil from the reservoir (Source oil, orange) and the two weathered oils (green and purple) collected from the sea surface on, or around, 16 May. It is not known how long the weathered samples were on the sea surface before being collected. GC/MS analysis was used to measure the relative abundance concentrations of chemical compounds that make up the oil. The weathered oil samples exhibited an expected depletion of the more volatile compounds. The pseudo-component evaporation model used in ADIOS2 (Jones 1997) was initialized with oil-composition data provided by BP in conjunction with oil-composition data measured by NOAA/ERD. The ratio of components measured in the more weathered oil samples was compared to those predicted by the model. The extent of evaporative loss was based on the correlation between the measured and modeled ratios. These two weathered oil samples exhibit an average mass loss of 36%. Since the age of these samples is not known, this provides a lower bound on the possible evaporative loss of the surface oil.

SINTEF analyzed three samples of floating oil collected on June 4th and 5th for fraction evaporated (Leirvik, Daling et al. 2010). They analyzed the samples by GC/MS and related the fraction evaporated to the depletion of alkanes in the C14 to C16 range. They correlated the degree of evaporation with the depletion of these peaks using past results. Their measured data indicated a mass loss to evaporation of 44%, 47%, and 50%. They estimate that the time at sea for these three samples was 1-2 days, 2-3 days, and 4-5 days, respectively.

Laboratory measurements performed by S.L. Ross Environmental Research Ltd. (S.L. Ross Environmental Research Ltd., 2010) on unweathered Deepwater Horizon oil were consistent with measurements of the above-mentioned surface oil samples. They artificially weathered a 2cm thick slick of Deepwater Horizon oil in a wind tunnel for 2 weeks. They measured that approximately 35% had evaporated after 2 days, and 45% after 2 weeks. Their measurements exhibit a cumulative evaporation, which is essentially a logarithmic function of time with the majority of the evaporation occurring in the first few days.

Camili et al. (Camili, Reddy et al. 2010) from Woods Hole Oceanographic Institute measured the composition of oil collected from the top 30 m of the water column. They made no attempt to quantify the fractional loss but did attribute the loss of the more volatile compounds to evaporation. Their measurements can be viewed as an additional observation suggesting substantial evaporative loss.

As mentioned above, dissolution also affects oil composition and so losses to dissolution must be considered as contributing to the measured values. Measurements reported here constitute lower bounds to the possible combined losses to evaporation and dissolution of oil that reached the surface. Loss fractions range from 36% to 50% and are self-consistent. The authors of this report believe that these data provide a close lower bound to the fraction of surface oil lost to the combination of evaporation and dissolution.

The oil budget calculator based the evaporation/dissolution estimates on the compositional change observed in samples of surface oil. It approximates the evaporation/dissolution process as occurring over 2 days; the majority of the loss occurring in the first day. To simplify data entry, requirements to enter variable wind speeds were eliminated. Cumulative evaporation is sensitive to oil composition and temperature but is relatively insensitive to wind speed. The original approximation was 37% lost during the first day (potentially as high as 44% and as low as 33%) with a second day loss of 4% (potentially as high as 6% and as low as 0%). Hence the range of total evaporation of the oil that surfaced was between 37% and 50%. Currently, there is no plan to revise these values.

7. WEATHERING ESTIMATION BY EMULSIFICATION

An alternative approach to calculating mass loss has been suggested by Fingas (2010) that uses the fact that the surfacing oil formed emulsions. One important factor to the formation of emulsions is that oils often must weather to a certain percentage before a certain type of emulsion occurs. This is because the asphaltenes and resins must be at a sufficient content to stabilize the oil and also the viscosity must be high enough to retain water droplets long enough for asphaltene/resins stabilization to take place.

Oils from similar oil fields have a tendency to form similar emulsions with similar weathering tendencies. Gulf oils that formed stable emulsions had weathering percentages of 37.7, 26.2, 16.4, 25.5, 22.6, 24, and 35.2%. These average 26.8%. If the Deepwater Horizon oil shows similar tendencies, the weathering that took place near the release of the Deepwater Horizon was about 16 to 38% with the likelihood that it was near 27%. However, experimental studies by SL Ross Ltd. (see pp. 3 in Appendix 8) and studies at SINTEF showed that an evaporative loss of at least 40-45 wt %, (representing a 200 - 250C+ residue) is needed for this crude oil to start form a significant and stable emulsion. Some additional evaporation would occur as the surface oil moved away from the area, transported by winds and surface currents. Observations of large amounts of emulsified oil indicate that such emulsified oil, at least, had already weathered sufficiently to emulsify.

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8. NATURAL DISPERSION

While the oil released in this spill was buoyant, not all of the oil rose to the surface. Small droplets of oil stayed suspended in the water column just as small dust particles will stay suspended in the atmosphere due to the underlying fluid turbulence. Such droplets will eventually be assimilated through dissolution and biodegradation. They also may become attached to suspended sediment in the water.

Some limited data exists on dispersed oil from the results of RV Brook McCall Survey LISST (Laser In Situ Scattering and Transmissometry) measurements performed by the Bedford Institute of Oceanography (see Appendix 7). It lends support to the hypothesis that much of the oil released was dispersed into the water column. However, since the samples were subsurface, they may be preferentially sampling the droplet distribution with the larger droplets having risen to the surface. Payne's study reported plumes of oil droplets at depths greater than 2 km. away from the source with larger droplets on the top of the plume and smaller below. This would be consistent with a large amount of dispersion and weak buoyancy. One should be careful about over-interpretation of particle size distribution data that were collected for this specific purpose during the Gulf of Mexico oil spill emergency response operations. Under this emergency response effort, rapid, less than perfect actions had to be taken to support the requirement for immediate action to monitor the fate and transport of the oil.

The NOAA oil fate and behavior model, ADIOS2, uses the dispersion formulas developed by Delvigne and Sweeney (1988). These formulas estimate the distribution of droplets sizes based upon the dissipation energy rate e. For most surface spills, the turbulent energy comes from breaking waves. Li and Garret (1998) estimate that typical dissipation rates in breaking waves range from 0.1 to 10 $m^2/\sec^3$. Others have reported different values. For example, measurements in a wave tank gave values of 0.01 to 0.1 $m^2/\sec^3$ at the surface (Wickley-Olsen et al., 2007). Field measurements showed lower values varying between about 0.1 and 1 m^2/sec^3 (Gemmrich and Farmer, 2004, Gemmrich, 2010). Additional information on the value of ε can be found in Kaku et al. (2006).

ADIOS2 suggests that if this spill occurred at the surface under average conditions, only a few percent of the oil would disperse because the oil would emulsify. If emulsification is prevented, natural dispersion could be as much as 30%.

However, it is not breaking waves but the turbulence at the leak that formed these oil

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droplets. In this case, a new method had to be developed to estimate dispersion rate. ADIOS2, following standard guidelines (NRC 2003), assumes that droplets must be smaller than 70 microns in diameter to be considered permanently dispersed. While appropriate for surface spills, it is probably too restrictive for spills happening a mile deep. The Calculator uses 100 microns as a cutoff. Based upon the earlier discussion of surfacing time, this was also too restrictive but was consistent with the conservative approach used to calculate oil fate.

Following DS, $Q(\delta)$, the entrained droplet mass density for droplets of diameter δ is given by the equation

$$Q(\delta) = C\varepsilon^{0.57}\delta^{0.7} \tag{9}$$

where C is a constant that depends upon the properties of the oil slick.

For a surface spill, ADIOS2 would expect that the dispersed oil would be

$$M_{disp(bw)} = \int_0^{70\mu} Q_{bw}(\delta)d(\delta) = C\varepsilon_{bw}^{0.57}\frac{(70\mu)^{1.7}}{1.7} \tag{10}$$

where the *bw* subscript indicates that this applies to dispersion caused by breaking waves.

If we apply this method to the subsurface leaking pipe (subscript lp) then the same equation would be

$$M_{disp(lp)} = \int_0^{100\mu} Q_{lp}(\delta)d(\delta) = C\varepsilon_{lp}^{0.57}\frac{(100\mu)^{1.7}}{1.7} \tag{11}$$

and the ratio, *R*, between the two would be

$$R = \frac{M_{disp(lp)}}{M_{disp(bw)}} = 1.8\left(\frac{\varepsilon_{lp}}{\varepsilon_{bw}}\right)^{0.57} \tag{12}$$

Thus the estimate of the increase in natural dispersion becomes a problem of estimating ε_{lp} and ε_{bw} . Lasheras (2010) has suggested that, to first approximation (Friehe et al. 1972; Gibson, 1963), the maximum theoretical dissipation rate of turbulent kinetic energy can be estimated by

$$\varepsilon_{lp} \approx U_{lp}^3 / D_{lp} \approx 7m^2 / \sec^3 \tag{13}$$

where U_{lp} is the exit velocity of the flow jet and D_{lp} is the pipe diameter. He points out that experiments by Martinez –Bazan et al (1999) show that, for distances less than 15 pipe diameters from the orifice, the dissipation rate is much smaller, perhaps as little as 0.02 $m^2/\sec^3$. If we take a mid-range value from the Li and Garret suggested bounds for breaking wave dissipation rates compared to the theoretical maximum for ε_{lp} we get virtually all of the oil naturally dispersing. This obviously does not match observation. If, instead, we use the experimental results of Martinez-Bazan et al., we get approximately 20% subsurface natural dispersion. This more conservative value was used by the Oil Budget Calculator with an assumed maximum of 30% and a minimum of 10%. The minimum value is considered to be the lowest credible estimate consistent with Camilli et al. (2010) and the maximum the largest estimate consistent with the AVIRIS and LISST results.

Lasheras also pointed out that the characteristic size D_{char} of droplets small enough not to be broken by the turbulent shear forces can be estimated by a simple function of the oil-water surface tension:

$$D_{char} = \frac{\left(\frac{1.5\sigma_{o-w}}{\rho_{oil}}\right)^{3/5}}{\varepsilon^{2/5}} \approx 10mm \qquad (14)$$

This matches the North Sea experiments discussed earlier. While the Oil Budget Calculator conservatively assumes that oil that is not dispersed near the bottom would come to the surface, this is not the case. For example, marine snow present in Gulf waters would scavenge some of the oil droplets on their journey to the surface. The extent of this affect for this spill is uncertain at this time.

Oil droplet size distribution is greatly affected by viscosity and surface tension. Since some of the lighter ends are lost through dissolution on the oil journey to the surface and since the surface oil emulsifies, the viscosity of the surface oil was quite high compared to the oil at the leaking riser. The seas were usually relatively calm, although there were periods of high winds. The original Budget Calculator assumption was that the surface oil would have negligible natural dispersion. This was consistent with the standard to conservatively estimate any reduction in surface oil through either natural or cleanup actions, although certain experts disagreed with this assumption. They pointed out that much of the initial surface oil was not on the surface after storm events. Also, the studies by SINTEF indicate that the weakly emulsified oil is dispersible with enough energy input. Therefore the Calculator was modified to include 5 % natural dispersion of surface oil, based upon ADIOS2 model results. Low value was no dispersion and high value was 10%. As in other dispersion estimations, there was not a uniform consensus by the experts on this revised estimate.

9. CHEMICAL DISPERSION

A typical commercial dispersant is a mixture of three types of chemicals; solvents, additives and surfactants. The surfactants are the active ingredient and contain both hydrophobic and hydrophilic groups. This allows them, when coating the oil surface, to reduce its surface tension by as much as a factor of 20 or more, reducing mean droplet size in droplet formation caused by turbulent shearing (Li and Garrett, 1998). Caneveri et al. (1989) measured declines in oil-water interfacial tensions from 18 mN/m without dispersant to 0.1 mN/m with dispersant. More recently Khelifa and So (2009) used a spinning drop instrument to measure declines of oil-brine interfacial tension for three different oils. Declines from 18.3 mN/m without dispersant to 6.5 10^{-4} mN/m with Corexit 9500 at 1:20 dispersant to oil ratio (DOR) were measured. The same study showed that corresponding droplet size decreases from about 220 mm to 25 mm when the DOR increases from 1:500 to 1:10. (DOR is often expressed with the 1: omitted. Therefore, a DOR of 20 and a DOR of 1:20 refer to the same ratio).

Clayton et al. (1993) noted that successful dispersion of oil in actual dispersant applications only occurs if five requirements are met.

(1) The dispersant must reach the oil surface
(2) The dispersant must penetrate the oil surface
(3) The surfactant must orient at the oil-water interface
(4) The surface tension must be reduced
(5) Sufficient mixing energy must be applied

A total of 43,884 barrels of dispersant were used at the DWH incident:

- 18,379 barrels of dispersant were used by sub-sea addition to the discharging oil and gas stream.
  - Initially this was at 12 gallons/minute, later reduced to 7 gallons per minute.
  - The EPA imposed maximum sub-sea use of 15,000 gallons/day (357 bbl/day), equivalent to 10.4 gallons/min

- 25,505 barrels of dispersant were applied to oil on the sea surface (see Figure 8).

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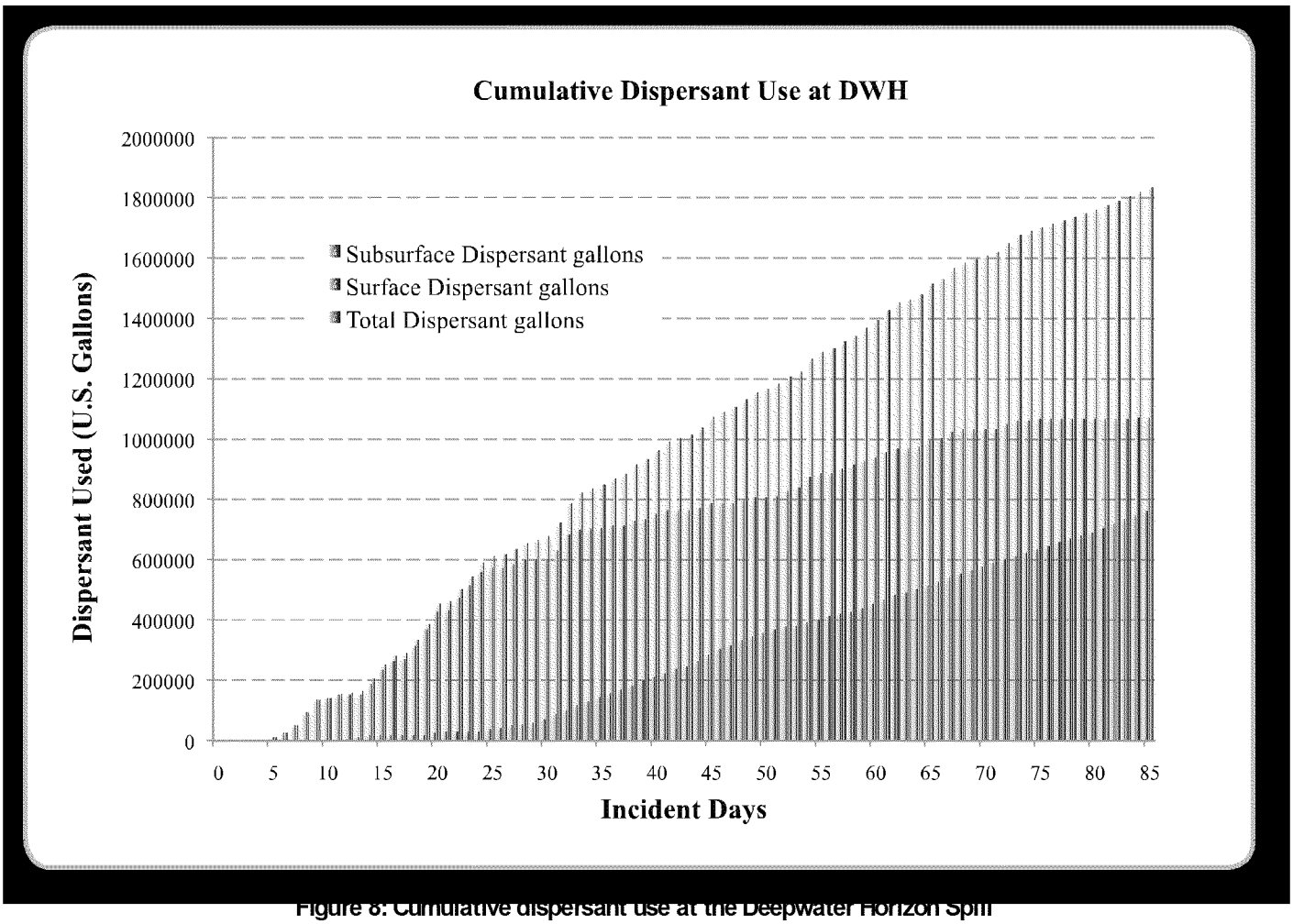

Figure 8: Cumulative dispersant use at the Deepwater Horizon Spill

Estimating effectiveness of these dispersant operations was the most difficult challenge in constructing the Budget Calculator, given the present state of oil response technology. As Lewis (2010) points out, the effectiveness of dispersant use at real oil spill incidents cannot be determined by measuring the dispersed-oil-in-water concentration in the water column with sufficient resolution in time or space to produce an accurate mass balance. Nor are there currently commercially available remote sensing techniques capable of measuring oil layer thickness with sufficient accuracy and with sufficient resolution to enable the volume of an oil slick to be determined at any point in time, or how the volume changes with time.

Some surface dispersant applications employed the SMART (2006) protocols. SMART (Special Monitoring of Applied Response Technologies) is a Federal cooperatively designed and regionally approved monitoring program for dispersant operations and *in situ* burning. However, SMART provides mostly qualitative, not quantitative, estimates of dispersant effectives. SMART teams could at best say that there was some dispersion caused by the dispersant applications.

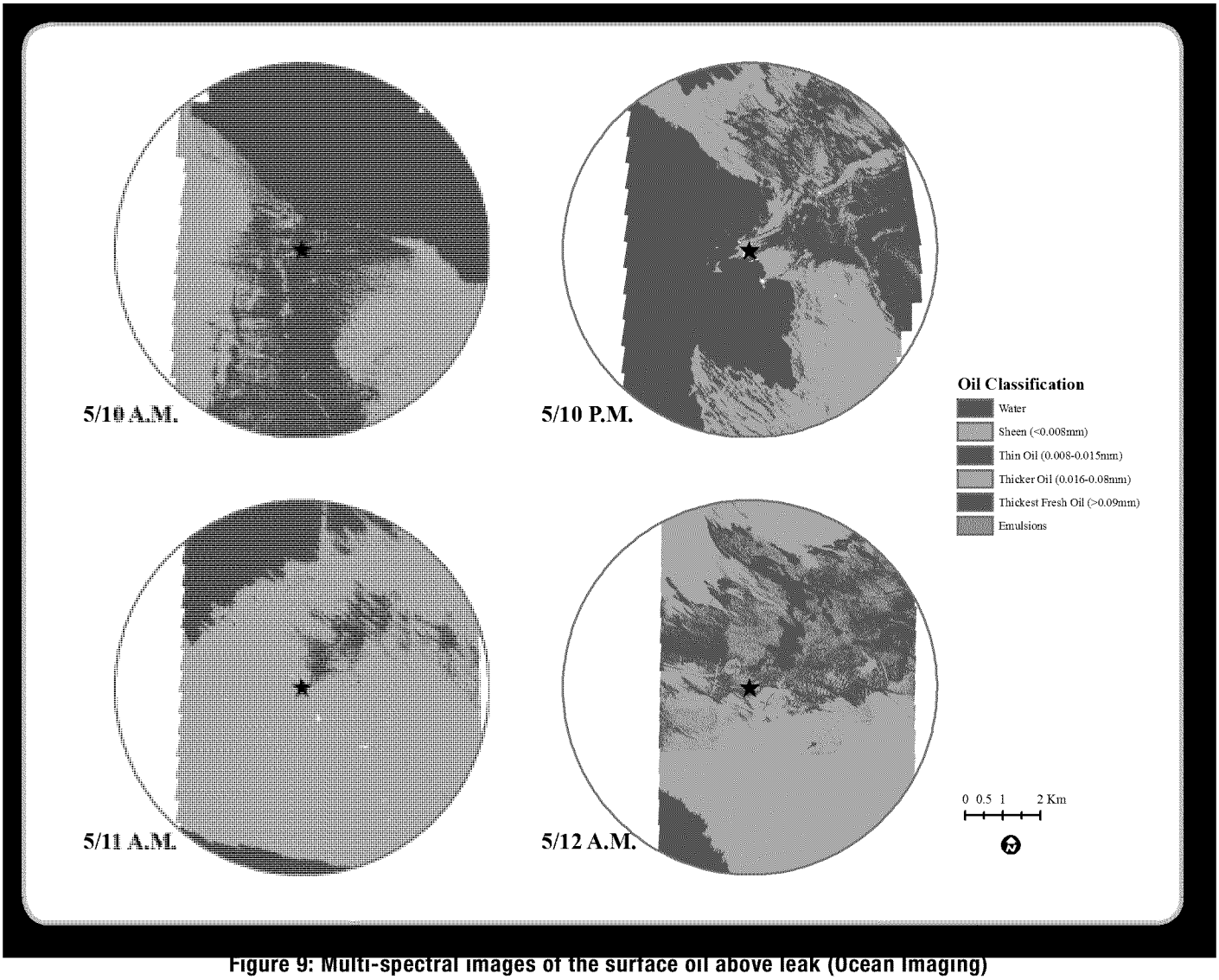

Figure 9: Multi-spectral images of the surface oil above leak (Ocean Imaging)

Ocean Imaging, using a multi-spectral scanner to estimate slick coverage at the water surface directly over the spill site, observed the oil appearance both during dispersant operations and no dispersant operations. Figure 11 shows a time period from May 10 through May 12. The individual images represent relative thickness measurements of surface oil at specific times. The larger the red area, the more thick oil is present. Surface conditions were reasonably similar during this time period. Subsurface injection began at 0430 hrs on May 10 and continued with an average injection rate of 8 gallons per minute. If the dispersant was as highly effective as suggested by certain experts, then more than half of the released oil should have been chemically dispersed. The May 10th A.M. image may be too early to show these results and May 10th P.M. seems to show a drop in surface oil. However, May 11th and May 12th show similar surface expressions although the latter should be displaying more oil. Therefore, these observations provide inconclusive results.

The R/V Brooks McCall field study (Appendix 7) gave some droplet size distribution information but not with sufficient clarity to separate the amount of oil chemically dispersed from the amount of oil naturally dispersed. Analysis was ongoing at the time of preparation of this report and may yet provide useful guidance on this matter.

Given the limited nature of the field data, the best that could be done was to estimate effectiveness using the experience and knowledge of dispersant experts. Unfortunately, reaching consensus among the experts was not possible.

9A. CHEMICAL DISPERSION: SURFACE APPLICATION

Surface application of dispersant for this spill was extensive. At over 25 thousand bbls, were it a spill by itself, it would be one of the larger spills in U.S. waters. Dispersants were normally applied by aircraft at a dosage of 5 gallons/acre (USGPA) (5000 liter/sq. km). The dosage (DOR) needed to disperse surface emulsions depends highly on the weathering degree (e.g., water content, viscosity) of the emulsion. In Figure 10, controlled laboratory testing shows (and is further discussed in Appendix 6, Figure 4.3) that for the low weathered dark brown (pos. 4) emulsions (i.e., the type of emulsions that the aerial applications was focused on), a very low "absolute" dosage of 1:250 is sufficient in order to disperse the dark emulsion effectively under high mixing energy (breaking waves). This means that an aerial application with typically 5 USGPA is sufficient dosage in order to disperse such dark-brown emulsion with thicknesses around 1 mm as long as the application is efficient and high mixing energy is available. SMART samples similarly show significantdispersed oil in the surrounding water after surface operations in 3 out of 19 samples (see Table 2). When the emulsion become more weathered (i.e. light brown-orange-reddish in color), with a typical water content of >50%, and a significantly higher viscosity, the emulsion was still dispersible under high mixing energy, but a more "traditional" dosage of 1:50 - 1:25 was needed in order to disperse the emulsion effectively using COREXIT 9500. It is probable that some sprayed dispersant missed the oil or was deposited on oil layers that are thinner (such as sheen) or much thicker (emulsified oil) than the nominal 0.1 mm thick oil layer that most dispersant spray systems are designed to treat. Also, the most heavily weathered state of the emulsified oil would impede dispersant success.

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Alternative View 1: We believe the Oil Budget Calculator overestimates the effectiveness of chemical dispersants because:

- The WHOI survey and the Ocean Imaging pictures do not support it
- The surface oil was emulsified and there was insufficient mixing in the subsurface injection.

Alternate View 2: We believe that the Oil Budget Calculator underestimates the effectiveness of chemical dispersants because:

- Lab studies show that both the fresh and emulsified oil are dispersible
- There was sufficient energy both subsurface and at the surface to disperse the oil.

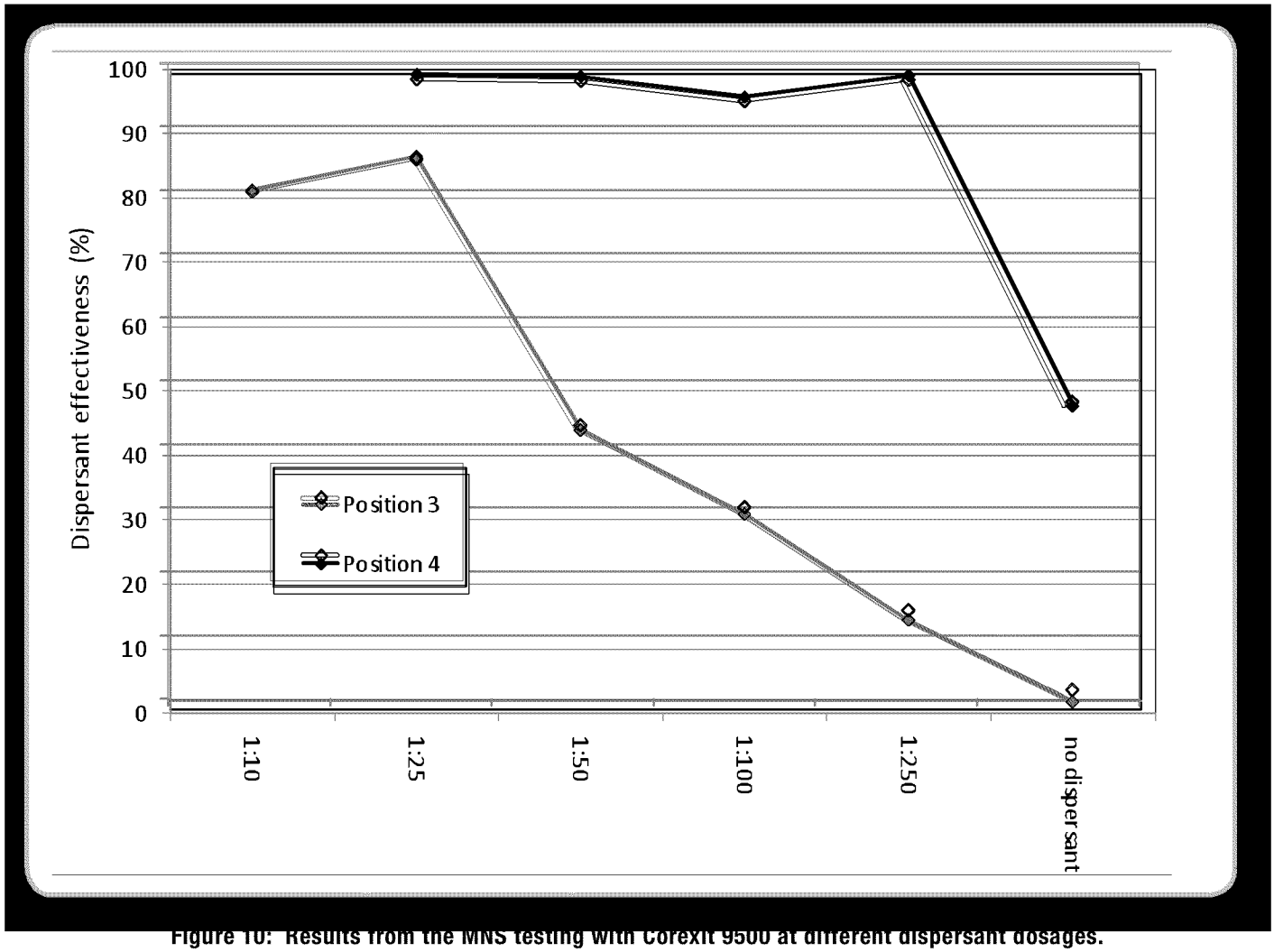

Figure 10: Results from the MNS testing with Corexit 9500 at different dispersant dosages. Position 3 Light brown / reddish emulsion: Viscosity 7200 cP, water content 50%; Position 4: Dark Brown emulsion: Viscosity 1250 cP, water content 33 %.

For the reasons stated in the subsurface dispersant application estimation, it was difficult to assess the efficacy of this effort, with a wide variation in the opinions of the experts. As in the case of subsea dispersant operations a compromise value is used in the new version of the Oil Budget Calculator in lieu of a consensus number. The expected DOR is 1:10 with a low value of 1:5 and a high value of 1:20

Table 2: USCG Surface Water Dispersant Study Sample Results.

USCG ID#	[redacted]
USCG-062	
USCG-063	
NSF-036-10-GB-064	
NSF-036-10-GB-065	
NSF-036-10-GB-067	
NSF-036-10-GB-068	
NSF-036-10-GB-070	
NSF-036-10-GB-071	
NSF-036-10-GB-072	
NSF-036-10-GB-073	
NSF-036-10-GB-075	
NSF-036-10-GB-076	
NSF-036-10-GB-077	
NSF-036-10-GB-078	
NSF-036-10-GB-079	
NSF-036-10-GB-080	
NSF-036-10-GB-082	
NSF-036-10-GB-083	
NSF-036-10-GB-084	
NSF-036-10-GB-085	
NSF-036-10-GB-086	
NSF-036-10-GB-087	
NSF-036-10-GB-088	
NSF-036-10-GB-089	
NSF-036-10-GB-090	
NSF-036-10-GB-091	
NSF-036-10-GB-092	

9B. CHEMICAL DISPERSION: SUBSURFACE APPLICATION

Measurement of subsurface operation was, at best, highly indirect. The most directly applicable was a published study by Camilli et al. (2010), who reported results from a subsurface hydrocarbon survey using an autonomous underwater vehicles and a ship-cabled sampler. Using BTEX results as an indicator of oil concentration, they concluded that an observed plume of oil at approximately 1100 m. depth represented about 6-7% of the oil leaking from the wellhead. The plume location was consistent with the expected location of subsurface dispersed oil based upon the Clarkson well blowout model (Latimer and Zheng, 2003).

Most of the experts believed that the conditions subsurface were good for dispersant operations. It is likely that all five of the conditions listed by Clayton et al (1993) were generally met. However, the addition of dispersant at 7 to 12 gallons / minute through a narrow diameter wand held by a ROV into the flow of escaping oil and gas would probably not have added dispersant to all of the oil; some oil would have escaped into the water column untreated with any dispersant. Without carrying out some experimentation, it is not possible to say what proportion of the escaping oil would and would not have been treated with dispersant. Also, using the estimated flow rate shown on Figure 3 and the data available on the daily rate of dispersant applications, the dosage of chemical dispersant (DOR) for subsurface application varies from 1:1200 to 1:92; 19% of the time (13 days) the DOR was less than 1:250, 34% of the time (23 days) it was between 1:150 and 1:250 and 43 % of the time (29 days) it was between 1:150 and 1:100. Yet, laboratory studies show that COREXIT 9500 is effective on this type of oil and there was more than sufficient turbulent energy.

The Oil Budget Calculator originally used a very conservative estimate for subsurface dispersant operations. The ITOPF Technical Information Paper for "The use of Chemical Dispersants to Treat Oil Spills" (http://www.itopf.com) recommends for planning purposes the use of 1 part dispersant for 20 parts oil as the dosage rate. They point out that spraying equipment is often preconfigured to achieve this. Some laboratory studies also support this number (Fingas et al. 1995; Khelifa and So, 2009).

Some experts were concerned that the entrained gas would reduce the effectiveness of the dispersant application by preventing contact between oil and surfactant. They also thought that the time of contact might be insufficient to achieve optimum effect. Their concerns are captured in the choice for minimum effectiveness. However, other experts believe that a 1:20 effectiveness ratio greatly underestimated that actual amount of oil dispersed. They point to successful applications in the North Sea, producing a larger ratio of dispersed oil to surfactant applied. Ratios as large as DOR 1:100 were suggested. One of the experts was concerned about hydrate interference with dispersant application.

Failing to achieve common agreement of the experts, the new calculator uses a compromise estimate of a DOR of 1:40 with a low estimate of 1:20 and high estimate of 1:90.

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10. BURNING

Burning *in-situ* was extensively used during the Deepwater Horizon Spill. Environmental conditions, location of the incident and the nature of the oil made this possible. Oil was gathered into areas enclosed with special booms and set afire.

For ignition to occur with most oils, the oil film must generally be greater than 2 to 3 mm. Ignition will depend upon the water content of the oil, emulsions of 20 to 25 % or more typically being very difficult to ignite. Since free-floating oil slicks are typically on the order of a tenth of a mm or less, most oil spills need to be contained in special fire-resistant booms. High winds and waves (typically in excess of 1 m short-period, wind waves) may prevent burn operations because of the difficulty of preventing entrainment and splash over within the fire boom, and, because of the difficulty of achieving an initial ignition. Most relatively fresh crude oils (even emulsions of 15% to 20% water) may burn with a "thickness-reduction" or "regression" rate of approximately 0.05 mm/sec, slightly more than a tenth of an inch per minute (ASTM, 2003). This represents an oil elimination rate of approximately 0.07 gpm/sq.ft. Higher water contents of approximately 25% to 40%, though very difficult to ignite, may burn at rates of approximately 0.05 gpm/sq.ft. During the burning of oil or emulsions on water, part of the oil is turned into smoke. The actual percentage depends upon the size of the burn and other factors, but usually is in the range of only 5% to 15% of the original volume of oil burned. With typically less than 5 % of the original volume remaining as burn residue, the controlled elimination of spilled oil through combustion is recognized as a highly efficient response option. The burn rates used during the Deepwater Horizon incident range from 0.07 gpm/sq.ft (representing lightly emulsified oils) to 0.05 gpm/sq.ft for burns that may have involved more highly emulsified oils. These oil elimination rates are in line with ASTM standards, and most burns were carried out on emulsions with relatively low water content and along convergence lines where unstable emulsions and wind-herded films had accumulated as dark brown to black oil layers. Daily estimates of the volume of oil burned were recorded as minimum and maximum values reflecting these oil elimination rates. The results were calculated throughout the Deepwater Horizon incident using surface and aerial observations that included the size and duration of each burn. Nearly all burns involved 500-ft-long booms towed in a U-configuration, while attempting to maintain a "gap ratio" (i.e., swath-to-boom-length ratio) of ~ 0.3. A single fire boom could therefore hold 500 to 1000 bbl of oil in its apex, the downstream area only ~1/3 of the way toward the leading ends of the boom. A single burn could often eliminate its contents within an hour or less. Field crews concluded that some surface slicks must have been in the range of 2.5 mm to 5 mm to achieve some of the larger burns. This represents a very thick oil emulsion layer.

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Figure 11 illustrates the minimum and maximum daily oil elimination rates based upon the burn rates described above. It should be noted that the percentage of burned oil reported by the Calculator applies to all the oil released by the well. If one computes burning share based only upon the volume of available surface oil, the fraction burned is much larger, representing a significant portion of the surface oil. The Oil Budget Calculator uses the range of reported burn values depicted in Figure 11 in its calculations. The uncertainty range for the amount of burned oil is small compared to the other processes discussed in this report.

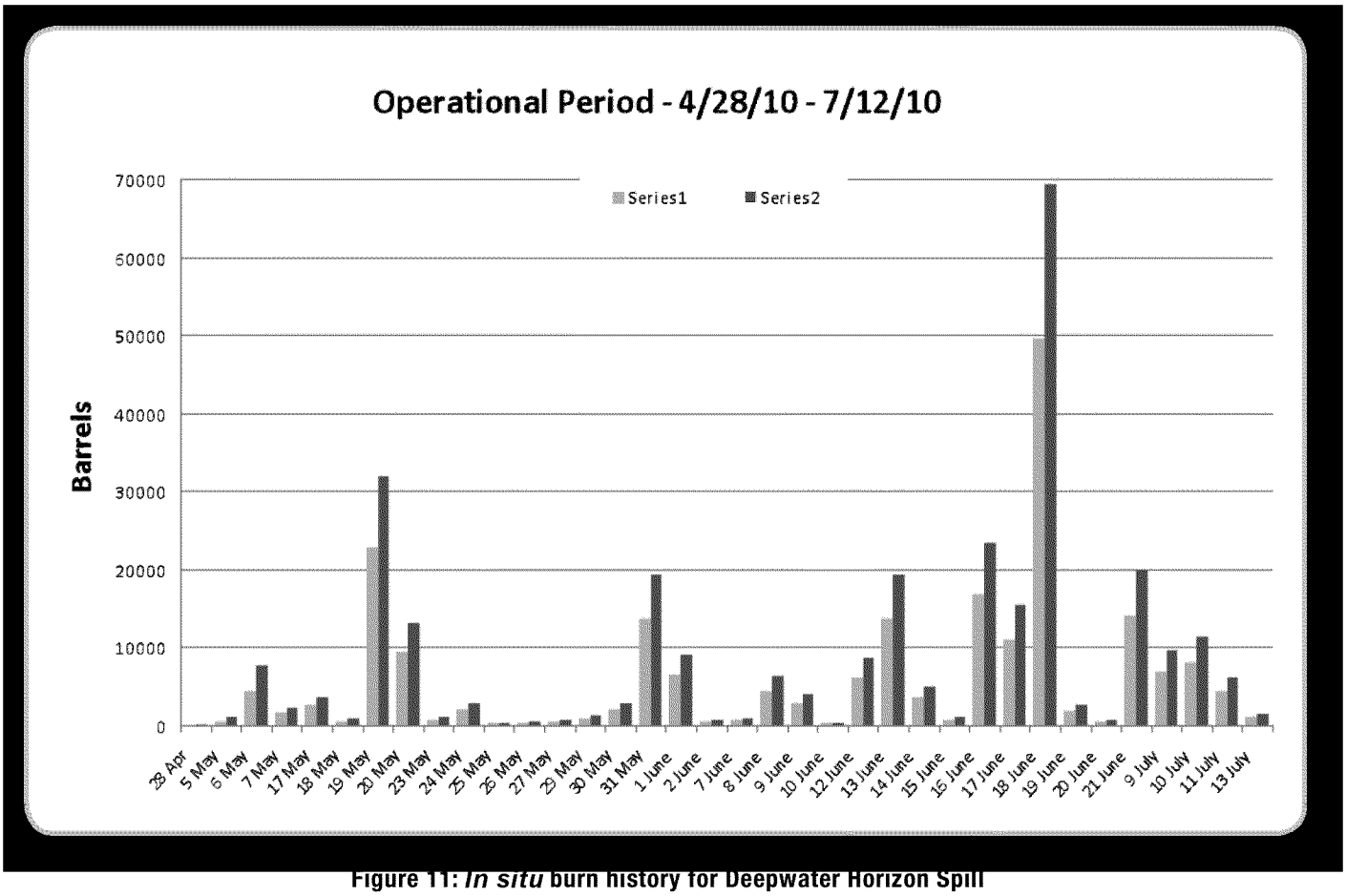

Figure 11: *In situ* burn history for Deepwater Horizon Spill

11. MECHANICAL RECOVERY

Skimmers were the most commonly used mechanical devices use to remove oil from the Gulf water surface. These skimmers varied greatly in size, application, and capacity, as well as in recovery efficiency and water pickup (Schulze, 1993; Schwartze, 1979). In the particular case of the Gulf oil spill the major issue was the amount of water recovered with the skimmed oil. Rather than estimate oil-water ratios, simple measurements of the barge oil would seem the rational way to determine this amount. However, to date, no such measurements are available. Therefore it was necessary to estimate skimmer performance based upon sea conditions, nature of the oil, and past experience.

A skimmer's performance is affected by a number of factors including the thickness of the oil being recovered, the extent of weathering and emulsification of the oil, the presence of debris, and weather conditions at the time of recovery operations. A skimmer's overall performance is usually determined by a combination of its recovery rate and the percentage of oil recovered. The maximum amount of oil that a skimmer could recover is called the 'Nameplate Recovery Rate' and is typically provided by the manufacturer of a skimmer (Fingas, 2010; Meyer et al, 2009). A similar definition is the 'Effective Daily Recovery Capacity', which is the amount that a skimmer could recover in daylight hours under ideal conditions. The recovery rate is the volume of oil recovered under specific conditions. It is measured as volume per unit of time and is usually given as a range. If a skimmer takes in a lot of water, it is detrimental to the overall efficiency of an oil spill recovery operation.

Skimmer performance is chiefly the product of three parameters. The Oil Recovery Rate (ORR) is the quantitative rate in volume per unit time, usually m^3/hour and is corrected for water recovery. The throughput efficiency (TE) is applicable only to advancing skimmers. The throughput efficiency is the percentage of oil presented to a skimmer versus that recovered, in percent. The recovery efficiency (RE) is the percent of oil recovered out of the total oil and water recovered. For the Gulf recovery effort, the RE is the most important factor. We know the total liquids recovered, but we do not know exactly how much oil was in this liquid and therefore must estimate the actual oil recovered. Past studies show that the average RE of the skimmers in wave conditions is 33%.

The measured water content of skimmed emulsions varied. An estimate of the actual recovered oil would be a product of the average RE times the oil content of the emulsion. The Calculator assumes that 20% of the skimmed liquid was oil, with a range between 10% and 40%. These are conservative estimates in line with the philosophy behind the Calculator. They are also considered temporary numbers, pending any measurement results.

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12. OTHER OIL

The Oil Budget Calculator does not quantify the amount of oil volume that becomes tar balls, forms surface slicks, sinks due too sedimentation, remains in the surf zone or impacts the shore and is subsequently cleaned up. These are instead grouped together as 'other oil'.

The amount of oil listed as 'other' is quite large. Obviously, there are no longer large surface slicks in the Gulf of Mexico. So where is this oil? Some obviously did impact the coastline, particularly the Louisiana coastline. Cleanup operations recorded the volume of oil debris that was recovered during shoreline cleanup. However, no estimates were made of the percentage of oil in this debris so it is not possible to give a reliable estimate of this amount. Based upon past spills, the oil content of collected debris mass is only a few percent. Some of the oil may have aggregated with sediment in the water column and settled to the sea bottom. The Oil Budget Calculator does not estimate sedimentation.

Much of this oil probably formed tarballs or millimeter scale oil droplets since the conditions of this spill were conducive to such tarball/droplet formation (turbulent subsurface release, large use of dispersant on weak emulsions, etc). The larger tarballs are very persistent in the marine environment and can travel hundreds of miles, sometimes re-concentrating in convergence zones far from the original spill site. Some limited efforts were made to collect and quantify the larger tar ball mass density in the nearshore areas but the available data was insufficiento make a global estimate. Thsmaller oil droplets behave in some respects almost as dispersed oil and are similarly subject to biodegradation, dissolution, and sedimentation.

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13. LONGER-TERM PROCESSES

While not tracked by the Oil Budget Calculator, there are other processes that work to break down the spilled oil. Two important ones for the Gulf of Mexico are photo-oxidation and biodegradation.

The combination of hydrocarbons with oxygen is called oxidation. The newly formed oxidized compounds may affect the oil slick by increasing dissolution, dispersion or emulsification. While trace metals in the oil may influence the oxidation process, ultraviolet light significantly increases oxidation. Virtually all of the molecules that evaporate from the slick undergo photochemical oxidation in hours or days. Also, beached oil will show the effects of exposure to sunlight. Even floating oil can show chemical changes due to this process. Overton (1981) exposed IXTOC I crude oil to sunlight and discovered the formation of tarry flakes, showing the involvement of photolysis. Observers at the *Mega Borg* spill in the Gulf of Mexico noticed the formation of crusts on floating tarmats and tar balls, with the hypothesis that this was due to photo-oxidation.

Hydrocarbons, including those found in oil slicks, are a food source for many microorganisms. The rate of such biodegradation depends upon the availability of nitrogen- and phosphorus-containing nutrients in the water, as well as the surface exposure of the oil to the organisms. Swannel and Daniel (1999) suggest that dispersant use on a slick may speed up biodegradation by promoting the growth of indigenous, hydrocarbon-degrading bacteria as well as increasing the surface area of the oil available for microbial colonization.

Bacteria capable of degrading various groups of petroleum hydrocarbons have been found in all oceans and in deep as well as shallow water. Research on biodegradation has occurred with many types of oils and fuels, at temperatures ranging from -1C (polar) to over 30 C (hot, tropical), and at natural oil seeps. Tools for documenting biodegradation rates include microbial taxonomy and abundance, nutrient uptake, oxygen utilization and mass loss.

The Deepwater Horizon blowout resulted in petroleum hydrocarbon contamination on sand beaches and marshes, at the sea surface, in the warm (30-35C) upper water column adjacent to dispersant operations, and in cold (4.5 to 5C) water at 1100 to 1300 m deep. Available results to date have been reported from surveys conducted in May and June, 2010, and focused on indicators of biodegradation in the contaminated deepwater layers (Camilli et al., 2010 and Hazen et al, 2010).

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Camilli et al (2010) reported presence of sub-surface volatile hydrocarbons and also only slight reductions of oxygen at depth and suggested biodegradation rates were low potentially resulting in many months of hydrocarbon persistence. Hazen et al (2010) reported that the dispersed hydrocarbons in deep water originating from the Deepwater Horizon blowout source stimulated deep-sea indigenous γ-proteobacteria that are closely related to known petroleum-degraders. Hydrocarbon-degrading genes coincided with the concentration of various oil contaminants, namely alkanes. Changes in hydrocarbon composition with distance from the source and incubation experiments with environmental isolates demonstrated faster than expected hydrocarbon biodegradation rates at 5°C. The half-life degradation rates ranged from about 2 to 6 days, depending on the alkane. Based on these results, Hazen et al (2010) concluded that the potential exists for intrinsic bioremediation of the petroleum hydrocarbons in the deep-water column without substantial oxygen drawdown.

Other studies unrelated to this incident have reported a wide range of hydrocarbon degradation rates depending on all the variables indicated above. The Hazen et al (2010) rates are not inconsistent with those published by Venosa and Holder (2007) for cold water using dispersed Alaska North slope crude oil.

Past biodegradation research has focused on marine waters of moderate to warm temperatures, including oil-contaminated sediment interstitial waters of beaches and marshes as well as dispersed/dissolved hydrocarbons. Going back into history, Walker and Colwell (1977) measured the loss of mass South Louisiana crude oil during replicated in situ incubation field experiments in a North Carolina estuary at 30C. The mean mass of 365 mg of oil was reduced to 235 mg in one week (35% reduction), 178.5 mg in 2 weeks 51.1 percent reduction) , 11.2 mg in 3 weeks (97.0 per cent reduction and and 8.8 mg in 4 weeks (97.6 per cent), yielding a half life of about 2 weeks (14 days). Bacteria counts reached maximum in 3 weeks then stared to decline. Presumably, the initial loss of mass was due to evaporation of more volatile components whereas the later stages were the result of biodegradation. These simple rate results fall somewhere between the predictions of Camilli et al (2010) and Hazen et al (2010).

Since the 1970's, there has been a considerable amount of field, mesocosm, and laboratory work done. The rates resulting from these studies also range widely depending on oil types, oil weathering, dispersion effectiveness, dispersant composition, nutrient loadings, and especially which target petroleum compounds or groups of compounds each research team analyzed. The National Research Council (NRC, 2005) reviewed much of the work done on biodegradation of dispersed oil concluding that most of the work has not been consistently

standardized sufficient to confidently extrapolate from the laboratory to the field. Further, there is a paucity of work on degradation of higher molecular weight polycyclic aromatic hydrocarbons, the most toxic compounds. Field studies in contaminated marshes and beach sediments, have demonstrated a wide range of biodegradation rates; oil biodegraded almost completely within a few weeks at some locations while it persisted for tens of years at other locations (Reddy et al., 2002; Short et al, 2004). Boufadel et al., (2010) noted low oxygen and nutrient concentration that might have prevented effective biodegradation of the Exxon Valdez oil spill. The study of Li and Boufadel (2010) highlighted that understanding beach hydraulics is a critical step in predicting the fate of oil within beaches. Therefore, we would expect this oil to undergo biodegradation at different rates in different compartments of the Gulf ecosystem

14. ASSESSMENT AND FUTURE PLANS

While pure scientific research can be done on oil spills, most oil spill science is applied science. Tools such as the Oil Budget Calculator are only useful if they provide information that will assist response decisions. Conversely, they need only be as accurate as the precision needed for these decisions. Improved accuracy beyond those levels may be important in the academic sense but not in the response area. Figures 12 and 13, below, show the output from the model, given the revisions described in this document. They vary somewhat from earlier calculations but probably not significantly according to the above criteria.

The estimates of the Calculator were admittedly rough for the reasons discussed in this report. However, the estimates were probably sufficient to meet the needs of the Response. Ultimately, of course, that judgment will be made by the NIC. The experience in developing the Calculator points to areas of needed future research and planning:

(1) **Protocols for surface and subsurface sampling:** While oil samples were collected for impact assessment, few samples were properly collected and categorized for response. For example, samples often came from skimming barges, where oil in different states of degradation was blended together. Future response plans should specify methods for gathering proper representative samples.

(2) **Dispersed oil droplet size:** A major improvement in estimating dispersant efficiency would be possible if practical operational tools and methods existed to characterize droplet size distribution of subsurface oil.

(3) **Basic Models for Longer-term processes:** While longer-term processes such as biodegradation often happen outside the time frames of the response, understanding and being able to predict such longer-term changes may be useful in making response decisions.

(4) **Estimation of collected shoreline oil:** For a complete mass balance, procedures should be implemented that estimate the fraction that is oil or oiled debris gathered from shoreline cleanup.

(5) **Expanded modeling capabilities:** Many of the team members that assisted with the Oil Budget Calculator are also part of a working group of spill experts developing the specifications for the next generation of oil spill model. These specifications need to be translated into real code.

(6) **Revised interface:** A better interface is necessary to more properly display the intrinsic uncertainty in the Calculator.

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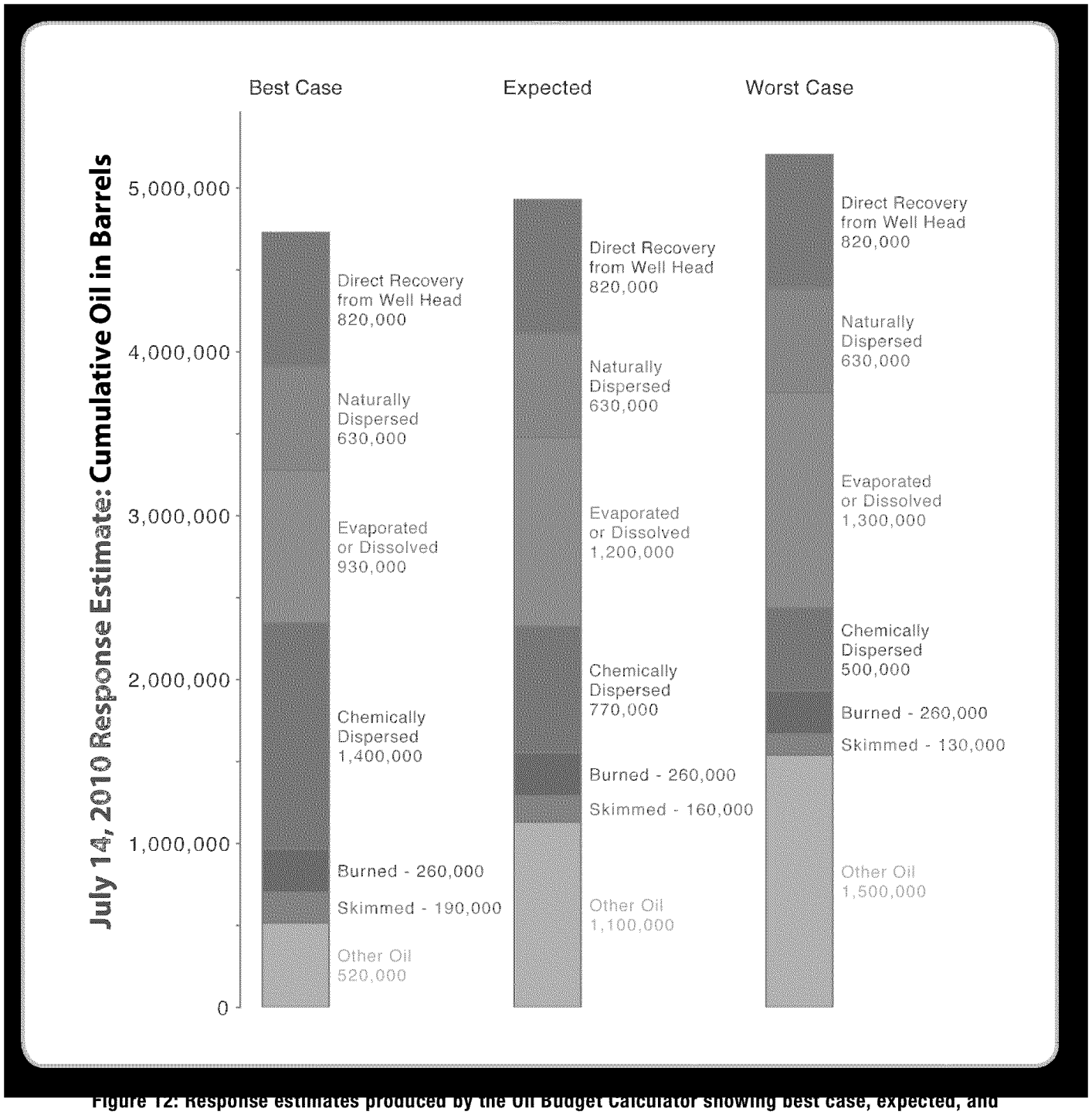

Figure 12: Response estimates produced by the Oil Budget Calculator showing best case, expected, and worst case volumes of the seven different portions that the calculator tracks individually, of the cumulative volume of oil discharged through July 14, 2010. These estimates served solely as a guide for the national response to the Deepwater Horizon MC252 Gulf Incident. The best and worst cases are defined in Appendix 1: they are the combinations of values of the seven variables depicted in each stack that correspond to the lower and upper endpoints of a 95% confidence interval for the volume of Other Oil .

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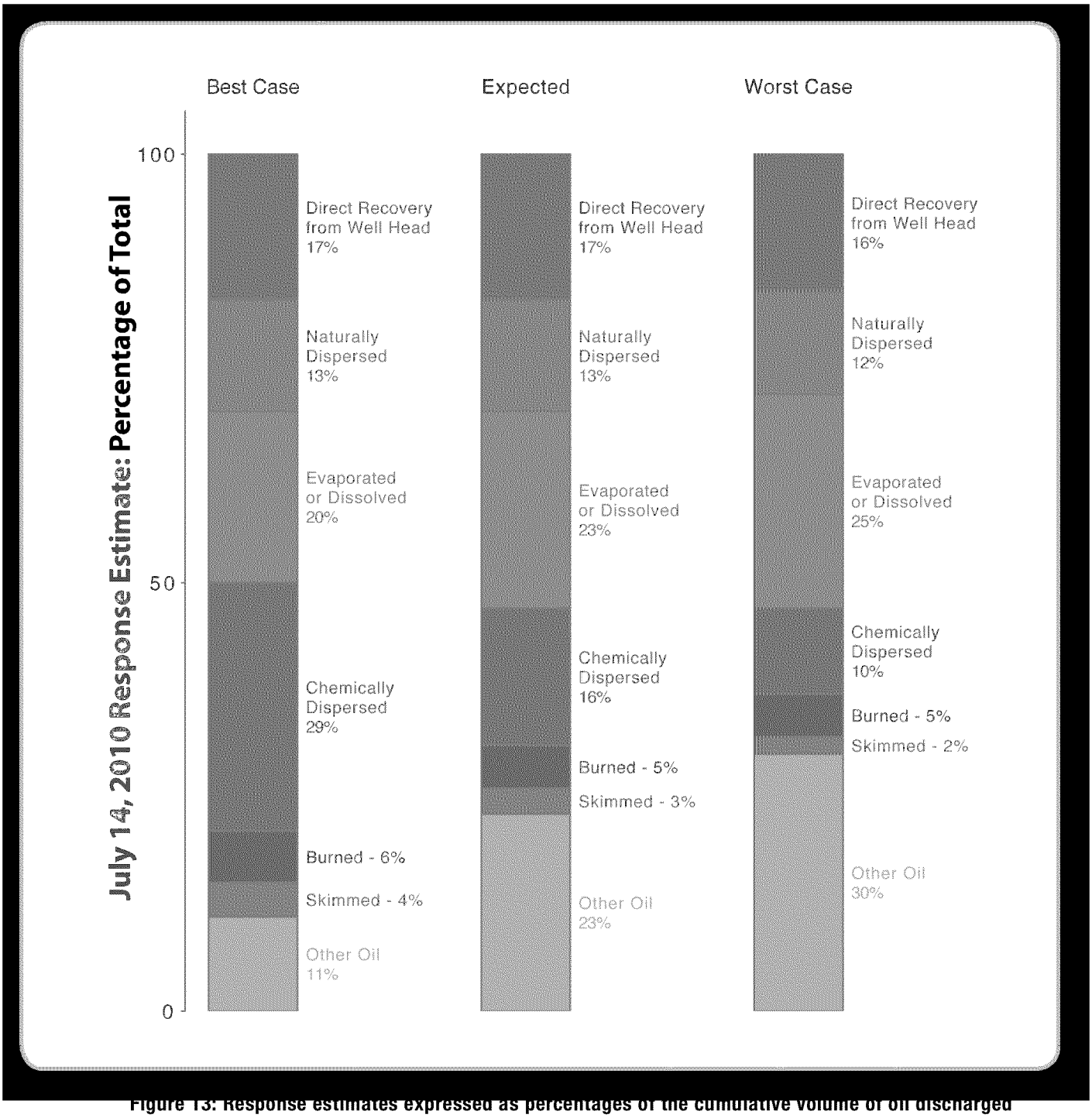

Figure 13: Response estimates expressed as percentages of the cumulative volume of oil discharged through July 14, 2010, in the best, expected, and worst cases. These estimates served solely as a guide for the national response to the Deepwater Horizon MC252 Gulf Incident.

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Appendix 1

A1 Uncertainty Assessment of Mass Balance Estimates

A1.1 Introduction

We have developed and applied statistical methods to gauge the uncertainty associated with the estimates of the volumes of the principal fractions of the oil spilled from the Deepwater (Macondo) well that the Oil Budget Calculator tracks individually, in addition to the volume of oil that has been recovered via the Riser Insert Tube Tool (RITT) or via the Top Hat: (i) oil that has been naturally or chemically dispersed; (ii) oil that has evaporated or dissolved; (iii) oil in skimmed oily seawater; (iv) oil that has been burned; and (v) residual (or, other) oil that remains either on or below the sea surface, in other forms.

The uncertainty associated with the volume of each of these fractions includes contributions from the uncertainty of the eight rate constants in the mass balance equations that describe where the spilled oil will have gone.

Figure A1.1 on page A1.7 shows the result of the uncertainty analysis for the volume of residual oil, depicted as an uncertainty envelope, throughout the 86-day period from April 20 (explosion and fire on Deepwater Horizon platform) to July 14, 2010 (last day with discharge from the well). The lower bound of this envelope corresponds to a best-case scenario, and the upper bound to a worst-case scenario. Section A1.8 describes the methods used to characterize these scenarios quantitatively, and Appendix 2 shows the corresponding results.

A1.2 Input and Output Quantities

The quantities that we are primarily interested in, and whose values we track, are referred to as *output quantities*; and the quantities that these depend on (which are measured directly or indirectly, or that we have other prior knowledge of), are referred to as *input quantities*.

For example, the volume $V_{DC}(t)$ of oil that was dispersed on day t by underwater application of a volume $V_{CB}(t)$ of a chemical dispersant can be modeled as $V_{DC}(t) = (1 - k_7) \min\ 90k_2V_{CB}(t), V_R(t) - V_{DT}(t)$, where $V_R(t)$ denotes the volume of oil discharged from the well, of which $V_{DT}(t)$ will have been recovered via RITT/TopHat, and k_2 and k_7 denotes *rate constants*.

In this example, $V_{DC}(t)$ plays the role of output quantity, and $V_{CB}(t)$, $V_R(t)$, $V_{DT}(t)$, k_2, and k_7 play the role of input quantities. Of the latter, only $V_{CB}(t)$ and $V_{DT}(t)$ were measured directly; $V_R(t)$ was estimated by other teams in the Flow Rate Technical Group equation A1.1 on page A1.2; k_2 and k_7 are the results of assessments supplied by subject-matter experts.

The *mass balance equations* A1.1 on page A1.2– A1.16 on page A1.2 express relations between all the relevant quantities, and involve what we have been calling input and output quantities, as well as other quantities that we call intermediate quantities because they are used in the calculations but are not of primary interest for the purposes of the Oil Budget Calculator.

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$$V_{RE}(t) = V_R(t) - V_{DT}(t) \tag{A1.1}$$

$$X(t) = 90V_{CB}(t) \tag{A1.2}$$

$$V_{DC}(t) = (1 - k_7)\min\ k_2X(t), V_{RE}(t) \tag{A1.3}$$

$$Y(t) = V_{RE}(t) - \frac{V_{DC}(t)}{1 - k_7} \tag{A1.4}$$

$$V_{DN}(t) = (1 - k_7)\max\ 0, k_1Y(t) \tag{A1.5}$$

$$V_{DB}(t) = V_{DC}(t) + V_{DN}(t) \tag{A1.6}$$

$$V_{NW}(t) = k_6V_{OW}(t) \tag{A1.7}$$

$$Z(t) = V_{RE}(t) - \frac{V_{DB}(t)}{1 - k_7} \tag{A1.8}$$

$$W(t) = \max\ 0, (1 - k_4)Z(t) - V_{BU}(t) \tag{A1.9}$$

$$V_E(t) = k_4Z(t) + k_5W(t - 1) + \frac{k_7}{1 - k_7}V_{DB}(t) \tag{A1.10}$$

$$V_{NS}(t) = \max\ 0, k_8W(t) \tag{A1.11}$$

$$V_{DS}(t) = \min\ 20k_3V_{CS}(t), V_S(t - 1) \tag{A1.12}$$

$$V_D(t) = V_{DB}(t) + V_{DS}(t) + V_{NS}(t) \tag{A1.13}$$

$$V_{SD}(t) = V_{RE}(t) - V_E(t) + V_{NW}(t) + V_{BU}(t) + V_D(t) \tag{A1.14}$$

$$V_S(t) = V_{SD}(1) + \cdots + V_{SD}(t) \tag{A1.15}$$

$$V_C(t) = V_{DS}(t) + V_{DC}(t) \tag{A1.16}$$

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The input, intermediate, and output quantities are listed in Table A1.1 on page A1.4. Typically, all of these quantities vary from day to day, and this dependence will be indicated explicitly when necessary, as in $V_R(t)$, for the volume of oil discharged on day number t (day 1 being April 20, 2010).

All volumes are assumed to be expressed in barrels of oil (bbl), with 1bbl = 42 U.S. (liquid) gallons ≈ 159L. The policy of the National Institute of Standards and Technology (NIST) is to use the International System of Units (metric units) in all publications. In this document, however, the units used traditionally in the oil industry are also used.

All of the output quantities have cumulative counterparts, except $V_S(t)$, which, by definition, already includes contributions from oil released on day t as well as residues of oil that will have been released on prior days but have not yet been recovered, evaporated or dissolved, burned, or dispersed (which in practice means dispersion into droplets of less than 70μm to 100μm in diameter). $V_{SD}(t)$ is the contribution to the residual oil originating from oil spilled on day number t, and $V_S(t)$ is the corresponding cumulative sum (from day number 1 through day number t), as defined in equation A1.15 on page A1.2.

A1.3 Uncertainty

The *Guide to the expression of uncertainty in measurement* (GUM) [Joint Committee for Guides in Metrology, 2008a], and its companion *International vocabulary of metrology* (VIM) [Joint Committee for Guides in Metrology, 2008c], are international standards that codify the meaning of "uncertainty" in the context of measurement science, and provide the technical basis whereon it may be gauged quantitatively, and interpreted in practice.

The VIM defines *measurement uncertainty* as a "non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used." *Measurand* is the "quantity intended to be measured." In our case, the volumes of the different fractions of the spilled oil, aforementioned, that the Oil Budget Calculator tracks separately, all are measurands.

Here, and in many other studies, the measurands are not accessible for direct measurement, and the corresponding measured values, or estimates of their values, are obtained by applying *measurement functions* [Joint Committee for Guides in Metrology, 2008c, 2.49] to values of other quantities that are either measured directly, or themselves are functions of yet other quantities that will have been measured directly, or about which there exists some prior information. In our case, these measurement functions are the mass balance equations.

The uncertainty analysis we describe in Section A1.7 on page A1.11, serves to propagate the measurement uncertainty associated with the input quantities to the output quantities of interest. Since the methods used to model the uncertainty of the input quantities are probabilistic, and the methods used to propagate their uncertainties to the output quantities are statistical, the end-product of such analysis typically is an interval that, with some specified probability (typically 95 %) includes the true, albeit unknown value, of the output quantity.

For example, we will conclude that the volume of residual oil on day number 86 (July 14,

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INPUT QUANTITIES	
V_{BU}	Oil volume burned
V_{CB}	Dispersant volume sprayed, subsurface
V_{CS}	Dispersant volume sprayed, surface
V_{DT}	Oil volume recovered via RITT/TopHat
V_{OW}	Oily water volume recovered
V_R	Oil volume discharged
INTERMEDIATE QUANTITIES	
V_D	Oil volume dispersed, total
V_{DB}	Oil volume dispersed, subsurface
V_{DC}	Oil volume dispersed chemically, subsurface
V_{DS}	Oil volume dispersed chemically, surface
V_{RE}	Oil volume effectively discharged
V_{SD}	Oil volume contributed to residual, daily
W	Auxiliary variable
X	Auxiliary variable
Y	Auxiliary variable
Z	Auxiliary variable
OUTPUT QUANTITIES	
V_{DN}	Oil volume dispersed naturally, subsurface
V_{NS}	Oil volume dispersed naturally, surface
V_C	Oil volume dispersed chemically
V_E	Oil volume evaporated or dissolved
V_{NW}	Oil volume skimmed
V_S	Oil volume residual (or, other oil)

Table A1.1: Input, intermediate, and output quantities.

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2010), will have been between 0.53 and 1.5 million barrels (Mbbl) of oil, with 95% probability (Appendix 2). This means that one is prepared to bet at odds of 19:1 in favor of the true value of such volume indeed lying in this interval. Noting that 1bbl = 42U.S. (liquid) gallons ≈ 159L, that interval may equivalently be stated as 22×10^6 U.S. gallons to 63×10^6 U.S. gallons, or as 84×10^6 L to 240×10^6 L.

All the quantities in play here are affected by uncertainty. In the example above, it is not only the rate constants k_2 and k_7 that have associated uncertainty re?ecting the imperfect knowledge that experts have about their values. The values of $V_{CB}(t)$, $V_R(t)$, and $V_{DT}(t)$ all include some measurement error that we express as uncertainty about their true values.

However, the only quantities whose associated measurement uncertainty has been characterized are $V_R(t)$ (oil volume discharged) and V_{BU} (oil volume burned), and the rate constants $k_1, \ldots, k_8$. The subject-matter experts believe that these indeed are the major sources of uncertainty, and that the contributions made by measurement error affecting V_{DT}, V_{CB}, V_{CS}, and V_{OW} (all de?ned in Table A1.1 on page A1.4) are minor by comparison.

The mass balance equations that, among other outputs, produce an estimate of residual oil V_S, describe a simpli?ed model for the partition of the oil among the several fractions that we track, shortly after release, and re?ect a particular understanding of the physical and chemical processes that drive that partition.

Other models that could conceivably be entertained, or other choices that could be made about the values of the rate constants, which some oil spill experts might regard as equally reasonable, most likely would produce estimates for V_S different from those this model produces, even when applied to the same data. The corresponding dispersion of values of such alternative estimates would re?ect model uncertainty. Although our uncertainty analysis does not re?ect this, it is widely recognized that, in many studies, model uncertainty contributes substantially to the overall uncertainty.

A1.4 Approach

The uncertainties associated with the volume of oil discharged and with the rate constants in the mass balance equations are modeled probabilistically and then propagated to the output quantities using the Monte Carlo simulation method that, in one form or another, has been in use for many years in many different disciplines [Metropolis and Ulam, 1949], and that has been codi?ed for use in measurement science in the form of an international standard [Joint Committee for Guides in Metrology, 2008b].

The probabilistic models used for this purpose serve to describe the imperfect or incomplete knowledge about the values of a quantity. For example, in Section A1.5 on page A1.7, we model the uncertainty about the volume discharged on day t as $(1 + Q)V_R(t)$, where Q denotes a Gaussian (or "normal") random variable with mean 0 and standard deviation 0.05. This is one way of saying that, with high con?dence (95 %), the actual volume is within 10 % (= 2 × 0.05) of the value estimated for the volume discharged. The same can be said in other ways, too: for example, by modeling Q as a random variable with a uniform (or rectangular) distribution

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between - 0.1 and + 0.1.

The same limitation applies to all the models we shall employ to model uncertainty with. Even though we believe that they are reasonable for the situations at hand, ultimately they all reflect arbitrary choices, because the science regulating these matters is not yet sufficiently developed to identify a single model as necessarily better or more adequate than all the others. In Section A1.9 on page A1.14 we will assess the sensitivity of our conclusions to this, and to other modeling assumptions.

As noted already in Section A1.3 on page A1.3, and except for V_R, V_{BU}, and for the rate constants, the uncertainty associated with the input quantities (V_{DT}, V_{CB}, V_{CS}, and V_{OW}) has not been quantified. We proceed on the assumption that the measurement uncertainty of these input quantities is negligible by comparison with the uncertainty components attributable to the imperfect knowledge of the "true" values of the volume discharged and of the rate constants. Also as noted towards the end of Section A1.3 on page A1.3, model uncertainty is not captured either, even though we cannot claim that it is negligible.

The Monte Carlo simulation method that we have used to propagate uncertainty from input to output quantities comprises two steps: first, the generation of multiple scenarios defined by combinations of conceivable values of all the input quantities; second, the summarization of the values of the output quantities corresponding to these scenarios. The results reported in Appendix 2 are based on 100 000 scenarios.

More precisely: for each scenario, we drew (or simulated) values from the probability distributions that model the uncertainty associated with the volume discharged, with the volume burned, and with the rate constants, and then used these simulated values in the calculations that produce time series of daily values of the output quantities. The values simulated for the rate constants vary from scenario to scenario, not from day to day.

Consider $V_S(t)$, the volume of residual oil on day t, for example. Its counterparts that correspond to m simulated scenarios are denoted $V_{1,S}(t), \ldots, V_{m,S}(t)$, and we refer to them as *replicates* of $V_S(t)$.

These m replicates may be summarized in a histogram, or by their average and standard deviation, or, as we do in Figure A1.1 on page A1.7, by means of an interval, ranging from $V_{S,L}(t)$ to $V_{S,U}(t)$, that brackets a specified proportion of them, say 95 %, which we then regard as a 95 % confidence interval for the "true" value of $V_S(t)$, and interpret as explained in Section A1.3 on page A1.3. This is the so-called *percentile method* of constructing bootstrap confidence intervals [Efron and Tibshirani, 1993, §13.3].

The lower and upper envelopes depicted in Figure A1.1 on page A1.7 were obtained by joining with red lines the points corresponding to $V_{S,L}(1)$, $V_{S,L}(2)$, ... (for the lower envelope), and to $V_{S,U}(1)$, $V_{S,U}(2)$, ... (for the upper envelope).

In addition to these envelopes, we also compute the average of the simulated values of $V_S(t)$, over all m scenarios, for each day t. Owing to the non-linear way in which some of the participating quantities (rate constants or input variables) enter in the mass balance equations, and given that the probability distributions of some of the rate constants are markedly asymmetrical,

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with one tail much longer than the other, those averages need not coincide with the values that one obtains by solving the mass balance equations using the expected values of the rate constants, and the measured or estimated (but otherwise undisturbed) values of the input quantities.

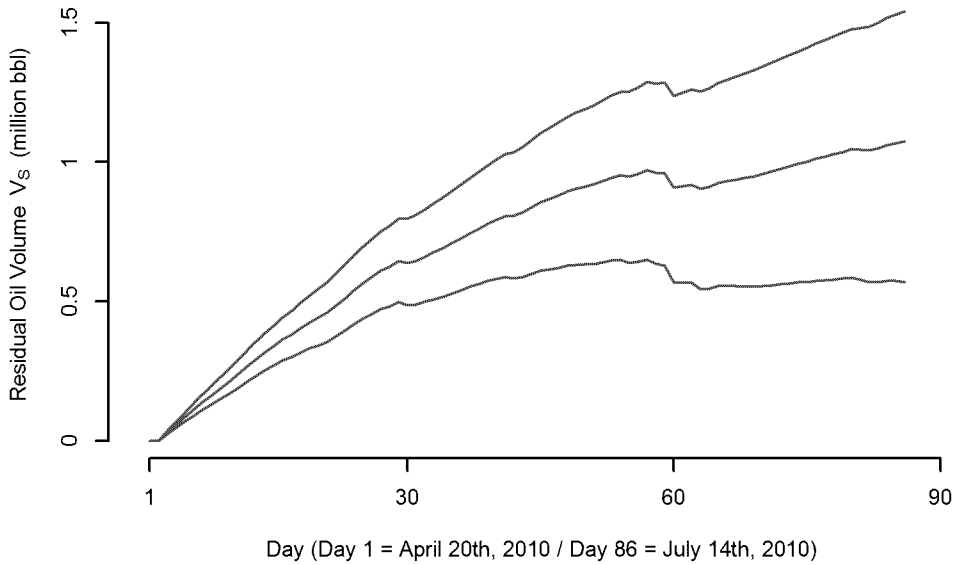

Figure A1.1: Volume of residual oil (V_S), and approximate 95 % con?dence band. The daily increments $V_{SD}(1), \ldots, V_{SD}(t)$ that $V_S(t)$ is the cumulative sum of, occasionally are negative, which explains the behavior of the curves around day 61 (June 18, 2010), when a large volume of oil was burned on the surface, indeed far more than the residual increment for that day. Since there was no additional discharge after day 86 (July 14, 2010), the curves ?atten beyond this date (not shown).

A1.5 Volume Discharged V_R and Volume Burned V_{BU}

The time series $V_R(1), V_R(2), \ldots$ of volume of oil discharged daily from the well, depicted in Figure A1.2 on page A1.8, is taken as an input to the mass balance calculations ($V_R(t)$ denotes the volume discharged on day t, with day 1 being April 20th, 2010): in fact, these daily volumes re?ect consensus estimates produced by the Flow Rate Technical Group (an explanation of how these estimates were derived will be published separately from this report).

The 10 % relative uncertainty that has been associated with the volume discharged is interpreted as follows: the simulated time series $V_R(1), V_R(2), \ldots$ of the daily discharge is modeled as the product

$$V_R(t) = (1 + Q)V_R(t), \text{ for } t = 1, 2, \ldots, \tag{A1.17}$$

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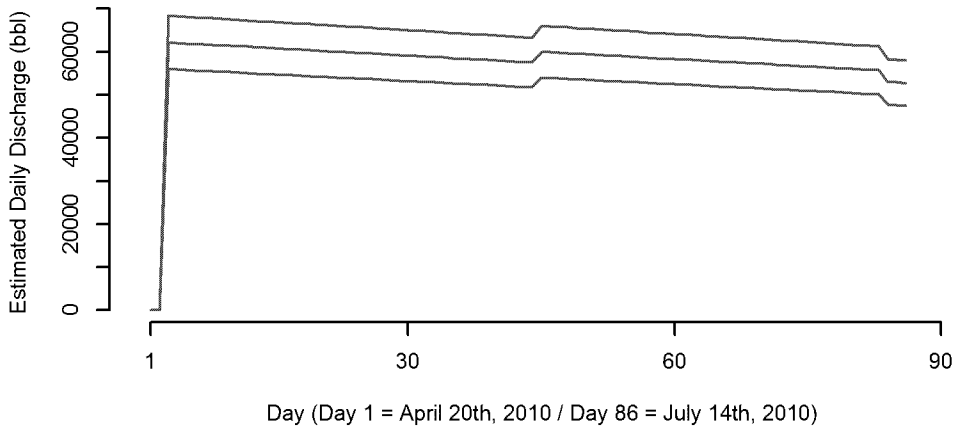

Figure A1.2: Daily volume of oil discharged from the Deepwater (Macondo) well. The best estimate is represented by the blue line, while the red envelope defines a range of ±10% around the best estimate. Since there was no additional discharge after day 86 (July 14, 2010), the curves drop to zero beyond this date (not shown).

where $V_R(t)$ denotes the nominal discharge on day t, and Q is a Gaussian random variable with mean 0 and standard deviation 0.05.

In these circumstances, and with high probability (95 %), the actual discharge should be within 10 % (= 2 × 0.05) of the nominal discharge; however, the model entertains a small chance (5 %) that it could deviate by more than ±10% from nominal.

Whatever deviation from nominal is selected for one particular scenario, it is assumed to apply to all the days of that scenario. For example, if we were 3 % too low in one scenario (meaning that $Q = -0.03$), then we would be 3 % too low in every day of that scenario; and if, in another scenario, we were 7 % too high ($Q = 0.07$), then we would be 7 % too high in every day of this scenario.

Over a two and half-month period, about 400 controlled burns of oil on the surface were conducted, which eliminated about 5 % of the oil that was discharged from the well. For the several burns that typically occurred each day, estimates of the minimum and maximum volume burned were provided.

We model the uncertainty associated with the total volume burned on a particular day as uniformly distributed between the given minimum and maximum. The corresponding standard deviation equals the difference between the maximum and the minimum divided by $\sqrt{12}$. The relative standard deviation equals the standard deviation divided by the average of the minimum and the maximum.

For the purpose of generating stochastic scenarios, these daily relative standard deviations were summarized by their geometric average, which turned out equal to 9.65 %. Similarly to how we

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treat the volume discharged, we have modeled the uncertainty associated with the daily volume of oil burned $V_{BU}(t)$ as described in equation A1.18, where the $\{B(t)\}$ denote independent Gaussian random variables with mean 0 and standard deviation 0.0965.

$$V_{BU}(t) = \quad 1 + B(t) \;\; V_{BU}(t), \text{ for } t = 1, 2, \ldots. \tag{A1.18}$$

Note that, differently from how we modeled the uncertainty of the volume discharged, here we perturb the estimates of the daily volumes of oil burned, independently from day to day.

A1.6 Probability Models for Rate Constants

The mass balance equations listed above include *rate constants* $k_1, \ldots, k_8$. Subject-matter experts have described their state of knowledge about the values of these constants by regarding them as outcomes of random variables, and by providing location and spread information about the corresponding probability distributions, listed in Table A1.2. This is a standard statistical device to express uncertainty assessments, and should not be interpreted as suggesting that these rate constants are intrinsically random, according to any of the common meanings of randomness.

RATE CONSTANT	DEFINITION	$_{0.025}$	μ	$_{0.975}$
k_1	Natural dispersion (subsurface)	0.10	0.20	0.30
k_2	Chemical dispersion (subsurface)	2/9	4/9	1.00
k_3	Chemical dispersion (surface)	0.05	0.10	0.20
k_4	1st day evaporation	0.33	0.37	0.44
k_5	2nd day evaporation	0.00	0.04	0.06
k_6	Net oil fraction in skimmed oil	0.10	0.20	0.40
k_7	Dissolution of dispersed oil	0.05	0.075	0.10
k_8	Natural dispersion (surface)	0.00	0.05	0.10

Table A1.2: Rate Constants. Expected values (μ) and 2.5th ($_{0.025}$) and 97.5th ($_{0.975}$) percentiles of the probability distributions that model the associated uncertainties.

We have interpreted the information in Table A1.2 as follows: the probability is approximately 95 % that the true value of a rate constant lies in the interval from $_{0.025}$ to $_{0.975}$, and has expected value μ. In addition, we also assume that the possible values for the rate constants are non-negative, and also that they are no larger than 1, except possibly for k_2 and k_3.

Once the probability model described below was fitted to the information in Table A1.2, these assumptions were satisfied (with probability just about equal to 1) for all but k_5 and k_8. Indeed, as modeled, both k_5 and k_8 could be negative with probability about 2.5 %: for this reason, their distributions were truncated at 0.

For k_2, k_3, k_4, and k_6, it so happens that the distance from the expected value (μ) to the 97.5th percentile ($_{0.975}$) is greater than or equal to the distance from the expected value (μ) to the

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2.5th percentile ($_{0.025}$): that is, their probability distributions have the right tail longer than the left tail (in other words, they are skewed to the right). For k_5 the opposite happens, and its distribution is skewed to the left. The distributions for k_1, k_7, and k_8 are approximately symmetrical.

Many different probability models are available that describe right skewness, and a few can describe skewness either to the left or to the right, and still involve no more than three adjustable parameters, which is the number of pieces of information listed for each rate constant in Table A1.2 on page A1.9.

One of these, which includes the normal distribution as a special case, is the skew normal distribution described by Azzalini [1985], and implemented by Azzalini [2010] in package sn for the R environment for statistical programming and graphics [R Development Core Team, 2010].

Another model that we have considered, given that the rate constants have values essentially between 0 and 1, was the beta distribution. Since the skew normal distribution managed to reproduce the information available about the rate constants much more accurately than the beta distribution, we have used the skew normal distribution as a model for all of the rate constants.

The adjustable parameters of the skew normal distribution are the location , the scale , and a shape parameter that controls skewness. The values we selected for these parameters that reproduce the entries in Table A1.2 on page A1.9 are listed in Table A1.3 on page A1.11. We obtained them by taking the following steps (Figure A1.3 depicts the resulting probability densities):

(a) If $_{0.975}$ and $_{0.025}$ denote the 97.5th and 2.5th percentiles of a skew normal distribution, the ratio ($_{0.975}$ - μ)/(μ - $_{0.025}$) (which depends neither on μ nor on) is an effective proxy for the distribution's skewness. Since the shape parameter is a monotonically increasing function of the skewness of the skew normal distribution, we built an interpolating spline [Venables and Ripley, 2002] → such that ≈ → ($_{0.975}$ - μ)/(μ - $_{0.025}$) with negligibly small error for values of over a suitably wide range.

(b) For each rate constant, first we estimated using the function → just described, by applying it to the values in Table A1.2, and then found values of and that minimize

$$_{0.025} - F^{-1}_{,,}(0.025)^2 + {}_{0.975} - F^{-1}_{,,}(0.975)^2 + \mu - + \frac{\overline{2}}{\sqrt{(1+{}^2)}}{}^2,$$

where $F^{-1}_{,,}$ denotes the inverse of the cumulative probability distribution function of the skew normal distribution with location , scale , and shape . The idea here is to choose values for the adjustable parameters that best reproduce the mean and percentiles given for each rate constant. The last term in the foregoing expression is determined by the fact that the expected value of a skew normal distribution with location , scale , and shape , is + $\overline{2}/\sqrt{(1+{}^2)}$.

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RATE CONSTANT			
k_1	0.200	0.0500	0.00
k_2	0.191	0.356	760
k_3	0.0470	0.0681	176
k_4	0.332	0.0483	8.44
k_5	0.0612	0.0272	- 167
k_6	0.0940	0.136	176
k_7	0.075	0.0128	0.00
k_8	0.0500	0.0255	0.00

Table A1.3: Parameters of Probability Distributions for Rate Constants. Values of the location , scale , and shape of the skew normal distributions used to represent the information available about the values of the rate constants.

A1.7 Uncertainty Analysis

The uncertainty analysis is based on statistics of multiple scenarios, generated by Monte Carlo simulation, as outlined in Section A1.4 on page A1.5. Each scenario is de?ned by a value of the random variable Q introduced in equation A1.17 on page A1.7, by values of the random variables $\{B(t)\}$ in equation A1.18 on page A1.9, and by a set of values of the rate constants obtained by sampling the probability distributions?tted as described in Section A1.6 on page A1.9. The scenario proper consists of the time series of values of the output variables that correspond to the simulated values of Q and of the rate constants.

The fact that the same sampled value of each rate constant is used for every day of each scenario effectively induces statistical dependencies between the quantities that are functions of the rate constants. The uncertainty analysis does take these dependencies into account.

More precisely, we have taken the following steps:

(a) We selected a value for m, the number of scenarios (m = 100 000 for the results in Appendix 2).

(b) For $i = 1, \ldots, m$:

(b1) We drew a sample of size one from the probability distribution of Q, and used it to generate a replicate of the time series of the values of oil volume discharged, by application of equation A1.17 on page A1.7.

(b2) We drew a sample of size one from the probability distribution of each of the random variables $\{B(t)\}$, and used them to generate a replicate of the time series of the values of oil volume burned, by application of equation A1.18 on page A1.9.

(b3) We drew a sample of size one from the probability distribution?tted to each rate constant.

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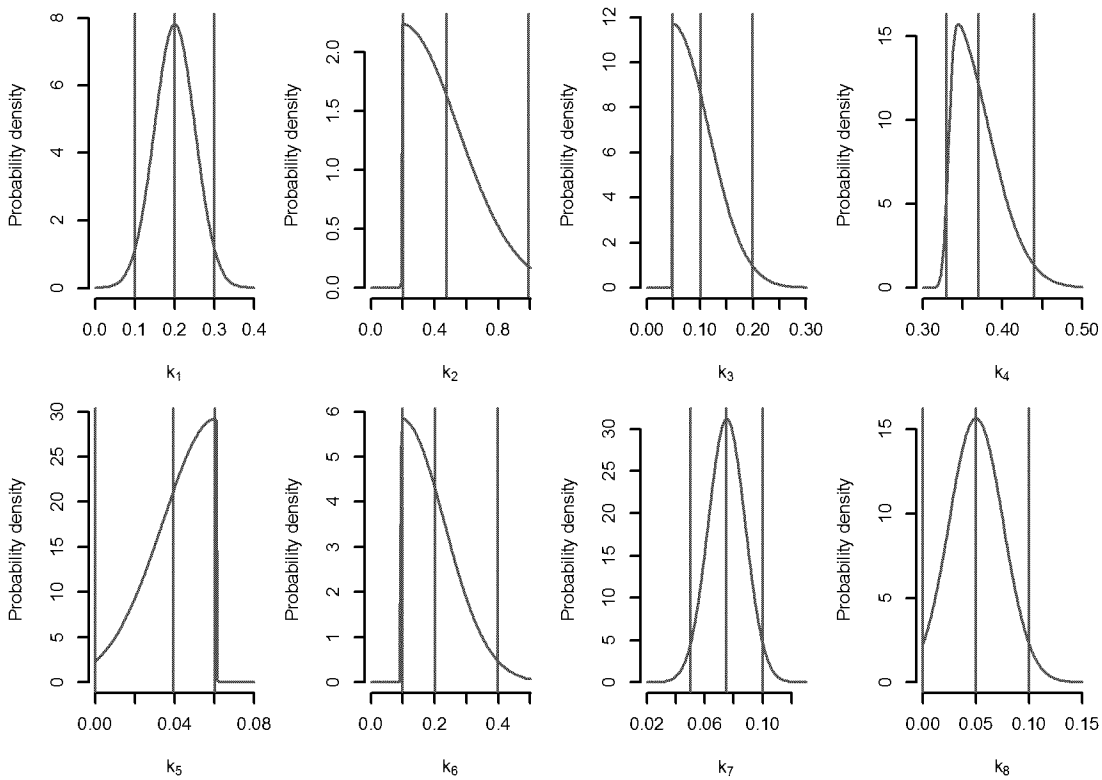

Figure A1.3: Skew normal probability densities for the rate constants. The vertical red lines mark the locations of the 2.5th percentile $_{0.025}$, the expected value μ, and the 97.5th percentile $_{0.975}$, which reproduce the values specified by the subject-matter experts, listed in Table A1.2 on page A1.9.

(b4) Using the time series obtained in step b1 on page A1.11, the values for the rate constants obtained in step b3 on page A1.11, and the values of the input quantities, we used the mass balance equations (equations A1.1 on page A1.2– A1.16 on page A1.2), to compute the time series of daily values of the output quantities, and of their cumulative sums (where applicable).

(c) Step b on page A1.11 produced m simulated values of each output quantity on each day, whose 2.5th and 97.5th percentiles define the lower and upper 95 % probability envelopes for the value of the output quantity.

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A1.8 Best-Case and Worst-Case Scenarios

For any particular day t, the corresponding points on the lower and upper bounds (red envelope) for $V_S(t)$, depicted in Figure A1.1 on page A1.7 and whose ordinates are $V_{S,L}$ and $V_{S,U}(t)$, bracket the true volume of residual oil on that day, with 95 % probability.

Given their fairly extreme nature, we take these endpoints to represent best-case and worst-case scenarios, even though there are scenarios that are better than that best, and worse than this worst because the interval from $V_{S,L}(t)$ to $V_{S,U}(t)$ encompasses only the middlemost 95 % of the m simulated replicates $V_{1,S}(t), \ldots, V_{m,S}(t)$ that will have been generated for $V_S(t)$.

This approximate, practical characterization of what the "best" and "worst" situations may be is motivated by the desire to focus the management of the crisis on scenarios that, although fairly extreme, still are "buffered" by non-negligible tail probabilities that lend them statistical credence, rather than on speculatively extreme cases.

Now, given $V_{S,L}(t)$ for day t, we wish to find the combinations of values of all the other variables that correspond to this best-case scenario, and that also satisfy the mass balance equations. Similarly for $V_{S,U}(t)$, and for the worst-case scenario.

It is not immediately obvious what these combinations of values should be because $V_{S,L}(t)$ does not necessarily correspond to the case where all the rate constants, and the variables Q and $\{B(t)\}$, simultaneously have their "best" values. This is so for two reasons: first, these variables are assumed to vary independently of one another from scenario to scenario (an assumption that is discussed and probed in Section A1.9 on page A1.14); second, such "best" values may yield a far more extreme, and practically irrelevant, value for the volume of residual oil, than what we have defined $V_{S,L}(t)$ to be.

Since the volume of residual oil depends on the values of several other quantities, and does so in the complicated way that the mass balance equations describe precisely, we will write $V_S(t) = h(V_R(t), \ldots, V_{NW}(t))$ to denote this dependence summarily, omitting reference to Q, to the $\{B(t)\}$, and to the rate constants. The function h subsumes all the mathematical manipulations that these quantities undergo finally to produce $V_S(t)$.

Our goal is to find the most likely values of $V_R(t), \ldots, V_{NW}(t)$ that, once processed through h, yield $V_{S,L}(t)$ as the volume of residual oil left on day number t, and that satisfy the mass balance equations. (Recall that $V_{S,L}(t)$ denotes the 2.5th percentile of the set of m simulated values of the volume of residual oil, as defined in Step c on page A1.12.) And then to do similarly for $V_{S,U}(t)$, the 97.5th percentile.

Taken together, those most likely values will then define the best-case scenario. (And similarly the worst-case scenario.) Since this amounts to "inverting" the function h, our goal can be fairly described as *scenario inversion*. The problem, of course, is that h is not invertible in the strict sense of mathematics because there are many combinations of values of $V_R(t), \ldots, V_{NW}(t)$ that yield the same value of $V_S(t)$.

To perform a satisfactory scenario inversion that yields the best-case scenario, we start from the realization that such scenario will correspond to some combination of values of $V_R(t), \ldots, V_{NW}(t)$ that, once processed through h, produces a value for $V_S(t)$ that is close to $V_{S,L}(t)$.

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To find such combinations of values of the arguments of the function h, we selected a suitably small positive value , and searched through the set of simulated values of $V_R(t), \ldots, V_{NW}(t)$ for those that satisfy $|h(V_{i,R}(t), \ldots, V_{i,NW}(t)) - V_{S,L}(t)| <$. Let S_L denote the resulting subset of combinations of values of $V_R(t), \ldots, V_{NW}(t)$.

Since S_L comprises many such combinations, the problem remains of selecting one that is representative of the best-case scenario. We did this by finding, for each output variable of interest that the volume of residual oil is a function of, its average over those of its values that are present in S_L.

We also verified that these averages indeed are representative of the values they subsume, by inspecting their locations in histograms of these values. This process was repeated, using a comparably defined set S_U for the worst-case scenario. These best-case and worst-case scenarios for July 14, 2010 (day t = 86) are characterized quantitatively, and depicted graphically, in Appendix 2.

A1.9 Sensitivity Analysis

As described in Section A1.7 on page A1.11, the uncertainty analysis is based on simulated scenarios, and each of these scenarios is defined by a time series of simulated values of discharged oil, by a time series of volumes of burned oil, and by a set of simulated values of the rate constants.

These simulations are based on particular models (probability distributions) for all the participating quantities: although reasonable, other models could also reasonably be entertained. For example, we mentioned already, in Section A1.4 on page A1.5, that the variable Q that appears in equation A1.17 on page A1.7, and which we assumed had a particular Gaussian distribution, conceivably might also have been modeled as having a particular uniform distribution instead. The same applies to the variables $\{B(t)\}$ relating to the volume of oil burned.

One assumption that we have made but that we have not yet discussed is that the random variables modeling the rate constants are stochastically independent. Although this represents an approximation suggested by the subject-matter experts, it is not only possible but indeed likely that some of them should be interrelated.

For example, it is reasonable to expect that the rates of evaporation, k_4 and k_5, on the first and second days after discharge of a fresh batch of oil into the sea should vary together over time, because they may be driven by common factors. Similarly, k_2 and k_3, the rate constants that describe the effectiveness of chemical dispersion under and on the sea surface, may be interrelated for similar reasons.

To ascertain the sensitivity of our results to our modeling assumptions, we have focused on the volumes of residual oil V_S, and performed an alternative uncertainty analysis assuming that the correlation coefficient between k_2 and k_3, and between k_4 and k_5, was $\sqrt{0.5}$, rather than 0. This assumption about the correlations means that the potential variability in k_2 over time would "explain" about 50% of the corresponding variability in k_3 (and similarly for k_4 and k_5).

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To impose correlations between these two pairs of rate constants, we used a Gaussian copula [Nelsen, 2006, Possolo, 2010], which is a standard technique for this purpose. This creates a multivariate probability distribution with the correlations specified ($\sqrt{0.5}$ between k_2 and k_3 and also between k_4 and k_5, and 0 between all the other possible pairs), and such that the individual rate constants, when taken each one by itself, still has the same skew normal distribution that was fitted as described in Section A1.6 on page A1.9.

We have also studied the sensitivity of the results to the assumptions we made about the random variable Q, introduced in equation A1.17 on page A1.7, and about the random variables $\{B(t)\}$ introduced in equation A1.18 on page A1.9. The former drives the variability between simulated scenarios, of the time series of volume of oil discharged from the well. The latter models the measurement uncertainty associated with the volume of oil that has been burned. Originally we assumed that Q has a Gaussian distribution with mean 0 and standard deviation 0.05. For the sensitivity analysis we have assumed instead that Q is uniformly distributed between -0.1 and $+0.1$. Similarly for the $\{B(t)\}$.

The results of this sensitivity analysis, depicted in Figure A1.4 on page A1.16, show that the presence of such statistical dependence as we have entertained for selected pairs of rate constants, possibly in conjunction with a different model for Q and for the $\{B(t)\}$, widens the uncertainty envelope for the time series of values of V_S. However, it changes the upper bound hardly at all, and depresses the lower confidence envelope, thus suggesting that the assumptions we made originally are the more conservative ones among the alternatives we have considered.

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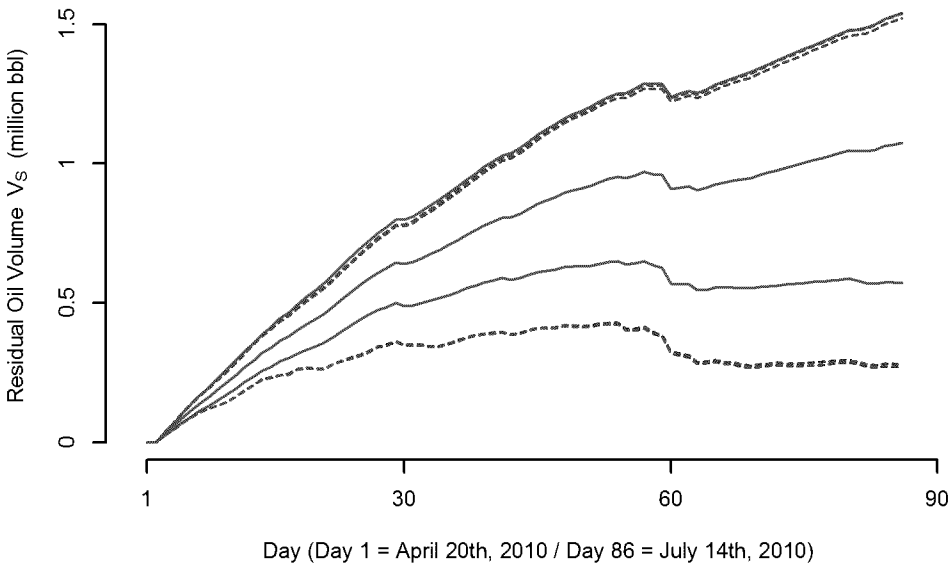

Figure A1.4: Sensitivity Analysis. Volume of residual oil (V_S) and variants of the approximate 95 % confidence band, corresponding to assuming that k_2 and k_3, as well as k_4 and k_5, are correlated (dashed, green line), or that, in addition to this, the random variable Q and the random variables $\{B(t)\}$, introduced in equation A1.17 on page A1.7 and in equation A1.18 on page A1.9, respectively, are uniformly distributed, rather than Gaussian (dotted, brown line). These alternatives mostly reduce the lower confidence envelope, thus suggesting that the assumptions we made originally are the more conservative ones among the alternatives we have considered. Since there was no additional discharge after day 86 (July 14, 2010), the curves flatten beyond this date (not shown).

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Appendix 2

A2 Oil Budget Calculator Web-based Tool

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Background

One of the most visible aspects of the Oil Budget Calculator is the technological application that was created as a response tool for personnel with National Incident Command (NIC). The first iteration of an oil budget calculator was built in a Microsoft Excel spreadsheet by U.S. Coast Guard (USCG) staff with the National Response Center. This tool captured simple daily variables from the response effort (e.g., amount of oil skimmed from the surface) and instantiated basic formulas for a best- and worst-case scenario based on calculations used in previous spill events. The USCG requested help from the Interagency Solutions Group established from NIC for help with the spreadsheet tool in terms of reporting and characterizing the results along with help from a science team in the underlying calculations and assumptions.

To address this need, the Interagency Solutions Group consulted a U.S. Geological Survey (USGS) computer science team on the tool itself and National Oceanic and Atmospheric Administration (NOAA) scientific support personnel to engage a team of oil fate and behavior scientists. After discussing the basic requirements for the final tool needed by NIC staff, in particular the need for ease of access without new software requirements, the USGS team opted for the creation of a Web-based application. This section of the report discusses the engineering of the Web-based system and its relationship to the scientific model developed by partners in NOAA and the National Institute of Standards and Technology.

Requirements for the Calculator

Initial requirements for the purpose and use of the calculator were received in phone conversation with NIC staff on June 17, 2010 (National Incident Command Personnel, 2010). Further requirements and requests for features in the application continued to evolve through the course of the project as NIC staff, scientific support personnel, and others began using reports from the tool in response activities. All technical requirements, features, and associated tasks for the tool were captured in an online project management system used by the USGS team as a way to document the evolution of the application and a record for any future activities.

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A high-level discussion of requirements is summarized below:

- The tool needed to be easily accessible by NIC staff and NOAA scientific support personnel providing input to response activities, not requiring any additional desktop software or a major learning period.
- The tool needed to be secure so that only authorized personnel could access the system, and specific NIC staff needed the ability to specify who could perform specific functions in the system.
- Only certain personnel could be authorized to enter data into the Daily Values Database, and all data needed to be logged so that individual entries could be tracked to the user who entered them and when they were entered.
- Only certain personnel could be authorized to access daily and summary reports from the system, and those accesses needed to be logged.
- Only certain personnel involved with scientific support could be authorized to change the underlying calculations and assumptions used to calculate the oil budget.
- The tool needed to include the ability to view the daily and cumulative total figures and associated charts for any day in the incident.
- The tool needed to provide a print feature so that authorized report users could output a daily executive summary used by response and communications personnel.
- The tool needed a feature to output all daily values entered into the system in a spreadsheet table so that the figures could be shared and viewed independently.

In total, 98 separate features or improvements were captured and tracked in the project management application used for the work during the course of the engineering and development effort.

Scenarios

The oil budget calculation needed to incorporate the concept of scenarios to include at least a theoretical best and worst case scenario in terms of the amount of oil being discharged and the relative effectiveness of response activities. A third scenario used mean values to provide a probable case, or at least a baseline set of numbers predicated on the best available knowledge of oil fate and behavior. The requirement to essentially bound the problem and effectiveness of the response played a critical role in the design of the application and reports.

During the period when the well was still discharging oil, the Oil Budget Calculator used a simplistic approach to calculating and presenting scenarios that used only the difference in flow rate estimates as the variable between scenarios. After continued examination of the tool with the statistical experts working on the oil budget model, the final iteration of the calculator (version 2.0) included a more rigorous presentation of the scientific uncertainty in the theoretical best- and worst-case scenarios. This version of the tool

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incorporated the upper and lower bounds of uncertainty for the effectiveness of individual response activities in addition to the uncertainty bounds for the flow rate.

Components of the Calculator

The tool consisted of the following basic elements:

- Daily Variables – daily variables entered by USCG staff with the NIC
- Global Variables – global flow rate values based on government estimates and formulas stored as variables to produce cumulative totals from the oil budget calculating model
- Modeling Application technological application to pass daily variables to a scientific model that encapsulated assumptions and statistical calculations to produce daily oil budget figures
- Reporting Application executive summary reporting component that presented daily oil budget numbers and charts

These components were brought together as a Web-based tool within a Java application framework called Grails (Grails Community, 2010) and several existing infrastructural elements already in place within the USGS network and able to be tuned toward the application. Front-end Web services were provided on an Apache Web server platform (Apache Project, 2010). Database elements were stored within a PostgreSQL (PostgreSQL, 2010) environment using Hibernate (JBoss Community, 2010) for data object and relational mapping and persistence. Authentication services were provided by a USGS framework founded on a technology called Java Open Single Sign-On (JOSSO Community, 2010). The Oil Budget Calculator model was written in the R scientific programming language (R Project, 2010) using a dedicated virtual machine set up as an "R Application Server." All application components were configured to run on servers using the Red Hat (Red Hat, 2010) version of the Linux operating system.

Daily Variables

A simple database table managed through the Web application housed variables of the response effort entered by NIC personnel. In some cases, the values were direct measurements, and in others the values were the results of established standard measurement protocols used by the USCG for incident response (National Incident Command Personnel, 2010).

- Oil Collected via RITT/Top Hat (barrels) – Values for the amount of oil recovered by the vessels Helix Producer, Discoverer Enterprise and the Q4000 and reported by British Petroleum.
- Oil Burned (barrels) Total oil burned using standard rates from the American Society for Testing and Materials (American Society for Testing and Materials, 2006).
- Oily Water Collected (barrels) – Total of estimated measurements from multiple collection methods and contractors.

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- Subsurface Dispersants Used (gallons) Direct report from dispersant operations.
- Surface Dispersants Used (gallons) Direct report from dispersant operations.

Later in the response effort, once inland recovery of oil reached a point where total numbers could be captured, a value of tons of oily debris was added to the daily variables database as a reporting value. This figure was not used in the oil budget calculation but was included in the reporting tool. Based on the requirement to have an output of daily variables in a spreadsheet format, a feature was added to export all daily values as an Excel spreadsheet file.

Global Variables

The Oil Budget Calculator went through three distinct iterations based on the best government estimates of flow/discharge rate from the leaking well. All values were provided to the Oil Budget Calculator team from the Deepwater Horizon Flow Rate Technical Group and were refined over time as more and better information became available. The need to include multiple scenarios resulted in flow estimates of high, low, and mean being stored in the global variables portion of the database and used in the calculations.

The global variables data also contained several formulas stored as a simple formula language and used in the final calculations of cumulative totals on the output from the oil budget model. Global variables were considered the domain of the oil fate and behavior science team building the model and were only editable by application administrators.

Modeling Application

The initial iteration of the Oil Budget Calculator employed a very simple model based directly on the individual calculations provided in an interim report. These formulas were stored in the application as global variables and acted directly on daily variables, triggered whenever daily variables were modified in any way. Initial reports from this method shared amongst the development and science teams prior to production release of the application indicated a need for an increased level of statistical sophistication in the model.

Following engagement of personnel from the National Institute of Standards and Technology (NIST), the oil budget calculations were refactored into a statistical model and codified using the R scientific programming language (R Project, 2010). The development team engineered an application server environment to house and run the R processing engine, receive values from the application maintaining daily variables, trigger the model to run calculations, and ingest calculated output variables from the model back into the final database.

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Reporting Application

The reporting toolset was built within the same Grails application framework (Grails Community, 2010). The executive summary report presented two to three scenarios over the course of the application. Initially, the application presented only a high flow scenario, based on the government's maximum discharge estimate, and a low flow scenario, based on the government's minimum discharge estimate. Personnel from NIC later requested the addition of a scenario based on mean discharge as a single value report that could be used in certain planning and communication processes. For each scenario, the reporting tool provided a table of the calculator output of daily and cumulative totals.

The report also included charting generated using the JFreeChart Java library (JFree.org, 2010). The Oil Budget pie chart provided a response estimate representation of the total amount of oil released over time for the actual government estimates of discharge as well as a higher flow and lower flow estimate from the ±10% uncertainty factor, the relative amounts of oil recovered or dispersed by both natural and response methods, and the total remaining oil calculated by the oil budget model. A stylized stacked bar chart was used in place of the pie chart in earlier iterations of the tool.

The reporting application included a feature to select any day in the incident and view the full report for the day, showing cumulative totals at that point. The reports could be viewed online via a Web browser and exported in Adobe Acrobat (PDF) format. Charts could also be viewed individually as image files for incorporation into alternate presentations.

Evolution of the Oil Budget Calculator

The Oil Budget Calculator online tool went through several distinct iterations recorded as versions of the tool throughout its lifecycle. The iterations of the tool used for the incident response activity were recorded as 1.x versions through the final version 1.3.1. This first generation of the tool was used for the public release of information about the Oil Budget Calculator (NOAA, 2010).

Based on input from the science team responsible for the final Oil Budget Calculator report to National Incident Command and a significant reworking of the scientific model, a second generation (version 2.0) of the tool was prepared. The major difference between the two generations of the tool was the calculation and characterization of scientific uncertainty for the variable elements in each of three scenarios. Version 1.x of the tool used only a variable discharge rate based on the ±10% uncertainty in the official government estimates of discharge produced by the Deepwater Horizon MC252 Flow Rate Technical Group - 62,200 bbl on April 22, 2010 to 52,700 bbl on July 14, 2010 (Lehr and others, 2010) – to produce reports for three scenarios (official government estimates, high flow scenario, and low flow scenario). Version 2 of the tool used calculations of scientific uncertainty for individual elements of the report to produce

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expected, best case, and worst case scenarios as discussed in Appendix 1 of the Oil Budget Calculator report.

Version 2 of the online tool was not used in the actual response effort. Rather it was prepared as the next generation of the tool and presented to National Incident Command as an improvement on the calculations based on increased information and knowledge about the Deepwater Horizon incident provided by the science team. It was meant to help inform future development of the response tool for other incidents.

The following sections present report elements from the two generations of the online tool captured for July 14, 2010 the last day in the incident where reported values for skimming and burning oil were recorded.

Oil Budget Calculator – Version 2.0

Table A2.1 comes directly from version 2.0 of the online tool using the calculations described in Appendix 1 of the report. The colors next to the individual calculated values correspond to colors in the charts that are part of the generated oil budget report. Two of the charts showing cumulative total oil and percentage of total are provided in the body of the report for the same day, July 14, shown in the table.

Table A2.1. Oil Budget Calculator cumulative totals for the official estimated discharge rate and expected scenario (62,200 bbl on April 22, 2010 to 52,700 bbl on July 14, 2010) through July 14, 2010 (from version 2.0 of the Oil Budget Calculator)

Calculated Values	Cumulative	July 14
Discharged	4,900,000	53,000
Recovered via RITT and Top Hat	820,000	13,000
Dispersed Naturally	640,000	5,200
Evaporated or Dissolved	1,200,000	9,500
Available for Recovery	2,300,000	25,000
Chemically Dispersed	770,000	13,000
Burned	260,000	1,100
Skimmed	160,000	5,200
Other Oil	1,100,000	6,000
Recorded Values		
Dispersant Used	43,695	327
Inland Recovery (Cumulative)	0 tons	

*** All unlabeled values in barrels; rounded to 2 significant digits**

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Oil Budget Calculator – Version 1.x

Table A2.2 and figure A2.1 show the cumulative oil budget from the version of the online tool used in the response effort. The response tool used a numbered versioning scheme of 1.x, ending with 1.3.1. This version of the tool and the table and figure included here provide background documentation on the evolution of the tool. The previous section on version 2.0 represents a significant improvement in the Oil Budget Calculator based on the substance of this report.

Table A2.2. Oil Budget Calculator cumulative totals for the official estimated discharge rate (62,200 bbl on April 22, 2010 to 52,700 bbl on July 14, 2010) through July 14, 2010 (from version 1.3.1 of the Oil Budget Calculator)

Calculated Values	Cumulative	July 14
Discharged	4,928,100	52,700
Recovered via RITT and Top Hat	817,739	12,843
Dispersed Naturally	763,948	6,924
Evaporated or Dissolved	1,242,668	11,168
Available for Recovery	2,103,745	21,765
Chemically Dispersed	418,075	5,237
Burned	263,900	1,100
Skimmed	156,694	5,110
Remaining	1,265,075	10,318
Recorded Values		
Dispersant Used	43,695	327
Inland Recovery (Cumulative)	0 tons	

*** All unlabeled values in barrels.**

Table A2.2 comes directly from the online tool. The colors next to the individual calculated values correspond to colors in the charts that were part of the generated oil budget report. Significant refinements occurred between the version of the tool used during the response the new version presented in the final report. Most notably for the table of values:

- The term Remaining was changed to Other Oil to help alleviate an impression that the other calculated values in the report might not remain in the environment at all.
- Numeric figures were rounded to two significant digits to better represent the level of scientific uncertainty inherent in the calculations.

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Figure A2.1. Cumulative percentage of oil from the calculator for natural processes and response activities using the official estimated discharge rate (62,200 bbl on April 22, 2010 to 52,700 bbl on July 14, 2010) through July 14, 2010 (from version 1.3.1 of the Oil Budget Calculator)

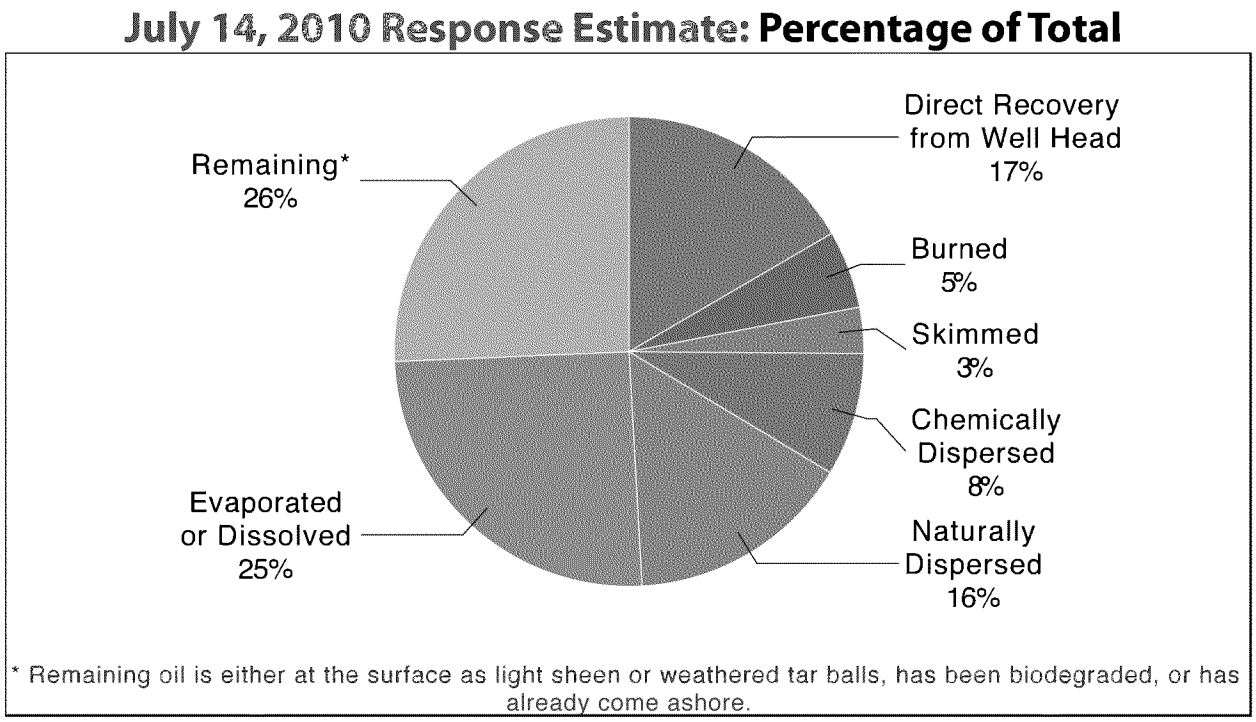

Figure A2.1 comes directly from the online tool. Significant refinements occurred between the charts included in the version of the tool used during the response and the new version presented in the final report. Most notably, the single pie chart that presented only one possible scenario at a time in three separate images was replaced with a bar chart that presented best case, expected, and worst case scenarios in one graphic to help show the scientific uncertainty inherent in the model. These charts are included in the body of the report.

Application Security and Logging

Authentication for the application was provided using an existing framework in the USGS based on JOSSO technology (JOSSO Community, 2010) and a directory service of user accounts. Users were placed into one of three roles within the application:

- Report Readers Access to view and print reports for any day in the incident
- Data Entry Personnel – Access to view and print reports and to enter and maintain daily variables
- Administrators Each of the above rights plus access to enter and maintain global variables

All accesses to the online application were logged via the authentication system. Changes to daily and global variables were logged separately and available for viewing within the application. Printed reports, generated as a PDF download, were stamped with a user ID and date in the footnote of every page.

All versions of the Web application and R statistical model were tracked as they were deployed onto the technological framework using a versioning system called Subversion (Apache.org, 2010). Subversion logs and underlying Web site access logs are stored in a secure data storage framework and available as necessary.

Future of the Oil Budget Calculator Web Application

The overall utility of the online application proved a valuable tool for the response and communication efforts as reported by NIC and NOAA staff involved directly in response activities. The first generation of the tool was still in use for the Deepwater Horizon incident at the time of writing, and USCG staff indicated a desire to continue discussions about either ongoing partnership with the USGS or technology transfer to a USCG facility.

Following the production of this report and major input by the oil fate and behavior science team, version 2.0 of the Oil Budget Calculator was prepared with modifications to the calculator model and major changes to the presentation of scientific uncertainty in the output reports. The scientific reasoning behind the calculations is discussed extensively in the report, and the new model is laid out within Appendix 2. The new model resulted in significant differences in the final cumulative totals and associated visualizations with a higher overall degree of confidence based on the extensive review of the model and input by the science team preparing the Oil Budget Calculator report.

The technological framework developed for the calculator, including the separation between data entry, model calculations, and reporting was created to be extensible and scalable to other incidents using variations on the model and to entirely different applications of similar concepts. Further discussions with NIC personnel will determine the eventual fate of the tool beyond the Deepwater Horizon incident.

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Appendix 3

A3 Data Input Used by Calculator

Date	Government Estimate of Discharge VRG bbls	Inland Recovery IR tons	Oil Burned VBU bbls	Oil Collected via RITT/TopHat VDT bbls	Oily Water Collected VOW bbls	Subsurface Dispersants VCBg gallons	Surface Dispersants VCSg gallons
04/20/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
04/21/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
04/22/2010	62200.00	0.00	0.00	0.00	0.00	0.00	1701.00
04/23/2010	62100.00	0.00	0.00	0.00	1630.00	0.00	0.00
04/24/2010	61900.00	0.00	0.00	0.00	155.00	0.00	0.00
04/25/2010	61800.00	0.00	0.00	0.00	0.00	0.00	9818.00
04/26/2010	61700.00	0.00	0.00	0.00	7832.00	0.00	14486.00
04/27/2010	61600.00	0.00	0.00	0.00	18557.00	0.00	27078.00
04/28/2010	61500.00	0.00	95.00	0.00	3306.00	0.00	42143.00
04/29/2010	61400.00	0.00	0.00	0.00	3245.00	0.00	40913.00
04/30/2010	61300.00	0.00	0.00	0.00	1427.00	2196.00	4900.00
05/01/2010	61200.00	0.00	0.00	0.00	992.00	0.00	11653.00
05/02/2010	61000.00	0.00	0.00	0.00	0.00	3399.00	0.00
05/03/2010	60900.00	0.00	0.00	0.00	0.00	5812.00	0.00
05/04/2010	60800.00	0.00	0.00	0.00	9996.00	7580.00	34273.00
05/05/2010	60700.00	0.00	880.00	0.00	0.00	0.00	49575.00
05/06/2010	60600.00	0.00	6155.00	0.00	21452.00	0.00	28770.00
05/07/2010	60500.00	0.00	2010.00	0.00	13788.00	0.00	7270.00
05/08/2010	60400.00	0.00	0.00	0.00	26189.00	0.00	41690.00
05/09/2010	60200.00	0.00	0.00	0.00	33865.00	0.00	55932.00
05/10/2010	60100.00	0.00	0.00	0.00	8957.00	9460.00	56220.00
05/11/2010	60000.00	0.00	0.00	0.00	0.00	2100.00	7940.00
05/12/2010	59900.00	0.00	0.00	0.00	0.00	0.00	39710.00
05/13/2010	59800.00	0.00	0.00	0.00	0.00	0.00	41620.00
05/14/2010	59700.00	0.00	0.00	0.00	0.00	0.00	44031.00
05/15/2010	59600.00	0.00	0.00	500.00	0.00	7222.00	14208.00
05/16/2010	59400.00	0.00	0.00	900.00	6987.00	6300.00	670.00
05/17/2010	59300.00	0.00	3175.00	1030.00	23873.00	7980.00	13213.00
05/18/2010	59200.00	0.00	785.00	1200.00	13903.00	3450.00	12386.00
05/19/2010	59100.00	0.00	27350.00	3000.00	11849.00	4879.00	3352.00
05/20/2010	59000.00	0.00	11150.00	2200.00	13600.00	14151.00	1.00
05/21/2010	58900.00	0.00	0.00	2175.00	13126.00	14400.00	29892.00
05/22/2010	58800.00	0.00	0.00	1361.00	12025.00	14130.00	52946.00
05/23/2010	58700.00	0.00	950.00	1120.00	14108.00	14738.00	18104.00
05/24/2010	58500.00	0.00	2450.00	0.00	4135.00	14494.00	630.00
05/25/2010	58400.00	0.00	350.00	6078.00	3943.00	12925.00	200.00
05/26/2010	58300.00	0.00	450.00	2596.00	7681.00	11529.00	7752.00
05/27/2010	58200.00	0.00	700.00	0.00	9936.00	14347.00	1029.00
05/28/2010	58100.00	0.00	0.00	0.00	10110.00	13670.00	18445.00
05/29/2010	58000.00	0.00	1200.00	0.00	27319.00	14588.00	2900.00
05/30/2010	57900.00	0.00	2550.00	0.00	10471.00	13073.00	17631.00
05/31/2010	57700.00	0.00	16550.00	0.00	11845.00	13936.00	11686.00
06/01/2010	57600.00	0.00	7900.00	0.00	11719.00	12201.00	0.00
06/02/2010	57500.00	0.00	700.00	0.00	18241.00	8073.00	3375.00

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Date	Government Estimate of Discharge VRG bbls	Inland Recovery IR tons	Oil Burned VBU bbls	Oil Collected via RITT/TopHat VDT bbls	Oily Water Collected VOW bbls	Subsurface Dispersants VCBg gallons	Surface Dispersants VCSg gallons
06/03/2010	60000.00	0.00	0.00	0.00	4833.00	17753.00	6200.00
06/04/2010	59900.00	0.00	0.00	6087.00	8912.00	20655.00	13701.00
06/05/2010	59800.00	0.00	0.00	10496.00	8568.00	20306.00	125.00
06/06/2010	59700.00	0.00	0.00	11119.00	3123.00	13937.00	0.00
06/07/2010	59500.00	0.00	850.00	14842.00	11754.00	14732.00	10744.00
06/08/2010	59400.00	0.00	5450.00	15006.00	5350.00	13763.00	8324.00
06/09/2010	59300.00	0.00	3500.00	15816.00	12802.00	12112.00	2100.00
06/10/2010	59200.00	0.00	350.00	15402.00	9658.00	10163.00	5872.00
06/11/2010	59100.00	0.00	0.00	15554.00	18510.00	8447.00	14305.00
06/12/2010	59000.00	0.00	7550.00	15039.00	14459.00	4852.00	10356.00
06/13/2010	58900.00	0.00	16600.00	15208.00	12383.00	9916.00	36012.00
06/14/2010	58800.00	0.00	4300.00	15421.00	6083.00	9800.00	10741.00
06/15/2010	58600.00	0.00	1000.00	10448.00	11891.00	11726.00	2768.00
06/16/2010	58500.00	0.00	20150.00	18227.00	16995.00	8777.00	13593.00
06/17/2010	58400.00	0.00	13300.00	25295.00	9185.00	5763.00	12423.00
06/18/2010	58300.00	0.00	59550.00	24552.00	16436.00	9148.00	15711.00
06/19/2010	58200.00	0.00	2300.00	21041.00	12713.00	16911.00	8510.00
06/20/2010	58100.00	0.00	600.00	23291.00	11335.00	14070.00	19576.00
06/21/2010	58000.00	0.00	17050.00	25836.00	25583.00	14233.00	11217.00
06/22/2010	57800.00	0.00	0.00	27097.00	8828.00	9793.00	2008.00
06/23/2010	57700.00	0.00	0.00	16866.00	4660.00	9891.00	5099.00
06/24/2010	57600.00	0.00	0.00	23735.00	9875.00	12871.00	21088.00
06/25/2010	57500.00	0.00	0.00	24548.00	14530.00	12540.00	4633.00
06/26/2010	57400.00	0.00	0.00	22758.00	17462.00	12654.00	23022.00
06/27/2010	57300.00	0.00	0.00	24455.00	18641.00	11558.00	6626.00
06/28/2010	57200.00	0.00	0.00	23400.00	0.00	13174.00	0.00
06/29/2010	57100.00	0.00	0.00	25223.00	50.00	11560.00	324.00
06/30/2010	56900.00	0.00	0.00	23079.00	290.00	13609.00	0.00
07/01/2010	56800.00	0.00	0.00	25154.00	284.00	10558.00	17852.00
07/02/2010	56700.00	0.00	0.00	25291.00	74.00	11065.00	14210.00
07/03/2010	56600.00	0.00	0.00	25198.00	1966.00	11698.00	432.00
07/04/2010	56500.00	0.00	0.00	24960.00	854.00	10429.00	3079.00
07/05/2010	56400.00	0.00	0.00	24982.00	7417.00	11688.00	803.00
07/06/2010	56300.00	0.00	0.00	24761.00	218.00	11655.00	473.00
07/07/2010	56100.00	0.00	0.00	24578.00	156.00	11770.00	1245.00
07/08/2010	56000.00	0.00	0.00	24379.00	26.00	11512.00	0.00
07/09/2010	55900.00	0.00	8300.00	24792.00	12140.00	10748.00	0.00
07/10/2010	55800.00	0.00	9850.00	15199.00	25924.00	13210.00	0.00
07/11/2010	55700.00	0.00	5300.00	8235.00	18296.00	15420.00	0.00
07/12/2010	53000.00	0.00	0.00	8302.00	9397.00	14038.00	0.00
07/13/2010	52900.00	0.00	1400.00	17064.00	9998.00	13997.00	999.00
07/14/2010	52700.00	0.00	1100.00	12843.00	25551.00	13746.00	0.00
07/15/2010	0.00	0.00	350.00	9307.00	10793.00	8391.00	0.00
07/16/2010	0.00	0.00	1100.00	0.00	14135.00	0.00	0.00
07/17/2010	0.00	0.00	0.00	0.00	7601.00	0.00	0.00
07/18/2010	0.00	0.00	0.00	0.00	5122.00	0.00	0.00
07/19/2010	0.00	0.00	100.00	0.00	3113.00	0.00	200.00

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Date	Government Estimate of Discharge VRG bbls	Inland Recovery IR tons	Oil Burned VBU bbls	Oil Collected via RITT/TopHat VDT bbls	Oily Water Collected VOW bbls	Subsurface Dispersants VCBg gallons	Surface Dispersants VCSg gallons
07/20/2010	0.00	0.00	0.00	0.00	930.00	0.00	0.00
07/21/2010	0.00	0.00	0.00	0.00	56.00	0.00	0.00
07/22/2010	0.00	0.00	0.00	0.00	142.00	0.00	0.00
07/23/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/24/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/25/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/26/2010	0.00	0.00	0.00	0.00	1.00	0.00	0.00
07/27/2010	0.00	0.00	0.00	0.00	226.00	0.00	0.00
07/28/2010	0.00	0.00	0.00	0.00	390.00	0.00	0.00
07/29/2010	0.00	0.00	0.00	0.00	264.00	0.00	0.00
07/30/2010	0.00	0.00	0.00	0.00	35.00	0.00	0.00
07/31/2010	0.00	0.00	0.00	0.00	79.00	0.00	0.00
08/01/2010	0.00	0.00	0.00	0.00	105.00	0.00	0.00
08/02/2010	0.00	0.00	0.00	0.00	51.00	0.00	0.00
08/03/2010	0.00	0.00	0.00	0.00	15.00	0.00	0.00
08/04/2010	0.00	0.00	0.00	0.00	11.00	0.00	0.00
08/05/2010	0.00	0.00	0.00	0.00	2.00	0.00	0.00
08/06/2010	0.00	0.00	0.00	0.00	98.00	0.00	0.00
08/07/2010	0.00	0.00	0.00	0.00	2.00	0.00	0.00
08/08/2010	0.00	0.00	0.00	0.00	179.00	0.00	0.00
08/09/2010	0.00	0.00	0.00	0.00	2.00	0.00	0.00
08/10/2010	0.00	41693.00	0.00	0.00	170.00	0.00	0.00
08/11/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/12/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/13/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/14/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/15/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/16/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/17/2010	0.00	4222.00	0.00	0.00	0.00	0.00	0.00
08/18/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/20/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/22/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/23/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/24/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/25/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/26/2010	0.00	2424.00	0.00	0.00	0.00	0.00	0.00
08/27/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/28/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/29/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/30/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/31/2010	0.00	2134.00	0.00	0.00	0.00	0.00	0.00
09/01/2010	0.00	126.00	0.00	0.00	0.00	0.00	0.00
09/02/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/03/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/04/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Date	Government Estimate of Discharge VRG bbls	Inland Recovery IR tons	Oil Burned VBU bbls	Oil Collected via RITT/TopHat VDT bbls	Oily Water Collected VOW bbls	Subsurface Dispersants VCBg gallons	Surface Dispersants VCSg gallons
09/05/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/06/2010	0.00	427.00	0.00	0.00	0.00	0.00	0.00
09/07/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/08/2010	0.00	429.00	0.00	0.00	0.00	0.00	0.00
09/09/2010	0.00	405.00	0.00	0.00	0.00	0.00	0.00
09/10/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/11/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/12/2010	0.00	562.00	0.00	0.00	0.00	0.00	0.00
09/13/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/14/2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00
09/15/2010	0.00	493.00	0.00	0.00	0.00	0.00	0.00

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Appendix 4

A4 ICS 209 Form (Oil Budget Component)

1. Incident Name	2. Operational Period (Date / Time) From: To: Time of Report	ICS 209-CG OIL/HAZMAT ATTACHMENT

3. HAZMAT/Oil Spill Status (Estimated, in gallons)			
Common Name(s):			
UN Number:		■ Secured	■ Unsecured
CAS Number:		Remaining Potential (bbl):	
		Rate of Spillage (bbl/hr):	
	Adjustments To Previous Operational Period	Since Last Report	Total
Volume Spilled/Released			
Mass Balance - HAZMAT/Oil Budget			
Recovered HAZMAT/Oil			
Evaporation/Airborne			
Natural Dispersion			
Chemical Dispersion			
Burned			
Floating, Contained			
Floating, Uncontained			
Onshore			
Total HAZMAT/Oil accounted for:	N/A	N/A	
Comments:			

4. HAZMAT/Oil Waste Management (Estimated, Since Last Report)			
	Recovered	Disposed	Stored
HAZMAT/Oil (bbl)			
Oily Liquids (bbl)			
Liquids (bbl)			
Oily Solids (tons)			
Solids (tons)			
Comments:			

5. HAZMAT/Oil Shoreline Impacts (Estimated in miles)			
Degree of Impact	Affected	Cleaned	To Be Cleaned
Light			
Medium			
Heavy			
Total			
Comments:			

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Appendix 5

A5 Oil Properties

Table A5.1: Macondo reservoir fluid composition, based upon Pencor data provided by BP.

Gas-Liquid Ratio 2.89 scf/stb	Vapor Gravity	0.807	(Air = 1.00)
	API Gravity	35.2	°API at 60 °F (Water Free)
	Water Content	0.02	weight %

Component (Symbol / Name)		Atmospheric Liquid (mole %)	Atmospheric Liquid (weight %)
N_2	Nitrogen	0.000	0.000
CO_2	Carbon Dioxide	0.000	0.000
H_2S	Hydrogen Sulfide	0.000	0.000
C1	Methane	0.003	0.000
C2	Ethane	0.148	0.021
C3	Propane	0.456	0.097
iC4	i-Butane	0.263	0.073
nC4	n-Butane	0.958	0.268
iC5	i-Pentane	0.943	0.327
nC5	n-Pentane	1.536	0.533
C6	Hexanes	3.977	1.648
C7	Heptanes	8.318	3.747
C8	Octanes	11.541	5.960
C9	Nonanes	9.103	5.250
C10	Decanes	7.837	5.048
C11	Undecanes	5.965	4.215
C12	Dodecanes	4.982	3.855
C13	Tridecanes	4.754	4.000
C14	Tetradecanes	4.254	3.886
C15	Pentadecanes	3.563	3.528
C16	Hexadecanes	3.455	3.688
C17	Heptadecanes	2.755	3.139
C18	Octadecanes	2.685	3.240
C19	Nonadecanes	2.274	2.874
C20	Eicosanes	1.963	2.594

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C21	Heneicosanes	1.599	2.237
C22	Docosanes	1.421	2.083
C23	Triacosanes	1.281	1.959
C24	Tetracosanes	1.149	1.827
C25	Pentacosanes	0.938	1.555
C26	Hexacosanes	0.850	1.467
C27	Heptacosanes	0.892	1.603
C28	Octacosanes	0.791	1.474
C29	Nonacosanes	0.704	1.361
C30	Triacontanes	0.642	1.283
C31	Hentriacontanes	0.607	1.255
C32	Dotriacontanes	0.543	1.159
C33	Tritriacontanes	0.470	1.035
C34	Tetratriacontanes	0.458	1.039
C35	Pentatriacontanes	0.379	0.885
C36	Hexatriacontanes	0.346	0.832
C37	Heptatriacontanes	0.333	0.823
C38	Octatriacontanes	0.316	0.802
C39	Nonatriacontanes	0.273	0.712
C40	Tetracontanes	0.268	0.717
C41	Hentetracontanes	0.195	0.534
C42	Dotetracontanes	0.217	0.610
C43	Tritetracontanes	0.194	0.557
C44	Tetratetracontanes	0.186	0.548
C45	Pentatetracontanes	0.169	0.508
C46	Hexatetracontanes	0.146	0.450
C47	Heptatetracontanes	0.160	0.503
C48	Octactetracontanes	0.135	0.434
C49	Nonatetracontanes	0.123	0.402
C50+	Pentacontanes Plus	2.482	11.355
Total		100.000	100.000
Calculated Mole Weight		208.03	
Measured Mole Weight		208.03	

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Table A5.2: Analysis by Louisiana State University of fresh oil samples compared to reference oil.

Source Oil, Pre-spill **Sample Weight:** 310 mg **Final Extracted Volume:** 30 mL		**LSU ID#: Lab Ref Oil** **South Louisiana Crude** **Sample Weight:** 500 mg **Final Extracted Volume:** 20 mL	
Alkane Analyte:	**Concentration (ng/mg)**	**Alkane Analyte:**	**Concentration (ng/mg)**
nC-10 Decane	2600	nC-10 Decane	2600
nC-11 Undecane	2600	nC-11 Undecane	2700
nC-12 Dodecane	2600	nC-12 Dodecane	2600
nC-13 Tridecane	2500	nC-13 Tridecane	2600
nC-14 Tetradecane	2400	nC-14 Tetradecane	2300
nC-15 Pentadecane	2000	nC-15 Pentadecane	2200
nC-16 Hexadecane	1800	nC-16 Hexadecane	2000
nC-17 Heptadecane	1700	nC-17 Heptadecane	1900
Pristane	960	Pristane	970
nC-18 Octadecane	1500	nC-18 Octadecane	1700
Phytane	770	Phytane	910
nC-19 Nonadecane	1300	nC-19 Nonadecane	1500
nC-20 Eicosane	1300	nC-20 Eicosane	1400
nC-21 Heneicosane	1100	nC-21 Heneicosane	1300
nC-22 Docosane	1000	nC-22 Docosane	1200
nC-23 Tricosane	940	nC-23 Tricosane	1100
nC-24 Tetracosane	890	nC-24 Tetracosane	1000
nC-25 Pentacosane	600	nC-25 Pentacosane	620
nC-26 Hexacosane	510	nC-26 Hexacosane	510
nC-27 Heptacosane	350	nC-27 Heptacosane	360
nC-28 Octacosane	300	nC-28 Octacosane	310
nC-29 Nonacosane	250	nC-29 Nonacosane	260
nC-30 Triacontane	230	nC-30 Triacontane	230
nC-31 Hentriacontane	150	nC-31 Hentriacontane	190
nC-32 Dotriacontane	120	nC-32 Dotriacontane	150
nC-33 Tritriacontane	100	nC-33 Tritriacontane	110
nC-34 Tetratriacontane	90	nC-34 Tetratriacontane	110
nC-35 Pentatriacontane	92	nC-35 Pentatriacontane	110
Total Alkanes	***30752***	***Total Alkanes***	***32940***
LSU ID#: 2010133-02 **Source Oil** **Sample Weight:** 310 mg		**LSU ID#: Lab Ref Oil** **South Louisiana Crude** **Sample Weight:** 500 mg	

Final Extracted Volume: 30 mL		Final Extracted Volume: 20 mL	
Aromatic Analyte:	**Concentration (ng/mg)**	**Aromatic Analyte:**	**Concentration (ng/mg)**
Naphthalene	750	Naphthalene	710
C1-Naphthalenes	1600	C1-Naphthalenes	1300
C2-Naphthalenes	2000	C2-Naphthalenes	1500
C3-Naphthalenes	1400	C3-Naphthalenes	1100
C4-Naphthalenes	690	C4-Naphthalenes	590
Fluorene	130	Fluorene	100
C1-Fluorenes	340	C1-Fluorenes	270
C2-Fluorenes	390	C2-Fluorenes	270
C3- Fluorenes	300	C3- Fluorenes	240
Dibenzothiophene	53	Dibenzothiophene	56
C1-Dibenzothiophenes	170	C1-Dibenzothiophenes	210
C2-Dibenzothiophenes	220	C2-Dibenzothiophenes	280
C3- Dibenzothiophenes	160	C3- Dibenzothiophenes	240
Phenanthrene	290	Phenanthrene	200
C1-Phenanthrenes	680	C1-Phenanthrenes	360
C2-Phenanthrenes	660	C2-Phenanthrenes	340
C3-Phenanthrenes	400	C3-Phenanthrenes	200
C4-Phenanthrenes	200	C4-Phenanthrenes	84
Anthracene	6.1	Anthracene	6.2
Fluoranthene	4.2	Fluoranthene	4.5
Pyrene	8.9	Pyrene	7.1
C1- Pyrenes	68	C1- Pyrenes	43
C2- Pyrenes	84	C2- Pyrenes	31
C3- Pyrenes	96	C3- Pyrenes	31
C4- Pyrenes	54	C4- Pyrenes	20
Naphthobenzothiophene	11	Naphthobenzothiophene	7.8
C-1 Naphthobenzothiophenes	48	C-1 Naphthobenzothiophenes	30
C-2 Naphthobenzothiophenes	37	C-2 Naphthobenzothiophenes	30
C-3 Naphthobenzothiophenes	22	C-3 Naphthobenzothiophenes	25
Benzo (a) Anthracene	5.5	Benzo (a) Anthracene	5.4
Chrysene	36	Chrysene	14
C1- Chrysenes	100	C1- Chrysenes	28
C2- Chrysenes	100	C2- Chrysenes	27
C3- Chrysenes	54	C3- Chrysenes	18
C4- Chrysenes	19	C4- Chrysenes	5.6
Benzo (b) Fluoranthene	2.3	Benzo (b) Fluoranthene	1.7

Benzo (k) Fluoranthene	1.8	Benzo (k) Fluoranthene	1.5
Benzo (e) Pyrene	6.6	Benzo (e) Pyrene	2.9
Benzo (a) Pyrene	1.0	Benzo (a) Pyrene	1.0
Perylene	0.92	Perylene	0.89
Indeno (1,2,3 - cd) Pyrene	0.20	Indeno (1,2,3 - cd) Pyrene	0.22
Dibenzo (a,h) anthracene	1.3	Dibenzo (a,h) anthracene	0.92
Benzo (g,h,i) perylene	1.2	Benzo (g,h,i) perylene	1.1
Total Aromatics	***11203***	***Total Aromatics***	***8394***

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SINTEF REPORT

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BP

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ABSTRACT

A study using the MNS and IFP dispersibility tests has been performed at SINTEF on three emulsions from the DWH spill.

Difference in effectiveness of different dispersant products: The products Corexit 9500, Corexit 9527 and OSR 52 were tested on two emulsions with different degrees of weatering (Viscosities of 2700 and 7200mPas). Corexit 9500 show good efficiency for both emulsions, Corexit 9527 showed reduced effectiveness for the heavily weatered emulsion, while OSR 52 showed reduced dispersibility for both tested emulsions

Dispersant dosage: Tests were performed on two emulsions with a range of dispersant dosages. Results show that a relatively high dosage (DER = 1:25 or higher) was required to obtain good dispersant efficiency for the heavily weathered emulsion. For less weathered emulsions a lower dosage was sufficient..

-Aerial application of dispersants at a low dosage (5USGPA) can be recommended for moderately weathered emulsion (dark brown colour)

-Boat application is recommended for highly weathered emulsions (light brown/orange). A high dosage should be used (25USGPA), and reapplication should be considered if necessary.

Mixing energy requirements: Results from tests with different energy input were compared to assess the requirement for mixing energy on the sea surface to disperse the emulsions. Results show that as long as mixing energy is sufficiently high (i.e. breaking waves) even the most weathered sample showed good dispersibility (given sufficient dosage of dispersants). At low sea states artificial mixing energy may be a recommended option 0.5-1 hour after dispersant application.

Viscosity Limit for use of dispersants: Testing indicate reduced dispersibility for emulsions with viscosity >9000 mPas, and poor dispersibility >25000mPas. These limits are valid for DER=1:25.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1		
GROUP 2		
SELECTED BY AUTHOR		

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1 Background

A sampling campaign were conducted in the vicinity of the DWH release point cruise in the period June 2-5. Three samples were taken of weathered DWH-oil and the physical properties of the samples have been characterised. The sampled emulsions had a span in weathering time estimated to 1 to 5 days on the sea surface. The span in weathering gives the emulsions very different physical properties. Sampling and physical characterisation of the emulsions are described in the cruise report (Leirvik,*et.al.*2010).

As the physical properties change the dispersibility of the emulsions will change. From an operational point of view this would mean that different dispersant application strategies may be needed for emulsions at different stages of weathering.

A dispersibiltiy study has been performed at SINTEF on the sampled emulsions. The following operational aspects have been studied:

- Dosage of dispersant at different stages of emulsion weathering.
- Effectiveness of three dispersant products at different stages of emulsion weathering
- Mixing energy required to efficiently disperse the DWH emulsions.
- Viscosity Limit for the dispersibility of DWH emulsions.

The IFP and MNS dispersibility tests are described in Chapter 2. Sampling positions and the physical properties of the emulsions are summarised in Chapter 3. Results from the dispersibility testing are given in Chapter 4. Conclusions and operational recommendations are given in Chapter 5.

2 Experiemental Setup

There are several different tests for evaluating the effectiveness of chemical dispersants. Energy input will differ in different tests, and the obtained effectiveness will be representative for different wave energies. Most tests in this study is performed using the medium-to-high energy MNS test (representing breaking wave conditions). The MNS test is described in chapter 2.1. To assess the energy requirement for dispersing emulsions at different stages of weathering. Tests have also been performed with the low energy IFP test. The IFP test is described in chapter 2.2 .

2.1 The MNS Test

The MNS test (Mackay-Nadeau-Szeto, Mackay and Szeto, 1980) is estimated to correspond to a medium to high sea-state condition with breaking waves. The energy input in this system, applied by streaming air across the oil/water surface, produces a circular wave motion. The sample of the oily water is taken under dynamic conditions after a mixing period of 5 min. The test apparatus is shown in Figure 2.1.

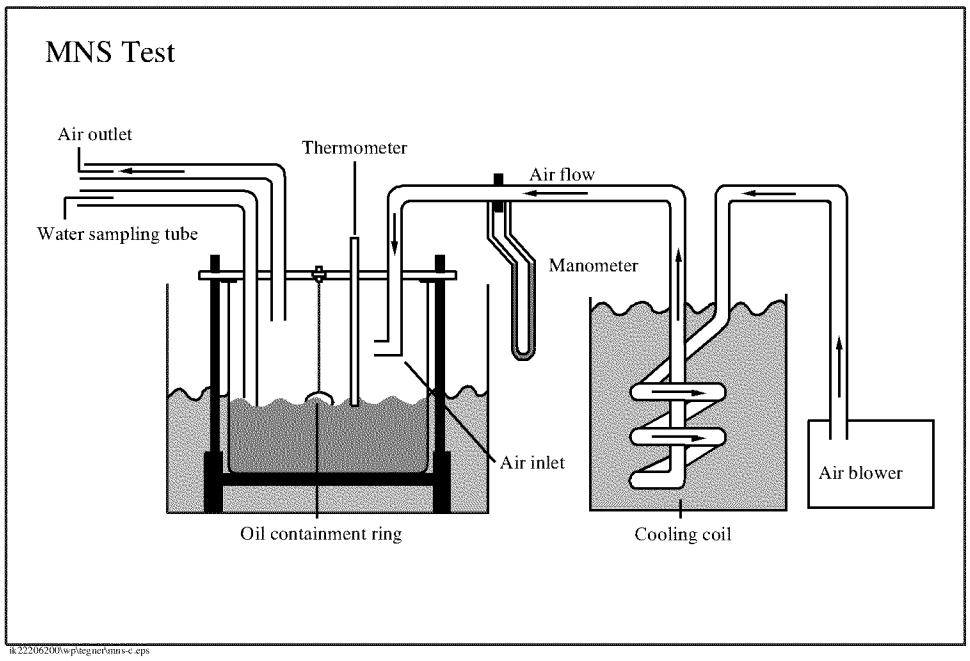

Figure 2.1 MNS test apparatus.

When the test results in the MNS test shows an effectiveness > 70 – 80%, the emulsion is considered to be easily (good) dispersible. In the range down to 5% effectiveness, the emulsion is still dispersible, however, the dispersion process may need some more time. Effectiveness < 5% means that the emulsions is poorly dispersible when using dispersant. These laboratory-derived dispersibility borders have been established based on correlations to field studies (Daling and Strøm, 1999).

2.2 The IFP Test

The IFP Test (Institute Francais du Petrole test, Bocard *et al*, 1984) is a low energy test estimated to represent low wave energies (2 - 5 m/s wind speed). A ring beating up and down in the test vessel at a given frequency, gives energy input to the seawater column. The water column is continuously diluted, which gives a more realistic approach to field conditions compared to other tests. The test apparatus is shown in Figure 2.2.

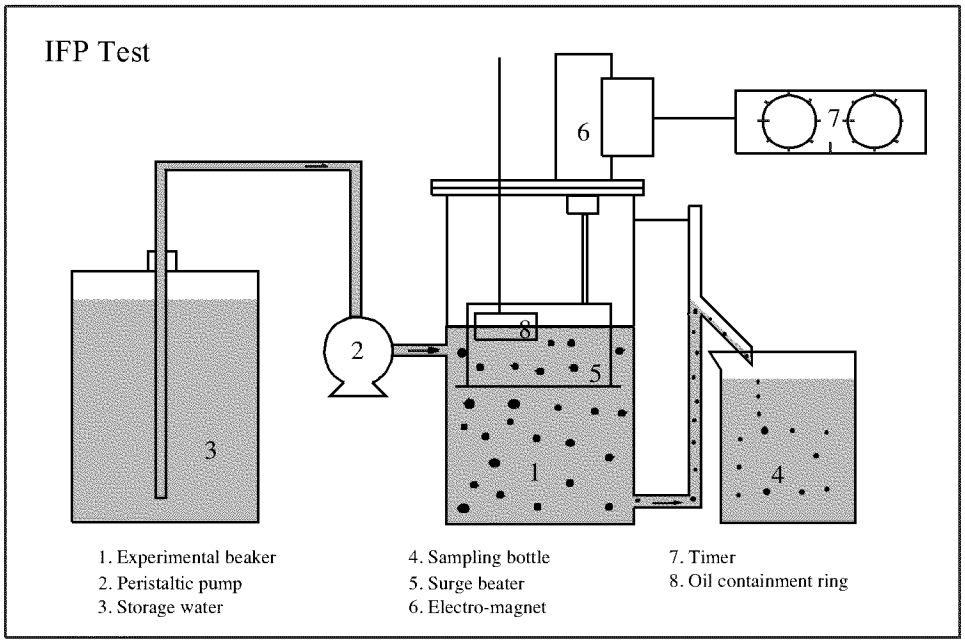

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Figure 2.2 IFP test apparatus.

When the test results in the IFP test shows an effectiveness ~ 50%, the emulsion is considered to be easily (good) dispersible- even at low sea conditions. If the effectiveness is below 40 -50% effectiveness, the emulsion may still be dispersible. During a response operation under calm conditions in the field, additional mixing energy may be required. This extra turbulence can be supplied by e.g. propel-washing from vessels or by using high delivery FI-FI monitors 1-2 hours after a dispersant application in order to fulfil the dispersion process.

3 Sampling and Physical Characterisation of the Test Emulsions

The physico-chemical properties of the sampled emulsions were characterised both on site, and in analysis at SINTEF laboratories. The results from the measurements are summarised in Table 3.1. The sampling positions are shown in Figure 3.1, and the samples are described in brief below. Sampling and analysis is described in detail in the cruise report (Leirvik *et.al.*,2010).

Table 3.1 Summary of physical and chemical properties of the sampled emulsion

	Position 2	Position 3	Position 4
Evaporative loss (wt%)	47	50	44
Estimated time on sea surface (days)	1-1.5	4-5	2-3
Emulsion thickness (mm)	1.3	2.6-3.7	0.9-1.4
Water content (vol%)	67	50	33
Density (g/ml)	0.961	0.975	0.956
Viscosity (mPas)10 s^{-1} at 32°C	2770	7230	1250
Viscosity (mPas)10 s^{-1} at 27°C	3540	12500	2030
Viscosity (mPas)10 s^{-1} at 25°C		17900	
Viscosity (mPas)10 s^{-1} at 22°C		24700	
Viscosity (mPas)10 s^{-1} at 20°C		32300	

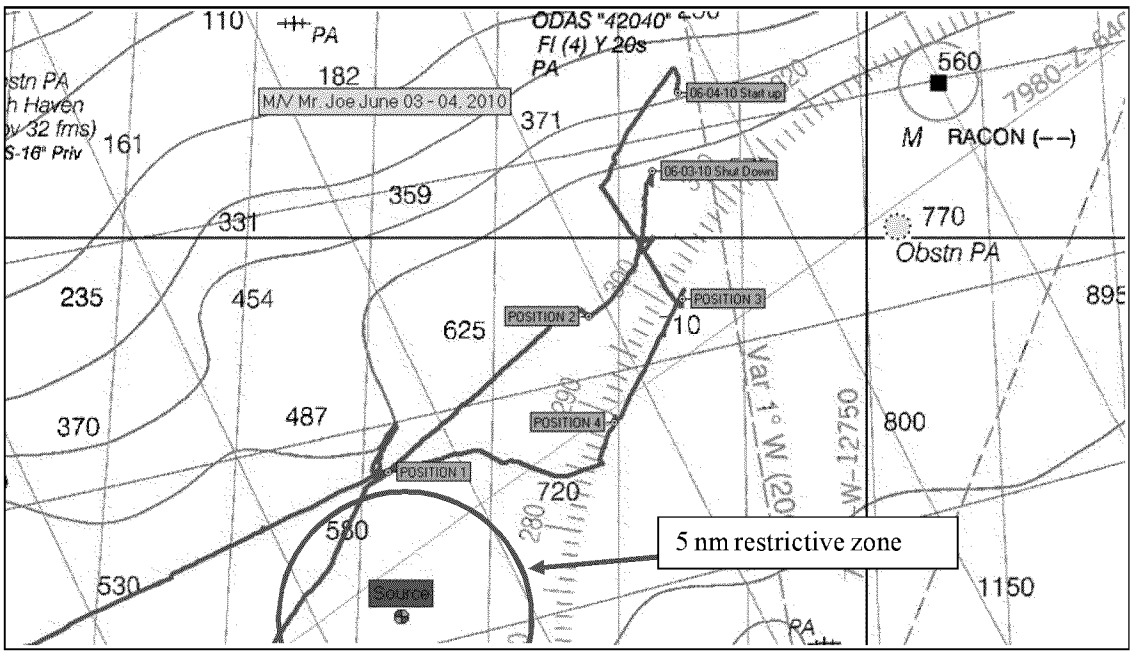

Figure 3.1 Sample positions compared to the DWH source

Position 2
Samples were taken 12 nm miles NE (downwind) from the DWH source. The slick was only 100–200 m long and 2–10 m wide, and the oil was readily spreading on the sea surface. The emulsion was light brown in color, indicating significant emulsification.

Figure 3.2 Emulsion in Position 2

Position 3
Samples were taken 17nm NE (downwind) from the DWH source. The slick was approximately 100 x 30 meters. The emulsion was light brown /orange /reddish in color and appeared more elastic and less prone to spreading on the sea surface, which indicates that this slick had been heavily weathered (evaporative loss, emulsification and photo-oxidation).

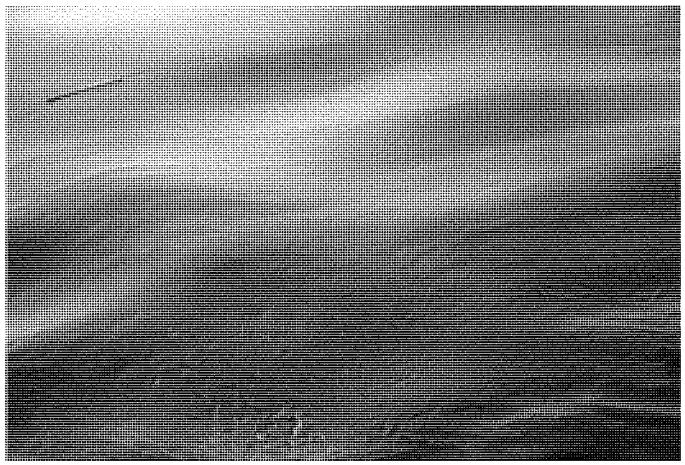

Figure 3.3 Emulsion in Position 3

Position 4
Samples were taken 10 nm miles NE (downwind) from the DWH source. The sampled slick was approximately 50 x 30 meters, and was part of a continuous belt of slicks aligned downwind from the DWH source. The emulsion was dark brown, and darker than the emulsions in Positions 2 and 3. This dark color indicates a lower degree of weathering than the emulsion in Positions 2 and 3.

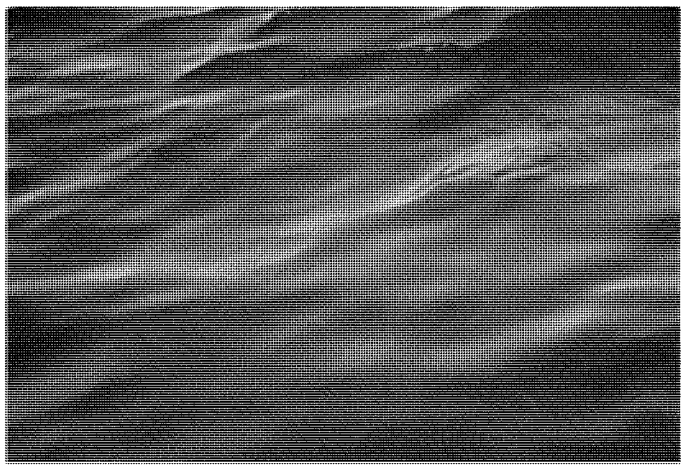

Figure 3.4 Emulsion in Position 4

4 Experimental Results

Laboratory tests have been performed to study different operational aspects. Comparative testing between different dispersant products is described in chapter 4.1. Results from testing with different dispersant dosages are shown in chapter 4.2. The requirement for energy is studied by testing with a low energy test representing sea states without breaking waves (IFP), and a Medium/high energy test (MNS) representing sea states with breaking waves. The results are shown in chapter 4.3. Viscosity limits for the dispersibility of DWH emulsions have been established by testing at increasing viscosities. This work is presented in Chapter 4.4.

4.1 Testing with Various Dispersants

Tests have been performed with different dispersant products for samples from position 2 and position 3. The three tested products were Corexit 9500, Corexit 9527 and OSR52. The comapartive tests were performed with a **dispersant/emulsion-ratio (DER)** of 1:25.

Table 4.1 Results from the MNS test with different dispersant products. DER=1:25 in all tests.

	Position 3 (7200 mPas)	Position 2 (2770 mPas)
Corexit 9500	86	91
Corexit 9527	55	90
OSR 52	71	62
blank	2	44

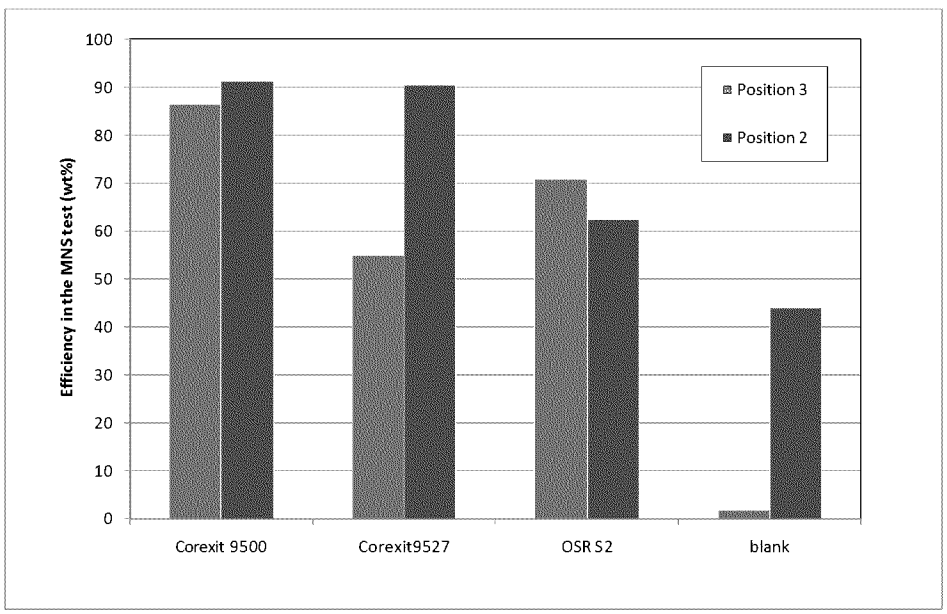

Figure 4.1 Results from the MNS test with different dispersant products. The dosage is 1:25 in all tests.

Reduced effectiveness in the MNS test is defined as <75% (Daling and Strøm,1999), while poor dispersibility is defined as <5%. The two Corexit products show good efficency for the moderatly weathered emulsion from position 2, while OSR 52 have a somehow reduced dispersibility. For the heavily weathered emulsion sampled in position 3, only Corexit 9500 show good dispersibility, while Corexit 9527 and OSR 52 showed reduced dispersibility.

4.2 Testing with Various Dispersant Emulsion Ratios (DER)

Tests have been performed to study the dispersant effectiveness as a function of dispersant dosage. The tests have been done on the emulsions from position 3 and position 4. The medium/high energy MNS test has been used in the study. Results are shown in Table 4.2 and in Figure 4.2.

Table 4.2 Results from the MNS test with Corexit 9500 at different dispersant dosages

DER	%Effectiveness in the MNS test	
	Position 3 (7200 mPas)	Position 4 (1250mPas)
1:10	81	
1:25	86	99
1:50	44	99
1:100	31	96
1:250	15	99
no dispersant	2	48

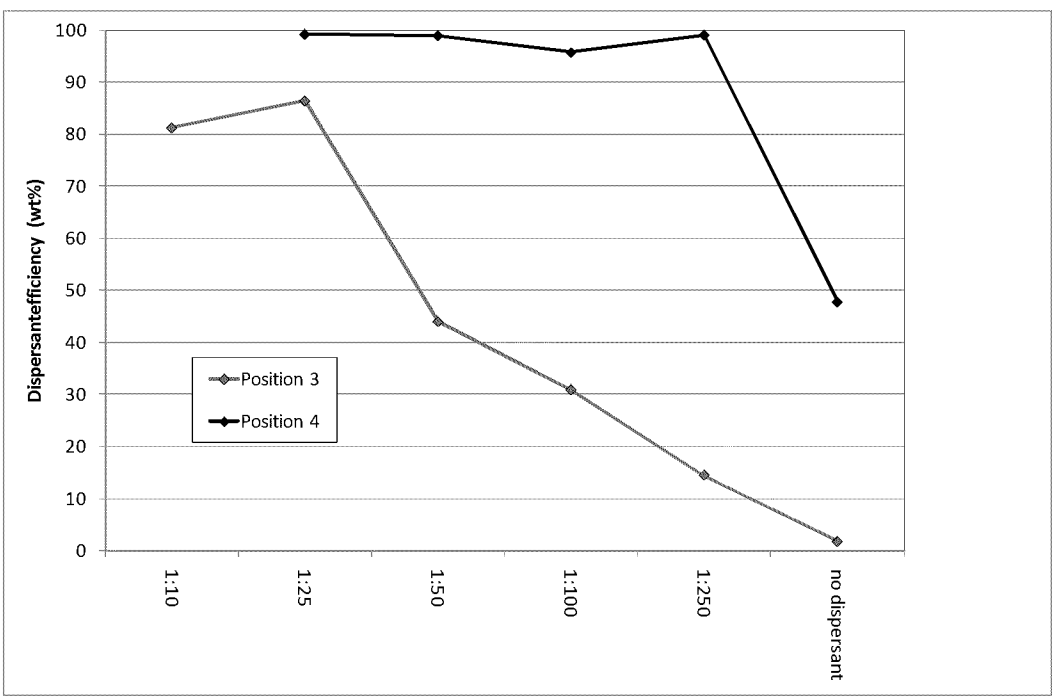

Figure 4.2 Results from the MNS testing with Corexit 9500 at different dispersant dosages.

Results show that at a dosage of 1:25 and higher, the dispersant efficiency is high for the highly weathered emulsion sampled in position 3. At lower dosages the efficiency will gradually decrease. Tests performed on the least weathered emulsion (position 4) show a good efficiency for all the tested dosages.

4.3 Testing with Different Energy Input

To study the effect of energy input on the dispersibility testing has been performed with both the MNS and IFP tests. The MNS is a high energy test representative to high sea states. The IFP test supply a relatively low energy input and is thought to be representative for low sea states without breaking waves. Results from testing with the two methods are shown in Table 4.3 and in Figure 4.3.

Table 4.3 Results from the MNS and IFP tests with samples from the different positions using Corexit 9500 and DER=25.

	Test effectiveness (wt%) w/ Corexit 9500 and DER=1:25	
	MNS	IFP
Position 4	99	46
Position 2	91	48
Position 3	86	34

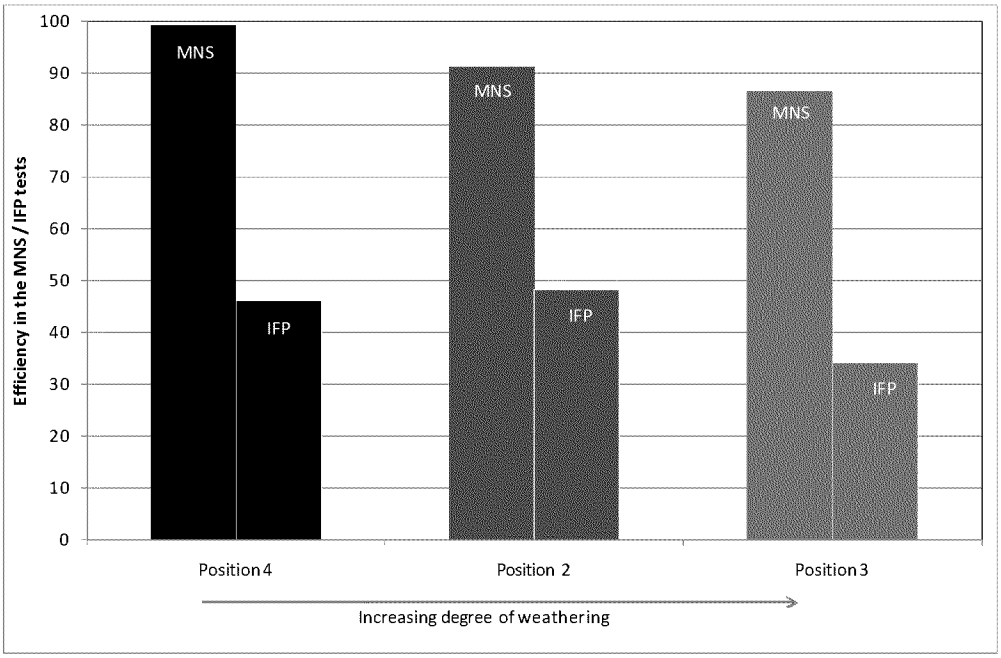

Figure 4.3 Results from the MNS and IFP tests with samples from the different postions using Corexit 9500 and DER=1:25.

Results show that whith a dosage of 1:25 of Corexit 9500 all the samples show a relative good dispersibility for the MNS test. This is in accordance to the conclusions for the tests performed with the Field Effectiveness Test onboard Mr.Joe (Leirvik,*et.al.*2010). For the low energy IFP samples from positions 2 and 4 show a slightly reduced dispersibility. The heavily weathered sample from position 3 show a significant reduction in dispersibility.

4.4 Chemical Dispersibility vs Viscosity

In systematic weathering studies performed over the past 20 years at SINTEF (Daling and Strøm,1999) an upper viscosity limit for an oils dispersibility is determined. The viscosity limit is strongly related to the specific oil that is investigated. In this study with a limited amount of emulsions even the most weathered emulsion had a good dispersibility (at32°C), a viscosity limit could not be established. Therefore additional testing where performed at lower temperatures to yield dispersibility data on higher viscosities. The results from all tests done with the MNS test is compared with the emulsion viscosities in Table 4.4.

Table 4.4 Results from the MNS test and the Viscosity of the emulsions. The table includes the additional tests performed at lower temperatures. Tests are performed with Corexit 9500 and DER=1:25.

Position	Temperature (°C)	Temperature (°F)	Viscosity at shear rate $10s^{-1}$(mPas)	MNS dispersant efficiency (wt%)
4	32	90	1250	99
2	32	90	3700	91
3	32	90	7230	86
3	28	82	12500	66
3	25	77	17000	44
3	22	72	24700	16
3	20	68	32300	0

The dispersant effectiveness from the MNS test is plotted against the emulsion viscosity in Figure 4.4.

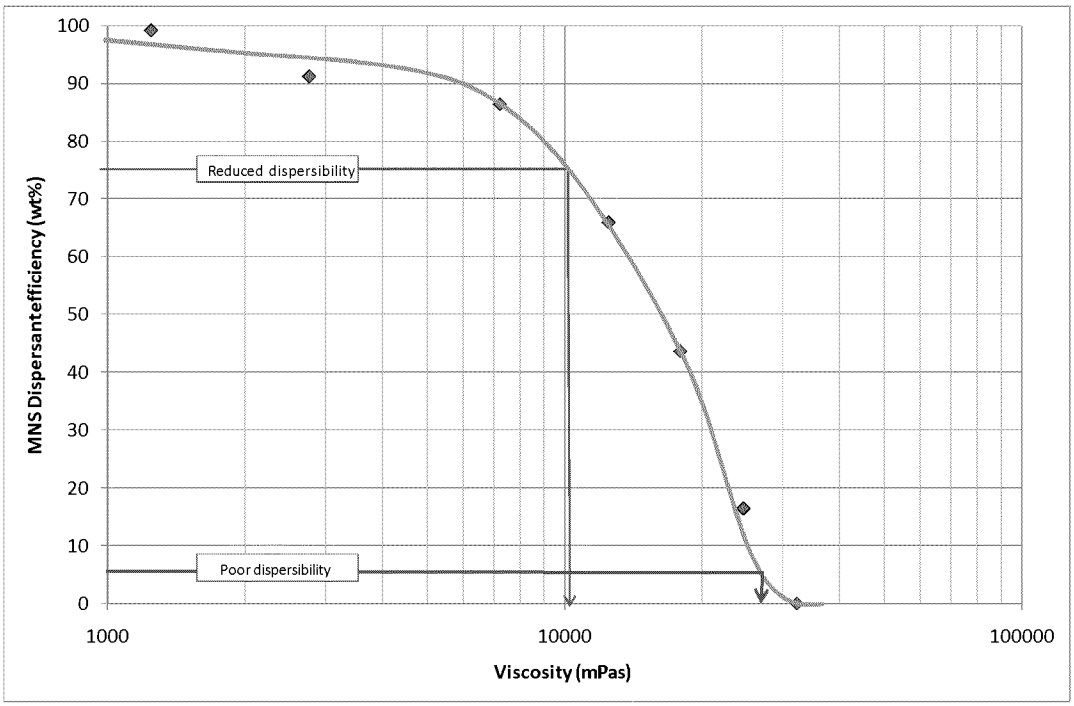

Figure 4.4 Dispersant efficiency in the MNS tests plotted against viscosity. Viscosity is reported at shear rate $10s^{-1}$.

As described in chapter 2.1, in the MNS test reduced dispersibility is defined as below 75%, while poor dispersibility is defined below 5%. Based on the curve drawn in Figure 4.4 reduced dispersibility will occur for viscosites above 10000mPas, while poor dispersibility can be expected for viscosities exceeding 25000 mPas. The drawn limits is based on studies using a dispersant/emulsion-ratio of 1:25.

The time it take for emulsions to reach the defined viscosity limits will depend on the wind speed and temperatures. The weatering time for the tested emulsions where estimated based on the evaporative loss of the samples in the cruise report (Leirvik,*et.al.*,2010). The estimated time on the sea surface for the emulsions is shown in Table 4.5.

Table 4.5 - Tentative time at sea based on evaporative loss and use of the SINTEF Oil Weathering Model.

	Evaporative loss (wt%)	Viscosity (mPas)	Tentative time at sea
Position 2	47%	3700	2-3 days
Position 3	50%	7200	4-5 days
Position 4	44%	1250	1-2 days

4.5 Visual Observations During Testing

The moderately weathered emulsions sampled in position 2 and 4, generally dispersed well. For the emuslion from position 4 small droplets were formed within the first minute of the test as shown in *Figure 4.5*

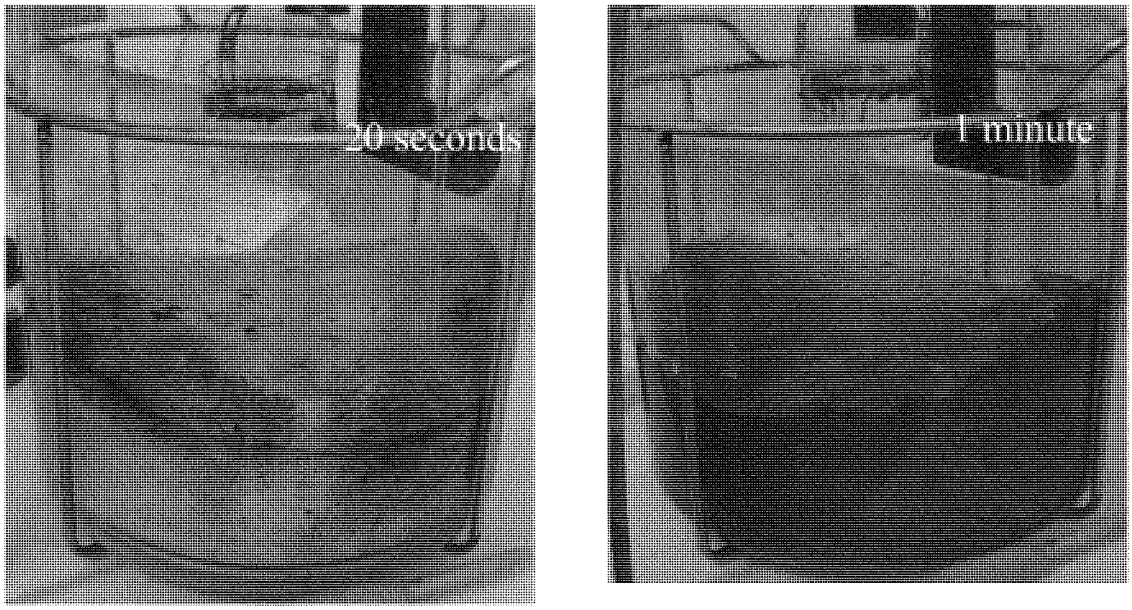

Figure 4.5 Gradual formation of small droplets with time in the MNS test. The image is from testing with Emulsion 4 and Corexit 9500 at DER=1:25

In tests performed with the heavily weathered emulsion from position 3, the formation of small droplets was slower. After five minutes (the test duration) a significant amount of small droplets were formed, but strings of emulsion were still present in the water. This is demonstrated in Figure 4.6.

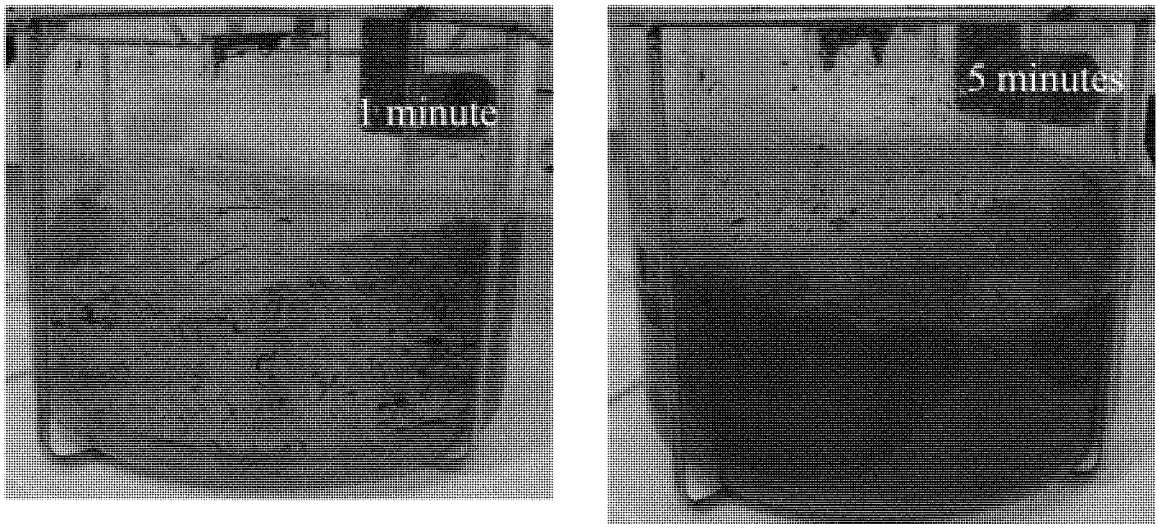

Figure 4.6 Gradual formation of small droplets with time in the MNS test. The image is from testing with Emulsion 3 and Corexit 9500 at DER=1:25

In the IFP test the same effects could be observed. For the less weathered emulsions (Position 2 and 4) small droplets were formed to make a cafe au lait coloured suspension. In the tests with the heavily weathered emulsion from position 3 the particles in suspension were non-spherical and larger in size. This is examplified in Figure 4.7.

Figure 4.7 Droplet formation in the IFP test with the emulsion from position 3. The test is performed with Corexit 9500 and DER=1:25.

Even though not all dispersed particles are within the optimal particle size range, the dispersant will contribute to breaking up the viscous emulsion and significantly reduce the lifetime of oil on the sea surface.

Emulsions were also tested without addition of dispersants. Images from the tests are shown in Figure 4.8. The natural dispersion in the tests with emulsions from position 2 and 4 were relatively high. The emulsion from position 2 even formed quite small droplets. The emulsion from position 3 did not spread on the surface of the test vessel, and few droplets formed at all.

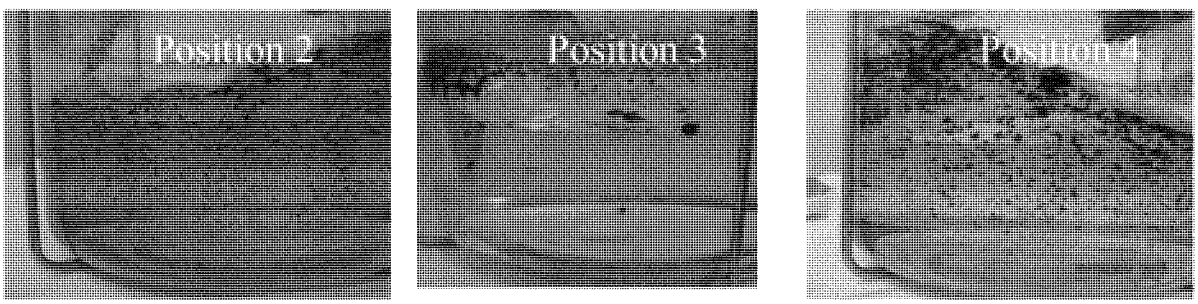

Figure 4.8 Droplet formation in the MNS tests without addition of dispersant in the different positions.

5 Conclusions and Operational Recommendations

5.1 Testing with different dispersant products

Tests have been performed with different dispersant products for one moderately weathered emulsion (position 2 / 2770mPas) and one heavily weathered emulsion (position 3 / 7250mPas). The three tested products were Corexit 9500, Corexit 9527 and OSR52. The comapartive tests were performed with a DER of 1:25.

The two Corexit products show good effectiveness for the moderatly weathered emulsion from position 2, while OSR 52 showed a somehow reduced dispersibility. For the heavily weathered emulsion sampled in position 3, only Corexit 9500 show good dispersibility, while Corexit 9527 and OSR 52 showed reduced dispersibility (<75% effectiveness in the MSN test).

5.2 Dispersant dosage requirement

A minimum DER is required to yield efficient dispersion of a slick. The required dosage usually increases as the oil weathers on the sea surface. As the physical properties of the emulsion change the thickness of the slick will also increase and the required dosage will increase accordingly. In dispersant application operations the dosage is often given in US Gallons Per Acre (USGPA). Dispersant/Emulsion-ratio at different dosages is given at differing slick thicknesses in Table 5.1.

Table 5.1 Dispersant/Emulsion-ratio at different dosage and slick thickness

	DER at varying Slick thickness		
USGPA	1 mm	2 mm	4mm
5	1:200	1:400	1:800
25	1:50	1:100	1:200
2x25	1:25	1:50	1:100

<u>Low/Moderately weathered emulsions (dark brown appearance)</u>

The results show good dispersibility in the MNS test for the least weathered emulsion (Position 4). The emulsion disperses even at DER as low as 1:250 in the MNS test. The slick sampled in position 4 had a thickness of ~1mm. To achieve a dispersant/emulsion-ratio of 1:250 for a slick of this thickness an application dosage of 5 USGPA is required (Table 5.1). This mean that the low dosage used in standard aerial application will be sufficient for emulsions at a such low degree of weathering.

Highly weathered emulsions (light brown/orange appearance)
The results show good dispersibility in the MNS test for the most weathered emulsion (Position 3) at DER of 1:25 and above. At ratios under 1:50 the efficiency in the MNS test were gradually decreasing. The highly weathered slick sampled in position 3 had a documented thickness of up to 4 mm. A dosage of 5 USGPA would correspond to a dispersant/emulsion-ratio of 1:800 for a slick with this thickness (Table 5.1). According to the test results, this is a too low dosage to disperse the emulsion. A dispersant/emulsion-ratio above 1:50 is recommended as the minimum dosage for heavily weathered emulsions such as the sample from position 3. According to Table 5.1 a minimum dosage of 25 USGPA is required to efficiently disperse heavily weathered emulsion similar to the tested emulsion from position 3.
The slick should be monitored after the dispersant treatment, and if emulsion is still on the surface a re-treatment of the slick should be considered in order to achieve sufficient dosage.

5.3 Sea state dependency

Tests were conducted with the high energy MNS test and with the low energy IFP test. The MNS is thought to be representative for energy at high/medium sea states with presence of breaking waves (typically >5m/s). The IFP test is representative to calmer sea states with no breaking waves. The comparative tests were carried out on all the sampled emulsions and with a dispersant/emulsion-rate of 1:25. At this dosage all emulsions dispersed readily in the MNS test. The dispersibility was slightly reduced in the IFP test for the moderately weathered emulsions from position 2 and 4, while dispersibility was significantly reduced for the heavily weathered sample from position 3. This means that the emulsions are dispersible given sufficient wave energy. In calm sea conditions, introduction of additional mixing-energy/turbulence 0.5-1 hour after dispersant treatment, could be a rational operational strategy. Such mixing energy could be supplied to the treated slick e.g. by prop-washing or by spraying the slick with the vessels FI-FI system.

5.4 Viscosity limit for use of dispersants

As an emulsion weather on the sea surface the physical properties will change, and the dispersibility will gradually decrease. The change in physical properties and thus the changes in dispersibility are highly dependent on the wind/wave conditions. In the systematic weathering studies performed in general at SINTEF, dispersant effectiveness is linked to the viscosity of the emulsion. The viscosity is predicted by use of the SINTEF Oil Weathering Model (Daling and Strøm,1999) and a time window for effective use of dispersants can be estimated. The weathering properties of the DWH oil are not studied and predictions of the change in physical properties can not be done. A defininite time window for use of dispersants can therefore not be established. In this study only the relationship between dispersibility and viscosity has been established.

The most weathered sample tested in this study had a viscosity of 7200 mPas after an estimated weathering time of 4-5 days on the sea surface under relative calm weather conditions. This emulsion still showed good dispersibility in the high energy MNS test at a dispersant/emulsion-ratio of 1:25. In lack of more viscous emulsions the emulsion from position 3 is tested at lower temperatures to gain higher viscosities. The tests indicate that at a dispersant/emulsion-ratio of 1:25 the dispersibility will be reduced at a viscosity of 10000 mPas. Poor dispersibility will occur as the emulsion reaches a viscosity of approximately 25000mPas.

6 References

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Leirvik,F., Daling,P.S.,Trudel,K.,Parschal,B.2010. ”Cruise report – Assessment of dispersibility of DWH oil at different stages of weathering”

Mackay, D.and Szeto, F. 1980. Effectiveness of oil spill dispersants - development of a laboratory method and results for selected commercial products. Institute of Environmental Studies, University of Toronto, Publ. no. EE-16.

A7 "Bench Top" LISST Particle Size Analysis

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The standard operational procedure (SOP) for LISST-100X particle size analysis used in the Gulf of Mexico oil spill monitoring program (i.e., Deepwater Horizon Spill) was developed for the measurement of particle-size distributions under two scenarios. The first was bench top measurement of small particles, and the second was continuous in-situ monitoring with the instrument deployed over the side of the vessel at specific depths.

Laboratory ***"bench-top"*** measurements with the LISST-100X instrument on board the vessel were specifically targeted at measuring ***small particles*** (d < 70 μm) suspended in the water column. For this purpose, discrete samples were collected from both the surface (with bucket), and from different depths in the water column using CTD casts with a Niskin rosette sampler. On average, the total length of time between the recovery of sample and the bench-top LISST-100X analysis was more than half an hour including casting of rosette Niskin bottles, sub-sampling, and data acquisition by LISST-100X. Due to the buoyant nature of dispersed oil droplets in the water column, larger particles (Lunel, 1993; Lunel, 1995) would have risen at a speed that is beyond the limit of the time period for handling discrete seawater samples (Table 1).

TABLE 1 - Rise time of oil droplets

Diameter (μm)	Rise velocity (cm/min)	Time to rise 1 metre (min)
10	0.03	3330
20	0.132	760
30	0.294	340
40	0.522	190
50	0.84	120
70	1.62	62
80	2.10	48
100	3.30	30
150	7.20	14
200	13.20	8
300	29.40	3
400	52.2	2
500	81.6	1

The LISST-100X particle size analyzer (Type C) is an optical device that measures light intensity over a series of detector rings (numbered 1 through 32). After the acquisition of light intensity for the 32 discrete rings and eight other auxiliary parameters, the raw data are subsequently processed with the manufacturer provided inversion algorithm to automatically calculate volume concentrations (in μl/l) for particle size bin number 1 through 32 (corresponding with the detector ring numbers), along with output of 10 other parameters including laser transmission sensor power, laser reference sensor in calibrated

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units, pressure, temperature, computed optical transmission over path, and beam-attenuation, etc.

Under ideal conditions, the data acquired using the bench-top measurement SOP would have recorded discrete particle size volume concentrations over the first 20 size bins (bins 1-20 or 2.5 - 68.8 μm) only, and would have shown zero or close to zero readings for the large-sized bins (#21 – 32, or 68.8 to 500 μm). However, the recorded data do not always show the low readings expected. Instead, extremely high values over the last several bins were recorded. A number of conditions may exist that lead to high apparent values of large particles:

(1) Variation of the seawater temperature of the samples collected from different depths in the water column and the ambient air temperature. The water temperatures vary widely from close to freezing (4°C) at maximum depths to very warm water at the surface (30°C). Stratification of the water inside the small chamber may cause laser beam reflection and a false signal of the presence of larger particles (Mikkelsen et al., 2008; Styles, 2006). Corrective action was taken in late June, 2010 to overcome the effect of temperature variation by introducing a full-path mixing chamber.
(2) Slight miss-alignment of the LISST-100X (#1215 and #1174) that may impact the inner ring light intensity reading. This will subsequently propagate through inversion process to affect several numbers of upper-end particle size bins, but negligible impact on medium and small particle size data (communication with the manufacturer)
(3) The presence of actual particles larger than the upper limit of our targeted small particles (68.6 μm). This is not unexpected, for a number of reasons such as the retention of larger oil droplets within the counting cell of the instrument due to (a) the relatively short time between sample recovery and analysis for the samples that were collected from the surface or near the surface (0-50m depth), (b) the potential presence oil droplets with a density close to the seawater because of the dissolution of light components, and (c) potential coalescence of small particles into larger ones. Furthermore, large particles other than oil (e.g., biogenic material) may also exist.

Considering the high uncertainties involved in the analysis of large particles, analysis of "bench top" data and interpretation should be focused on the small sized particles ($d < 70$ μm) which have been recognized in the oil spill community as permanently dispersed oil droplets. We discourage over-interpretation of particle size distribution data that were collected for this specific purpose during the Gulf of Mexico oil spill emergency response operations. Under this emergency response effort, rapid, less than perfect actions had to be taken to support the requirement for immediate action to monitor the fate and transport of the oil following subsurface injection of dispersant.

Preliminary data analysis was performed with particle size bins 1 through 25, corresponding to particle size ranges of 2.5 to 157 μm (Table 2). Figures 1 and 2 display discrete particle size distribution of the surface samples for all stations, and Figures 3 and 4 the peak total particle concentrations in sub-surface samples. The peaks that were used are defined as the maximum small particle concentration at depth for each station. These particle size distribution histograms clearly demonstrate the presence of a large amount of

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very small particles (d < 10 μm), suggesting the presence of chemically dispersed oil droplets (Li et al., 2008; Li et al., 2009; Lunel, 1993; Lunel, 1995). The strong signal of the chemically dispersed oil particles is also indicated by the observed multimodal distribution profiles rather than a mono-modal size distribution that is often generated by natural dispersion (Li et al., 2009).

Figures 5 to 8 summarize the fraction of small particles (d < 68.8 μm) within the complete range of particle sizes (2.5 – 157 μm). These data clearly indicate that the vast majority of volume fractions of the measured particles are in the small particles range. However, exceptions do exist for a number of stations where large fractions of particles appear to fall in the range above 70 μm (e.g. the surface samples of stations 101-104 and subsurface samples of stations 101 and 102 of R/V Brooks McCall, surface samples of stations 60-80 and subsurface samples of stations 60-80 of R/V Ocean Veritas). This needs to be further investigated.

Figures 9-12 present the cumulative particle size distribution of all measured particles from all the surface stations and all the peak sub-surface stations. These graphs show that nearly 80-90% of the measured surface and subsurface particles are □ 70 μm (bin 1 to 21), and the median diameters of the measured particles of both surface and subsurface particles are nearly 20 to 30 μm. These size data are in good agreement with previous observations at sea (Lunel, 1993; Lunel, 1995).

Due to the restriction of time, more detailed data analysis and interpretation are certainly yet to be done. The association with field operational and oceanographic parameters needs to be further investigated. Nevertheless, the preliminary results and elementary data analysis suggest high effectiveness of chemical dispersants in oil dispersion from subsurface application. An estimation of the amount of oil dispersed based on the operational parameter, namely dispersant to oil ratio, in calculating the amount of chemically dispersed oil may not be the most accurate approach. A thorough inspection of all the field collected data, including discrete samples and continuous in-situ (over-the-side) vessel deployment data (to be addresses in future reports), and numerous other field sampling data should be synthesized and digested to provide a more scientifically sound estimation of dispersant effectiveness, the amount of oil naturally or chemically dispersed from the subsurface and surface dispersant application, and the oil mass balance on the whole. The possible impact of dispersant-containing oil in rising and after rising to the water-air interface should not be neglected. Effective chemical dispersion of oil after adding dispersant in calm sea proves still effective after prolonged standing time in static and flowing waters before increased wave energy becomes available (Lewis et al., 2010). Such a scenario may happen to the subsurface dispersant injection situation, in which an excellent mixture of oil and dispersant in situ at depth can facilitate continued dispersion of oil wherever turbulent mixing energy is encountered – regardless of whether it is at the surface or subsurface.

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Table 2: The lower, medium and upper limit of each size bin in microns for the LISST-100X particle counter

Size bin #	Lower	Medium	Upper
1	2.50	2.72	2.95
2	2.95	3.20	3.48
3	3.48	3.78	4.11
4	4.11	4.46	4.85
5	4.85	5.27	5.72
6	5.72	6.21	6.75
7	6.75	7.33	7.97
8	7.97	8.65	9.40
9	9.40	10.2	11.1
10	11.1	12.1	13.1
11	13.1	14.2	15.4
12	15.4	16.8	18.2
13	18.2	19.8	21.5
14	21.5	23.4	25.4
15	25.4	27.6	30.0
16	30.0	32.5	35.4
17	35.4	38.4	41.7
18	41.7	45.3	49.2
19	49.2	53.5	58.1
20	58.1	63.1	68.6
21	68.6	74.5	80.9
22	80.9	87.9	95.5
23	95.5	104	113
24	113	122	133
25	133	144	157

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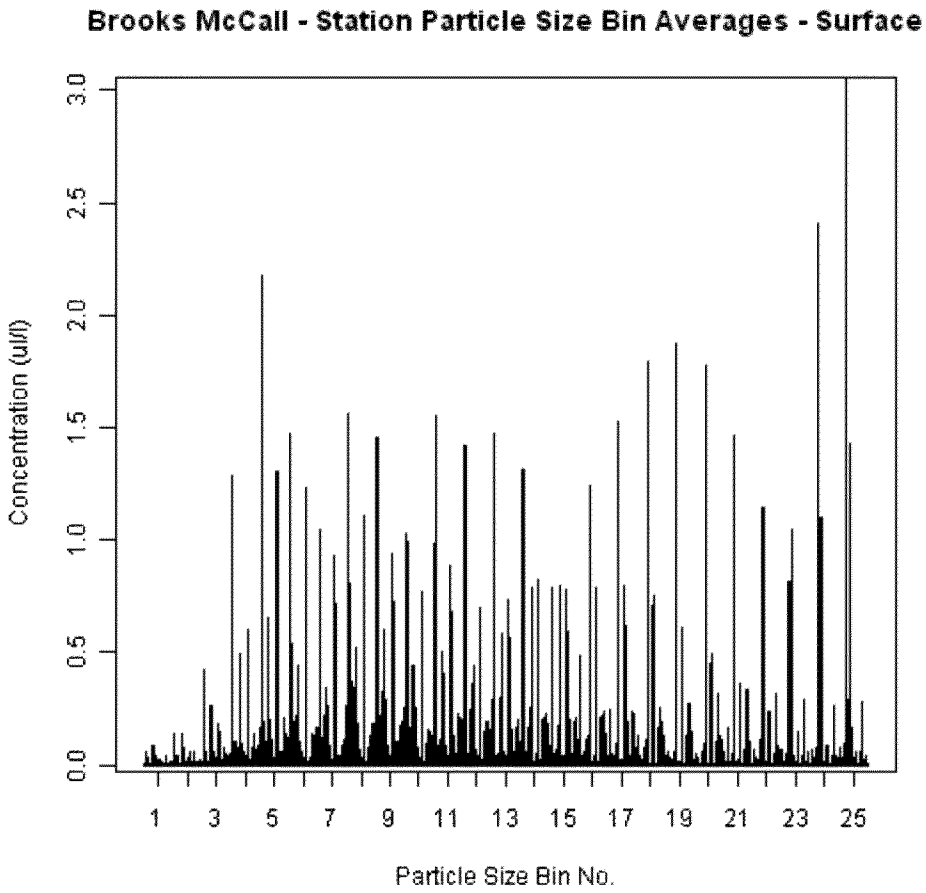

Figure 1: Particle-size distributions (see Table 1 for size range of corresponding Bin No.) for the surface samples of all stations of the R/V Brooks McCall.

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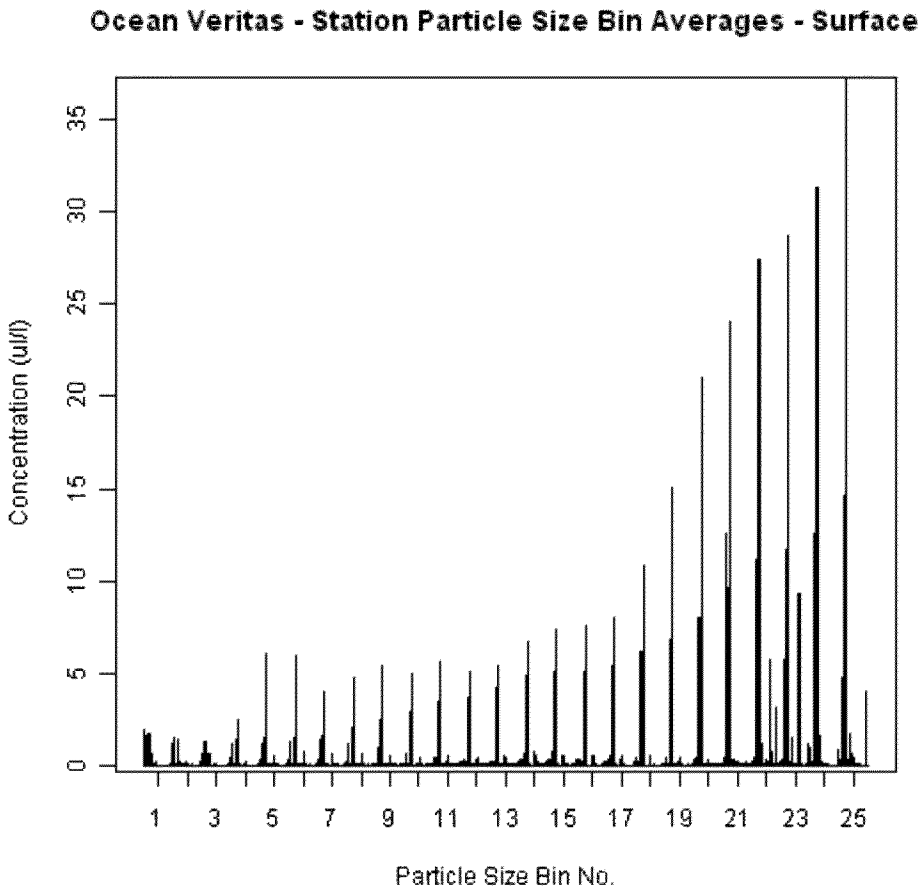

Figure 2: Particle-size distributions for the surface samples of all stations of the R/V Ocean Veritus.

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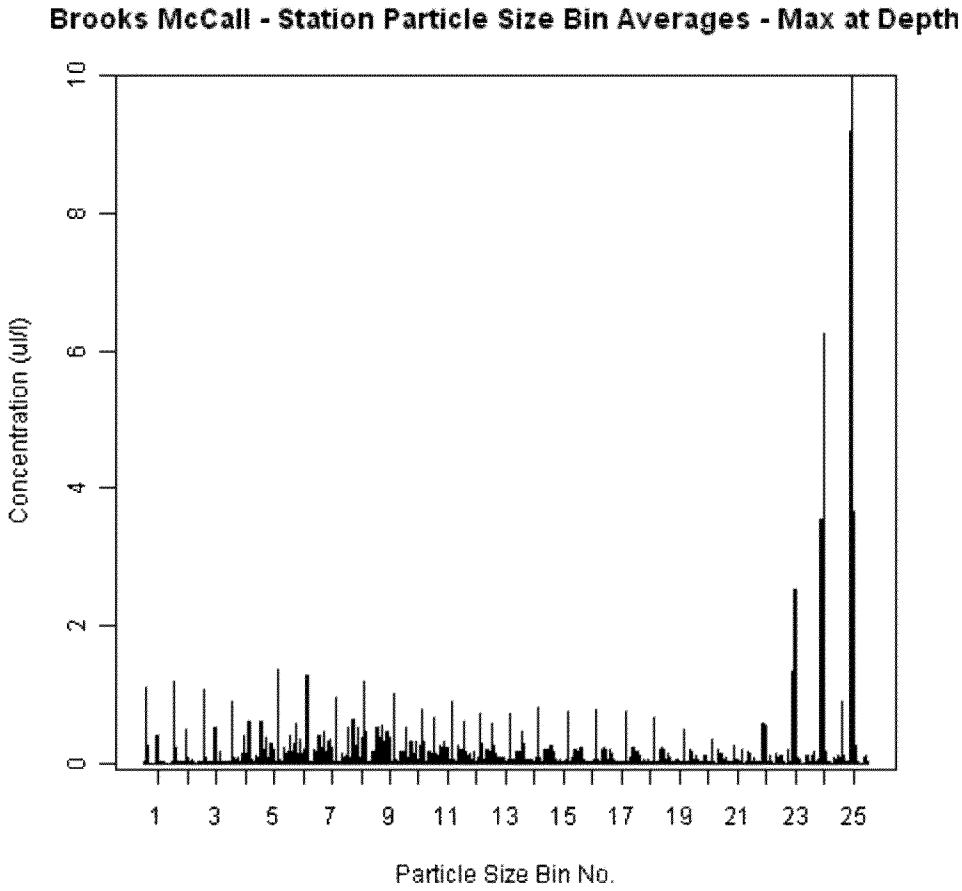

Figure 3: Particle-size distributions for the peak total concentration in sub-surface samples of all stations of the R/V Brooks McCall.

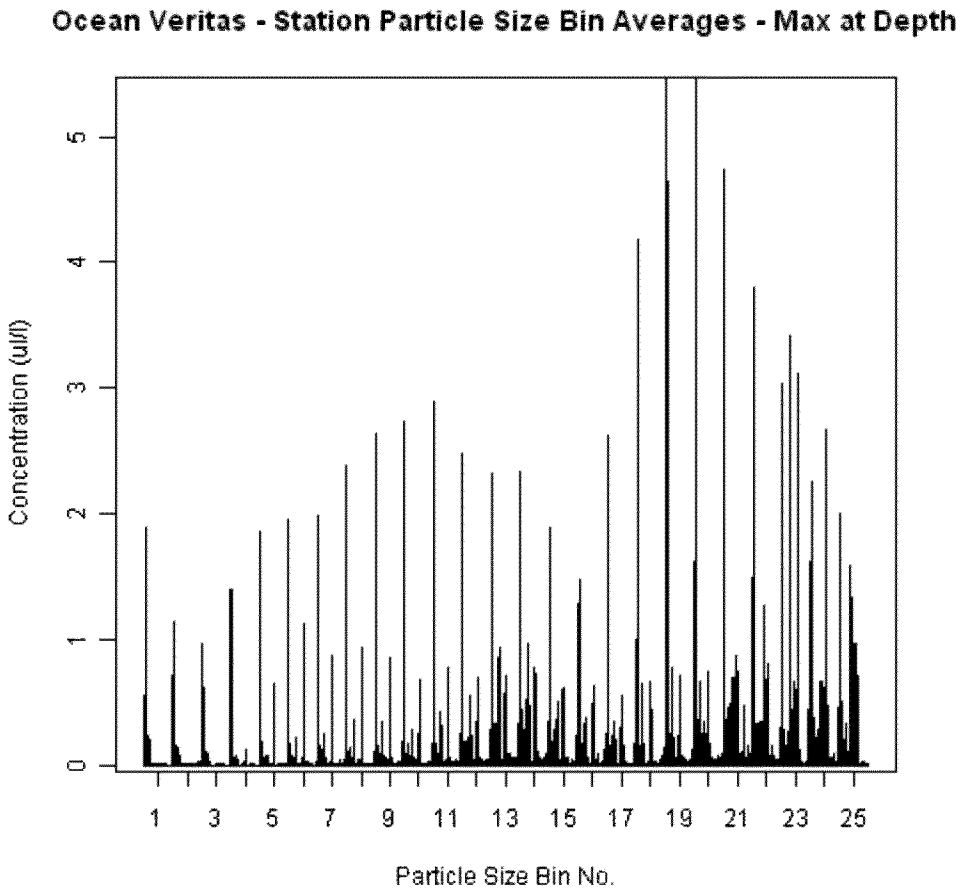

Figure 2: Particle-size distributions for the peak sub-surface samples of all stations of the R/V Ocean Veritus.

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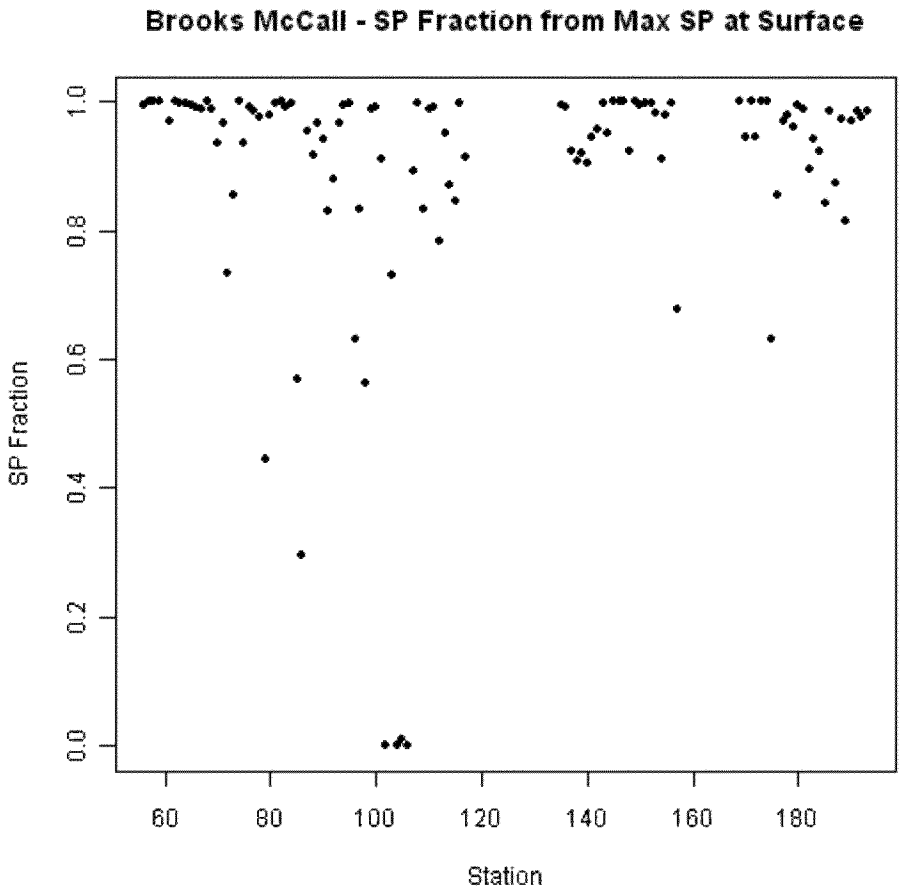

Figure 3: Small particle (d < 68.6 um) fraction of the total measured particles (2.5 – 157 um) for the surface samples of all stations of the R/V Brooks McCall.

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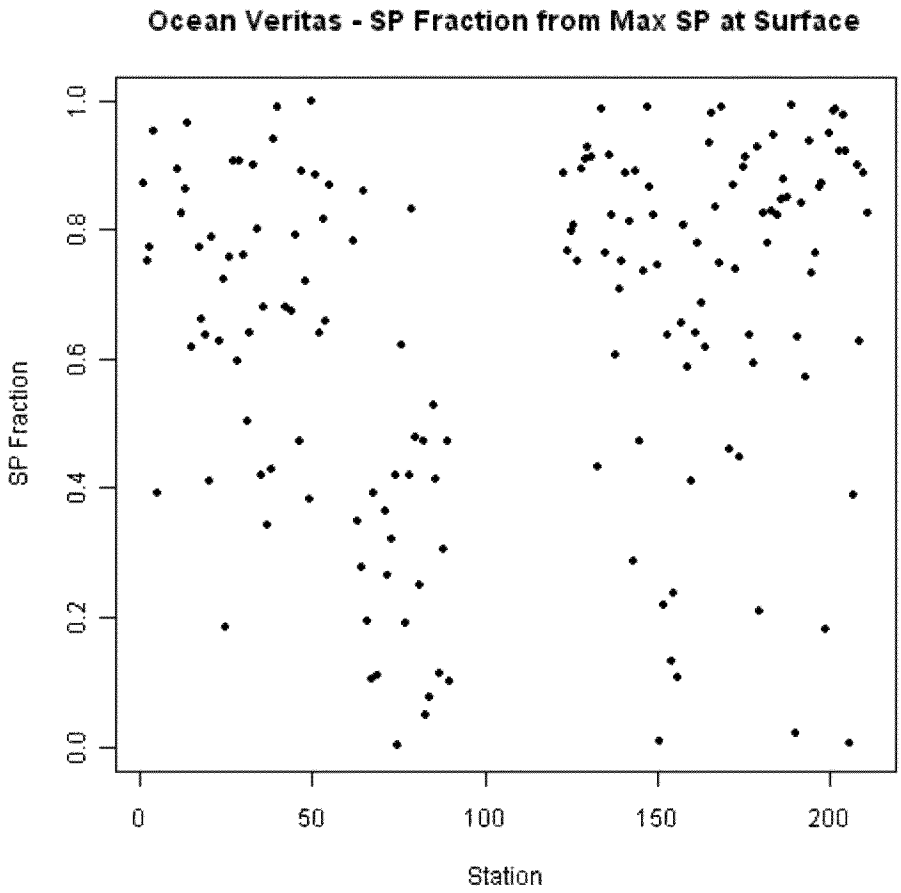

Figure 6: Small particle (d < 68.6 um) fraction of the total measured particles (2.5 – 157 um) for the surface samples of all stations of the R/V Ocean Veritas.

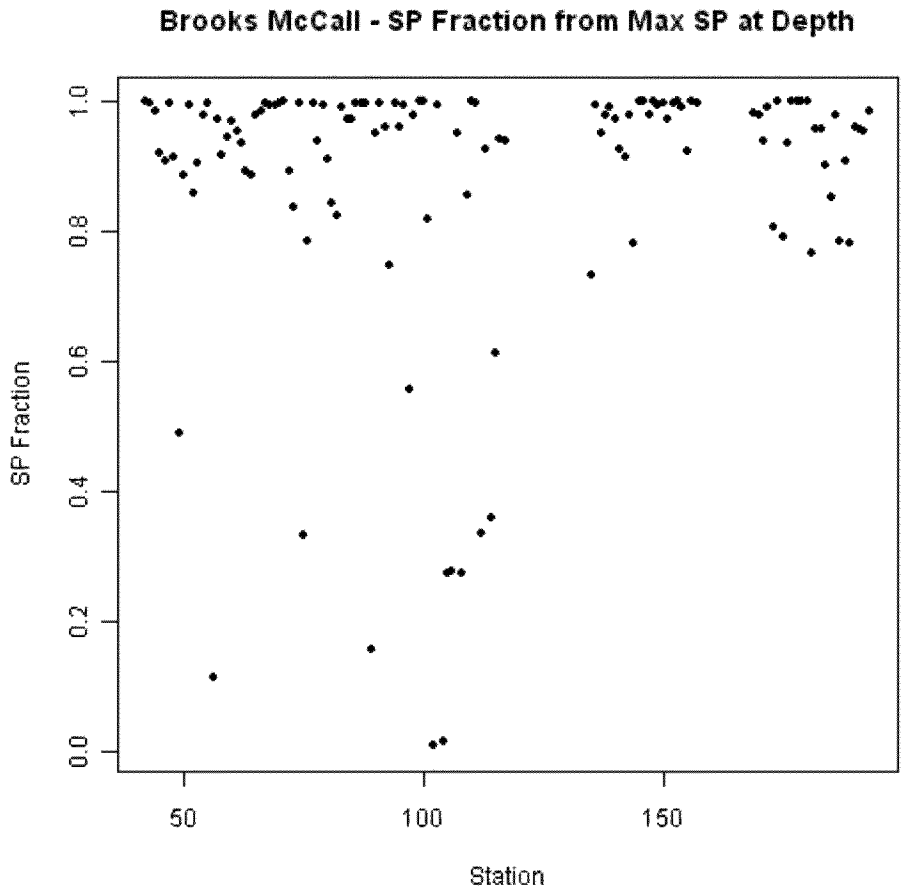

Figure 7: Small particle (d < 68.6 um) fraction of the total measured particles (2.5 – 157 um) for the peak sub-surface samples of all stations of the R/V Brooks McCall.

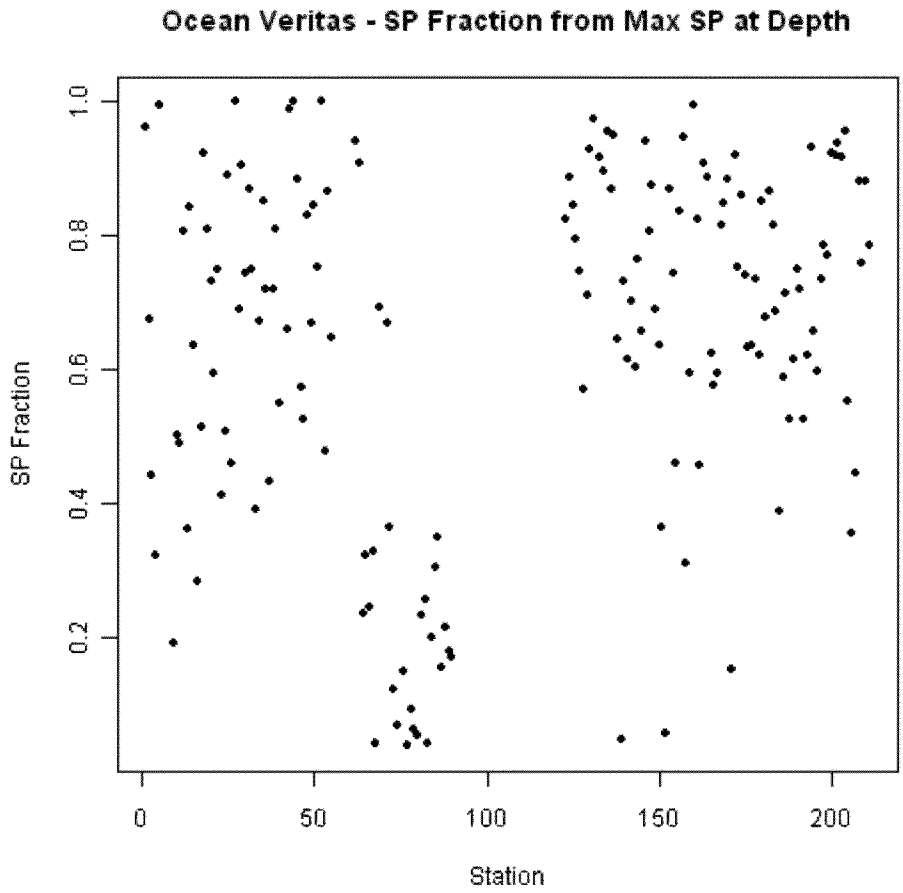

Figure 4: Small particle (d < 68.6 um) fraction of the total measured particles (2.5 – 157 um) for the peak sub-surface samples of all stations of the R/V Ocean Veritas.

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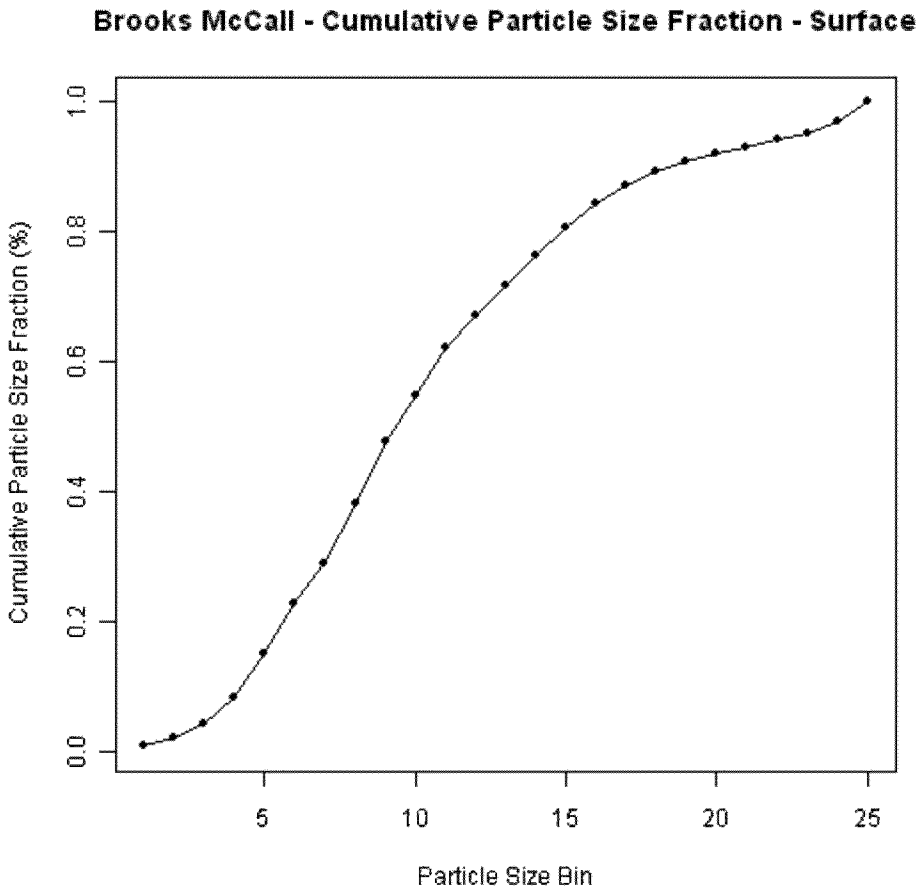

Figure 5: Cumulative particle-size distribution for all the surface samples of all stations of the R/V Brooks McCall.

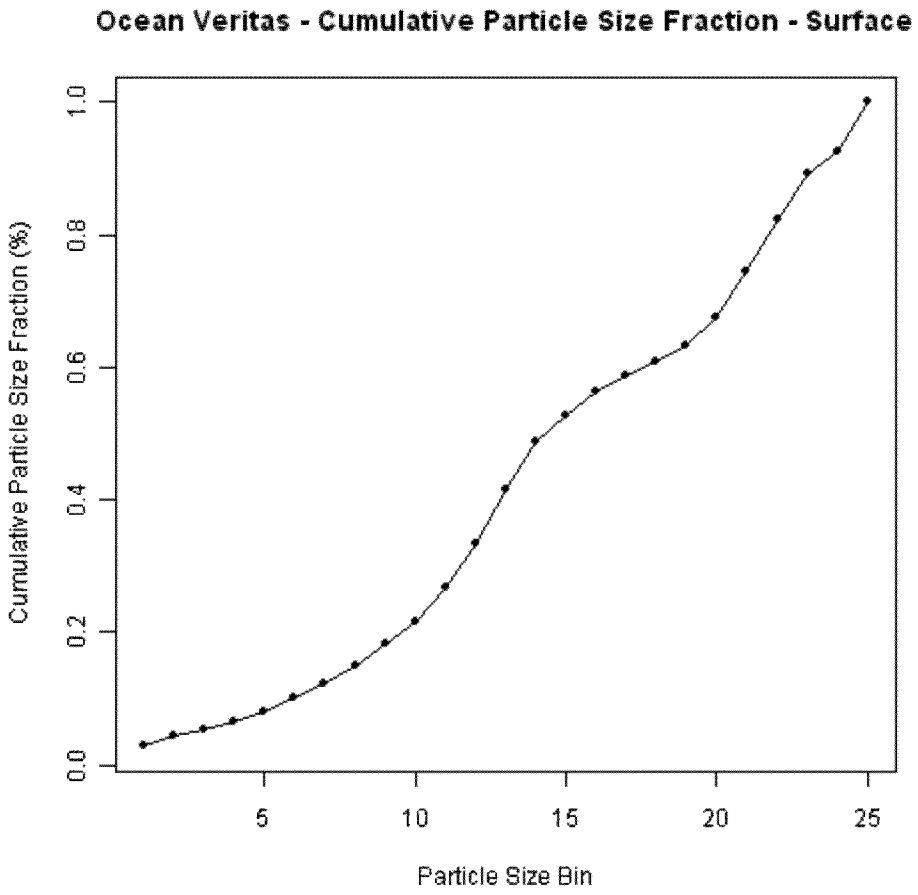

Figure 10: Cumulative particle-size distribution for all the surface samples of all stations of the R/V Ocean Veritas.

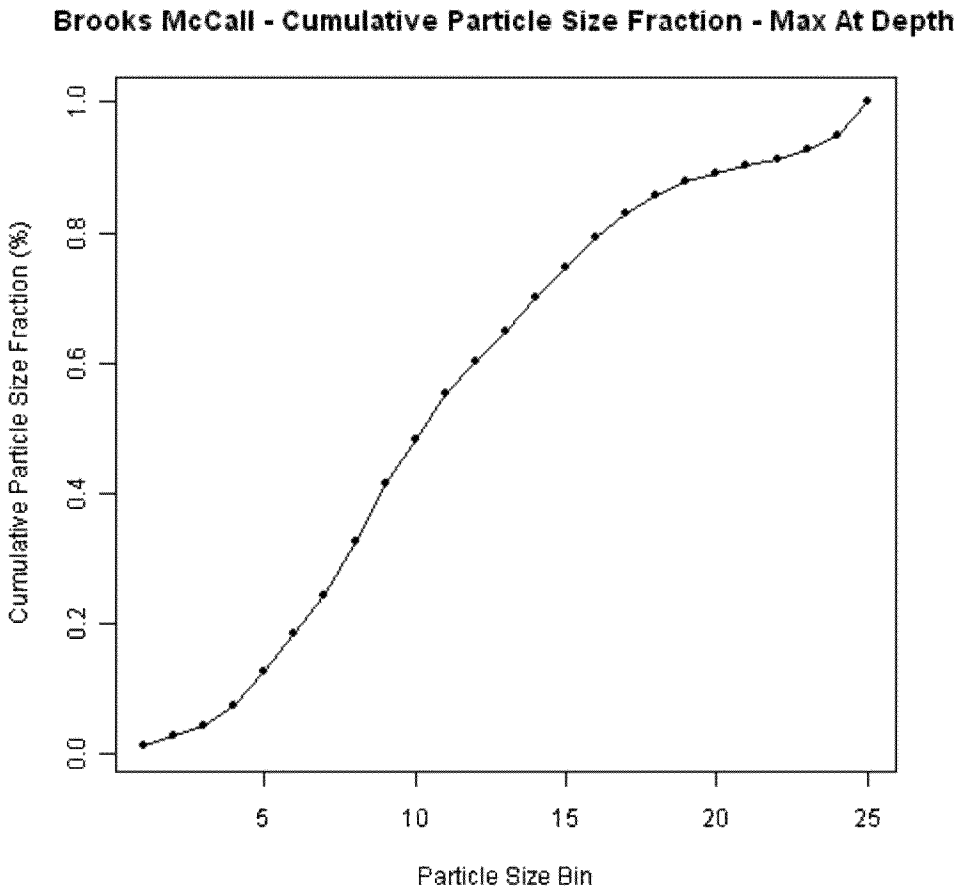

Figure 11: Cumulative particle-size distribution for all the peak sub-surface samples of all stations of the R/V Brooks McCall.

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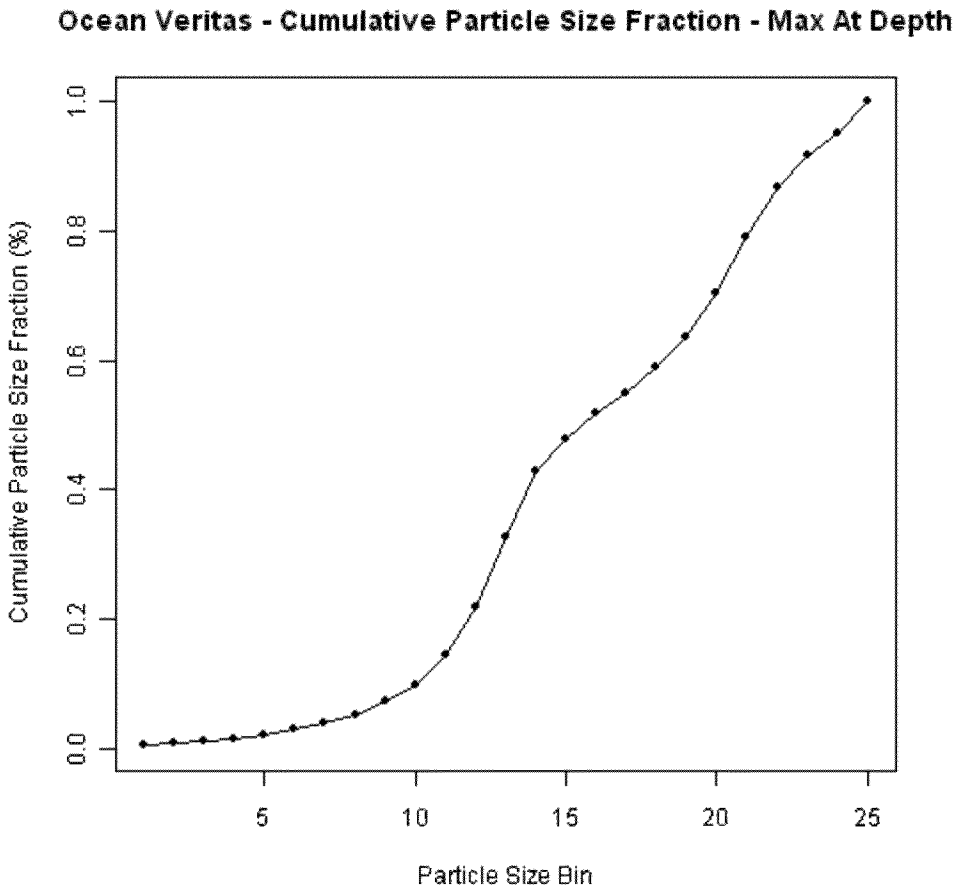

Figure 6: Cumulative particle-size distribution all the peak sub-surface samples of all stations of the R/V Ocean Veritas.

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Appendix 8

A8 Spill Related Properties of MC 252 Crude Oil Sample ENT-052210-178

For

BP

by

SL Ross Environmental Research Ltd.

July, 2010

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1. INTRODUCTION

When oil is spilled in the marine environment its physical and chemical properties will change over time through processes such as evaporation and emulsification. These changes will affect both the fate and behavior of the spill and the opportunities for using countermeasures effectively. For example, an oil may be relatively fluid and non-viscous when initially spilled, but may become viscous within a short time. It is important to know whether this will happen and how long it will take, defining the so-called Window of Opportunity for countermeasures.

The objective of this study was to conduct simulated oil spill weathering experiments on MC 252 ENT-052210-178 crude oil. The quantitative results of the tests (involving both fresh and weathered oil) can be used as input to most oil spill models that are used internationally to predict the fate and behavior of spills of specific oils.

2. PHYSICAL PROPERTY TESTS: METHODS AND RESULTS

The laboratory testing described here involved 2.7 L of the crude oil. The oil was subjected to the analyses outlined in Table 2-1. Test temperatures were chosen to cover the typical range of seasonal variation for the open water season in the target region. Temperature of 15°C and 35°C were chosen.

A discussion of the methodology of each of these tests is presented in Appendix A, along with an explanation of the effect that each oil property has on spill behavior.

The results of the weathering and analyses of the crude oil are presented separately in the following section. Complete test results can be found in Appendix B.

Table 2-1 Test Procedures for Spill-Related Analysis of MC 252 ENT-052210-178 Crude Oil

Property	*Test Temperature(s)*	*Equipment*	*Procedure*
Evaporation	Ambient	Wind TunnelASTM Distillation Apparatus	ASTM D86
Density	15° and 35°	Anton Paar Densitometer	ASTM D4052
Viscosity	15° and 35°	Brookfield DV III+ Digital Rheometer c/w Cone and Plate	Brookfield M/98-211
Interfacial Tension	Room Temperature	CSC DuNouy Ring Tensiometer	ASTM D971
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
Emulsification Tendency/Stability	15° and 35°	Rotating Flask Apparatus	(Mackay and Zagorski 1982; Hokstad and Daling 1993)

2.1 RESULTS

The results of the property analysis of MC 252 ENT-052210-178 are summarized in Table 2-2. The complete test results can be found in Appendix B. The two levels of evaporation noted in the table represent the amounts evaporated from a 2 cm-thick slick in the wind tunnel after two days and two weeks, respectively.

2.1.1 Evaporation

MC 252 ENT-052210-178 is a light crude with an API gravity of 37.2°. Approximately 35% of the oil evaporated after two days in the wind tunnel, and about 45% evaporated after two weeks of exposure.

Figure 2-1 is a predicted evaporation curve for a spill involving a 10-mm thick slick in a 5 knot wind at 25°C (77°F). Please note that the curve only applies at a water temperature of 25°C. If other temperatures (or slick thicknesses and wind speeds) are of interest, these curves can be generated using the equations in Appendix A and data in Appendix B[1]. Computerized oil spill models automatically do these calculations.

Figures 2-2, 2-3 and 2-4 show the effect of evaporation on the properties of oil viscosity, density and pour point.

[1] The evaporation curve of the oil in the wind tunnel is shown in Appendix B, plotting the volume fraction of oil evaporated, Fv, on the y-axis versus evaporative exposure, 2, on the x-axis, where 2 is the unit of time expressed in dimensionless form. Equations described in Appendix A and data in Table 2-2 of Appendix B can be used to convert this curve into a more usable form for estimating oil evaporation under various spill conditions of temperature, elapsed time and wind speed.

Table 2-2 Spill-Related Properties of MC252 Crude Oil

Spill-related properties	BP MC252 ENT-052210-178	API ° = 37.2	
Evaporation (Volume %)	0	34.50	44.66
Density (g/cm^3)			
15 °C	0.839	0.882	0.897
35 °C	0.825	0.868	0.883
Dynamic Viscosity (mPa.s)	at approx 460 s^{-1}		
15 °C	4.1	43	85
35 °C	1.4	10	23
Kinematic Viscosity (mm^2/s)			
15 °C	4.8	49	95
35 °C	1.7	12	26
Interfacial Tension (dyne/cm)			
Oil/ Air	23.5	26.8	30.1
Oil/ Seawater	23.3	22.6	22.5
Pour Point (°C)	<-9	6	6
Flash Point (°C)	<-8	54	100
Emulsion Formation-Tendency and Stability @		22.5 °C	
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content	0%	0%	0%
Emulsion Formation-Tendency and Stability @		34 °C	
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content	0%	0%	0%
ASTM Modified Distillation			
	Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
	IBP	84	39.8
	5	111.6	77.4
	10	124.4	91.7
	15	137	102.4
	20	151.2	115.8
	25	168.8	116
	30	188.2	126.4
	35	208	150
	40	227	129.7
	45	248	142.5

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\square\exp(C_2-C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
□ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 5472
C_2 = 12.90
C_3 = 5739

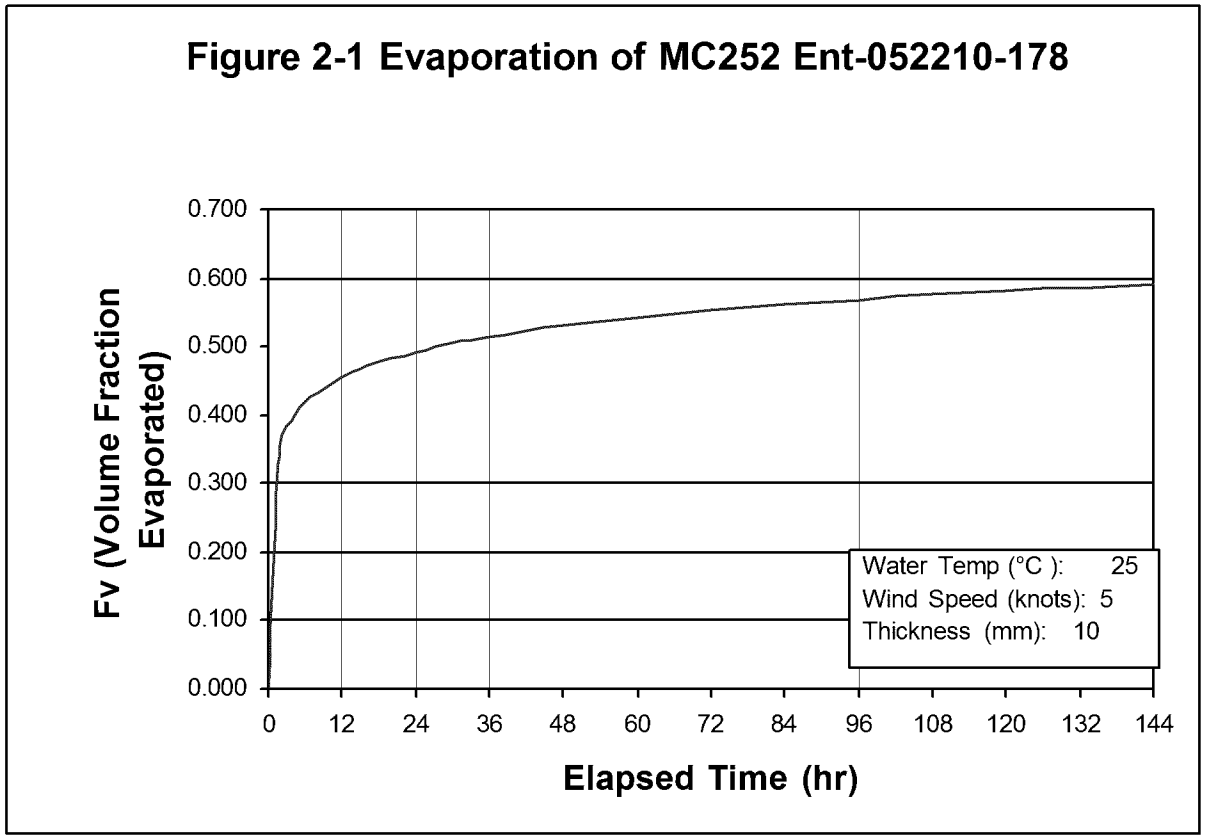
Figure 2-1 Evaporation of MC252 Ent-052210-178
Fv (Volume Fraction Evaporated)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
12
24
36
48
60
72
84
96
108
120
132
144
Elapsed Time (hr)
Water Temp (°C): 25
Wind Speed (knots): 5
Thickness (mm): 10

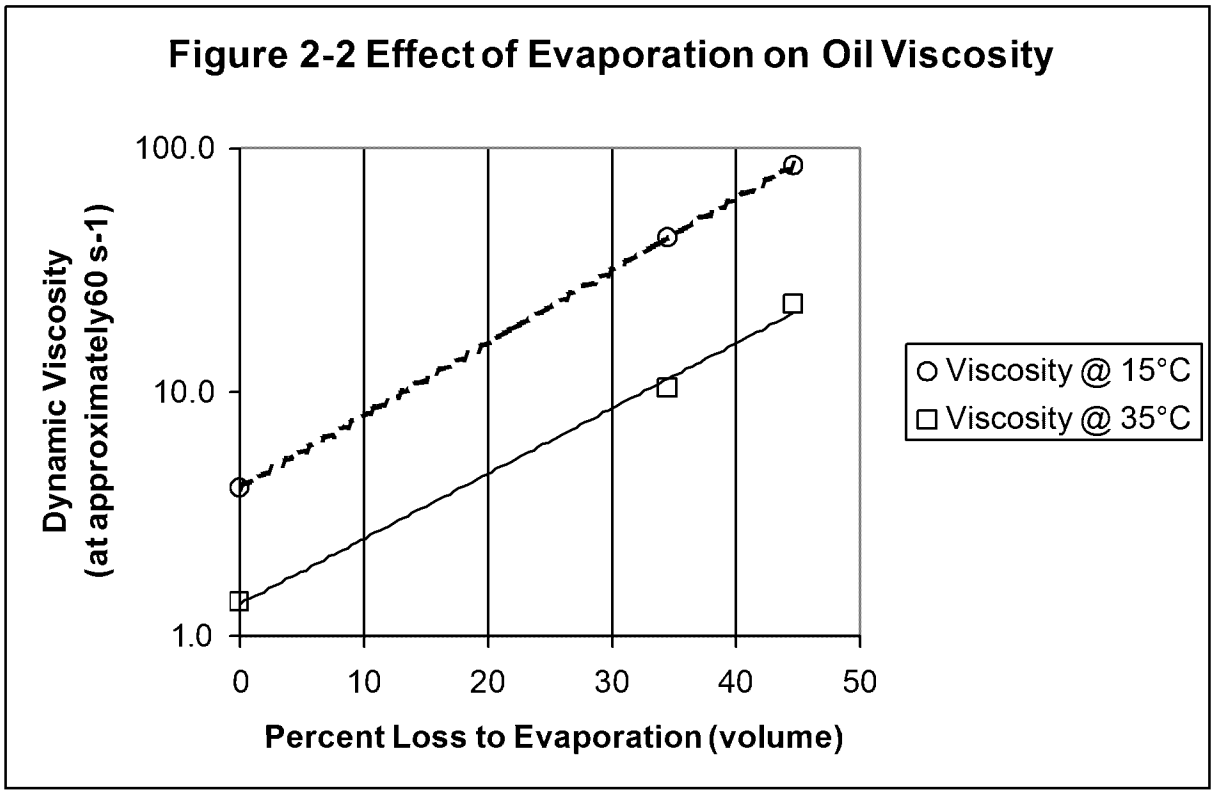
Figure 2-2 Effect of Evaporation on Oil Viscosity
Dynamic Viscosity (at approximately60 s-1)
100.0
10.0
1.0
0
10
20
30
40
50
Percent Loss to Evaporation (volume)
Viscosity @ 15°C
Viscosity @ 35°C

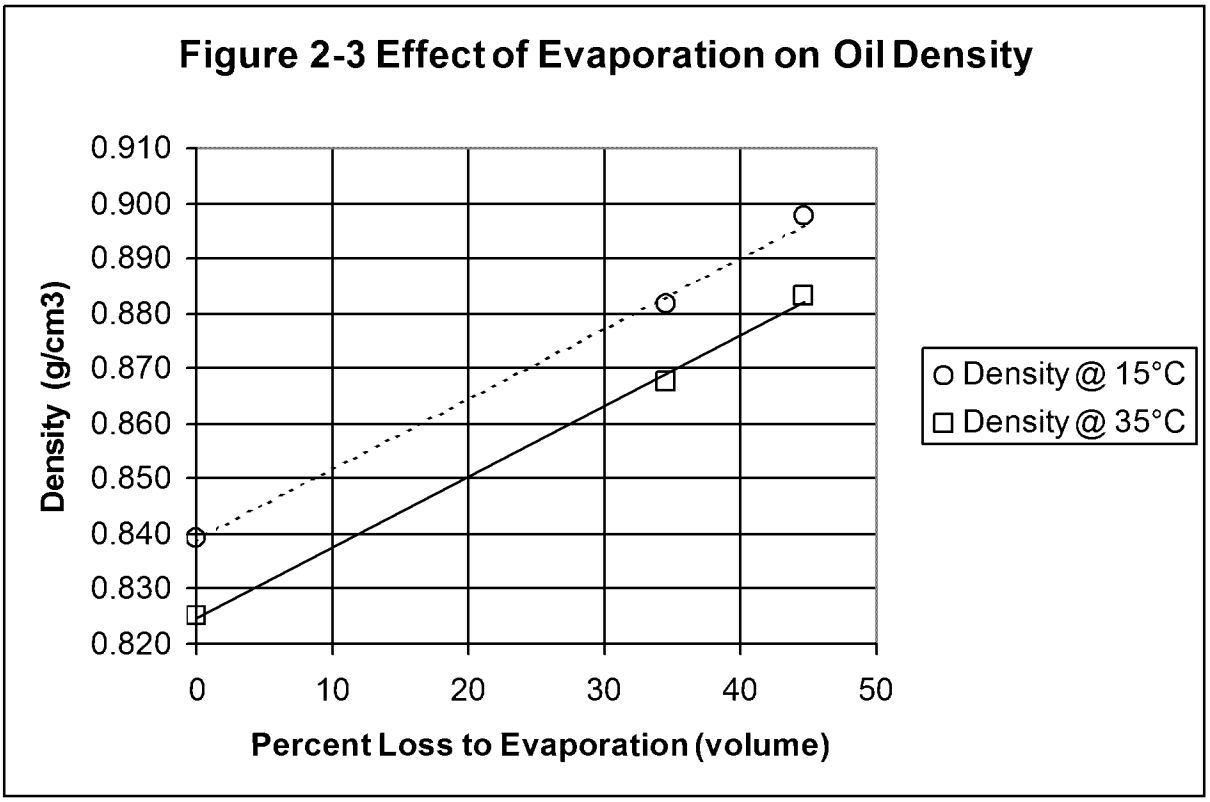
Figure 2-3 Effect of Evaporation on Oil Density
Density (g/cm3)
0.910
0.900
0.890
0.880
0.870
0.860
0.850
0.840
0.830
0.820
0
10
20
30
40
50
Percent Loss to Evaporation (volume)
Density @ 15°C
Density @ 35°C

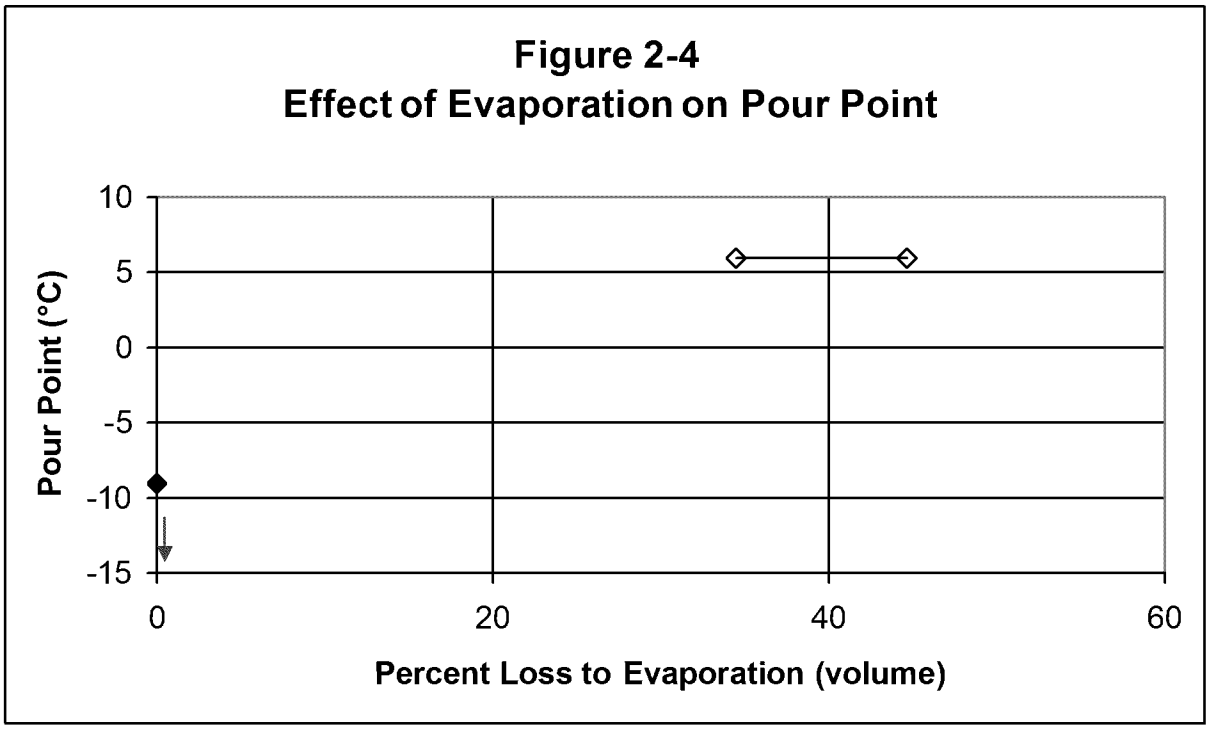
Figure 2-4
Effect of Evaporation on Pour Point
Pour Point (°C)
10
5
0
-5
-10
-15
0
20
40
60
Percent Loss to Evaporation (volume)

2.1.2 Density

MC 252 oil is a light crude oil, with a density of 0.839 g/cm^3 at 15°C (API gravity of 37.2°).

2.1.3 Viscosity

The oil has a very low viscosity that is typical of light oils. At 15°C the viscosity of the fresh oil is about 4.1 cP (mPa.s). The viscosity increases to 42.9 cP after 35% evaporation and to 85.1 cP after 45% evaporation. The crude oil exhibits minor non-Newtonian behavior (slightly pseudo-plastic, or shear-thinning, characteristics) at 15°C. It is a Newtonian fluid at 35°C.

2.1.4 Interfacial Tension

The oil/water interfacial tension of MC 252 ENT-052210-178 crude was measured using standard laboratory water with 35 ppt of salt. The value measured was 23.7 dynes/cm, which is in the range of most crude oils.

2.1.4 Pour Point

MC 252 ENT-052210-178 crude has a pour point of less than -9°C when fresh. This increases to 6°C at 35 and 45 percent evaporation.

2.1.5 Flash Point

MC 252 ENT-052210-178 has a low flash point (below -8°C) when fresh. This rises after 45% evaporation to 100°C.

2.1.6 Emulsification Tendency and Stability

From the viewpoint of spill countermeasures and slick persistence, emulsification is a very negative process because strongly emulsified oils are highly viscous — they can have ten to 100 times the viscosity of the parent oil. It is general believed that oils that have relatively high concentrations of asphaltenes are the most likely to form stable water-in-oil emulsions. Some oil spills do not form emulsion immediately, but once evaporation occurs and the asphaltene concentration increases, the emulsification process begins and usually proceeds quickly thereafter.

The MC 252 ENT-052210-178 crude oil has no tendency to form stable water-in oil emulsions when mixed with seawater. At sea, it is observed that MC 252 crude does eventually form stable emulsions. The reason that the ENT-052210-178 sample does not could be due to several factors:

- The ENT-052210-178 sample evaporated in the wind tunnel for two weeks is equivalent to only about 10 hours at sea for a 1-mm thick slick or 100 hours for a 10-mm thick slick and the onset of emulsification may not occur until greater degrees of evaporative exposure that this are reached.
- The sample may have been exposed to an anti-foaming agent and/or methanol during it's collection from the damaged riser by the RITT and this exposure may inhibit emulsification.

- Exposure to sunlight (not a part of the SL Ross weathering protocol) can produce photo-oxidation products that promote emulsification.

Enough of the two-week weathered sample from the wind tunnel remains to place a thinner slick back into the wind tunnel and further expose it to the equivalent of one week at sea for a 1-mm slick. The emulsification of this sample will then be measured. As well, during the earlier alternative field-testing program, surface samples of the slick were collected and shipped to the SL Ross lab. Aliquots of these will be subjected to the laboratory emulsification test to determine their emulsification characteristics.

3. REFERENCES

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APPENDIX A. OIL PROPERTY TEST METHODOLOGY AND RELATIONSHIP TO SPILL BEHAVIOR

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A.1 E VAPORATION

The oil was divided into three aliquots. Two aliquots were weathered in a wind tunnel: one for two days and one for two weeks. Depending on the conditions at a spill site, this is typically equivalent to a few hours and a few days at sea. In addition, the fresh oil was subjected to a modified ASTM distillation (ASTM D86-90, modified in that both liquid and vapor temperature are measured) in order to obtain two oil-specific constants for evaporation prediction purposes. Evaporation is correlated using Evaporative Exposure (θ), a dimensionless time unit calculated by:

$$\theta = kt/x$$

where: k = a mass transfer coefficient [m/s] *(determined experimentally in the laboratory wind tunnel or by an equation related to wind speed for spills at sea)*
t = elapsed time [s]
x = oil thickness [m]

The distillation information is used in conjunction with the wind tunnel data to predict evaporation rates for oil spills at sea.

A.2 P HYSICAL PROPERTIES

The oils were subjected to the analyses outlined in Table 1. Test temperatures are chosen to represent typical values for the region for those tests that are temperature-sensitive, such as density and viscosity.

Table 1: Test procedures for oil analysis

Property	Test Temperature(s)	*Equipment*	Procedure
Evaporation	Ambient	Wind Tunnel ASTM Distillation Apparatus	ASTM D86
Density	15° and 35 °C	Anton Paar Densitometer	ASTM D4052
Viscosity	15° and 35 °C	Brookfield DV III+ Digital Rheometer c/w Cone and Plate	Brookfield M/98-211
Interfacial Tension	Room Temperature	CSC DuNouy Ring Tensiometer	ASTM D971
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
Emulsification Tendency/Stability	15° and 35 °C	Rotating Flask Apparatus	(Mackay and Zagorski 1982; Hokstad and Daling 1993)

A.2.1 Density

Density, the mass per unit volume of the oil (or emulsion), determines how buoyant the oil is in water. The common unit of density is grams per millilitre or cubic centimetre (g/mL or g/cm^3); the SI unit is kg/m^3, which is numerically 1000 times the value in g/mL. The density of spilled crude oil increases with weathering and decreases with increasing temperature. Density affects the following spill processes:

- Sinking - if the density of the oil exceeds that of the water it will sink;
- Spreading - in the early stages of a spill, more dense oils spread faster;
- Natural dispersion - more dense oils stay dispersed more easily; and,
- Emulsification stability - dense oils form more stable emulsions.

A.2.2 Viscosity

Viscosity is a measure of the resistance of oil to flowing, once it is in motion. The common unit of dynamic viscosity is the centi-Poise (cP); the SI unit is the milli-Pascal second (mPas), which is numerically equivalent to the centi-Poise. The common unit of kinematic viscosity (calculated by multiplying the dynamic viscosity by the density) is the centi-Stoke (cSt) the SI unit is the square millimetre/second (mm^2/s), which is numerically equivalent to the centi-Stoke. The viscosity of spilled crude oil increases as weathering progresses and decreases with increasing temperature. Viscosity is one of the most important properties from the perspective of spill behavior and affects the following processes:

- Spreading - viscous oils spread more slowly;
- Natural and chemical dispersion - highly viscous oils are difficult to disperse;
- Emulsification tendency and stability - viscous oils form more stable emulsions; and,
- Recovery and transfer operations - more viscous oils are generally harder to skim and more difficult to pump.

A.2.3 Interfacial Tension

Interfacial tension is a measure of the surface forces that exist between the interfaces of the oil and water, and the oil and air. The common unit of interfacial tension is the dyne/cm; the SI unit is the milli-Newton/metre (mN/m), which is numerically equivalent to the dyne/cm. Chemical dispersants work by reducing the oil/water interfacial tension to allow a given mixing energy (i.e., sea state) to produce smaller oil droplets. Emulsion breakers also work by lowering the oil/water interfacial tension; this weakens the continuous layer of oil surrounding the suspended water droplets and allows them to coalesce and drop out of the emulsion. Interfacial tensions (oil/air and oil/water) are fairly insensitive to temperature, but are affected by evaporation. Interfacial tension affects the following processes:

- Spreading - interfacial tensions determine how fast an oil will spread and whether the oil will form a sheen;
- Natural and chemical dispersion - oils with high interfacial tensions are more difficult to disperse naturally, chemical dispersant work by temporarily reducing the oil/water interfacial tension;
- Emulsification rates and stability; and,

- Mechanical recovery - oleophilic skimmers (e.g., rope-mop and belt skimmers) work best on oils with moderate to high interfacial tensions.

A.2.4 Pour Point

The pour point is the lowest temperature (to the nearest multiple of 3 °C) at which crude oil will still flow in a small test jar tipped on its side. Near, and below this temperature, the oil develops a yield stress and, in essence, gels. The pour point of an oil increases with weathering. Pour point affects the following processes:

- Spreading - oils at temperatures below their pour points will not spread on water;
- Viscosity - an oil's viscosity at low shear rates increases dramatically at temperatures below its pour point;
- Dispersion - an oil at a temperature below its pour point may be difficult to disperse; and,
- Recovery - crude oil below its pour point may not flow towards skimmers or down inclined surfaces in skimmers

A.2.5 Flash Point

The flash point of crude oil is the temperature at which the oil produces sufficient vapors to ignite when exposed to an open flame or other ignition source. Flash point increases with increasing evaporation. It is an important safety-related spill property.

A.2.6 Emulsification Tendency and Stability

The tendency of crude oil to form water-in-oil emulsions (or "mousse") and the stability of the emulsion formed are measured by two numbers: the Emulsification Tendency Index (Zagorski and Mackay 1982, Hokstad and Daling 1993) and the Emulsion Stability (adapted from Fingas *et al.* 1998). The Emulsification Tendency Index is a measure of the oil's propensity to form an emulsion, quantified by extrapolating back to time = 0 the fraction of the parent oil that remains (i.e., does not cream out) in the emulsion formed in a rotating flask apparatus over several hours. If a crude oil has an Emulsification Tendency Index between 0 and 0.25 it is unlikely to form an emulsion; if it has a Tendency Index between 0.25 and 0.75 it has a moderate tendency to form emulsions. A value of 0.75 to 1.0 indicates a high tendency to form emulsions. Recently the Emulsion Stability assessment has been changed to reflect the four categories suggested by Fingas *et al.* 1998. Emulsion types are selected based on water content, emulsion rheology and the visual appearance of the emulsion after 24 hours settling. The four categories, and their defining characteristics, are:

1. Unstable – looks like original oil; water contents after 24 hours of 1% to 23% averaging 5%; viscosity same as oil on average
2. Entrained Water – looks black, with large water droplets; water contents after 24 hours of 26% to 62% averaging 42%; emulsion viscosity 13 times greater than oil on average
3. Meso-stable – brown viscous liquid; water contents after 24 hours of 35% to 83% averaging 62%; emulsion viscosity 45 times greater than oil on average
4. Stable – the classic "mousse", a brown gel/solid; water contents after 24 hours of 65% to 93% averaging 80%; emulsion viscosity 1100 times greater than oil on average

Under the old emulsion stability assessment scheme, the stability was determined by the fraction of the original oil that remained in the emulsion after 24-hours settling (0 to 0.25 = unstable, 0.25 to 0.75 = fairly stable, 0.75 to 1 = very stable).

Both the Tendency Index and Stability generally increase with increased degree of evaporation. Colder temperatures generally increase both the Tendency Index and Stability (i.e., promote emulsification) unless the oil gels as the temperature drops below its pour point and it becomes too viscous to form an emulsion. Emulsion formation results in large increases in the spill's volume, enormous viscosity increases (which can reduce dispersant effectiveness), and increased water content (which can prevent ignition of the slicks and *in situ* burning).

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APPENDIX B. OIL PROPERTY ANALYSIS RESULTS FOR MC 252 ENT-052210-178 CRUDE OIL

Oil Weathering

BP MC252 ENT-052210-178

	Tray 7	Tray 8	Average Air Temp	
Tray Mass (g)	240.4	240.8	24.7	°C

Volume Weathered(ml)	970
Volume for 2cm thick	969.50
Tray thickness (m)	0.02001031

Date/Time	Mass of Oil + Tray Tray 7 (g)	Mass of Oil + Tray Tray 8 (g)	Mass of Oil Tray 7 (g)	Mass of Oil Tray 8 (g)	Fm Tray 7	Fm Tray 8	Oil Density (g/cm^3)	Fv Tray 7	Fv Tray 8
07/06/2010 17:17	1032.7	1040.2	792.3	799.4	0.000	0.000	0.832	0.000	0.000
07/06/2010 17:50	1001.2	1009.5	760.8	768.7	0.040	0.038	0.837	0.046	0.045
07/06/2010 19:00	963.1	971.6	722.7	730.8	0.088	0.086	0.844	0.101	0.099
07/06/2010 19:30	949.0	957.7	708.6	716.9	0.106	0.103	0.847	0.121	0.119
07/06/2010 22:35	927.1	936.0	686.7	695.2	0.133	0.130	0.850	0.152	0.149
08/06/2010 10:30	833.6	839.6	593.2	598.8	0.251	0.251	0.868	0.282	0.282
08/06/2010 19:30	815.1	822.3	574.7	581.5	0.275	0.273	0.871	0.307	0.305
09/06/2010 10:22	795.8	800.7	555.4	559.9	0.299	0.300	0.874	0.333	0.334
09/06/2010 17:10	786.8	791.8	546.4	551.0	0.310	0.311	0.876	0.345	0.345
10/06/2010 10:13		776.3		535.5		0.330	0.879		0.366
11/06/2010 13:45		763.3		522.5		0.346	0.881		0.383
14/06/2010 13:16		742.2		501.4		0.373	0.885		0.410
16/06/2010 9:48		732.0		491.2		0.386	0.887		0.423
17/06/2010 11:15		728.4		487.6		0.390	0.887		0.428
21/06/2010 16:45		713.9		473.1		0.408	0.890		0.447

Fv vs. Theta Modeling

Evaporative Exposure (Corrected)	Model Evaporate (Fv)
0.0	0.000
199.0	0.108
621.1	0.165
802.0	0.178
1917.5	0.224
6228.9	0.288
9485.1	0.311
14863.8	0.335
17324.0	0.343
23492.6	0.360
33454.1	0.379
59328.6	0.410
75440.6	0.423
84648.3	0.429
121370.6	0.449

	2-day	2-week
Fm	0.310	0.408

	2-day	2-week
Fv	0.345	0.447

Density **BP MC252 ENT-052210-178**

Measurements

Mass Evaporated (Fm)	Density (g/cm^3)	Temperature (°C)
0	0.838	16.6
0	0.823	37.8
0.31	0.880	17.3
0.31	0.866	37.4
0.41	0.896	17.1
0.41	0.881	38.2
0	0.832	24.69
0.31	0.875	24.69
0.41	0.891	24.69

slope	0.142
intercept	0.832
r^2	0.999

Density Constants for SL Ross Model

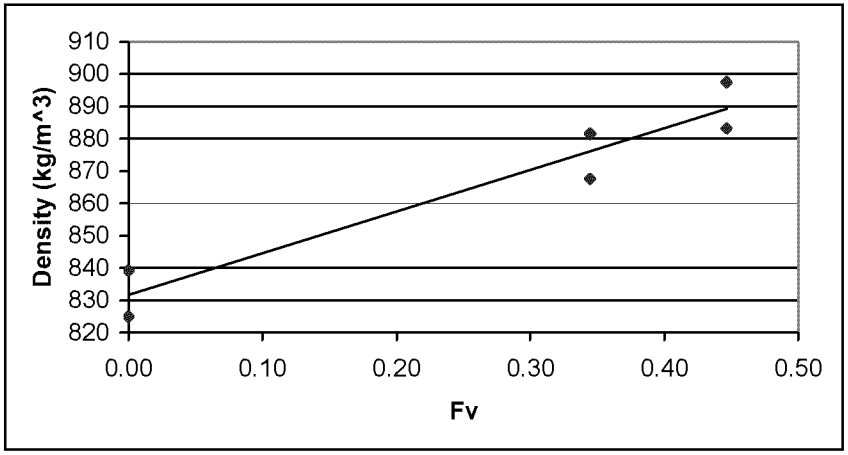
Density Constant 1 (slope, kg/m^3)	128.770
Density Constant 2 ($kg/K.m^3$)	0.705

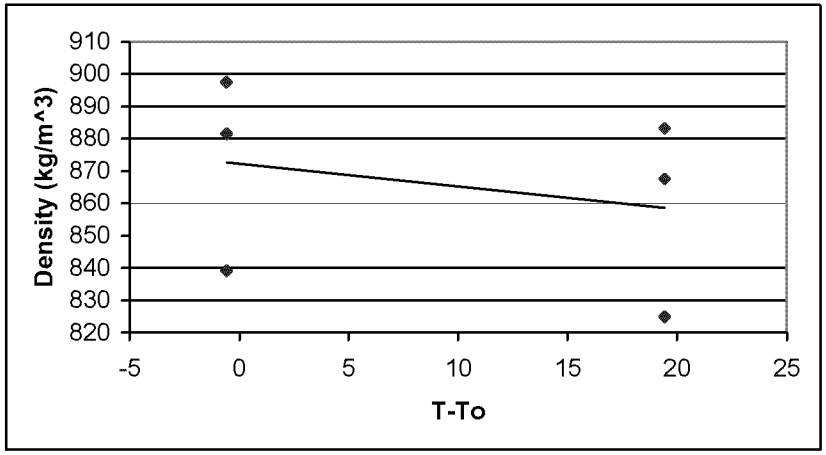
API Gravity

Standard Density Temperature, To (K)	288.72
Standard Density (kg/m^3)	838.736
API Gravity @ 15.5°C	37.21

Calculations

Temperature (°C)	Density (g/cm^3)	Density (kg/m^3)	Volume Evaporated (Fv)	T-To (K)
15	0.839	839	0	-0.56
15	0.882	882	0.345	-0.56
15	0.897	897	0.447	-0.56
35	0.825	825	0	19.44
35	0.868	868	0.345	19.44
35	0.883	883	0.447	19.44
15.5	0.897	897	0.000	





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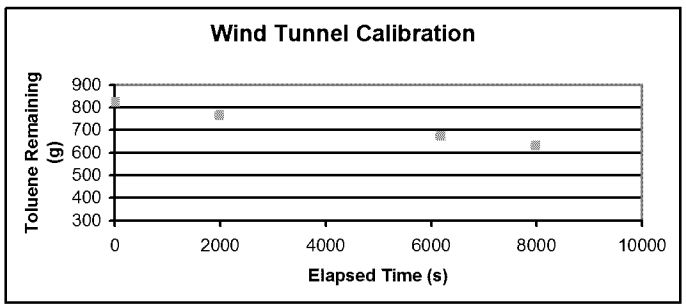
Wind Tunnel Calibration **Toluene**

Tray Mass (g)

Elapsed Time (s)	Mass Toluene Tray 9 (g)	Tray 6
0	825.0	829.2
1980	765.3	776.1
6180	673.2	686.7
7980	630.7	645.7
19080	549.1	567.0

	Tray 9	Tray 6	Average
slope	-0.01384046	-0.013238	-0.013539

E (kg/s)	-1.3539E-05		
Wind Tunnel Temperature, T (K)	297.8499	24.69	°C
Toluene Vapor Pressure, P (kPa)	3.733		
Ideal Gas Constant (R, kPa.m^3/kg.mol.K)	8.314		
Molecular Weight of Toluene (W, kg/kg.mol)	92.13		
Tray Area (A, m^2)	0.048475		
K = ERT/APW (m/s)	-0.002011016		



ASTM Distillation **BP MC252 ENT-052210-178**

200 ml Fresh oil

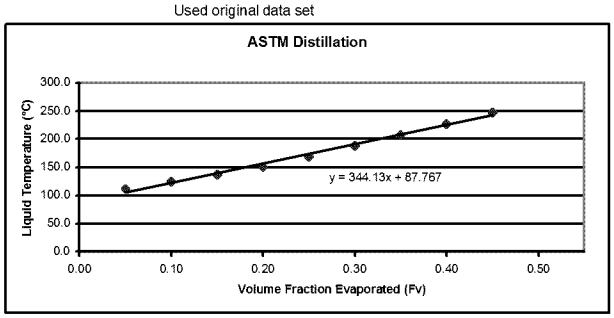
Water Subtracted

Volume Distilled (mL)	Fraction Distilled (Fv)	Temperature Liquid (°C)	Vapor (°C)
IBP	0.00	84.0	39.8
10	0.05	111.6	77.4
20	0.10	124.4	91.7
30	0.15	137.0	102.4
40	0.20	151.2	115.8
50	0.25	168.8	116.0
60	0.30	188.2	126.4
70	0.35	208.0	150.0
80	0.40	227.0	129.7
90	0.45	248.0	142.5

slope	344.1
intercept	87.8

Distillation Constant A (slope, K)	344.1
Distillation Constant B (intercept, K)	360.9

Used original data set



Mackay Constants **BP MC252 ENT-052210-178**
(automated)

Point	Fv	Tb/T	H	ln(H)
1	0.022	1.238	2.244E-04	-8.402
2	0.072	1.295	1.287E-04	-8.958
3	0.109	1.338	1.089E-04	-9.125
4	0.134	1.367	2.737E-05	-10.506
5	0.215	1.461	3.071E-05	-10.391
6	0.293	1.551	7.128E-06	-11.851
7	0.319	1.581	5.345E-06	-12.139
8	0.339	1.604	4.785E-06	-12.250
9	0.356	1.623	3.308E-06	-12.619
10	0.374	1.644	1.708E-06	-13.280
11	0.396	1.670	1.060E-06	-13.757
12	0.417	1.693	8.178E-07	-14.017
13	0.426	1.704	5.036E-07	-14.501

	calculated	adjusted
Fv vs. Theta B (-slope)	12.30515	15.9
Fv vs. Theta A (intercept)	7.032316	12.9

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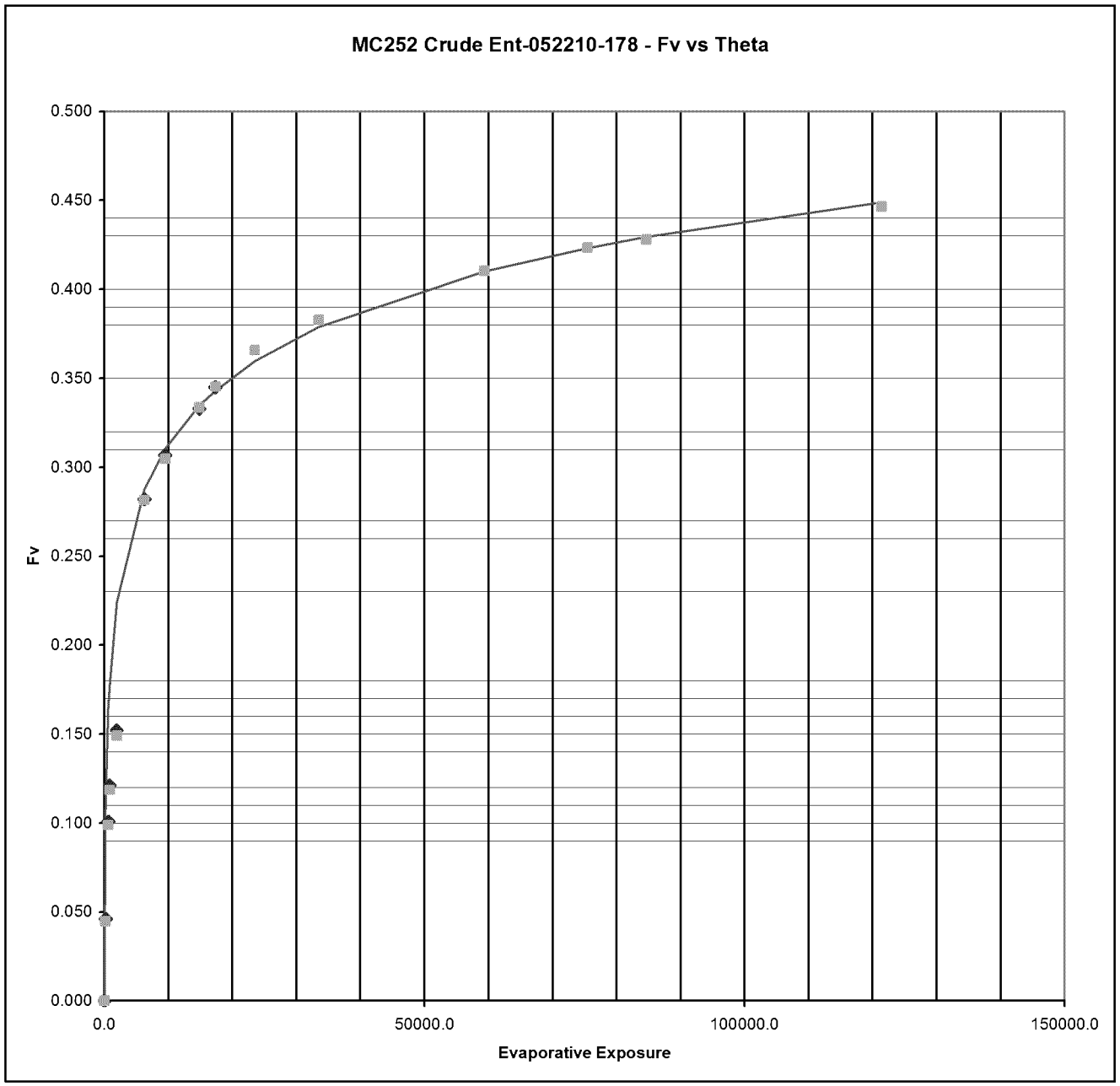

MC252 Crude Ent-052210-178 - Fv vs Theta
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
Fv
0.0
50000.0
100000.0
150000.0
Evaporative Exposure

Viscosity **BP MC252 ENT-052210-178**

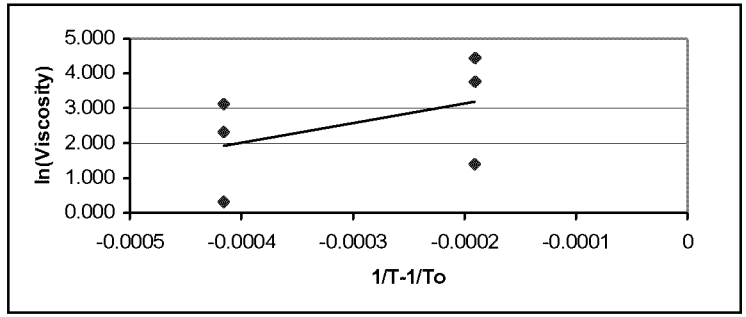
Mass Evaporated (Fm)	Viscosity (cP)	Temperature (°C)	rpm	Spindle #	Shear Rate (s^{-1})	ln(Viscosity)
0	4.1	15.0	120.0	CP-42	461.0	1.399
0	1.4	35.0	120.0	CP-42	461.0	0.329
0.31	42.9	15.0	120.0	CP-42	461.0	3.759
0.31	10.3	35.0	120.0	CP-42	461.0	2.332
0.41	85.1	15.0	120.0	CP-42	461.0	4.444
0.41	22.8	35.0	120.0	CP-42	461.0	3.127

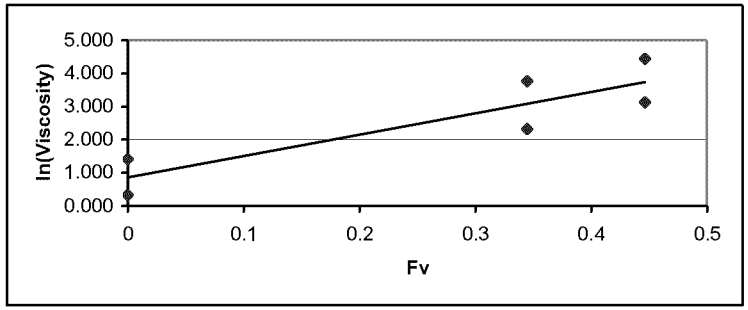
Volume Evaporated (Fv)	Viscosity (cP)	Temperature (°C)	ln(Viscosity)	1/T-1/To (K^{-1})
0	4.1	15.0	1.399	-0.000190564
0	1.4	35.0	0.329	-0.000415685
0.34	42.9	15.0	3.759	-0.000190443
0.34	10.3	35.0	2.332	-0.000415685
0.45	85.1	15.0	4.444	-0.000190443
0.45	22.8	35.0	3.127	-0.000415685

Volume Evaporated (Fv)	Viscosity 1°C (cP)	Viscosity 15°C (cP)
0	4.1	1.4
0.34	42.9	10.3
0.45	85.1	22.8

Viscosity Constants for SL Ross Model

Standard Viscosity Temperature (K)	273.16
Standard Viscosity (cP)	9.03
Viscosity Constant 1	6.49
Viscosity Constant 2 (K^{-1})	5646.99





Pour Point — BP MC252 ENT-052210-178

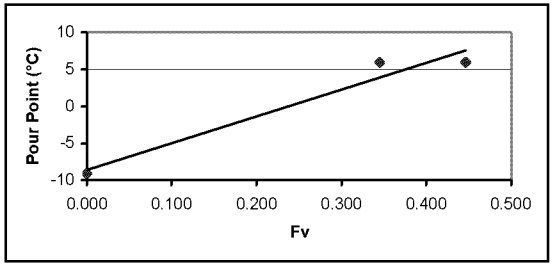
Test Results

Fv	Pour Point Measured (°C)	Pour Point Reported (°C)	
0.000	<-10	-9	less than
0.345	5	6	
0.447	5	6	

slope 36.11327
intercept -8.528878

Pour Point Constants for SLR Spill Model

Initial Pour Point (K)	264.6211
Pour Point Constant	0.136472



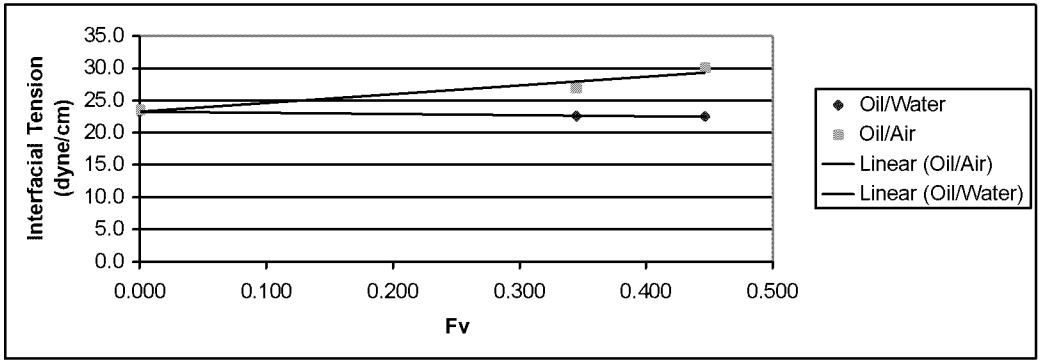
Interfacial Tension — BP MC252 ENT-052210-178

Fv	Interfacial Tension Oil/Water (dyne/cm)	Interfacial Tension Oil/Air (dyne/cm)	Dial Reading Oil/Water (dyne/cm)	Dial Reading Oil/Air (dyne/cm)	Correction Factor (F) Oil/Water	Correction Factor (F) Oil/Air
0.000	23.3	23.5	23.7	26.4	0.985	0.893
0.345	22.6	26.8	22.4	30.0	1.007	0.896
0.447	22.5	30.1	22.1	33.4	1.019	0.900

slope	-1.841	13.365
intercept	23.273	23.300

Interfacial Tension Constants for SL Ross Model

Oil/Water Interfacial Tension (dyne/cm)	23.273
Oil/Water Interfacial Tension Constant	-0.079
Oil/Air Interfacial Tension (dyne/cm)	23.300
Oil/Air Interfacial Tension Constant	0.574



Flash Point — BP MC252 ENT-052210-178

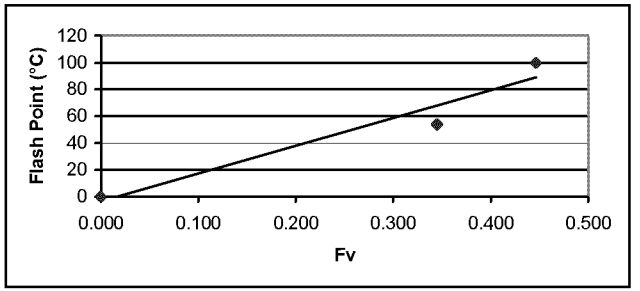
Test Results

Fv	Flash Point (°C)
0.000	<-8
0.345	54
0.447	100

slope 452.664693
intercept 170.989269

Flash Point Constants for SLR Spill Model

Initial Flash Point (K)	170.989
Flash Point Constant	2.647



SL Ross Model — BP MC252 ENT-052210-178

Modeling Constants

Standard Density	838.736	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	128.770	kg/m3
Density Constant 2	0.70499	kg/K.m3
Standard Viscosity	9.03203	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	6.4856	
Viscosity Constant 2	5646.99	K-1
Oil/Water Interfacial Tension	23.2729	dyne/cm
Air/Oil Interfacial Tension	23.3002	dyne/cm
Oil/Water Interfacial Tension Constant	-0.07910	
Air/Oil Interfacial Tension Constant	0.57362	
Initial Pour Point	264.621	K
Pour Point Constant	0.13647	
ASTM Distillation Constant A (slope)	344.133	K
ASTM Distillation Constant B (intercept)	360.927	K
Emulsification Delay	9999999999	
Initial Flash Point	170.989	K
Flash Point Constant	2.64733	
Fv vs. Theta A	12.90000	
Fv vs. Theta B	15.90000	
B.Tg	5471.72	
B.To	5738.73	

Emulsification Formation - Tendency and Stability **BP MC252 ENT-052210-178**

Emulsification Tendency and Stability - 23°C

Test Results		
300ml H2C	22.5	°C
oil @	39.0	°C
mixing don	22.7	°C
settling dor	22.7	°C
Final 24 hr	22.7	°C

two replicates of each oil

		Fresh Oil				Weathered Two Days				Weathered Two Weeks			
	All measurements in mm	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil
	Start	0	10	0	10	0	10	0	10	0	10	0	10
	After first hour mixing	10	0	10	0	11	0	11	0	10	0	10	0
	plus 10 minutes	0	9	0	9	10	0	0	9	0	9	10	0
	plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	After second hour mixing	0	9	0	9	10	0	10	0	10	0	10	0
	plus 10 minutes	0	9	0	9	0	9	10	0	10	0	10	0
	plus 20 minutes	0	9	0	9	0	9	10	0	10	0	10	0
	plus 30 minutes	0	9	0	9	0	9	10	0	0	9	10	0
	After third hour mixing	0	8	0	9	10	0	10	0	10	0	10	0
	plus 10 minutes	0	9	0	9	10	0	10	0	0	9	0	9
	plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	After fourth hour mixing	0	9	0	9	10	0	10	0	10	0	10	0
	plus 10 minutes	0	9	0	9	0	9	0	9	10	0	10	0
	plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
	plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
Appearance	Brown solid	0		0		0		0		0		0	
	Brown viscous liquid	X		X		X		X		X		X	
	Black with large droplets	0		0		0		0		0		0	
	Looks like oil	X		X		X		X		X		X	
	plus 24 hour	0	9	0	9	0	9	0	9	0	9	0	9

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content (after 24 hr)	0%	0%	0%

Emulsification Tendency and Stability - 35°C

Test Results

300ml H2C	34.0 °C
oil @	40.0 °C
mixing don	36.0 °C
settling dor	22.0 °C
Final 24 hr	36.0 °C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil
Start	0	0	0	10	0	10	0	10	0	10	0	10
After first hour mixing	0	9	0	9	0	9	0	9	0	9	0	9
plus 10 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
After second hour mixing	0	9	0	9	0	9	0	9	0	9	0	9
plus 10 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
After third hour mixing	0	9	0	9	0	9	0	9	0	9	0	9
plus 10 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
After fourth hour mixing	0	9	0	9	0	9	0	9	0	9	0	9
plus 10 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 20 minutes	0	9	0	9	0	9	0	9	0	9	0	9
plus 30 minutes	0	9	0	9	0	9	0	9	0	9	0	9
Appearance: Brown solid	0		0		0		0		0		0	
Appearance: Brown viscous liquid	0		0		0		0		0		0	
Appearance: Black with large droplets	0		0		0		0		0		0	
Appearance: Looks like oil	X		X		X		X		X		X	
plus 24 hour	0	9	0	9	0	9	0	9	0	9	0	9

note: 0

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content (after 24 hr)	0%	0%	0%

Viscosity Measurements with Brookfield DV-III+ Rheometer

Nominal Test Temperature	15.0				35.0			
	Viscosity	RPM	Spindle	Shear Rate	Viscosity	RPM	Spindle	Shear Rate
Fresh	4.1	120.0	CP-42	461.0	1.4	120.0	CP-42	461.0
2 Day Weathered	42.9	120.0	CP-42	461.0	10.3	120.0	CP-42	461.0
2 Week Weathered	85.1	120.0	CP-42	461.0	22.8	120.0	CP-42	461.0

	Spindle	RPM	% Torque	Viscosity cP	Shear Rate	Temp °C	
Fresh	CP-42	15	0.3	2.6	57.6	14.9	
		30	0.8	3.4	115.0	14.9	
		45	1.5	3.7	173.0	14.9	
		60	1.8	3.8	230.0	14.9	
		90	2.8	4.0	346.0	14.9	
		120	3.8	4.1	461.0	14.9	<===
		180	5.8	4.1	691.0	14.9	
		250	8.1	4.2	960.0	14.9	
2 Day Weathered	CP-42	15	6.8	58.0	57.6	14.9	
		30	12.3	52.5	17.4	14.9	
		45	17.4	49.5	173.0	14.9	
		60	22.3	47.6	230.0	14.9	
		90	31.5	44.8	346.0	14.9	
		120	40.2	42.9	461.0	14.9	<===
		180	57.0	40.5	691.0	14.9	
		250	75.6	38.7	960.0	14.9	
2 Week Weathered	CP-42	15	15.1	128.9	57.6	15.1	
		30	26.9	114.8	115.0	15.1	
		45	37.1	105.5	173.0	15.0	
		60	46.3	98.8	230.0	15.0	
		90	63.7	90.6	346.0	15.0	
		120	79.8	85.1	461.0	15.0	<===
		180	-over-	-over-	691.0	15.1	
Fresh	CP-42	15	0.1	0.9	57.6	35.0	
		30	0.2	0.9	115.0	35.0	
		45	0.5	1.4	173.0	35.0	
		60	0.7	1.5	230.0	35.0	
		90	1.0	1.4	346.0	35.0	
		120	1.3	1.4	461.0	35.0	<===
		180	2.2	1.6	691.0	35.0	
		250	3.0	1.5	960.0	35.0	
2 Day Weathered	CP-42	15	1.2	10.2	57.6	35.0	
		30	2.4	10.2	115.0	35.0	
		45	3.7	10.5	173.0	35.0	
		60	4.9	10.5	230.0	35.0	
		90	7.3	10.4	346.0	35.0	
		120	9.7	10.3	461.0	35.0	<===
		180	14.4	10.2	691.0	35.0	
		250	19.9	10.2	960.0	35.0	
2 Week Weathered	CP-42	15	2.8	23.9	57.6	35.0	
		30	5.5	23.5	115.0	35.0	
		45	8.3	23.6	173.0	35.0	
		60	10.9	23.3	230.0	35.0	
		90	16.1	22.9	346.0	35.0	
		120	21.4	22.8	461.0	35.0	<===
		180	31.6	22.5	691.0	35.0	
		250	43.4	22.2	960.0	35.0	

Appendix 9

A9 Expert Resumes

Mr. Alan A. Allen has over 43 years experience as a technical advisor and field supervisor involving hundreds of oil spills around the world. He has developed specialized strategies and equipment for the prevention, surveillance and control of oil spills; and he has conducted many hundreds of oil spill training courses under arctic, temperate and tropical conditions. Mr. Allen is listed as a technical advisor for emergency response to oil spills in numerous emergency response plans worldwide. A few of the spills on which he has worked include the Santa Barbara blowout (1969), the Mizushima tank failure in Japan (1974), the *Ixtoc* blowout off Mexico (1979), the *Exxon Valdez* grounding (1989), the Gulf of Arabia war-related spills (1991), the *Sea Prince* grounding off South Korea (1995), the Deepwater Horizon blowout in the Gulf of Mexico (2010), and a number of pipeline spills onshore and in wetlands.

Dr. Michel Boufadel is Professor and Chair of the Department of Civil and Environmental Engineering at Temple University, Philadelphia, Pennsylvania, USA. He is a Professional Engineer (Environmental Engineering) in the Commonwealth of Pennsylvania (USA). He is also a Professional Hydrologist (hydrogeology) as accredited by the American Institute of Hydrology (USA). His area of expertise is Environmental Hydrology, where he develops methods to account for changes in the environment due to natural and anthropogenic stressors. He has been the lead researcher on various projects funded by the Oil Spill Research program within the United States Environmental Protection Agency (USEPA). He is currently investigating the lingering of the Exxon Valdez oil (1989) in the beaches of Prince William Sound, where he and his team conducted field studies on various beaches and are exploring remediation technologies for dealing with the 20-year old spill. Dr. Boufadel is author of numerous articles in publications such as NATURE geoscience, Environmental Science and Technology, the Journal of Environmental Engineering, Environmental Geology, Journal of the American Water Resources Association, Journal of Contaminant Hydrology, and Journal of Stochastic Environmental Research and Risk Assessment. The work of Dr. Boufadel has been reported in various media outlets such as the New York Times, the Washington Post, and the BBC World News and numerous international media outlets.

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Mr. Sky Bristol leads a computer and information science research and development effortwith the U.S. Geological Survey (USGS), pursuing a concept called the Integrated Information Environment. Before coming to the USGS in 2004, Sky held various positions with the U.S. Fish and Wildlife Service (USFWS) as a biologist in the Environmental Contaminants Program and an engineer and developer with the Information Resource Management Program. Sky was educated as a wildlife biologist and criminologist at the University of New Mexico, learning computer and information science as a secondary vocation in the course of creating program in these areas for the USFWS and USGS.

Dr. Thomas S. Coolbaugh is a Distinguished Scientific Associate with ExxonMobil Research & Engineering. Dr. Coolbaugh has extensive experience in a variety of research settings as a research scientist and research leader and currently leads ExxonMobil's downstream oil spill response technology group. Dr. Coolbaugh earned a B.A., magna cum laude in Chemistry from Amherst College, and a Ph.D. in Chemistry from the California Institute of Technology with Prof. Robert Grubbs, 2005 Nobel laureate in Chemistry. He also earned an M.S. in Management of Technology from Polytechnic University (New York).

Mr. Per Daling is a Senior Research Scientist at Marine Environmental Technology Dept. at SINTEF. He has 30 years of experience within the field of oil pollution, and has been project manager and scientist responsible for many research programs involving weathering and behaviour of oil at sea, field and laboratory testing of oil spill dispersants and countermeasure techniques and oil spill planning. Mr. Daling has authored or co-authored 40 refereed publications, and more than 150 non-refereed publications, papers and invited presentations. He has a MSc in Organic Analytical Chemistry from Institute of Chemistry, University of Trondheim.

Dr. Merv Fingas was Chief of the Emergencies Science Division of Environment Canada for over 30 years and is currently working privately in Western Canada. His specialities include; spill dynamics and behaviour, spill treating agent studies, remote sensing and detection, and in-situ burning. He has over 750 papers and publications in the field. Dr. Fingas has been an editor of the Journal of Hazardous Materials for 6 years. He has served on two committees on the National Academy of Sciences of the United States on oil spills including the recent 'Oil in the Sea'. He is chairman of several

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ASTM and inter-governmental committees on spill matters. Dr. Fingas has a PhD in environmental physics from McGill University, three masters degrees; chemistry, business and mathematics, all from University of Ottawa.

Dr. Deborah French-McCay is a Principal at Applied Science Associates (ASA, Narragansett, RI, USA), where she specializes in quantitative assessments and modeling of oil and chemical releases: transport and fates, exposure, bioaccumulation of pollutants by biota, toxicity, and effects on populations and aquatic ecosystems. Dr. French McCay was principal investigator in the development of NRDA models, established in the US Federal regulations for simplified assessments under CERCLA and the Oil Pollution Act. She has been principal investigator and primary author of more than one hundred technical reports and papers, and is an internationally recognized expert in oil spill fate and effects modeling. Dr. French-McCay received her bachelor's degree in Zoology from Rutgers in 1974 and her Ph.D. in Biological Oceanography from the University of Rhode Island in 1984

Dr. Ron Goodman attended the University of Saskatchewan and graduated with a Bachelor of Arts in Science with specialization in physics. He undertook graduate studies at McMaster University in Hamilton and obtained a PhD. in nuclear physics in 1964. Innovative Ventures Ltd. (IVL) was started by Dr. Goodman in 1971 to consult on Arctic Environmental issues. Joining Imperial Oil in 1978, he developed the only industry-based oil-spill research program in Canada. He served as the manager of surveillance and tracking for the Exxon Valdez response during 1989. Dr. Goodman retired from Imperial Oil in 2000, and reactivated Innovative Ventures Ltd. IVL has been involved in the JESSICA spill in the Galapagos Islands and the rail spill at Wabamun, Alberta Canada. He has been in the oil-spill technology business for thirty-fiveyears, specializing in remote sensing, arctic oil-spill response and oil-spill models. Dr. Goodman has served on a number of national and international committees including IMO/ MEPC and ASTM. He has published over 200 papers.

Dr. Ali Khelifa is Head of the Spill Modelling Laboratory at the Emergencies Science and Technology Section of Environment Canada. He received his Master in 1992 and PhD in 1998 in Environmental Hydraulics from Laval University in Québec in Canada. Dr. Khelifa has conducted extensive research on transport and fate of pollutants spilled in the environment using computer and laboratory modelling for the last 20 years. The last nine years of his

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research were devoted to developing quantitative understanding of the fate of physically and chemically dispersed oils in the aquatic environment. He has authored over a hundred of scientific papers and technical reports and his extensive contribution related to oil dispersion and oil-sediment interaction is internationally recognized.

Dr. Robert Jones is a Chemist in NOAA's Office of Response and Restoration, Emergency Response Division, He is extensively involved in the development of computer models used to predict the fate and transport of chemicals in the environment and is a member of the spill response team.
Dr. Jones received his B.S. in Chemistry from Xavier University, and his Ph.D. in Physical Chemistry from Indiana University. After graduation he worked as a research associate at the National Institute of Standards and Technology in Washington D.C. Prior to joining NOAA in 1988, Dr. Jones was an assistant professor in the chemistry department at Western Washington University.

Mr. Patrick Lambert is a chemist with twenty years experience in the environmental field of chemical and oil spill research and development, and twenty-three years of laboratory experience in both the private and public sectors. He is Head of Field Work and Response, Emergencies Science and Technology Section, Environment Canada. He has was part of the science team in numerous oil spill projects such as the Newfoundland Offshore Burn Experiment and has extensive operational experience with contaminated sites, environmental emergency response, contaminated site and counter-terrorism related.

Dr. Kenneth Lee is a senior research scientist and Director of the Centre for Offshore Oil and Gas Environmental Research, Fisheries and Oceans Canada. The centre is responsible for the coordination of a national strategic program in environmental and oceanographic research relating to oil and gas activities. Dr. Lee is the recipient of Fisheries and Oceans Canada's Prix d'Excellence (Science) for his research contributions on environmental issues associated with offshore oil and gas activities; and the Government of Canada's Federal Partners on Technology Transfer (FPTT) Leadership Award for the development of oil spill countermeasures. He currently serves as a Committee Member of NATO's Science for Peace and Security Program.

Dr. Ira Leifer has a Ph.D. in bubble-mediated air-sea interaction from the

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Georgia Institute of Technology, Earth and Atmospheric Sciences Department. Over the last decade, he has been a leader in research related to natural seepage, including numerical bubble modeling, video observations of bubbles including oily bubbles, multibeam sonar bubble plume observations, remote sensing of atmospheric methane and of oil slicks by imaging spectroscopy, weathering of oil slicks from natural seepage, and in situ measurements of light n-alkanes in the air and water. Research sites have spanned the Gulf of Mexico, to Santa Barbara Channel, to Norwegian and Russian Arctic waters, from submarines to research vessels, to airplanes.

Dr. William (Bill) J. Lehr is Senior Scientist at the Office of Response and Restoration of the National Oceanic and Atmospheric Administration (NOAA). He was previously Spill Response Group Leader for the same organization. Dr. Lehr has also served as an adjunct professor for the World Maritime University and oil spill consultant for UNESCO. Dr. Lehr is a world-recognized expert in the field of hazardous chemical spill modeling and remote sensing of oil spills. He has served as guest editor for the journal, Spill Science and Technology and the Journal of Hazardous Materials and as Co-Chair of the International Oil Weathering Committee. NOAA and the United States Coast Guard have awarded him several medals for his spill response efforts at major spill incidents of national or international significance. He has numerous publications in the field. Dr. Lehr holds a Ph.D. in Physics from Washington State University.

Dr. Alan Mearns is Senior Staff Scientist, Ecology, with NOAA's Emergency Response Division (ERD), Office of Response and Restoration. Dr. Mearns holds a PhD in Fisheries from the University of Washington, and Master of Science and Bachelor of Science degrees from California State University at Long Beach. He is past leader of the Biology Division of the Southern California Coastal Water Research Project and served as Ecologist for the NOAA Puget Sound MESA Program. He has provided support to the US Coast Guard and the NOAA Scientific Support Coordinators (SSC's) on numerous oil spills throughout the US and internationally. He supports numerous oil spill science training programs, is a member of several technical advisory committees in Alaska and has recently started a third decade of annual shoreline monitoring in Prince William Sound. He has received various awards from California State University and NOAA.

Dr. Edward B. Overton is Professor Emeritus in the Department of Environmental Sciences, School of Coast and the Environment at LSU He received his B.S.(1965) and Ph.D.(1970) degrees from the University of Alabama, Tuscaloosa. His research interests include understanding the fates and distributions of hydrocarbons following an oil spill, the environmental chemistry of hazardous chemicals, and the detection of environmental pollutants at the site of sample collection. Dr. Overton held the Clairborne Chair in Environmental Toxicology and Air Quality prior to his retirement, and was honored as an LSU Distinguished Faculty in 2008, and was the 1996 Louisiana Technologist of the Year.

Dr. James Payne has been involved in oil-spill research for over 36 years, including work at the Woods Hole Oceanographic Institution, the University of California Bodega Marine Laboratory, Science Applications International Corporation, and the last 12 years as President of Payne Environmental Consultants, Incorporated. He has conducted oil fate and behavior research and studies on oil-spill dispersants since 1979, and he has served on four National Academy of Sciences/National Research Council Committees dealing with petroleum in the marine environment. Most recently he served on the NRC Committee on Understanding Oil Spill Dispersants.

Dr. Antonio Possolo is a statistician and Chief of the Statistical Engineering Division at the National Institute of Standards and Technology (NIST, U.S. Dept. of Commerce). He has been a statistician at General Electric and at Boeing, and has taught at the University of Washington in Seattle and at Princeton University. His areas of specialty include statistical modeling of spatio-temporal data and uncertainty analysis. Dr. Possolo holds a Ph.D in Statistics from Yale University.

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Appendix 10

A10 Reviewer Comments and Replies

Sixteen reviewers (see Table 1) with diverse background were selected by the Coastal Response Research Center to review all or part of the report. Fourteen responded within the allotted time frame. We would like to thank all the reviewers for their efforts under conditions that required expeditious action on their part. While the list of names is provided in this Appendix, individual comments were provided to the team anonymously. One should not, for example, identify Reviewer 1 with the first name in Table 1. Page numbers refer to the unedited draft report and may not correspond to those in the final report.

First	Last	Affiliation
Eric	Adams	Massachusetts Institute of Technology (MIT) Dept. of Mechanical Engineering
Kathryn	Burns	Austrailian Institute of Marine Sciences, Organic Geochemist, Water Quality Team
Robert	Chen	University of Massachusetts Boston, Environmental Earth and Oceans Sciences
Kurt	Hansen	U.S. Coast Guard, Research & Development Center
Terry	Hazen	Lawrence Berkeley National Laboratory - Ecology Dept.
Wolfgang	Konkel	ExxonMobil
Buzz	Martin	Texas General Land Office - Oil Spill Prevention & Response
Joseph	Mullin	Bureau of Ocean Energy Management, Regulation & Enforcement (BOEMRE)
Michael	O'Brien	Internation Tanker Owners Pollution Federation Ltd. (ITOPF)
Rob	Swift	University of New Hampshire, Mechanical Engineering/Ocean Engineering
Terry	Wade	Texas A & M
Xiaomong	Wang	Florida State University, Dept. of Mathematics
Tom	Weber	Center for Coastal & Ocean Mapping
Steven	Werely	Purdue University

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Reviewers' comments are in italics and replies are in plain text.

Reviewer 1:

This section focuses on estimating the amount of oil recovered by surface skimmers. The total amount of oil and water mixture held in tanks on the skimmers is measurable, but the percent that is actually oil, referred to as the recovery efficiency (RE), is needed to calculate the amount of oil collected. The report states that a RE of 33% was used based on "prior studies" (no reference). To assess whether this is a reasonable value, the types of skimmers employed would have to be taken into account. Oliophilic mechanisms such as disk and drum skimmers can have RE's of 90% or better (see, for example, Schulze, 1998). Suction or weir skimmers, on the other hand, typically have RE values of a few percent unless the slick is unnaturally thick and the surface is without waves. Thus assuming an average RE for the skimming fleet should be based on the distribution of skimmer types (as well, of course, sea state and slick thickness).

It should also be pointed out that determining the water content in recovered oil and water mixtures is a standard laboratory analysis done at the OHMSETT oil spill test facility. It would seem that their protocol could be adapted to either on-board determination of RE or representative samples could be transported to a shore laboratory for RE analysis.

Skimmers were the most commonly-used mechanical devices used to remove oil from the Gulf water surface. These skimmers varied greatly in size, application, and capacity, as well as in recovery efficiency and water pickup. (Schulze, 1998; Schwartz, 1979). In the particular case of the Gulf oil spill the major issue is the amount of water recovered. A skimmer's performance is affected by a number of factors including the thickness of the oil being recovered, the extent of weathering and emulsification of the oil, the presence of debris, and weather conditions at the time of recovery operations. A skimmer's overall performance is usually determined by a combination of its recovery rate and the percentage of oil recovered. The maximum amount of oil that a skimmer could recover is called the 'Nameplate Recovery Rate' and is typically provided by the manufacturer of a skimmer (Fingas, 2010; Meyer et al, 2009). A similar definition is the 'Effective Daily Recovery Capacity', which is the amount that a skimmer could recover in daylight hours under ideal conditions. The recovery rate is the volume of oil recovered under specific conditions. It is measured as volume per unit of time, e.g., m^3/h, and is usually given as a range. If a skimmer takes in a lot of water, it is detrimental to the overall efficiency of an oil spill recovery operation. The

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summary results of performance testing on various types of skimmers are given in Table 1 (Schulze, 1998;Fingas, 2010).

Table 2 shows the three most important values of skimmer performance, ORR, TE, and RE. This is a sample table showing a fraction of the skimmers tests reported in the reference (Fingas, 2010). The Oil Recovery Rate(ORR) is the quantitative rate in volume per unit time, usually m^3/hour and is corrected for water recovery. The throughput efficiency (TE) is applicable only to advancing skimmers. The throughput efficiency is the percentage of oil presented to a skimmer versus that recovered, in percent. The recovery efficiency (RE) is the percent of oil recovered out of the total oil and water recovered. For the Gulf recovery effort, the RE is the most important factor. We know the total liquids recovered, but we do not know exactly how much oil was in this liquid and therefore must estimate the actual oil recovered. Table 2 shows that the average RE of the skimmers in wave conditions is 33%.

The emulsion recovered typically contained 30- 60% water (Appendix 6). Using 40% as an average water fraction, the typical amount of oil in the recovered mixture is 0.6 X 0.33 or 0.20 (20%). The amount of liquid recovered was 735,000 barrels and thus the amount of oil recovered was about 20% of this or 147,000 barrels.

1 Schulze, R., *Oil Spill Response Performance Review of Skimmers*, ASTM Manual Series, ASTM, 1998

2 Schwartz, S.H., Performance Tests of Four Selected Oil Spill Skimmers, *AMOP*, 493, 1979

3 Fingas, M.F., Weather Effects on Oil Spill Countermeasures, Chapter 13 in *Oil Spill Science and Technology*, p. 339-426,2010

4 Meyer P., W. Schmidt, J.-E. Delgado, D. DeVitis, S. Potter, E. Haugstad and M. Crickard, Application of the American Society of Testing and Materials' (ASTM) New Skimmer Test Protocol, *AMOP*, 323, 2009

5 SINTEF, Laboratory study of the dispersibility of DWH surface emulsion, 2010

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Table 1 Performance of Typical Skimmers

	Recovery Rate (m^3/hr) for given oil type*			Percent
Skimmer Type	**Light Crude**	**Heavy Crude**	**Bunker C**	**Oil****
Oleophilic Skimmers				
small disc	0.2 to 2			80 to 95
large disc	10 to 20	10 to 50		80 to 95
brush	0.5 to 20	0.5 to 2	0.5 to 2	80 to 95
large drum	10 to 30			80 to 95
small drum	0.5 to 5			80 to 95
large belt	1 to 20	3 to 20	3 to 10	75 to 95
inverted belt	10 to 30			85 to 95
rope	2 to 20	2 to 10		
Weir Skimmers				
small weir	0.5 to 5	2 to 20		20 to 80
large weir	30 to 100	5 to 10	3 to 5	50 to 90
advancing weir	5 to 30	5 to 25		30 to 70
Elevating Skimmers				
paddle conveyer	1 to 10	1 to 20	1 to 5	10 to 40
Submersion Skimmers				
large	1 to 80	1 to 20		70 to 95
Suction Skimmers				
small	0.3 to 2			3 to 10
large trawl unit	2 to 40			20 to 90
large vacuum unit	3 to 20	3 to 10		10 to 80
Vortex/Centrifugal Skimmers				
centrifugal unit	0.2 to 10			2 to 20

* Recovery rate depends very much on the thickness of the oil, type of oil, sea state, and many other factors

** This is the percentage of oil in the recovered product or recovery rate. The higher the value, the less the amount of water and thus the better the skimmers' performance

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Table 2 Skimmer Performance (Sample cases)*

Skimmer	Year of Test	Oil Type	Oil Viscosity mPa. S	Slick Thick. mm	#of Tests	Speed m/s	Wave height m	Wave Conditions	ORR m^3/h	TE %	RE %
Harbour/small skimmers											
Skimming Barrier	1977		200	120	3	0.25	calm		58.2		56
Skimming Barrier	1977		200	120	5	0.25	0.3	harbour chop	47.4		34.5
Skimming Barrier	1977		200	120	4	0.5	0.3	regular	71.7		48.9
Sirene Skimming Barrier	1979		545	3	1	0.75	calm		15.8	11	26
Sirene Skimming Barrier	1979		545	3.2	1	0.38	0.6	harbour chop	18.6	99	31
Sirene Skimming Barrier	1979		545	3.2	1	0.38	0.5	regular	16.4	99	27
Lori Brush Skimmer	1979	med. oil	600	ns	1	1.5	calm		0.96		78
Lori Brush Skimmer	1979	med. oil	600	ns	1	0.75	0.16	regular	0.35		81
Disc skim. - flat -CCG tests	1993	lt. crude	5 to 50	10	1	0	0.4	regular			65
Disc skim. - flat -CCG tests	1993	lt. crude	5 to 50	10	1	0	0.8	harbour chop			48
Disc skim. - flat -CCG tests	1993	lt. crude	5 to 50	25	1	0	calm				96
Disc skim. -T-disk -CCG tests	1993	lt. crude	5 to 50	10	1	0	0.4	regular			46
Disc skim. -T-disk -CCG tests	1993	lt. crude	5 to 50	10	1	0	0.8	harbour chop			24
Paddle skimmer	1977	heav. oil	1900	26	1	0	calm		9.4	91	84
Paddle skimmer	1977	heav. oil	1900	26	1	0	0.2	regular	4.8	70	18
Rope Mop towed single	1978	med. oil	793	5	1	1.3	0.6	harbour chop	5.7		49
Rope Mop towed single	1978	med. oil	793	5	1	1.5	0.6	harbour chop	5		46
Oil Mop ZRV	1976	lt. crude	65	4 ave	1	1.25	calm		7	36	23
Oil Mop ZRV	1976	lt. crude	65	4 ave	1	1.5	0.6	harbour chop	4.8	21	10
Marco Belt skimmer	1976	heav. oil	837	8 to 11	6	0.5	calm		11.5	85	57
Marco Belt skimmer	1976	heav. oil	837	8 to 11	4	1.5	calm	harbour chop	20.6	62	76
DIP 2001	1973	Alberta crude	8	.7 ave	1	1.3	calm		2.7	88	30
DIP 2001	1975	Arab crude	24	0.5	1	1	calm		0.9	77	94
DIP 2001	1975	Arab crude	24	1	1	0.5	0.4	natural	0.9	81	95
Stationary skim. - Manta Ray	1975	DOP	79	20	6		calm		20.1		27
Stationary skim. - Manta Ray	1975	DOP	79	20	1		0.6	harbour chop	15.2		22

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Stationary skim. - Skim pak	1980	medium	200	7	3		calm		2.5		8
Stationary skim. - Skim pak	1980	medium	200	7	1		0.26	regular	2		7
Destroil weir skimmer	1979	heavy	810	5	5		calm		16.2		69
Destroil weir skimmer	1979	heavy	810	5	2		0.47	harbour chop	11.5		59
GT-185	1988	Bunker c	11700		1		0.4	regular	15		50
GT-185	1988	Terra Nova	100-600		1		calm		30		100
Walosep	1988	Bunker c	>100k		1		calm		38		2
Walosep	1988	Bunker c	>100k		1		0.4	regular	10		2
Veegarm towed weir	1980			1	1	0.25	calm		11	100	8
Veegarm towed weir	1980				1	0.25	1.9	regular	10	40	5
Veegarm towed weir	1980	light	9	2	1	0.25	0.19	harbour chop	5	60	5
Averages (taken from whole Table)					476		mixed wave conditions		15	58	**44**
										under test conditions	
* See reference 3 for the full table								under typical wave conditions			**33**

Reviewer 2:

Page 11, paragraph 2: This paragraph is not based on data and only media reports from some dramatized news conferences. I would not include this speculation.

Paragraph is modified to note that extensive DHS oil on the bottom has not been confirmed in the ongoing sampling programs.

Page 39, paragraph 1:

The factors affecting biodegradation rates are as follows:

1. Type of oil

2. limiting nutrients, P, N, O, and in the ocean Fe

3. Concentration of the oil

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4. how weathered the oil is

5. oil droplet size

6. adaption of microbial community to long-term episodic events like natural seeps.

The purpose of the report is to describe the oil budget calculator, not provide an in-depth study of long-term weathering processes. Therefore, we feel it would be inappropriate to expand on the admittedly brief discussion of biodegradation.

Reviewer 3:

P 7, line 2 remove: if slightly dull
P 8, Item 4, Line 2-3: replace bottom with lower water column
P 9, Line 3-4, rephrase: Hence, this oil is assumed to have already lost all oil that might evaporate.
P 10, Para 3, Line 4: Formed an emulsion when surfacing.... on
P 11, Para 1 Line 6, formed emulsion on the water surface within Km's of wellhead. This needs to be consistent.
P11, Para 1, last line: this sentence is unclear

Revisions made for the above.

P 11, Para 2, Line 3: Basing anything here on News Reports would seem to be a dramatic flaw. The news reports were abysmally incorrect with respect to all aspects of the science of the DWH spill.

Paragraph is modified to note that the claim of extensive DWH oil on the bottom has not been confirmed in the ongoing sampling programs.

P 12, Para 2, Line 6: Can "44% oil percentage" be replaced with a unitless GOR (Gas Oil Ratio) for accuracy and understanding here and throughout the document? (e.g. P14, para 1, Line13)

We have kept the units of the cited report for consistency.

P 14, Para 1, Line 13: Should high not be low?
P 14, Para 2, Line 9: Replace globs with accumulations of droplets or particles

Section text revised

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P 15, Para 2, Line 1: Replace old saying with proverb.
P 15, Para 2, Line 3: Replace unimportant with less important
P 17, Para 2, Line 5: Is this naturally or chemically dispersed oil?
P 19, Para3, Last line: to the wind speed and temperature
P 20, Para 2 , Line 4: from the sea

P 22, Figure 8 and all additional similar figures: Please make a table, these are indecipherable

Figure 8 and similar figures have been removed

P 22, Para 4, Line 5: I am not familiar with cubic seconds. My utilization of horizontal and vertical spreading rates have been as m2/sec.Check here and following

The unit of m^2/sec^3 relates to the energy dissipation rate and not to spreading. It is equivalent to energy per unit mass per unit time.

P 27, Last line: remove =
P 28, Para 1, Line 4: Less oil, not more oil
P 28, Figure 12, Move under 9a Header.
P 29, Section 9a, Location of tables and figures is awkward and needs to be revised.

Revisions made

P 30, Table 2 Concentration as what units, also please provide detail regarding these samples, e.g. depth sampled, time after dispersants applied, measured how, etc. If this is a scattershot of nonspecific sampling, please say so.

New table 2 Heading inserted

P 31, Last line: for
P 36, Para 2, Line 2: to
P 36, Para 3, Line 8: What evidence is there that oil settled to bottom in offshore areas?

The text was revised to say some of the oil has combined with sediment in the water column and settled to the bottom in the nearshore or, perhaps, offshore areas.

P 39, Does this paper not deserve conclusions? We've spent 39 pages getting to this point, provide the DWH Mass Balance.

New mass balance figures included in Section 14

Reviewer 4:

Generating a modeling tool such as the Oil Budget Calculator is no simple task, not least because there is a paucity of information – both theoretical and empirical - on which to base it. The need for better information on which to base the model is apparent throughout much of the document, with a few exceptions (e.g., section 6 on Evaporation). Still, assembling the Calculator seems to have been a worthwhile exercise for two reasons: 1) it provides a framework for assembling actionable data; 2) it highlights areas where the information gaps are the largest (e.g., direct observations of subsea dispersant effectiveness). I would encourage the further development of this tool both through efforts to better model the processes (e.g., chemical and natural subsurface dispersion) and by adding more capability to the model. If the latter could be done in such a way that the model could adaptively tune itself to new scenarios using field data (see comment 4. below), it could become very powerful.

There are several technical issues which should be addressed. These are listed below. In addition, the writing of this document should be tightened up considerably. There are better editors than myself for doing this, so I won't provide an exhaustive list of corrections, but will say that there are many ambiguous comments or phrases (e.g., a "good" fraction; "very" rapid;) and several unnecessary comments and colloquialisms (e.g., filling out an ICS209 is "slightly dull"; "the old saying that oil and water do not mix…'). Physical interpretations and definitions for the rate constants do not belong in an appendix – this makes following the body of the text too onerous. The figures that take the form of Figure 8 are totally non-intuitive – this information should be provided in a much clearer way. Clearly, this document is in draft form – a thorough polishing and reworking is warranted.

Corrections to the language have been implemented. Unfortunately, multiple authors and strict publication deadlines prohibit extensive wordsmithing or style uniformity. Figure 8 and similar figures have been removed.

1. *The amount of subsurface dispersed oil is assumed to be high (seemingly, greater than 25% of the oil based on the combination of rate constants), although the data presented here do not seem to either support or refute that assessment. If the goal is to bring a conservative*

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assessment (from the perspective of not underestimating the response resources required, such as skimmers, burners, surface dispersant, amount of subsurface chemical dispersant – the "lesser of two evils" - to be used,etc.) to the Unified Command, as was stated, than I would have to conclude that the analysis of the dispersed oil at the bottom was incorrect (too high). I recognize that there have been many observations of subsurface oil, and would not be surprised to learn that enough oil made it into the subsurface to have a large and long term impact (in fact, I would be more surprised to learn the opposite). But given that 4.9 million barrels were released, even this finding would not suggest that a large fraction of the oil was dispersed into the subsurface . That is, it is conceivable that even 5% of 4.9 million barrels of oil could have a large, long term impact (clearly, better methods for empirically determining the amount of subsurface oil are needed). Specific comments along the lines of this theme follow.

I do not see how the LISST data support the hypothesis that "much" of the oil released was dispersed into the water column, as stated on page 22, or that they "suggest the high effectiveness of the chemical dispersants…from subsurface application" as stated in appendix 6. Assuming that equations (13) and (14) are correct (and they need to be better supported than a personal communication with Lasheras), it does seem reasonable to expect that the only way to generate these small droplets is through the use of chemical dispersant (otherwise, it would seem that the smallest characteristic size of a droplet would be about 1 mm). However, the LISST measurements only provide estimates of these very small droplets – they don't appear to say anything about the relative quantity of the small droplets compared to larger droplets. Based on these measurements, it appears just as likely that the application of subsea dispersant was ineffective, and that only a small fraction of chemically dispersed bubbles was created, some of which eventually had the eventual fate of being sampled. From the perspective of figuring out how much surface oil can be responded to, it would seem more conservative (and just as likely based on these measurements) to say that only a small amount of oil was dispersed and that the chemical dispersant was ineffective.

Equation 13 is supported by the two preceding references to peer reviewed publications. Equation 14 has been proposed by Hinze (1955). It gives an estimate of the characteristic droplet size in a dispersion process based on the assumption that the dynamic pressure forces due to turbulent fluctuations control droplet formation due to breakup. It is provided in this report for background only (it is not used in the Calculator). The natural dispersion model itself is a variation of the Delvigne model, commonly used to estimate natural dispersion.

The LISST data found oil droplets in the locations consistent with dispersed

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oil and subsurface current patterns. The lack of such droplets would be a strong indicator of little dispersion. Therefore, the Report states that these findings lend support to the hypothesis of significant dispersion, while citing other findings that do not support this hypothesis. As noted in the report, the experts were unable to reach a consensus on the amount of dispersion and a compromise value was used for the Calculator. This is obviously an area that requires further research.

Hinze, J.O., (1955). Fundamentals of the hydrodynamic mechanism of splitting in dispersion processes. AIChE Journal, Vol. 8 (4), 289-295.

Due to the limitations of available technologies in droplet size measurement (for example, current available LISST can only go as deep as 300 m, LOPC has detection limit of > 100 um and resolution of 10^6 counts/m^3), the present LISST method has been used to monitor small particles generated in the water column by retrieving water column samples using Niskin bottles and surface bucket sampler. It is unfortunately that the current method did not measure the full spectrum of droplet size distributions in subsurface, and in particular, there were large uncertainties and measurement gaps for large particles. However, it is not true to say that "they don't appear to say anything about the relative quantity of the small droplets compared to larger droplets". As a matter of fact, the data presented in Figures A7-5~8 are the fractions of small particles (d < 68.8um) to the total particles in an expanded range between 2.5 and 157 um. Similarly, Figures A7-9~12 present cumulative particle size fractions between 2.5 and 157 um, too. These data all indicate that the vast majority of the measured particles are within the defined small particle frame (i.e., d < 68.8 um), and therefore support our conclusion that dispersion of oil was effective at subsurface. However, we do emphasize there are tremendous amount of unknowns in terms of efficacy evaluation of the subsurface dispersant injection, and the knowledge gaps in this regard must be bridged in the forthcoming research activities now that the importance of this issue has come into light.

Are Payne's reports of oil droplets at depths greater than 2 km (page 22) supported by any other measurements (e.g., CDOM fluorometer, hydrocarbon fluorometer, DO, etc.)? What is the mechanism by which the oil droplets sank through the water column into a stable deeper plume? Most importantly, how can these type of observations be translated into the stated assessment that there was a "large amount of dispersion"? That is, why couldn't Payne have been observing the result of a small amount of dispersion? If Payne had a way to extrapolate a few observations to a general behavior, it should be clearly stated here. Otherwise, the conservative approach (from the perspective of figuring out how much surface oil can be responded to) would be to assume that Payne's observations support a small amount of dispersion.

The report of dispersed oil droplets between 1000 and 1200 m was based on: 1) visual (video and digital photographic) observations of droplets (0.5-3 mm) in the water column and impinging on a down-ward facing grid mounted on the ROV; 2) video and digital recording of said droplets with white (tungsten) and "black light" illumination: 3) CDOM fluorometry; 4) DO anomalies or "sags" in the water-column within that depth range; and 5) GC/MS measurements of PAH in dissolved (filtered) seawater samples and SHC plus PAH associated with particulate-phase components (trapped on 0.7 um glass fiber filters) from finite water samples collected at these depths. In addition, the dispersed droplet concentrations were high enough to be observed by sonar (670 kHz) on the ROV, and we photographed droplets of different sizes (between 100 and 500 micrometers) at different depths using the Holographic Camera provided by Cabell Davis of WHOI.

These plumes were observed consistently within this depth range on two cruises on the M/V Jack Fitz in the May-June time-frame out to 4 km from the well head, and other vessels observed similar DO anomalies and fluorometer signals elsewhere at distances up to 18 km from the well head during that period. These other vessels did not have the ROV and video/digital photography to document the droplet sizes, but the chemistry data on whole water samples collected between 1000 and 1300 m yielded similar PAH and SHC patterns documenting the presence of dissolved components and whole oil droplets. More recently (in August and September 2010), PAH components associated with finite oil droplets in this depth range have been measured by UV/fluorescence using AquaTracka fluorometers and confirmed by GC/MS well beyond 200 km from the well head. Measurements above and below these depths do not show the oil signal. In more recent cruises, the Aqua Tracks signals also corresponded with DO anomalies at the same depth.

With regard to the mechanism of how these droplets reached this depth, it is important to stress that we are not implying that they were dispersed at the surface and somehow «sank» or were entrained to 1000 m. Rather, we believe that the physically (and chemically) dispersed oil released from the well head at depth broke up to yield finite droplets that advected away from the well as they slowly rose toward the surface, and that those droplets removed from the rapidly rising gas plume and within a particular size range became entrained within a density or stratification layer at this depth. Particle size measurements clearly indicated that the larger droplets were still slowly rising (between 1300 and 1000 m), and that smaller droplets were left behind over time. This entrainment of smaller oil droplets in the 0.2 – 3 mm size range follows the expected behavior described by Socolofsky and Adams (2002, 2003), where oil is detrained (along with seawater) from the plume as it ascends through a density-stratified ocean and passes a level of neutral buoyancy. Such detrainment events are clearly evident in laboratory mea-

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surements of gas and water plumes and in field experiments of oil and gas mixtures released at depth (Masutani and Adams 2000; Adams and Socolofsky 2005), and evidence for such detrained oil droplets was observed in subsurface plumes between 1300 and 1000 m from numerous vessels and over 4-5 months.

Masutani, S., and E. Adams. 2000. Experimental study of multiphase plumes with application to deep ocean oil spills. Final report to U.S. Dept of Interior, Minerals Management Service. Contract No. 1435-01-98-CT-30946. http://www.mms.gov/tarprojects/377.htm.

Socolofsky, S. and E. Adams. 2002. Multiphase plumes in uniform and stratified crossflow. J. Hydr. Res., 40: 661-672.

Socolofsky, S. and E. Adams. 2003. Liquid volume fluxes in stratified multiphase plumes. J. Hydr. Engrg. 129: 906-914.

Adams, E.E. and S. A. Socolofsky. 2005. Review of Deep Oil Spill Modeling Activity Supported by the Deep Spill JIP and Offshore Operator's Committee. Final Report.

It seems odd, and not very conservative, to assume that 1 gallon of dispersant generates 20 gallons of dispersed oil at the surface and 90 gallons of dispersed oil subsurface. Multiplying these values by k3 and k2 respectively, it appears that 1 gallon of dispersant would generate 2 gallons of dispersed surface oil, or 40 gallons of dispersed subsurface oil if deployed at depth. This disparity should be clearly addressed.

The expected subsurface DOR is 40 and the expected surface DOR is 10. The reason for the disparity is explained in sections 9a and 9b. In many respects, the subsurface operations were ideal dispersant applications. The oil was fresh and in direct contact with the dispersant. There was significant turbulent energy. This was not always the case for the surface operations.

The report states on page 30 that the best (most) direct evidence collected during the spill suggested that 6-7% of the oil – in a plume where models expected the subsurface plume to be – was dispersed near the bottom (apparently negating the remote sensing estimate on page 13). Presumably this was both chemically and naturally dispersed. So why not use 6-7% rather than the approximately 5 times this amount suggested by the rate constants?

The Camilli study concluded that 6-7% of the BTEX leaking from the well was required to support the plume that they found. This defines a lower bound to the dispersed oil, not an upper bound since one cannot presume

that they detected all of the subsurface oil. The Camilli study is not in contradiction to the AVIRIS findings since the latter looked at the cumulative amount of oil that both made it to the surface and did not evaporate. Also, it must be noted that the remote sensing estimate has a high degree of uncertainty.

Even if the chemical dispersant was effective, just because a droplet is small doesn't necessarily mean it takes a long time to get to the surface. If the volume fraction of the dropletsis high enough, there can be a net transport upward that is faster than the individual rise speed of the droplets. If bubbles are added to the mix – and they apparently constitute 56% of the mix as stated on page 12 of this report – the upward net transport can be even greater (this type of group behavior can be demonstrated in the extreme by going to a bar and ordering a pint of Guiness and watching the individually buoyant bubbles flow downward). A conservative assessment of the amount of surfacing oil should either explain why this net transport isn't happening, or conversely it should take it into account.

The reviewer is correct. In the dynamic zone above the riser (the first tens of meters or more, depending on the intensity of jet), the vertical transport of small droplets is mostly controlled by the jet flow and its bouncy, and later on by the flow induced by the movement of large oil droplets and gas bubbles rising to surface. Above this dynamic zone there is abundant evidence that gas bubbles will separate from the plume of oil-gas mixture (explained in Section 3) and the small droplets will continue to rise to the surface according to their terminal rising velocity controlled by their size and effective density. In deep waters, the last process is dominant (because of the long distance the droplets have to travel to reach the sea surface), while in relatively shallow water (water depth of few tens of meters or possibly hundred meters) the first process (induced upward transport) becomes dominant and cannot be neglected in accessing oil movement to the sea surface. The depth at the DWH oil spill is 1.5 km, which is large enough to assume that oil droplets will travel the major part of this depth according to their terminal rising velocity as explained above and shown from previous well blowout incidents, field experiences and modeling (Johansen, 2000, 2003; Johansen et al., 2001, 2010; Chen and Yapa, 2007; Yapa and Chen, 2004)."

Chen F., and Yapa, P.D., (2004). Estimating the Oil Droplet Size Distributions in Deepwater Oil Spills. Journal of Hydraulic Engineering, 133(2), pp. 197-207.

Johansen, O., (2003). Development and verification of deep-water blowout models. Marine Pollution Bulletin. 47, pp. 360–368.

Johansen, O., (2000). DeepBlow - a Lagrangian Plume Model for Deep Water Blowouts. Spill Science & Technology Bulletin, 6 (2), pp. 103-111.

Johansen, O., Rye, H., and Durgut I., (2010). Generalized integral plume model for simulation of marine discharges. In AMOP proceeedings, Environment Canada, Ottawa, 1, pp. 863-878.
Johansen, O., H. Rye, A.G. Melbye, H.V. Jensen, B.Serigstad, T. Knutsen (2001). Deep Spill Jip Experimental Discharges of Gas and Oil at Helland Hansen, Technical Report STF66 F01082, 159p.
Yapa, P.D., and Chen F., (2004). Behavior of Oil and Gas from Deepwater Blowouts. Journal of Hydraulic Engineering, 130(6), pp. 540-553

The report (p13) assumes that gas associated with the plume dissolved before reaching the surface. Without evidence to the contrary, I find it hard to believe that the surface flow around the bubble would push enough oil on a bubble surface to the downstream hemisphere so that the gas transfer rate out of the bubble or methane-seawater contact was not appreciably changed. Although the oil budget does not keep track of gas, adsorption of oil onto gas bubbles is a mechanism by which the oil can surface more quickly and by which smaller droplets can reach the surface. Therefore, it is not sufficient (or conservative, from the calculator perspective) to simply neglect the gas, especially when it is estimated to be more than 50% of the discharge volume (page 12).

Although the mechanism suggested by the reviewer is perhaps possible and worthy of further study, it does not reflect existing understanding of subsurface well blowouts, as discussed in the references cited. As stated on page 8, the Calculator is not a research tool.

The model inherently appears to assume that the oil that is skimmed, naturally dispersed, or evaporated at the surface is negligible compared to the oil that is burned (see calculation of W). This may have been accurate for DWH (I couldn't say), but it doesn't seem to be appropriate to assume that this will always be correct.

This is not correct. The model does not neglect skimmed, naturally dispersed or evaporated oils. These are important in the oil budget calculations. Skimmed oil is counted as shown in equation A1.7), naturally dispersed in equation A1.11, and evaporated oil is counted by the terms $k_4Z(t) + k_5W(t-1)$ in equation A1.10. The note "(neglecting natural surface dispersion and skimming)" mentioned in the report applies to calculation of evaporation from the previous day and still available on day t, as mentioned in the report "The oil that rose to the surface on day t-1 and is still left". This "old" oil is estimated by the intermediate variable W.

*The report states that some 18,000 barrels of subsea dispersant were used, and multiplying this by (1-k7)*90*k2 (from equation 2) gives 700,000 barrels of chemically dispersed oil in the subsurface. Figures 1 and 2 in Appendix 2 (example outputs from day 86, the last day dispersant was used, I believe)*

*gives an answer of only about 400,000 barrels. Why is this different? Note that 90*k2Vcb should always have been smaller than the government estimate of the discharge even when 12 gallons/minute of subsurface dispersant was being used.*

Figures 1 and 2 in Appendix 2 refer to the earlier version of the Oil Budget Calculator (version 1.3) while the formulas listed in the Report are those for the present version (2.0). See Appendix 2, Figure 3 for the equivalent tables using the new formulas.

2. *One of the stated goals is to provide the UC with actionable data even when there is missing or incomplete data. I'm wondering what happens when the estimate of the discharge is either not available or has a very high level of uncertainty. If stated too low, this would presumably result in a response (dispersant, skimmers, etc.) that was too low, if state too high, this would result in too much dispersant deployed and inefficiency (too many skimmers floating around). If either of these scenarios occur, I don't see any built-in mechanism (e.g., feedback) that allows the calculator to adjust, which could render the calculator ineffective. Given the uncertainty surrounding the flow rate for a significant portion of the DWH spill timeframe, this seems likely to occur. I would suggest that future work include exploration of feedback mechanisms. One that readily comes to mind is tracking the daily amount of oil estimated to be reaching the surface, which is $V_{RE} - V_{DC}/(1-k_7) - V_{DN}/(1-k_7)$, and comparing it with the daily amount of oil skimmed and burned (normalized by effort) . One could imagine a scenario in which such a tracking mechanism is used to tune the basic model inputs (e.g. the leak discharge rate), which in turn gives the response the indirect ability to tune decisions for which the result is difficult to monitor (e.g., amount of subsurface dispersant). Place holders for new feedback mechanisms (advances in technologies to assess surfaced or subsurface oil amounts or characteristics) could also be added.*

Mass balance was used by another group to estimate flow rate during DWH. Certainly having a corrective feedback mechanism in future model applications would be useful.

3. *Considering that V_{DC} cannot be greater than V_{RE} by definition, the "max" in equation (3) does not seem to be necessary.*

True, but it does not affect the calculations. Equation was written this way for consistency .

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4. *It seems misleading to state that a similarity between DWH and Ixtoc is that relief wells were used to stem the flow in both cases. Didn't DWH utilize a cap to almost completely stem the flow? In any case, what is the relevance of the method of stemming the flow to the assessment of oil fate and transport before the flow is stemmed?*

The use of relief wells is mentioned because in both cases this was the final method to assure no future leakage and because it was believed during both responses that this was possibly the ultimate method to stop the flow. For IXTOC, this proved to be the case. As noted by the Reviewer, DWH was successfully capped at the top.

5. *In describing the difference between DWH and Ixtoc, it is stated that Ixtoc I oil formed a "chocolate mousse." Wasn't this also observed in DWH? I recall seeing something that could be described as a "mousse", at any rate.*

Both oils emulsified although the Deepwater Horizon spill formed a less stable emulsion and took longer to emulsify.

6. *On page 11, there is a statement suggesting that "current news reports" provide evidence that a scientific hypothesis (that a "good" fraction of the oil is settling to the bottom) is true. Given the inaccuracies often associated with press reports, and the lack of peer review associated with news media report, I would suggest that the report only state that such a hypothesis exists but has not yet been evaluated, and that references to the news media be deleted. Further, what is a "good" fraction? These kind of ambiguous statements found throughout the document.*

Sentence discussing bottom oil is modified to note that these reports have not been confirmed

7. *What is a "glob" of oil (page 14)?*

Corrected

I don't see how the 5-10% dissolution rate is supported. It would seem to me that in order to assess this, you would need to know a) the oil composition; b) the dissolution rates as a function of droplet size (not solubility – presumably the Gulf of Mexico is still under-saturated; c) the droplet size distribution. I don't see that any of this is sufficiently known to estimate a dissolution rate. The text makes the case that some oil will dissolve, but does not go further. This should be addressed; if it is a guess, than this should be clearly stated

Dissolution was only considered as a separate process for dispersed subsurface oil (less than 100 micron droplet size). As stated in the Report, the dissolution rate depends directly upon surface area, which was proportionally larger per volume spilled for this spill incident compared to a normal surface spill by factors of 100 to 1000. Mackay and Leinonen (1977) concluded that, for droplets less than 100 microns in diameter, dissolution is very rapid for any component that will dissolve at all. Using the known composition of the oil, we arrived at the 5-10% number.

Reviewer 5:

This document needs a more straightforward description of what the major processes are that need to be considered. Once the simple formula is provided then they can describe their more sophisticated formulas for deriving the estimate. Here is a simplified example of how they should proceed. The fate of oil in the marine environment has been of concern for many years and the major processes determining its fate are known in relative terms. A budget can be constructed which would contain these parameters:

Total oil discharged = TD
Oil Recovered before entering the ocean = REC
Oil Dissolved/Dispersed = DD
Oil on sediments/shore = SED
Oil on the ocean surface = SURF
Oil evaporated = EV
Oil Biodegraded = BD
Oil Burned =BUR
Oil Skimmed = SK

Then the following equation can be used:

$$TD = REC + DD + SED + SURF + EV + BD + BUR + SK$$

The National Incident Command (NIC) is most interested in the surface oil (SURF) as that is where they can attempt to burn skim or disperse the oil or set up booms to keep the oil from sensitive ecosystems. The equation is therefore solved to estimate this term:

$$SURF = TD - (REC + DD + SED + EV + BD + BUR + SK)$$

Since the spill occurred offshore where the suspended sediment load is small sedimentation near the spill site is not likely to be a major term in this budget

for this spill. This term for the offshore areas was assumed to be comparatively small. The NIC was trying to keep the oil of the shore. Once on the shore it is difficult to estimate the amount of oil stranded and how much of that oil is recovered. This oil budget calculator does not attempt to estimate this process, but includes this oil with the surface oil. The equation for the calculater is therefore:

SURF + SED = Other Oil = TD – (REC + DD + EV + BD + BUR + SK)

The budget then uses the physical properties of the oil, estimated rates and developed a model to calculate and estimate the above parameters. Modelers and other experts will need to comment on how well they were able to estimate these parameters. Based on my review of the parameters that the oil budget calculator used it has captured the most important aspects. While SED can be assumed small it does not mean it is not important especially for selected near shore areas and perhaps some off shore areas.

Spilled oil undergoes a number of processes. Dispersion and evaporation are just two examples. Collectively they are called weathering. The circumstances surrounding the Deepwater Horizon incident resulted in interdependence of these processes. To address this the approach taken was to follow a logic structure beginning at the wellhead and the released oil. Unfortunately, interdependencies of the weathering/cleanup processes made the simple approach proposed by the Reviewer not possible. For example, evaporation depends upon surface oil but surface oil depends upon the amount of oil that disperses subsurface. The formulas chosen by the development team were as simple as we believed possible while still retaining these basic dependencies. However, a descriptive narrative has been added to the section before the formal equations are presented.

My conclusion is that they have oil budget calculator used it has captured the most important aspects of the fate of the oil.

The Oil Budget Calculator is designed to capture short-term oil behavior as it affects response. Environmental Impact Assessment studies are needed to track the ultimate fate of the oil.

Specific sections Comments

Dissolution and Evaporation:

I discuss these sections together as it make since for the calculator to talk about these processes together. The discussion in these sections is very good. They explains how the unique aspects of this spill led to enhanced

dissolution even of sparingly soluble components. Based on the paucity of studies they have done a good job of estimating dissolution process. And since the same components of the oil are more water soluble and more volatile it makes since to combine as a process called "weathering" as it is difficult to establish which was the dominate process. Separating the two processes is also of limited value for the NIC. Some editorial comments:

Page 17 Figure 6. The open and filled circles are not labeled.

We are reluctant to modify a figure produced by someone outside the development group. The original figure appeared in the proceedings of the 1987 Oil Spill Conference.

Page 17 ...lose between 5-10% of its volume. Is this also 10 % of the mass since mass in used in the calculator.

The Calculator uses volume in its calculations and output. However, oil density changes little so that mass and volume percentages are quite similar.

Page 18 "The Oil Budget Calculator groups these terms" change "terms" to "dissolution and evaporation".
Page 19 Figure caption change to ...alkanes below C-14 have been removed...

Change implemented

Residual Oil (in my letter) or **Other Oil** (in draft document) plus **Program Structure & Interface** (Appendix 2 Oil Budget Calculator-Web-based Tool)).

In the equations I provided above the Other Oil is equivalent to my term SURF + SED. This is the most important parameter for the NIC. This is the oil that they have the oil that they have to attempt to mitigate (skim, disperse, burn) or contain (booms) and the proportions that they were unable to keep from the shore. In short it is the number they wanted calculated. The final test of this Oil Budget Calculator is was it of value to the NIC to make management decisions. It would be good to include in this report a statement by the NIC that this Oil Budget Calculator was useful or that they think it would be helpful in the event of future spills. They are the ultimate primary users. It is also important to attempt to improve these estimates as the results contradict some of the original unrealistic predictions.

We agree that the ultimate judge of the usefulness of the Calculator was/is the unifiedcommand. The development team was encouraged by the support given to its development by the NIC who are reviewing future plans for the tool.

Other Comments:

Figures 8, 9, 13, 15 and 16 appear to be taken from appendix 2 figure 4. It would be better to just use that figure in the main text and delete the other figures as they are hard to understand until you see figure 4 Appendix 3.

Figure 8 and other related figures have been removed.

Appendix 2 Figure 1 and 3 (which are actually tables unless the colors have some significance) appear to be the same accept rounding. One should be eliminated or the reason to have both explained.

Specific Comments:

Page 7 A copy of ICS 209 should be available as an appendix.

A copy of the ICS 209 form has been added as an Appendix

Page 8 The model uses not assumes. This whole page should use the same terminology found in Figure 1 Appendix 2. For example "(1) Subtract off direct recovery from total amount escaping from the reservoir", just say recovered. This section is extremely had to follow and should be edited by a non-technical person.

A challenge in a document of this type is to reconcile precise technical terminology with more common descriptions. 'Direct recovery' is used to distinguish this oil from other oil recovered by, for example, skimming operations. We have simplified the equation expressions, added an introductory narrative to them and added a table of acronyms to the final version to assist the reader.

Page 12 Par 3 add surface after water.
Page 14 ...converted to hydrates at a much higher level... do you mean shallower depth or deeper depth?

Shallower depth

Page 22 (representing a 200 -250C+ residue) is this a boiling point? Need to explain.

50degC+ residue is that the residue has lost all components with boiling point below 250degC

Page 25 Par 1. change "disappeared during" to was not on the surface after

Page 27 last line half=of ?
Page 32 Par 2. 2 to 3 mm thick…. Oil with emulsions…delete typically. …mm or less thick.
Page 35 Simple measurement of barge oil!!! This should be made a requirement!!

We agree when practical.

Page 39 (5) this is self advertisement and should be deleted. What is real code? Is there fake code!!

We disagree with this conclusion. A weakness of oil spill science in the past was translating new ideas into practical tools.

Page 39 (6) Jargon. Explain what the "Interface" you are talking about is. Consider deleting this as it seems to serve no purpose.

One of the key challenges for the team was to provide to the unified command output that is simple to understand yet captures the uncertainty in the estimates. We believe this is a topic that requires more research.

Conclusion

My conclusion is that this model appears to provide a valid estimation of the source and fate of the oil from the DWH incident. It generally agrees with what has been found by previous oil spill research and currently available research on this specific incident.

Unfortunately, the ultimate fate of the oil is more complicated than can be calculated by this tool. Environmental impact assessment is ongoing and will provide a more complete picture than the Oil Budget Calculator.

Reviewer 6:

<u>The OBC as an NRDA tool?</u>
The introduction in particular and the paper overall set the scene well and describe the operational needs that led to the creation of the OBC, the limitations that this development faced, and the authors' overall (and reasonable) conclusion that the OBC outputs "only need to be accurate to the extent that they correctly inform cleanup decisions and do not lead to errors in response actions." (p. 5) Explicit warnings are also made that the OBC tool is not appropriate for damage assessment. While there is no protection against misuse, perhaps the

paper could describe more explicitly just why the OBC is not appropriate as an NRDA tool.

The Oil Budget Calculator is unsuitable for NRDA because it does not track the final fate and environmental impact of the spilled oil. This is explicitly stated on page 3 of the report.

The problem with DOR

The model is a nest of part-weathering, part-response/fate equations describing processes that are partly simultaneous, partly consecutive. For example, while subsurface dissolution is nicely modelled as occurring after subsurface dispersion (i.e. consecutive processes), chemical dispersion, skimming and in-situ burning on the sea surface are all allowed to happen at the same time (simultaneous processes).

One key problem we have with the model is that a great part of the results (in fact, all the consecutive elements, such as evaporation, dispersion and dissolution) are based on the theoretical volume of oil that can be dispersed by a given quantity of dispersant (i.e. DOR = dispersant-to-oil ratios). These are the $90V_{CB}$ and $20\ V_{CS}$ elements of the equations. The issue is that outputs are measured solely in terms of inputs, albeit with the correction factors k_2 and k_3 (which must capture not only the 'encounter rate' of the dispersant application, but also all other technical and environmental factors that may influence the dispersant application). The Appendix (in particular) explains that outputs are measured on the basis of inputs, but we do not believe that this makes it acceptable.

In the real world, DORs are meant as a planning guideline, an indication as to the quantity of dispersant that should be made available (i.e. what should be put in), not the end result (i.e. what comes out). Further, they refer to the dispersibility of surface slicks of a certain thickness (0.1mm according to the ITOPF Technical Paper quoted).

The matter is made worse by the fact that the DOR figures come up so many times in the same equation/ model. For example, if the model equations are solved simultaneously for total evaporation/ dissolution (not even dispersion!), the $90V_{CB}$ component comes up numerous times in relation to:

- *Day t evaporation of non-chemically dispersed at bottom oil (that just rose)*
- *Day t evaporation of non-naturally dispersed at bottom oil (that just rose)*
- *Day t evaporation of non-chemically dispersed at bottom oil from the previous day(s)*
- *Day t evaporation of non-naturally dispersed at bottom oil from the previous day(s)*
- *Day t dissolution of chemically dispersed at bottom oil*

- *Day t dissolution of naturally dispersed at bottom oil*

The use of DOR to define effectiveness was based upon industry familiarity with this approach. Similar results would have been produced if the development team had used fraction dispersed as a function of dispersant applied to available oil with an upper limit on the fraction allowed. What is really needed is solid research to empirically determine effectiveness.

Multiple expert coefficients.
Although the model makes logical sense when analysed part by part, when the equations are solved simultaneously there are numerous places where the educated guesses of experts are multiplied by a series of other such educated guesses. For example, the 2 nd day surface evaporation (with coefficient k_5) is a function of the first day evaporation (with coefficient k_4) which is a function of sub-surface natural dispersion (with coefficient k_1) which is a function of sub-surface chemical dispersion (with coefficient k_2) which is a function of theoretical sub-surface chemical dispersibility (i.e. DOR = 90). In other words, that part of the overall evaporation function which looks like:

$$k_5 W(t-1)$$

really takes the following form when solved for "W" which includes "Z" which includes "Y" which includes "X":

$$+k_5\left[(1-k_4)\left[(1-k_1)\left[V_{RE}(t)-k_2 90 V_{CB}(t-1)\right]\right]-V_{BU}(t)\right]$$

As can be seen, if the equation is solved, the results include such elements as: $k_5 * k_4 * k_1 * k_2 * 90 * V_{CB}$ which is the multiplication of 5 guesses by the observed number of drums of dispersant applied. It is very, very hard to accept this as a meaningful result.
Naturally, the paper includes a number of various variance histograms for each of the main fate/ recovery alternatives, and the Appendix includes a long and detailed statistical model based on repeated computer simulations (i.e. the Monte Carlo analysis),. These do not, however, in our opinion, get over the fact that there are very few variables in the overall set of theoretical equations which are actually populated by real measurements, observations, or even observation-based estimates.
While an argument could be made that having an inaccurate result, even if far from reality, may be more useful than having no result at all when faced with emergency-phase decision making, it cannot be stressed enough that it is not appropriate to use the results in post-spill evaluations of impact or response actions.

The Reviewer is correct in assessing that these numbers chiefly rest upon the experienced judgment of the dispersant experts consulted for this project. However, using expert judgment when hard data is not available is often employed in many fields.

We agree that there are many alternative ways of re-writing the equations that describe the simplified model that we have adopted for the fate of the oil. Some of these may appear counter-intuitive. The formulation we have settled on represents our particular way of viewing the chronology, chemical reactions, and phase changes affecting the spilled oil, which is based on our own, varied experience with oil spills into the ocean. One of our colleagues, who has no expertise in this specific area, and merely as an exercise, did use our description of these processes to formulate an alternative set of equations, independently of our formulation. This alternative had shortcomings that were obvious to those with expertise in the subject. However, it produced estimates for the different volumes that we track that were within the uncertainty range of the estimates that the equations we did use had produced. This suggests that the simplified model we have adopted is fairly robust to varied interpretations, and that rather different sets of equations that may be used to represent our understanding may end-up bringing about no more than relatively minor changes to the bottom line.

Regarding the comment on the 2nd day surface evaporation, this is evaluated by the following expression after development and assuming that $V_{DC}=(1-k_7)\ k_2 90 V_{CB}$ and $V_{DN}=(1-k_7)\ k_1\ [V_{RE}- V_{DC}/(1-k_7)]$:

$$k_5 (1-k_4)\ (1-k_1)\ [V_{RE}- k_2 90 V_{CB}] - k_5 V_{BU}$$

This expression includes terms that are function of one rate constant such as $k_5\ V_{RE}$ and $k_5\ V_{BU}$, terms that are function of two rate constants such as $k_5\ k_1\ V_{RE}$ and $k_5 k_4\ V_{RE}$, terms that are function of three rate constants such as $k_5 k_4 k_1\ V_{RE}$ and $k_5 k_2\ 90\ V_{RE}$, and terms that are function of four and five rate constants such as the one mentioned in the reviewer comment. Of course, the terms that include less rate constants have more influence on the end results than the one multiplied with four and five rate constants, given that all the rate constants are less than or equal to 1. The other terms were kept in the equations of the Calculator for logical consistency and for transparency of the method used.

The uncertainty analysis certainly was done assuming that the rate constants were like realized values of independent random variables, whose probability distributions expressed the knowledge that the subject-matter experts had about their values. This assumption, of statistical independence, clearly is questionable for at least some of them. For this reason, Appendix 1 describes a study of the sensitivity of the conclusions to this assumption, by considering the effects that substantial dependence between several of them would bring about. As it turned out, this lowered the lower endpoint of the confidence interval for the volume of residual oil (or, "other oil"), but hardly changed the upper endpoint, meaning that the assumption of independence

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actually was conservative, at least for the variables considered in the sensitivity study.

Re-coalescence

The model has no explicit mechanism by which some part of the initially-dispersed (sub-surface or surface) oil re-coalesces and rises to join the surface oil. One could, of course, say that the oil that disperses in the model is, by definition, only that which is permanently dispersed. We do not believe that this is a particularly neat solution, given the important discussion in the spill world on the fact that naturally-dispersed oil tends to be less permanently dispersed than chemically-dispersed oil.

Near the riser, it is possible for dispersed oil droplets to collide and form larger droplets due to the abundance of oil droplets and sufficient mixing energy. However, due to the relatively low concentration of oil away from the source, the collision frequency of droplets is very small when one moves away from the riser. Thus, the conditions there are not favorable for coalescence. Any coalescence would compete with shear forces breaking up the larger droplets. There may be an intermediate area where coalescence dominates. The impact of coalescence near the riser might affect the overall effectiveness of dispersant but would be included in the wide uncertainty range selected for oil dispersion.

Dissolution from chemically- vs. naturally-dispersed oil

Related to the point just above, it would be expected that the (mean) droplet size for chemically- and naturally-dispersed oil would differ. This would surely have an important impact on the sub-surface dissolution potential (i.e. k_7), even disregarding the question of effect of droplet size on dispersion stability (as discussed above). In other words, k7 might be best split into two separate coefficients (e.g. k_{7C} and k_{7N}).

Mean droplet size would be considerably smaller for chemically dispersed oil. Mean droplet size for natural dispersion would be expected to be much larger than our cutoff value of 100 micron diameter. However, some droplets would be 100 microns or smaller. These are the ones considered naturally dispersed. Mackay and Leinonen (1977) concluded that, for droplets less than 100 microns in diameter, dissolution is very rapid for any component that will dissolve at all.

Emulsion & Emulsion effects for surface dispersant effectiveness

There is no explicit modelling of emulsion formation in spite of the fact that this was an important process in this incident. Likewise, there is no discussion of the effect of emulsification on surface dispersant effectiveness. This is a key factor, considering the practical experience that shows that emulsions, if dispersible at all, require greater quantities of dispersant than non-emulsified (surface) slicks.

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Emulsification is not a process that directly contributes to mass balance in the way that, for example, does evaporation. The observation that the oil did emulsify is reflected in the burn estimates and in the effectiveness of surface dispersion. Both were reduced to account for the characteristic behavior change of oil that has emulsified. Certain experts thought that the reduction was insufficient, a judgment summarized by Alternate View 1.

Weather & response activity

We find no explicit variables to account for variations in the weather and how these might have affected the response success, for example surface dispersion operations.

Several of the report authors have developed much more complex oil fate and behavior models than the Oil Budget Calculator. However, these models required more detailed input than the design specifications allowed for the Calculator. Sea state, in particular, affects surface processes but, for this spill, varied both temporally and spatially. Also, the subsurface release and extended duration of the leak were not compatible with the standard fate and behavior model used by NOAA and USCG for routine spills. Recommendation 5 suggests expanding existing modeling capabilities so that perhaps this difficulty will not arise in future incidents.

Equations

While we find no mathematical fault in the equations, there are places where slightly different forms would leave the equations more easily interpretable.

For example:

Equation number	*As presented*	*More easily followed form*
A1.4	$Y(t) = V_{RE}(t) - \frac{V_{DC}(t)}{(1 - k_7)}$	$= V_{RE}(t) - k_2 90 V_{CB}(t)$ *or* $= V_{RE}(t) - k_2 X(t)$
	Interpretation: Oil volume available to natural dispersion (and subsequent rising to the surface for that part that does not disperse), once chemical dispersion at the well head has run its course.	

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A1.8	$Z(t) = V_{RE}(t) - \frac{V_{DB}(t)}{(1-k_7)}$	$= (1-k_1)(V_{RE}(t) - k_2 90 V_{CB}(t))$ *or* $= (1-k_1)Y(t)$
	Interpretation: Oil that rises to the surface after chemical and natural dispersion has run its course.	
Part of A1.10	$\frac{k_7 V_{DB}(t)}{(1-k_7)}$	$+k_7 k_2 X + k_7 k_1 Y$
	Interpretation: That part of the subsurface chemically-dispersed and naturally dispersed oil that dissolves into the water column	

While the proposed forms to represent the three equations appear to be simpler than what is proposed in Appendix 1, these simplifications do not respect logical consistency in the formulation and the solution of the problem. The "min" and "max" functions were introduced in equations A1.3, A1.5, A1.9, A1.11, and A1.12 to ensure that the oil volume is conserved and no non-realistic results are generated in the Calculator.

Conclusions

The equations on which the OBC is based offer an interesting theoretical study of many of the fate and weathering processes relevant for a sub-sea blowout incident such as the DWH. There are some elements which could be added to the model such as explicit weather (e.g. wind, waves), emulsification, re-coalescence of dispersed oil, or refined such as droplet-size-based dissolution.

As a practical tool, however, the OBC suffers the same shortcomings of most mass-balance efforts: lack of real-world observations. In this case, lack of actual observations of dispersion effectiveness in particular render the overall result practically meaningless. The only true observations in the model appear to have been the volume of oil/water mix collected by skimming operations (traditionally a very suspect measure of actual oil volume collected), the volume of oil dispersant used (probably reasonably well counted but utterly meaningless in terms of estimating actually-dispersed oil), and the number and approximate size of in situ burns (a very rough value for a very rare activity).

One could argue that having the OBC result, although an inaccurate number, was better than having no number. The truth is, however, that the overall result could have been no better or no worse without it. In fact, the response operations were guided primarily by 1) the visible presence of oil, whether it was escaping from the wellhead, on the surface in the form of slicks that could be burned, skimmed, or dispersed, 2) the availability of resources, and 3) non-

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technical concerns (such as the maximum daily-dosage of subsurface dispersant application).

The Oil Budget Calculator was only one tool among many that the unified command used to make response decisions. As with any tool, it has its strengths and limitations. The skill of the decision maker is to utilize all the tools available in an appropriate manner to optimize the response. Based upon the request by the NIC for this tool, and its continued usage during the spill, we must conclude that they found some value in it.

Reviewer 7:

General;

I thought the report was informative and as precise as was possible under the constraints of the available data. Errors and uncertainties were identified. I was specifically asked to review Oil properties, Dissolution and long-term processes. I think each section was adequately presented under the terms of reference.

I suggest you provide a list of acronyms for all the various agencies, etc. "in situ" or "in situ" is not consistently presented in the report

A list of acronyms will be included.

I have the flowing specific suggestions to the text.
P12 p 2. L 6. "an average"...
P13 p1 L4 "considerably larger"
Fig 3. Define bopd in the figure caption.
Fig. 7 *The blue series is not described. Presumably it is a surface oil sample taken near the source. Thus the title should be amended to read "..., floating oil samples immediately adjacent to the source (red,blue).....*

The blue series is not a sample collected at the surface, but came from a sample from dispersant efficiency testing.

P. 20 p2. L10 "data provided (to, by???) BP"

Provided by BP. Correction will be made in the text.

Fig. 8 should be moved up 2 paragraphs to appear under its description.

P27 under Fig 11. L3 delete "when" L 7. delete "="

P27 under Fig 11. I could not see a conclusion from this paragraph. The issue of dispersant efficacy is left hanging. A statement that says there is no conclusion possible from the sattelite data would be useful.

Sentence added

However, May 11th and May 12th show similar surface expressions although the latter should be displaying more oil. Therefore, these observations provide inconclusive results.

P 29-30. Delete reference to Fig 13 here as the same sentence appears on P 13 just above the figure.
P31 last L "from"

P38 p1 L8 What is the basis for concluding hydrocarbon degradation in the water column occurs without oxygen drawdown? This needs to be expanded to clarify and justify this statement.

Hydrocarbon degradation doesn't occur without oxygen utilization. There was draw down, as discussed in the JAG 2 report. The fact that the DO2 drawdown was not as high as expected is most likely do to mixing as described in Appendix 2 of the JAG 2 report.

References:
P. 12 Yapa 2010 should be et.al.
P 19 Kirsten et al 1984 is not in the list
There are several citations in this section where multiple citations are not properly presented
Eg: P. 20 (Payne, Kirsten et al., 1984) should be (Payne et al, 1984; Kirsten et al., 1984)
There are 3 such citations on Page 20. Other sections of the report do it properly.

References in the list but not cited in text or figures
These should be cited, deleted or added as "additional useful references" or some such.

Belore, R. (2003). "Large wave tank dispersant effectiveness testing in cold water". International Oil Spill Conference; Prevention, Preparedness, Response and Restoration, Perspectives for a Cleaner Environment: April 6-11, 2003, Vancouver, British Columbia, Canada, pp 381-385.

Belore, R.C.; Trudel, B.K.; Lee, K. (2005). "Correlating wave tank dispersant effectiveness tests with at-sea trials". International Oil Spill Conference; Prevention, Preparedness, Response, and Restoration: May 15-19, 2005, Miami Beach Convention Center, Miami Beach, Florida, pp 65-70.
Brandvik, P.; Daling, P.S.; Lewis, A.; Lunel, T. (1995). "Measurements of dispersed oil concentrations by in-situ UV fluorescence during the Norwegian experimental oil spill with Sture blend". In Proceedings, Eighteenth Arctic Marine Oil Spill Program Technical Seminar, June 14-16, 1995, West Edmonton Mall Hotel, Edmonton, Alberta, Canada. Ottawa, Ont.: Environment Canada. pp. 519-535.
Brutsaert, W. (1982). Evaporation into the Atmosphere: Theory, History, and Applications. Dordrecht, D. Reidel Publishing Company.
Colcomb, K.; Salt, D.; Peddar, M.; Lewis, A. (2005). "Determination of the limiting oil viscosity for chemical dispersion at sea". In 2005 International Oil Spill Conference; Prevention, Preparedness, Response, and Restoration: May 15-19, 2005, Miami Beach Convention Center, Miami Beach, Florida. Washington, D.C.: American Petroleum Institute. pp. 53-58.
Daling, P.S.; Brandvik, P.J.; Reed, M. (1998). "Dispersant experience in Norway: dispersant effectiveness, monitoring, and fate of dispersed oil". In Dispersant Application in Alaska: A Technical Update, Anchorage Hilton Hotel, Anchorage, Alaska, March 18 and 19, 1998. Cordova, Ak.: Prince William Sound Oil Spill Recovery Institute. pp. 111-146.
Fiocco, R.J.; Daling, P.S.; DeMarco, G.; Lessard, R.R. (1999). "Advancing laboratory/field dispersant effectiveness testing". In Beyond 2000, Balancing Perspectives: Proceedings: 1999 International Oil Spill Conference: March 8-11, 1999, Seattle, Washington. Washington, D.C.: American Petroleum Institute. pp. 177-185.
Lehr, W.; Jones, R.; Evans, M.; et al. (2002). «Revisions of the ADIOS Oil Spill Model", Environmental Modeling & Software, Vol 17, Issue 2, pp. 191-199.
Lewis A.; Crosbie, A.; Davies, L.; Lunel, T. (1998b). "Dispersion of emulsified oil at sea". AEA Technology report. AEAT-3475. AEA Technology, National Environmental Technology Centre (NETCEN, Didcot, Oxfordshire, England.
Lewis A.; Crosbie, A.; Davies, L.; Lunel, T. (1998). "Large scale field experiments into oil weathering at sea and aerial application of dispersants". In Proceedings: Twenty-First Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, June 10 to 12, 1998, West Edmonton Mall Hotel, Edmonton, Alberta, Canada. Ottawa, Ont.: Environment Canada. pp. 319-344.
Lunel, T.; Rusin, J.; Bailey, N.; Halliwell, C.; Davies, L. (1997). "The net environmental benefit of a successful dispersant operation at the Sea Empress incident". In Proceedings: 1997 International Oil Spill Conference: Improving Environmental Protection: Progress, Challenges, Responsibilities: April 7-10, 1997, Fort Lauderdale, Florida. Washington, D.C.: American Petroleum Institute. pp. 185-194.

Lunel, T.; Lewis, A. (1999). "Optimization of oil spill dispersant use". In Beyond 2000, Balancing Perspectives: Proceedings: 1999 International Oil Spill Conference: ---44--- March 8-11, 1999, Seattle, Washington. Washington, D.C.: American Petroleum Institute. pp. 187-193.
Mackay, D.; Matsugu, R.M. (1973). "Evaporation rates of liquid hydrocarbon spills on land and water." Canadian Journal of Chemical Engineering, Vol. 51, pp. 434- 439.
National Research Council (1989) Using Oil Spill Dispersants in the Sea, National Academy Press, Washington DC, 335 pp.

Reviewer 8:

General comment. In the report use laboratory not lab.

Page 6, Top Paragraph, Third sentence – "Other longer-term processes" Name the processes are the authors referring to.

Sentence revised

Other longer-term processes such as biodegradation, photo-oxidation, and sedimentation may have an impact on the environment but are less amenable to response decisions

Page 7, Top paragraph, second sentence. Suggest changing "..usually a simple, if slightly dull, process" to "... usually a straightforward process." Do not minimize the task of correctly filling out Form ICS 209.

Page 8, (2) Determine the bottom chemical dispersion amount. The equation uses a term 90k_2. Why was 90 used? I reviewed Appendix 1. I see that k_2 is the constant for subsurface chemical dispersion Table A1.2. on pp. A1.9. Why was 90 added to the constant?

All the rate constants are defined in such a manner that they vary between 0 and 1. In the model, the DOR for subsurface dispersants has a maximum possible of 90. Therefore, the 90 appears as a scaling factor.

Page 10. The Ixtox Spill. First paragraph, last sentence refers to depth of the well "about 50 m". Last paragraph, First sentence has depth as "approximately 165 feet (51 m). Be consistent.

Comment for Section 3.0 Ixtoc spill - I suggest when comparing Ixtoc to DWH add the fact that that distance to shore was a factor in differences.

Comment for Section 3.0 Ixtoc spill – I suggest mentioning that dispersant application was more closely targeted for DWH than Ixtoc. During Ixtoc, dispersants were applied very close to shore, in the surf zone, and at the entrances to tidal creeks and other waterways.

Page 13, Top paragraph, Start of Third sentence. Is something missing at the start? The sentence starts out with "estimated"
Or does the sentence start out with the citation (Lehr , 2001….)? Not clear to the reviewer.

Page 27. Last paragraph. The multi-spectral scanner measures the thickness and distribution of the oil slick in coastal and offshore waters in real-time. I suggest the explanation of the 4-picture sequence be explained in better detail.

Explanation expanded

Found a number of references in Section 15 not in the report.

Belore (3002)
Belore et al (2005)
Brandvick et at (1995)
Brutsaert (1982)
Colcomb (2005)
Daling (1998)
Fiocco (1999)
Lehr (2002)
Lewis (1998b)
Lewis (1998)
Lunel (1997)
Lunel (1999)
Mackay (1973)
Mackay (1975)
NRC (1989)
The IXTOC I Oil Spill

Appendix 1 – Reference Section. No reference for W.N. Venables (2002) in the appendix.

The reference to Venables & Ripley (2002) is made on page A1.10 (Appendix 1), and the reference itself is specified on page A1.17.

Reviewer 9:

Overall: There were problems in following the calculations as the descriptions were in the front and the equations in the appendix. It is not clear if the equations had any background or references. Did the authors develop them independently or was there a background or previous papers on each? I also had difficulties following the Appendixes due to lack of consistent numbering.

A challenge in constructing a report of this nature is the diversity of the audience. We anticipate readers who will gravitate to the intricate mathematics of Appendix 1 while others will wish to see only the descriptive explanation of the model. As an imperfect compromise, the authors have chosen to provide the basic equations with a descriptive narrative at the beginning of the report, leaving the more complex mathematics to the Appendix. The equations themselves were constructed specifically for the calculator, based upon mass balance preservation and the spill experiences of the development team. Previous algorithms were used or modified for specific processes and are referenced in the main text.

Consider putting in Resumes for the other contributors so that when they are referenced through "Personal Communication", readers know their background to add credibility. (especially Yappa and Galt)

There are important differences between the major report contributors, who have all read the report and determined that it was acceptable for external review and the other contributors who may have not read the report in its entirety. We have chosen to acknowledge the latter's help but do not believe it would be appropriate to put them in an Appendix of major contributor resumes.

Check all figures and move so that they are placed conveniently. (For example, Figure 7 is on page 19 but referenced on page 20 and figure 8 should be placed before Section 7 On page 21.

Individual Comments.
1) Table of Contents: appendix names not consistent with titles in Appendix themselves.

2) page 8, report goes right into equations without enough explanation. Try adding a couple of sentences at top of page 8 after straightforward: Something like "There are eight general categories for identifying the mass balance and…"

Additional introductory material is added, including a narrative explanation

of the equations

3) page 8-9, any specific references to these equations? If not, consider stating "These equations are based on…". Also consider putting a copy of Table A1.1 near beginning of report.

See the new narrative.

4) page 22, the range of volume figures used throughout is confusing. Consider placing the left-hand line under the rectangle and labeling the individual dotted/shaded areas. It is not clear what these are showing unless somehow they are combined at the end to show range.

Figure 8 and similar figures in the report have been deleted.

5) page 23, again are equations from NRC 2003 or ADIOS2?

Equations are adapted from the Delvigne-Sweeney dispersion model (Delvigne and Sweeney, 1988)

6) move figure 12 to page 29.
7) page 39. Why are results given in Appendix?

Model results will be added to Section 14.

8) Appendix 1 is confusing due to multiple page numbers.

This has been improved pursuant to the reviewer's observation.

9) Need a better link from main section of report to Appendix 1. Note that there are 16 equations with limited explanations.

Appendix 1 provides the mathematical underpinning of the model. The purpose of the main section is to provide the science behind it. Section 2 provides an explanation of the important equations that control the processes. Deleted in this explanation, are auxiliary equations that sum results for graphing.

10) Table A1.2 – Not completely clear if and how rate constants are related to estimates given in main section.

Toward the end of each section is a discussion of the range of values that can be expected for that process. For example, the section on natural dispersion defines 20 % as the expected fraction of oil that will naturally disperse with a

range between 10% and 30%. This translates into an expected value for k_1 of 0. 2 with a range between 0.1 and 0.3.

11) Appendix 3, consider wrapping text in title cells so that all number can fit on single page for easier reading.

12) Appendix 4, need better explanation of how samples were collected and analyzed. Just a brief paragraph that provides more than the Figure titles.
13) Appendix 6, need to state in first paragraph that "this Appendix does not provide information on the in-situ monitoring.
14) Consider describing test apparatus/process. For example, is the water sample poured through a column that the LISST monitors?
15) Consider adding more information about sampling depths, etc.
16) Appendix 7 – Label and reference all tables and figures in Appendix B. Had much difficulty in correlating with explanations.

Appendices 4 through 7 reproduce already published reports reprinted here with the owners' permission to provide completeness to the report. We cannot modify them.

Reviewer 10:

Overall, this is a well-written document, with a clear objective of advising response options rather than being a comprehensive scientific study. The document references the literature of spill science well, and appropriate experts have contributed to various aspects of the report. It appears that the calculator was useful to inform response options over the summer. Below are several detailed comments:

The Executive Summary summarized the report well for the most part. Extra emphasis on the differences between a deep water spill such as this one and much more common surface spills should be made to overcome misconceptions that most managers will hold having only experienced shallow waters spills.

Introductory paragraph added to the Executive Summary

An estimate of the oil budget should be included in the Executive Summary. Maybe even just the pie chart (Figure 2 in the web-based tool section)

While there is much to be said for including the results in the executive summary, it was also recognized that this could lead to some readers

proceeding no further. The development team believes that it is essential to understand the purpose and limitations of the calculator before considering its results. As a compromise, the results are now included in Section 14 of the report where the Calculator itself is assessed.

Degradation rate of the oil components should be evaluated quantitatively if possible. Over the timescales relevant to the response, degradation rates are seen to be significant. Degraded oil should be a fate in Figure 2 pie chart.

The development team believes that this would lead the use of the Calculator away from response toward damage assessment, something that it is ill-suited to assist.

The changing composition of the oil should be part of the analysis. While this may seem to be too much detail for response, some fractions of oil are more toxic (will have bigger impacts) than others, so response options should consider the composition (e.g. toxicity) of the remaining oil in addition to just the total amount.

A good point but it exceeds the purpose of the Oil Budget Calculator since it is only about the oil budget. We have tried to stay as close as possible to the standard ICS 209 output categories. See new Appendix that includes that part of the ICS 209 form that deals with the oil budget.

The pie chart seems to be a good instantaneous visual for making decisions. If uncertainty could be built into the graphic, that would be very effective.

I think this is a point where you would finduniversal agreement among the Calculator developers. The challenge has been to provide that uncertainty explanation and yet keep the output graphic clear and understandable. We are still working on it. See recommendation number 6 at the end of Section 14.

My biggest criticism of the report is the handling of dissolution vs. evaporation of the oil. The discussion in Section 5 is good. It is most likely that dissolution of lower molecular weight hydrocarbons will occur at a much higher proportion for a deep water spill compared with a shallow water spill, especially as oil was dispersed. The processes of evaporation and dissolution, while similar, are not identical, and should not be treated as such in the sense that they will affect the composition of remaining oil differently. Of larger concern is that the composition of oil will be altered in sub-surface oil as well as surface samples, so the sampling protocols and expected compositions of oil would be different than for a shallow water spill. The ultimate fate of dissolved oil will not be considered with this model, and in some senses, dissolved oil is the most toxic as it is readily bioavailable. I would suggest the

dissolved quantities be separated from the evaporated quantities. Evaporative losses require no response as atmospheric processes act on wholly different spatial and temporal scales. The dissolved "losses" means that there is a significant amount of oil still in the ocean that needs consideration if not some hydrophobic recovery option.

Your points are well taken here and the group had considerable discussion about the merits of separating the two processes into two categories. Certainly, any environmental impact assessment calculation would be required to do that. However, this is strictly a response tool, and from the responder's point of view, there is no further cleanup applicable to evaporated or dissolved oil. Plus, we did not believe we had sufficient sample data to distinguish between the two overlapping processes. Therefore, we reluctantly kept them together. As more data become available, we may wish to revisit this decision.

The Longer Term Processes section was indeed needed in this report, even though it does not affect short-term response efforts. This section describes the processes of photodegradation and biodegradation. The literature review and discussion were good. A simple table illustrating the quantitative removal of various components of oil would be useful in communicating the fact that photo- and biodegradation are important processes that can remove (or at least change composition) of a significant amount of oil in the environment. Conditions (mainly temperature and depth) need to be included. This understanding of longer term impacts should affect decisions that are made in the short term, in that the ultimate fate and impact of the oil must be weighed against costs of response.

We included the section on longer-term processes to provide background to those who are new to spill science. We are wary of expanding this section because there are others preparing much more complete and detailed analysis on these phenomena that should be the true reference sources on the subject.

In the assessment and future plans section, #2 states that practical operational tools are needed to characterize droplet size. Has the LISST-100 (Sequoia) particle size analyzer been considered? It measures particle size in 32 size class bins from 1-55 um by laser, Mie scattering. An Optical Plankton Counter (e.g. Brooke Ocean Technologies)uses laser shadow graphs to measure particles from 100 um to over 1.5 mm. If these instruments cannot be used, it would be useful to know why not. If they were not tested, maybe they could be mentioned in the future plans section.

As noted in Appendix 7, the LISST-100X was used for particle size analysis

on the R/V Brooks McCall and the R/V Ocean Veritas. The accompanying documentation outlined the limitations of using the LISST in the bench-top mode for the provision of data for the calculation of total dispersed oil for calculation of mass balance. However, the mission was to verify if the chemical oil dispersants were effective by quantifying the formation of smaller oil droplets and to identify the presence of the subsurface oil plume. This was conducted successfully. However, in the bench top mode utilized, explained in Appendix 7, the team could not trust the data in the larger size class bins. At the time of the spill, Sequoia had discontinued the manufacture of of a LISST for deepwater deployment (>300m for the LISST-100X) due to the lack of sales (and apparent problems with leaks). A LISST DEEP (depth range of 2500-6000m) is now in production as direct result of demand generated by the Gulf of Mexico spill that will resolve some of the limitations of using the LISST in bench top mode.

A Laser Optical Plankton Counter (LOPC), developed by Dr. Alex Herman at Department of Bedford Institute of Oceanography, Fisheries and Oceans Canada, measures particles >100um. NOAA is currently deploying a LOPC with a *Moving Vessel Profiler* (MVP™) in the Gulf of Mexico. A new prototype for the monitoring of plankton in ballast water with a lower size limit of > 20 um is being evaluated. For the sampling work in the Gulf of Mexico, the sampling team chose to use the LISST-100X as chemically dispersed oil typically results in an increase in oil particles in the <10um size range. It is important to note that both the LISST and LOPC cannot distinguish oil droplets from other particles.

Regarding future plans, there is a need to evaluate the various other in situ instruments that may be capable of measuring of oil droplet size. Years ago, Dr. Jim Bonner at Texas A&M evaluated field instruments including the LISST for real time in-situ crude oil concentration measurements but not oil droplet size distributions.

For work in the Gulf of Mexico, the sampling team chose to use the LISST-100X as chemically dispersed oil typically results in an increase in oil particles in the <10um size range. It is important to note that both the LISST and LOPC cannot distinguish oil droplets from other particles.

Figures 4&5 of the Web-based tool section were informative in that the estimates were fairly close from worst case to best case so that the inherent uncertainty was not very large. I would agree with the report that some visual representation of the uncertainty in the calculator would help decision makers dramatically.

We agree.

Reviewer 11:

The report contains a lot of good information, and the approach to the budget calculations is sound. However, the draft could be improved in several ways. Firstly, it is somewhat uneven in its coverage (e.g., stronger coverage of surface processes such as evaporation and surface dispersibility than on corresponding sub-surface processes). Secondly, it would benefit the reader to include results of at least the base case budget, obtained using the calculator, in the main text and the Executive Summary, instead of just the appendix. Most importantly, I wonder if the motivation for the report should be expanded. The stated objective was for "response advice only and…not… any other purpose." This may be literally true but it seems very limited. Everyone understands that there was at least some oil in each of the "pieces of the pie", and there was a tacit assumption that it was worth responding to any oil that was amenable to clean-up. (A lot of effort was put into skimming surface oil even though it only amounted to 3% of the total release.) Do we really need a budget calculator for this purpose? Given the enormity of the spill, its environmental consequences, the fact that the opportunity for most clean-up procedures has passed, the threat of future spills, and our uncertainty regarding much of the science, a far more important motivation would to better understand the underlying processes affecting the oil's fate. And this calculator makes a good place to start. More specific comments (many minor) are provided below by section.

The Oil Budget Calculator was developed to meet response needs only and the group would strongly counsel against using it for any other purpose. The report was written to document for the external scientific community the inner workings of the Calculator and provide recommendation for future research.

Page 8 (and elsewhere). In several places the report refers to dispersed oil "at" the bottom. "Near" the bottom would be more descriptive.

Page 8. In calculating the chemically dispersed "bottom" oil (eq 2), the factor 90 is not explained. Nor is the factor 20 in eq 7 in the subsequent discussion of chemically dispersed surface oil. (I assume these relate to the respective DORs?)

Your assumption is correct. The two values relate to the respective maximum DOR and are used in the equations as scaling factors so that the rate constants will have a maximum range of 0-1.

Page 9. Since chemically dispersed surface oil is time dependent (efficiency

decreases with weathering, like evaporation), was consideration given to introducing time dependent (day 1, day 2...) values for k_3 as is done for evaporation (k_4 and k_5)?

This was considered. However, surface dispersant operations were applied to oil slicks at various states of weathering. Therefore, it would have been logistically impossible to assign a t-value to the sprayed surface oil.

Page 11, paragraph 2 mentions "Current news reports..." and Page 12, paragraph 1 mentions "At the time of this document preparation...". Better to include the date (or at least month) since the information may not be current when it is read.

Page 13, paragraph 2. The Clark et al (2010) study estimates a minimum amount of surface oil on May 17 as 66,000 to 120,000 bbl, but implies the value could have been as high as 500,000 bbl (a little less than 1/3 of the oil spilled at that point) which is the value used in the calculator. This fraction (~1/3) seems quite high, especially since, subsequent to May 17, sub-surface recovery and dispersant use would dramatically reduce the oil reaching the surface, and ongoing evaporation and natural surface dispersion would reduce the equilibrium fraction of oil on the surface.

The NASA/AVIRIS system was measuring cumulative oil remaining on the surface by mid-May. Through April and early May, burning, direct capture, and subsurface dispersant usage were limited, leaving more surface oil. Some of this early oil, probably emulsified, would still be on the surface during the NASA ER/2 flights. However, we agree that this would be at the high end of our estimates.

Pages 13 (bottom) and 14 (top) discuss the gas portion of the release and mention that a large portion of the gas dissolved and hence may never have made it to the surface. Is there observational evidence (or modeling) that suggests that ANY significant fraction of the gas made it to the surface? The paragraph mentions the potential for hydrate formation. Clearly hydrates were formed within the confining spaces of some of the earlier containment vessels, but was there evidence of their formation in the free plume? (If so, please indicate.) Since the principle components of natural gas (methane, ethane and propane) have different hydrate stability zones, it would be helpful to know the composition of the natural gas. Concentrations are given in Appendix 4, but I gather this is just for the oil. Steve Masutani from U. Hawaii performed some nice experiments demonstrating the effect that an oil film has in inhibiting hydrate formation on a gas bubble (Masutani and Adams, 2000).

See revised text. Leifer (2010) modeled plume behavior based on observations presented in Camilli et al. (2010) and concluded that the gas phase of the plume dissolved in the mid-water column and deeper and was transported by oil plume processes to the thermocline. Only gas components dissolved in oil reached the sea surface to exsolve and evaporate. As a result, atmospheric measurements (Leifer et al., 2010, in progress) do not show enhancement in atmospheric methane (except associated with flaring). In contrast, hexane and large organic compounds were enhanced. Tow sled video data (Asper, unpublished, 2010), showed extensive plumes of orange-white material uncommon to the deep sea (i.e., not marine snow), which was interpreted as oily hydrate flakes in the depth where others have reported enhanced CDOM (a fluorometric indicator of oil, albeit with very poor sensitivity).

Leifer, I., et al. (2010 in progress), Air quality implications of the Great Macondo Oil Spill.

Page 14, last paragraph. It is mentioned that the tiny oil droplets were continually exposed to uncontaminated Gulf waters and hence their dissolution was not controlled by equilibrium factors. It seems likely that much of the sub-surface oil was contained in thick (hundreds of meters in the horizontal and at least tens of meters in the vertical) intrusions with fluxes of thousands of cubic meters per second. So even without exposure to ambient GoM water, dissolution would not likely have been constrained by equilibrium build-up.

Point noted. The development team is cautious about reaching extensive conclusions on dissolved hydrocarbons while studies are ongoing.

Page 15 (Fig 4 on droplet rise velocity). It would be helpful to give the density of the oil that was assumed, and to expand the graph to the physically more interesting lower diameter range.

The graph was meant to illustrate the fact that the rise velocity for even larger droplets was small enough that the transit time to the surface was long. See the discussion and reference by Spaulding. The fresh oil density was 0.85 gm/cm3 (API 35).

Page 15 (and elsewhere). Much of the most useful information in the report has been provided by the experts, and cited as personal communication (Yapa on this page; also Galt, Lasheras elsewhere) or unpublished reports (Lewis). Can additional information be provided when there is no formal reference?

Common in spill response is research that is used before it is formally documented. The Oil Budget Calculator is one example. We hope that these

experts will formally publish their findings but are reluctant to release their private communications beyond what is necessary in the report. In all cases we have tried to cite published references to supplement their unpublished comments.

Page 17, paragraph 2. It was estimated that any oil exposed to conditions that could lead to dissolution would lose 5-10% of its volume... Presumably this explains the mean value of 0.075 for k_7? (It would help reinforce the readers' understanding if this was mentioned.) Can the authors relate Fig 6 showing the dissolution potential vs C-number to the oil composition in Appendix 4 to show the reader where the 5-10% comes from?

A dissolution potential of 5-10 % is a rough estimate based on earlier experiences from dissolution studies of various oils (referred to Melbye et al 1999 in the report) and with the present available chemistry of the DWH crude oil. Unfortunately, the detailed chemistry of the BTEX'es are not specified in the appendix 4 data. (which will be a significant contribution to the dissolution potential). That is why we ended up in this relatively wide span of 5-10 %. It is therefore difficult to directly relate the dissolution from the chemistry data in appendix 4 to Fig. 6.

More specific estimate of the dissolution potential will be calculated when the more detailed data of the crude oil chemistry are available.

Page 22 (Figure 8, and others like it). The range of volumes (mean and with uncertainty) relative to the total spill (4.9 Mbbl) is clear, but what does the placement of the colored bar mean? Is there a horizontal bar chart invisioned that aims to add all of these up? (I know there is a pie chart in Appendix 2.)

Figure 8 and similar figures have been removed

Pages 21 (bottom) and 22 (top). The discussion of emulsification is useful but brief. Where do the percentages (16 to 38) come from?

Most crude oils and petroleum products require weathering (evaporation) before they will form emulsions (NAS, 2000) This weathering is necessary to increase the viscosity and the asphaltene/resin content to the point where the next water-in-oil type is possible. Oils from similar oil fields have a tendency to form similar emulsions with similar weathering tendencies. It should also be noted that there are some exceptions to this as well. Table 2 shows the emulsification tendencies of Gulf of Mexico oils (Fingas, 2009). Table 2 shows that oils that formed stable emulsions had weathering percentages of 37.7, 26.2, 16.4, 25.5, 22.6, 24, and 35.2%. These averaged 26.8%.

1 NAS, *Oil in the Sea III, Inputs, Fates and Effects*, National Research Council, National Academies Press, Washington, D.C., 2002

2 Fingas, M. and B. Fieldhouse, Studies on Crude Oil and Petroleum Product Emulsions: Water Resolution and Rheology, *Colloids Surf. A*, 67, 2009

Table 2	Stable Emulsions from Gulf Oils										
	Weathering	to form emulsions								Complex	Water
Oil	%	Visual	Density							Modulus	Content
	evap.	Stability	(@15C)	Viscosity	Saturates	Aromatics	Resins	Asphaltenes	Stability	(mPa)	(%w/w)
Garden Banks 426	37.7	Stable	0.8993	136	56	32	10	3	588	8.00E+04	64.7
Mississippi Canyon 72	26.2	Stable	0.9095	195	52	34	11	3	1128	2.20E+05	74.4
Mississippi Canyon 807	16.4	Stable	0.9375	491	39	41	13	7	111	5.45E+04	67.5
Mississippi Canyon 807	25.5	Stable	0.9582	3454	31	43	18	8	46	1.60E+05	65.4
Neptune Spar (Viosca Knoll 826)	22.6	Stable	0.8986	187	61	29	8	2	4947	9.25E+05	62.5
Viosca Knoll 826	24	Stable	0.9067	325	59	29	8	3	1046	3.40E+05	64.1
Viosca Knoll 990	35.2	Stable	0.8905	91	62	28	8	2	1075	9.8E+04	63.9
average	26.8										
of weathering of Louisiana											
crudes to yield Stable emulsions											

Were there no direct measurements of emulsification in oil samples from the DWH spill?

Only very limited emulsion analysis was available at the time of the Calculator construction. It indicated a weak and easily broken emulsion.

How has percent emulsification been used in the budget? Was it used? (Since emulsified oil was skimmed and presumably could no longer be evaporated, does it matter to the budget calculator what its percentage was?) Where does the analysis from Appendix 7 enter the discussion?

The observed tendency of the oil to emulsify was used in reducing the effectiveness for burning and surface dispersion.

Page 22, Section 8, paragraph 2. Is there a reference for "Payne reports plumes of oil droplets…"?

See reply to the Fourth Reviewer of a similar question.

Page 23, paragraph 2 mentions that using 100 microns as an upper bound diameter for dispersible droplets is conservative (presumably in view of the fact that somewhat larger droplets are also slow to rise). It should be mentioned that this is conservative in that it may overestimate the amount of oil reaching the surface, but is NON conservative in estimating the oil retained sub-surface. Aren't both fractions important?

By overestimating surface oil, and hence oil that potentially could be subject to further recovery, we meet the Calculator definition of conservative. It may not be conservative in regard to environmental impact.

Page 23, eq 12. Is the ratio reversed? As written R appears to be the dispersed mass due to leaking pipe divided by dispersed mass due to breaking waves

Corrected expression inserted

Page 24, top. There is a huge (2.5 order of magnitude) difference in the predicted "theoretical" dissipation rate (Eq 13) of 7 m^2/s^3 and the Martinez-Bazen et al. (1999) value of 0.02 m^2/s^3 (rate = 0.003 U_o^3/D_o). The latter rate is based on actual measurements, but the measurements are for a pure water jet near the orifice, while the dissipation rate in a real oil/gas leak would be higher due to the turbulence introduced by the bubbles and droplets. Thus the real dissipation rate is likely to be in between as the authors state. (It would help to give the exit velocity and pipe diameter so that the reader could verify these computed dissipation rates.) Compounding the uncertainty in dissipation rates are the differences between a sub-surface oil plume and a surface oil slick. A sub-surface oil plume is reasonably steady and uniform (in an Eulerian framework), whereas surface wave conditions are quite patchy over space and time scales of tens of meters and hours. On the other hand, surface oil has a time window of a few days during which it is dispersible, while an oil parcel traveling through a plume has a window of only a few tens of seconds, since dissipation rate drops off rapidly with distance. (The dissipation rate is proportional to the plume velocity (which decreases) cubed divided by the plume diameter (which increases).) In view of the above, quantitative calculation of the rates of subsurface and surface natural dispersion are quite uncertain. Also, could the authors provide more explanation as to where the 10 to 30% figures come from?

Your observations are correct and illustrate the challenges faced in estimating subsurface dispersion, both natural and chemical. One of the unsettled points among the experts, for example, was whether there was sufficient mixing time between the surfactant and the oil for effective dispersion. Following the rule to be conservative, the lower dissipation rate of Martinez-Bazen is used, minimizing natural dispersion and increasing oil on the surface. The minimum natural dispersion value is considered to be the lowest credible estimate consistent with Camilli et al. (2010) and the maximum the largest estimate consistent with the AVIRIS and LISST results.

Information on exit velocity and pipe dimensions can be found in the FRTG report, Deepwater Horizon Release, Estimate by PIV, 215 pp. (2010),

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available on the USGS Deepwater Horizon website.

Page 31, second paragraph. It would be helpful to have more information about how the dispersants were added sub-surface. For example, how close to the plume was the narrow diameter wand held by a ROV? The high plume velocity would have introduced an entrainment (radially inward towards the plume) velocity of about 10% of the local plume centerline velocity, and this entrainment velocity should have carried dispersant into the plume if it were released anywhere near the plume edge.

The team did not have access to videos of dispersant injection, only data on the volume of dispersant used.

Page 31, bottom. There appears to be little consensus among the report authors as to the effectiveness of sub-surface dispersant use, making this a prime topic for further research. My feeling is that it was probably quite effective. In addition to the arguments presented by "Alternative View 2" on page 29, we know that vertical profiles of fluorescence (indicating oil), typically showed a major intrusion a few hundred meters above the seafloor, with much smaller intrusions similarly spaced above the first intrusion. (See figure from one of the R/V Brooks McCall surveys below.) I believe that the intrusions contain oil that is detrained (along with seawater) from the plume as it ascends through a density-stratified ocean and passes a level of neutral buoyancy. Such detrainment events are clearly evident in laboratory measurements of gas and water plumes (Socolofsky and Adams, 2002, 2003). Oil droplets would follow the seawater into the intrusion only if they were small, with insignificant rise velocity, as if chemically dispersed. (A small amount of dissolved oil could also be included in the intrusions.)

Many of our experts would agree with your conclusions. Unfortunately, others, including another reviewer, disagree. All would agree that there is little consensus on the subject and further research is required.

Appendix 1 (Uncertainty). I did not have time to do this section justice, but it appears to be solid. I do question if the k-values in Table A1.2 should be called "rate" constants. Rate constants usually have dimensions of reciprocal time, whereas the values of k are dimensionless.

We have used the expression "rate constant" by force of analogy with chemical kinetics, and agree with the reviewer that this may not have been the most accurate characterization for these constants: alternatives that came to mind, including "efficiency constants" and "yield factors", also suggest analogies that could be deemed deficient. Since we believe that the risk of misinterpretation is minor, we have chosen to retain this expression.

Appendix 2 (Oil budget calculator). The appendix should have a number (2) and its title should match that listed in the TOC. (Appendix 5 also needs a number.) These are small points, but "Figures" 1 and 3 are actually tables. It would also be nice to make the figure and table numbering consistent with the rest of the report, e.g., Figure A2.1, etc. Similar comments apply to other appendices.

Appendix 5 (SINTEF dispersibility study). The MNS tests were conducted for 5 minutes; for how long were the IFP tests conducted? Was there any thought given to similar studies with sub-surface oil like that in the plume (unweathered but subjected to relatively high energy for short periods of time)?

Appendix 6 (LISST measurements). Paragraph 1 of page 1 refers to both bench top LISST measurements (of collected samples brought onboard) and continuous in-situ measurements with the instrument deployed at specific depths. The text only describes the former. Were the in-situ measurements not useful? It seems they would have avoided some of the issues described on pages 2 and 3 concerning the finite handling times and corresponding loss of large droplets. I gather that the droplet size distributions (both discrete and cumulative) are number distributions, but it is not clear. For example, the captions for Figures 5-8 indicate that the figures plot the FRACTIONS of the total measured particles that are small, while the text that refers to these figures (third paragraph of page 3) suggests that the vast majority of VOLUME fractions ...are ...small. Assuming the plotted distributions are by number, it would help to also include cumulative mass (or volume) distributions so the reader could determine the droplet diameters below which a give portion of the dispersed oil was contained. The text mentions (last paragraph of page 3) that the median diameters are nearly 20-30 microns; however my reading of Figures 9-12 suggest that these ranges are closer to 9 to 16%. Figures 4, 5, 8, 9 and 12 are mis-numbered. It would also help if figure numbers were consistent with the whole oil budget calculator report instead of (or in addition to) starting over with each new appendix. (This comment refers to several appendices.)

The in situ measurements are very useful. The data analysis is currently ongoing and cannot be included here due to the deadline of this report.

All the LISST data presented in this appendix are based on volume concentration and are expressed in ul/l. This is stated on the first page of this Appendix.

Figures 4,5,8,9 and 12 were mislabelled. Their corrections are suggested in this response (see 2 above).

Note the x-axis of Figures A7-9~12 (Cumulative particle-size distribution is expressed as bin number, see Table 2 of this appendix for corresponding lower, medium, and upper size of each bin. For example, bin # 9 has medium size of 10.2um, and bin # 16 has medium size of 32.5 um.

Appendix 7 (Ross oil properties report). Table 2-2 gives MC252 oil properties at temperatures of 15 and 35 °C. What was the temperature of the oil as it emerged from the pipe? Much of the oil resided/resides in intrusions a few hundred meters above the seabed where the temperature is ~5 °C. It would help to know oil properties (especially density) at these temperatures. Can the authors suggest a reasonable way to extrapolate from the data at 15 and 35 °C? It is too bad that the emulsification tests were conducted with a 2 cm thick oil which is mentioned in the text as a possible reason the oil in the lab did not emulsify, while the oil in the field did. It makes sense to repeat the tests with a 1 mm thick sample as suggested. Has this been done already? Also why would a 20 mm thick sample weathered for two weeks (336 hr) correspond to a 1 mm field sample exposed for 10 hrs? Wouldn't it be 336/20 = 17 hrs?

Appendices 5 through 8 reproduce already published reports reprinted here with the owners' permission to provide completeness to the report. We cannot modify them. However, the author of Appendix 6 has offered the following reply. The IFT test is a dilution test conducted over a test periode of 1 hour. Both the medium/high energy MNS method and low-energy IFP method are both standard laboratory methods designed to test the relative effectiveness of dispersnt applied on surface oil/emulsions. In order to simulate and study the effectiveness of dispersant injection into a sub-surface oil plume, special designed laboratory test systems have to be constructed.

Appendix 8 (Expert resumes). Michel Boufadel is not represented.

He is now included

References

Masutani, S., and E. Adams. 2000. Experimental study of multiphase plumes with application to deep ocean oil spills. Final report to U.S. Dept of Interior, Minerals Management Service. Contract No. 1435-01-98-CT-30946. http://www.mms.gov/tarprojects/377.htm.
Socolofsky, S. and E. Adams. 2002. Multiphase plumes in uniform and stratified crossflow. J. Hydr. Res., 40: 661-672.
Socolofsky, S. and E. Adams. 2003. Liquid volume fluxes in stratified multiphase plumes. J. Hydr. Engrg. 129: 906-914.

Reviewer 12:

Overall, a very good document. I have only minor suggestions to offer.

Page: 3, Executive Summary
I really like the line "It is important to remember that the Deepwater Horizon incident was an emergency, not an experiment" from your introduction on page 5. You should consider incorporating it somewhere in your Executive Summary.

We also thought it was an important point but concluded that it would require too much additional explanatory material if it was added to the Executive Summary.

Page: 20, 1st paragraph
Since you mention the temperature of the oil here, it might be helpful to state the relationship between the oil's temperature and water temperature if it has not been previously stated.

Oil temperature is assumed to be the same as the water temperature. Report is revised to clarify this point.

Page: 21, 2nd full paragraph
In the sentence beginning with "The stronger color …" , replace the word "stronger" with "darker".

Page: 22
Figure 8 (and the other, similar figures) is a confusing graphic. I understand what the writer is trying to do, but this is unconventional to the point that it may cause confusion for some readers. It contains too many elements that are not important: height of the box and position of the shaded portion within the box.

Figure 8 and similar figures have been removed.

In Section 8, 2nd paragraph
The acronym LISST should be defined (Laser In-Situ Scattering and Transmissometry) at first use.

Page: 23
First paragraph
I can't tell if the sentence beginning with "ADIOS2 suggests that …" is part of the previous paragraph or if it's supposed to be the start of a new paragraph.

Second paragraph,
For the sentence beginning with "Also, ADIOS2, following …" delete the word "Also" so that the sentence reads "ADIOS2, following standard guidelines …".

Page: 25, 2nd paragraph
In the sentence beginning with "As before, the stronger color …" , replace the word "stronger" with "darker".

Page: 26
There's something wrong with the color assignments for the bars in this graph. There's some strange optical effect that makes it difficult to view.

Adjusted.

Page: 27
Second paragraph, second sentence
Add the phrase "and regionally approved" so that it reads "… is a Federal cooperatively designed and regionally approved …".

Figure 11
What is the blue rectangle that overlaps the 5/10 A.M. circular image?
Also, the legend for this figure is not legible.

Figure replaced

Last paragraph
There's a typo in the sentence that begins with "If the dispersant …" after the word "half" there's an "=" sign that shouldn't be there.

Page: 28
Second paragraph
The sentence that reads "Analysis was undergoing at the time …" should read "Analysis was ongoing at the time …".

Third paragraph
The sentence that reads "Given this limited nature …" should read "Given the limited nature …".

Reviewer 13:

The document is longer than I expected with 156 pages and the content goes well beyond my own expertise.

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The document addresses an urgent and difficult problem of estimating oil budget in the gulf due to the Deepwater Horizon Spill. Moreover, the authors tried to simplify the process so that the output (Calculator) can be used by non-specialized staff. The various kind of simplification leads to huge uncertainties. The authors have done a very good job in addressing many of these uncertainties. However, I'm not fully convinced that all these uncertainties are properly quantified (this is due partly to the limited time and the length of the document). There are also a few other minor issues:
1. Low resolution of some of the mathematical symbols and equations;
2. A few misconception (typo) such as the relationship between the kinematic viscosity and dynamic viscosity in A.2.2.

Reviewer 14:

General thoughts on each section:

1. *Introduction: no comments*
2. *Purpose and brief description: seems well thought through. The formulae seem to be well constructed and shouldn't lead to absurdities like more oil evaporating than leaving the well head. However, it seems that something like this should have appeared in the literature already from previous disasters yet there are no citations in this section.*
3. *Previous experience Ixtoc: Good discussion of most relevant previous case.*
4. *Leak Rate and Subsurface Oil Behavior: good discussion, no criticisms.*
5. *Dissolution: well referenced but out of my area of expertise*
6. *Evaporation: "To simplify data entry, requirements to enter variable wind speeds were eliminated. Cumulative evaporation is sensitive to oil composition and temperature but is relatively insensitive to wind speed." This statement should be supported, preferably with a citation to the literature. Evaporation rates depend strongly on temperature and also on the relative saturation of the air with the compound evaporating (for example, relative humidity in the case of water evaporating). It may be that keeping track of wind speed is prohibitively complicated and the model needs to be simplified but that argument is not well made.*

While the evaporation rate is sensitive to wind speed, cumulative evaporation depends upon the mole fractions of the hydrocarbons that make up the oil. If high wind on day 1 cause large amounts of evaporation, there will be less volatile hydrocarbons the next day, slowing evaporation rate. Calm winds on the first day lowers evaporation, making more of the volatile factions able to evaporate later. The cumulative fraction remains much the same after a

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few days in both cases, although second order effects such as evaporation reducing oil available for dispersion exist, but are not included in the calculator.

7. *Weathering Estimation by Emulsification: no comment*
8. *Natural Dispersion: good discussion, good references to the appropriate literature*
9. *Chemical Dispersion: there seems to be quite a diversity of opinion on the effectiveness of dispersants. In keeping with the nature of this report, a judgment needed to be made to estimate the amount of oil remaining in the sea. However, it is clear that more scientific research needs to be conducted into the use of dispersants, both on the surface and sub-surface.*
10. *Burning: good discussion*
11. *Mechanical Recovery: good discussion*
12. *Other Oil: this seems to be another area of considerable uncertainty.*
13. *Longer Term Processes: another area for future research.*
14. *Assessment and Future Plans: it is clear that we should learn from this terrible disaster. I hope that the recommendations (some of which I echo in my review) of this panel for future research are heard and acted upon so that we can more effectively respond to future accidents.*

Itemized list of spelling and grammar errors

Page 9, the following sentence fragment does not make sense: "Disperse the surface oil that is available for surface dispersion, after subtracting evaporation and burning,…"
Page 11, "chocolate mouse" should be "chocolate mousse" unless the quoted source also made this mistake.
Page 12, "The DOE/FRTG consensus generally accepted a average value of 44% oil percentage by …" 'a' should be 'an'.
Page 13, "This is considerable larger than the common maximum…", should be 'considerably'.
Page 13, Figure 3 has text on it saying "62 bopd" and the like. These labels should say "62 kbopd".
Page 20, "the two weathered oils (green and purple) collected from th sea surface on or around 16 May." The word 'the' is misspelled.
Page 22, "Payne reports plumes of oil droplets at depth over 2 km." awkward sentence.
Page 27, "…then more than half =of the released oil…" misplaced '='.

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Oil Budget Calculator

Deepwater Horizon

Layout and design by Jason D. McIntosh - www.5dcreative.com

To: Conmy, Robyn[conmy.robyn@epa.gov]
Cc: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Fri 12/4/2015 7:55:20 PM
Subject: CRRC 2012 Paper
Dispersant_Initiative_REPORT_CRRC_NOAA_2012.pdf

Referenced in the comments from the ALERT group on Sub J.

To: Barron, Mace[Barron.Mace@epa.gov]
Cc: Wilson, Gregory[Wilson.Gregory@epa.gov]
From: Principe, Vanessa
Sent: Thur 12/3/2015 9:38:04 PM
Subject: RE: Legal framework for dispersants
Legal Framework Dispersants_comments.pptx

Mace:

Here are some citations for them to double check some of their facts. We need to make clear these comments are informal/not representing the Agency's official position.

Call us if you have any questions. Thanks for sharing, V & G

From: Barron, Mace
Sent: Tuesday, December 01, 2015 4:22 PM
To: Principe, Vanessa <Principe.Vanessa@epa.gov>; Wilson, Gregory <Wilson.Gregory@epa.gov>
Subject: FW: Legal framework for dispersants

I just got this. Hoping you guys can comment.

Feel free to make comments directly on the slides if possible.

Sorry for short notice.

From: Melissa T Daigle [mailto:mtrosc2@lsu.edu]
Sent: Tuesday, December 01, 2015 3:10 PM
To: Barron, Mace <Barron.Mace@epa.gov>
Cc: Emily S Maung-Douglass <edouglass@lsu.edu>
Subject: Legal framework for dispersants

Dr. Barron -

Thanks again for offering to review the draft PowerPoint on the changes to Subpart J of the NCP; it is attached. I will be leaving Friday for vacation for a week, but if you have a chance to look at it before then, that would be great.

Thanks so much,

Melissa

Melissa Daigle

Research Associate, Louisiana Sea Grant Law & Policy Program

mtrosc2@lsu.edu

225-578-9968

LEGAL FRAMEWORK GOVERNING THE USE OF DISPERSANTS

MELISSA DAIGLE

LOUISIANA SEA GRANT LAW & POLICY PROGRAM

DECEMBER 15, 2015

KEY FACTS: DEEPWATER HORIZON

- Deepwater Horizon Dispersant Usage
  - Unprecedented volume and duration
  - First subsea application
  - Everything was done in accordance with existing law
- Results
  - Exposed serious weakness in the regulatory framework
    - Outdated protocols
    - Lack of monitoring requirements

EXISTING LAW: NCP

- National Oil and Hazardous Substances Pollution Contingency Plan (NCP)
  - Developed in 1968 in response to grounding of *Torrey Canyon* off the coast of Cronwall, England, which released 120,000 tons of crude oil
  - Last revised in 1994
    - In response to the passage of the Oil Pollution Act in 1990
  - Purpose – provide for efficient, coordinated, and effective action to minimize damage from oil and hazardous substances, including containment, dispersal, and removal or oil and hazardous substances
  - U.S. Coast Guard is the lead when spills occur in or threaten coastal waters

NCP PRODUCT SCHEDULE

- Developed and maintained by EPA
- Identifies
  - Dispersants that may be used in carrying out the NCP
  - Waters in which the dispersants may be used, and
  - Quantities of the dispersants that may be used in those waters
- Current definition of dispersant
  - "Chemical agents that emulsify, disperse, or solubilize oil into the water column or promote the surface spreading of oil slicks to facilitate dispersal of the oil into the water column."
- Dispersants must be listed on the schedule before they can be used
  - Corexit EC9527A – listed on March 10, 1978
  - Corexit EC9500A – listed on April 13, 1994

NCP PRODUCT SCHEDULE: TESTING PROTOCOLS

- What must be submitted to EPA
  - 12 data requirements Information on
    - Application
    - Storage
    - Effectiveness
      - Under current law – must disperse at least 45% of oil using a Swirling Flask Test
    - Toxicity testing results
      - Under current law - limited to studies on the immediate impact on one fish species and one shrimp species
- Dispersants must meet effectiveness and toxicity thresholds

NCP PRODUCT SCHEDULE: LISTING DETERMINATIONS

- Once the manufacturer submits a dispersant for consideration, EPA reviews the information and makes a decision
  - EPA does not perform independent testing
- Once on the list, this does not mean that EPA approves its use
  - Listing just allows the designated federal OSC to use
    - Use must be authorized by the Regional Response Teams
  - Manufacturer must notify EPA of any changes to the product
  - OSC may authorize use of products not on the schedule without obtaining concurrence of EPA if use is necessary to prevent or substantially reduce a hazard to human life
- How to remove a product from the schedule
  - There is currently no process for removal

PROPOSED REVISIONS

- January 22, 2015
  - EPA issued a proposed rule to amend Subpart J of the NCP
    - More than 80,000 comments during the first comment period
      - Closed April 22, 2015
    - Final rule expected in 2016
      - Once released, there will be another opportunity for public comment
  - You can track the rule and provide comments by signing up for email alerts
    - www.regulations.gov
    - Search Docket ID EPA-HQ-OPA-2006-0090-0010

PROPOSED REVISIONS

- Change definition of dispersant
  - Proposed definition: “Dispersants are typically mixtures of solvents, surfactants, and additives that promote the formation of small droplets of oil in the water column by reducing the oil-water interfacial tension.”
- Replace the Swirling Flask Test with the Baffled Flask Test (BFT)
  - Has undergone extensive scientific review
  - More reliable and reproducible results
- Increase effectiveness
  - Remove 55% - 75% of oil at two different temperatures (5°C and 25°C)
    - % required depends on temperature

PROPOSED REVISIONS

- Change toxicity species
  - Immediate impacts to two saltwater species
    - Americamysis bahia
    - Menidia beryllina
  - Test three different things
    - Dispersant alone
    - Dispersant mixed with Alaska North Slope crude oil
    - Dispersant mixed with Intermediate Fuel Oil
- Add a test on sea urchin embryo development
- Add requirement for long term impacts of dispersal alone to two saltwater species

PROPOSED REVISIONS

- Allow for removal of a product from the schedule for various reasons, including, but not limited to:
  - Misleading, inaccurate, or incorrect statements within the product submission or on labels, advertisements, or technical literature
  - Alterations to the product without proper notification
  - Failure to include the required disclaimers on labels and advertisements
  - New information concerning potential impacts to human health or the environment
- New requirement that OCS provide the Regional Response Team certain information after the use of a chemical or biological agent
  - Name of products used
  - Quantity and concentration
  - Duration of use
  - Locations used
  - Any data collected on the effectiveness or environmental effects

PROPOSED REVISIONS

- Biggest policy change – Establishment of monitoring requirement for dispersant use
  - Monitoring of use would be required in three situations
    - Subsurface use of dispersants in response to an oil discharge
    - Surface use of dispersants in response to oil discharges of more than 100,000 gallons occurring within 24 hours
    - Surface use of dispersants for more than 96 hours in response to an oil discharge
  - Responsible party would be required to document
    - Characteristics of oil and flow rate
    - Dispersant product information, including why that product was chosen
    - Application method, procedures, and rates
  - Would also require daily collection of the water column from the dispersed oil plume

FOR MORE INFORMATION CONTACT:

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(662) 915-7714
sshowalt@olemiss.edu

Melissa Daigle
Louisiana Sea Grant
(225) 578-9968
mtrosc2@lsu.edu

To: steve.lehmann@noaa.gov[steve.lehmann@noaa.gov]
From: Principe, Vanessa
Sent: Tue 11/17/2015 3:44:25 PM
Subject: FW: Your help needed - review?
Dispersant background - for review 11.03.15.pdf

From: Barron, Mace
Sent: Thursday, November 12, 2015 5:55 PM
To: Wilson, Gregory <Wilson.Gregory@epa.gov>; Principe, Vanessa <Principe.Vanessa@epa.gov>
Subject: Fw: Your help needed - review?

fyi. I sent my comments to Greg just now (provided as a scientist, not as an Agency review).

Mace

From: Larissa Graham <ljg0008@auburn.edu>
Sent: Thursday, November 12, 2015 3:33 PM
To: Barron, Mace
Subject: RE: Your help needed - review?

Hi Mace,

Just wanted to check in regarding our publication on dispersants. I'm particularly interesting in your feedback on Tables 1 & 2. We've been asked what chemicals are found in dispersants and were trying to present information in a way that would tell both sides of the story.

Please let me know if you have any questions.

Looking forward to your thoughts!

Thanks,

Larissa

Larissa Graham

Oil Spill Science Extension Specialist

Mississippi-Alabama Sea Grant Consortium

Office: (251) 438-5690

Cell: (251) 348-5436

Larissa.Graham@auburn.edu

From: Larissa Graham
Sent: Friday, November 6, 2015 10:32 AM
To: 'Barron, Mace' <Barron.Mace@epa.gov>
Subject: RE: Your help needed - review?

Great, thank you!

Have a nice weekend,

Larissa

Larissa Graham

Oil Spill Science Extension Specialist

Mississippi-Alabama Sea Grant Consortium

Office: (251) 438-5690

Cell: (251) 348-5436

Larissa.Graham@auburn.edu

From: Barron, Mace [mailto:Barron.Mace@epa.gov]
Sent: Friday, November 6, 2015 10:24 AM
To: Larissa Graham <ljg0008@auburn.edu>
Subject: Re: Your help needed - review?

I will get you comments next week Larissa.

From: Larissa Graham <ljg0008@auburn.edu>
Sent: Thursday, November 5, 2015 3:08 PM
To: Raimondo, Sandy; Barron, Mace
Cc: Wilson, Gregory; Steve Sempier
Subject: RE: Your help needed - review?

Hi Sandy,

Ok, thank you for letting us know.

Mace,

If you were willing to review as a scientist, we would really appreciate it.

Thanks,
Larissa

Larissa Graham

Oil Spill Science Extension Specialist

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Cell: (251) 348-5436

Larissa.Graham@auburn.edu

From: Raimondo, Sandy [mailto:Raimondo.Sandy@epa.gov]
Sent: Thursday, November 5, 2015 2:51 PM
To: Larissa Graham <ljg0008@auburn.edu>
Cc: Barron, Mace <Barron.Mace@epa.gov>; Wilson, Gregory <Wilson.Gregory@epa.gov>; Steve Sempier <stephen.sempier@usm.edu>
Subject: Re: Your help needed - review?

Mace, Larrissa,

Mace can provide a peer review as a scientist, but cannot provide an official EPA perspective.

Thanks,

Sandy

On Nov 5, 2015, at 1:46 PM, Larissa Graham <ljg0008@auburn.edu> wrote:

Hi Mace,

Sounds good. If we need you to review as a scientist, that's ok too. We just really want to make sure our information is accurate.

Please let me know what you find out.
Thanks,

Larissa

Larissa Graham

Oil Spill Science Extension Specialist

Mississippi-Alabama Sea Grant Consortium

Office: (251) 438-5690

Cell: (251) 348-5436

Larissa.Graham@auburn.edu

From: Barron, Mace [mailto:Barron.Mace@epa.gov]
Sent: Thursday, November 5, 2015 2:26 PM
To: Larissa Graham <ljg0008@auburn.edu>
Cc: Wilson, Gregory <Wilson.Gregory@epa.gov>; Raimondo, Sandy <Raimondo.Sandy@epa.gov>
Subject: Re: Your help needed - review?

Am happy to review. However, I ccd my branch chief Sandy and an Office of Emergency Management expert, Greg, as an fyi to see if there are any issues with what may be perceived as an Agency official review.

For example, there are likely no issues with me providing you a technical review as a scientist...but am uncertain about inferring EPA review aspects.

I will wait for Greg and Sandy to provide their thoughts before I open up the doc.

Mace

From: Larissa Graham <ljg0008@auburn.edu>
Sent: Thursday, November 5, 2015 1:07 PM
To: Barron, Mace
Subject: Your help needed - review?

Hi Mace,

I heard you met Emily! I'm glad you two were able to meet up and chat.

I'm looking forward to our meeting on the 17th but I was wondering if you could help me with something before then. I've been working on an outreach publication about dispersants. It's the first in our dispersant series and mainly provides some background information. Some of our reviewers wanted us to include information about the chemicals found in Corexit and Corexit, itself, so I added Tables 1 & 2.

Would you be willing to look over this publication on behalf of EPA and let me know what you think about the tables? If you have any other comments, I would love to hear them. We want to make sure we are sharing the best information possible, in a non-biased way.

Thank you!

Larissa

Larissa Graham

Oil Spill Science Extension Specialist

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Cell: (251) 348-5436

Larissa.Graham@auburn.edu

THE SEA GRANT and GOMRI PARTNERSHIP

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment. There are 33 university–based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10–year period to create the Gulf of Mexico Research Institute, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization and remediation technologies. GoMRI is led by an independent and academic 20–member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

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CHEMICAL DISPERSANTS AND THEIR ROLE IN OIL SPILL RESPONSE

Larissa J. Graham, Christine Hale, Emily Maung-Douglass, Stephen Sempier, LaDon Swann, and Monica Wilson

Nearly two million gallons of dispersants were used at the water's surface and a mile below the surface to combat oil during the Deepwater Horizon oil spill. Many Gulf Coast residents have questions about why dispersants were used, how they were used, and what the impacts dispersants could have on people and the environment. This publication serves to answer these questions.

The Deepwater Horizon site (NOAA photo)

On April 20, 2010, an explosion on the Deepwater Horizon oil rig killed 11 people. The rig was located 42 miles southeast of Venice, Louisiana. The ruptured wellhead had released an estimated 4.9 million barrels of Louisiana sweet crude oil before responders capped it on July 19, 2010. Some of this oil was collected at the site of the wellhead. Scientists estimate that the remainder of the oil, or about 4.1 million barrels (172 million gallons), were released into Gulf of Mexico waters.[1,2,3,4,5]

Emergency responders attempted to clean up the oil and prevent it from reaching the shoreline by skimming and burning the oil at the surface. They also applied nearly two million gallons of **dispersants** to break up the oil.

HOW DID RESPONDERS USE DISPERSANTS DURING THE DEEPWATER HORIZON OIL SPILL?

Responders used two types of dispersants, **Corexit** 9500 and Corexit 9527, during the Deepwater Horizon oil spill. Both are on the federal guideline list of dispersants approved for use during a spill. Responders first applied Corexit 9527 until they exhausted the supply. Then they switched to Corexit 9500 and continued using it throughout the cleanup efforts.[4,6]

During the spill, responders sprayed approximately one million gallons of dispersants over 300 square miles of oiled surface waters (Figure 1).[1,4] Regulations state that responders spraying dispersant from airplanes could not apply them within 2.3 miles of any vessel, within 3.45 miles of the shoreline or visible marine life, or in areas with water depths less than 33 feet deep.[4] Responders sprayed dispersants from boats in areas close to the wellsite where crews were working. This method reduced the amount of dispersant in the air, increasing the safety of the working environment. According to the U.S. Coast Guard, emergency responders applied 98 percent of the dispersants more than 11 miles offshore.[4]

For the first time in U.S. history, responders used dispersants at very deep depths. They applied approximately 771,000 gallons of Corexit 9500 nearly one mile beneath the sea surface at the source of the leak. They did this using a remotely operating vehicle to inject dispersant at the site of the wellhead.[1,4]

HOW DO DISPERSANTS BREAK UP OIL?

A typical commercial dispersant contains solvents and **surfactants**. Solvents help keep the chemicals mixed and help them dissolve into the oil. Surfactants allow oil and water to mix easily.

By allowing oil and water to mix, the oil slick breaks into many smaller oil droplets. The smaller droplets mix into the water column and then are carried away by currents, settle on the bottom, or evaporate.[7] Nature's "oil-eating" **microbes** are found in our oceans and have adapted

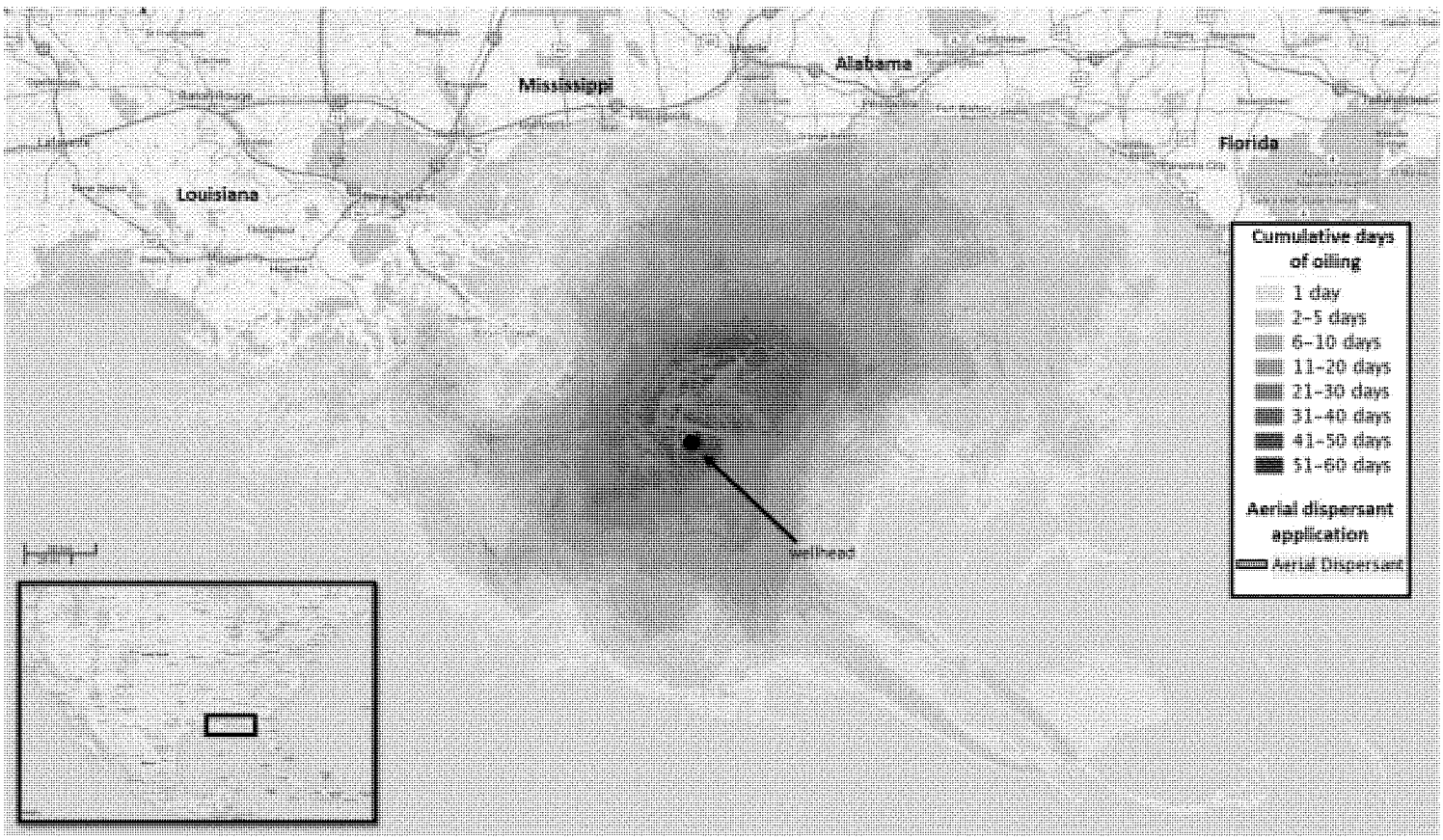


FIGURE 1. *This map shows the number of days that an area was oiled during the Deepwater Horizon oil spill. Responders found oil in areas that are shown in dark gray more days than those shown in light gray. In response to the oiling, responders applied dispersants to surface water. The orange lines represent where dispersant was sprayed using airplanes. Responders also sprayed dispersant from boats close to the wellhead and at subsurface depths (not shown on this map). (Environmental Response Management Application)*

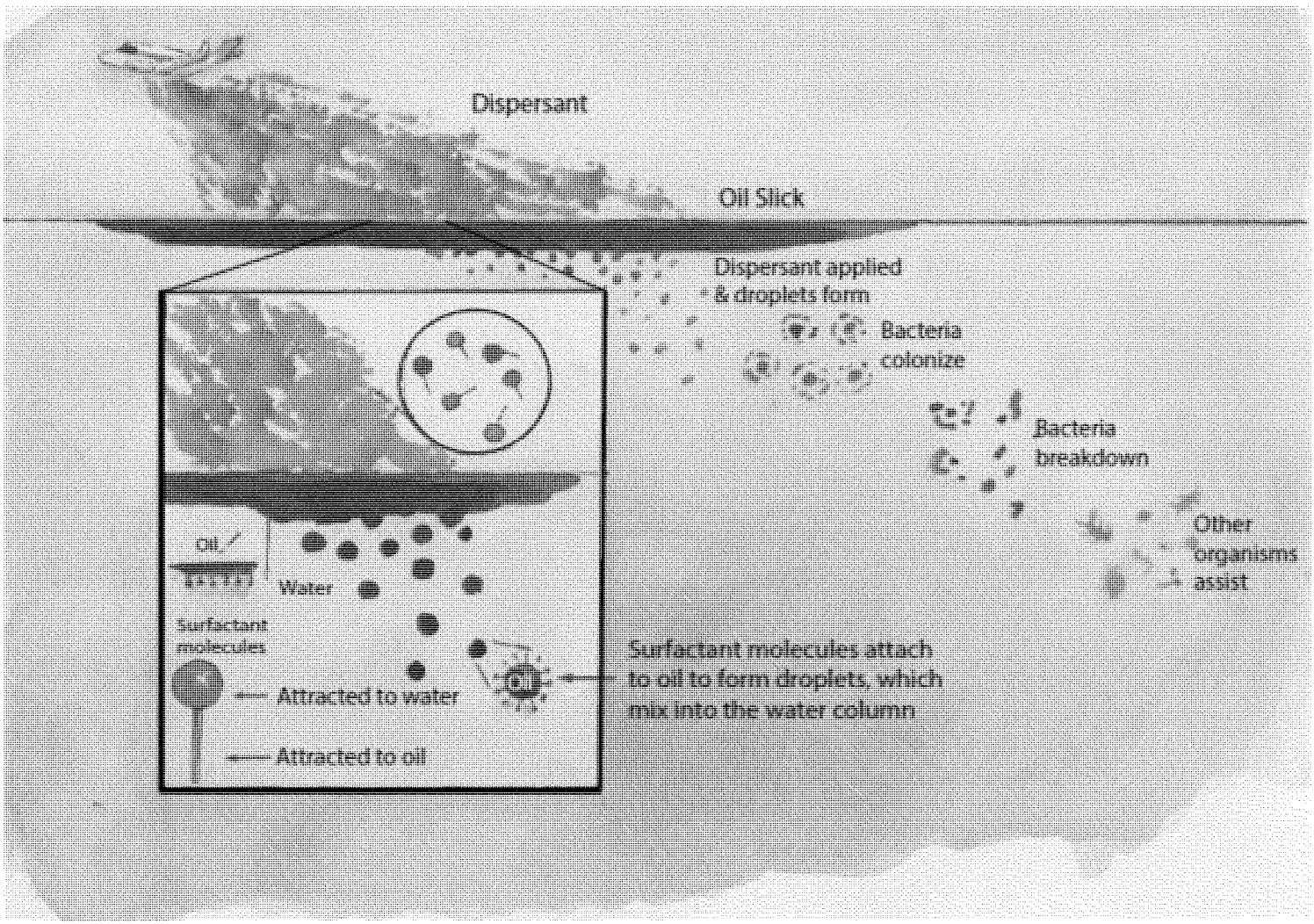


FIGURE 2. *Dispersants, which are one strategy used to respond to an oil spill, contain molecules that have one end that is attracted to water and one end that is attracted to oil. When responders apply dispersants to an oil slick, these molecules attach to the oil, allowing the oil slick to be broken up into smaller oil droplets. These smaller droplets then mix into the water column and naturally break down by microbes and other organisms. (Florida Sea Grant/Anna Hinkleday)*

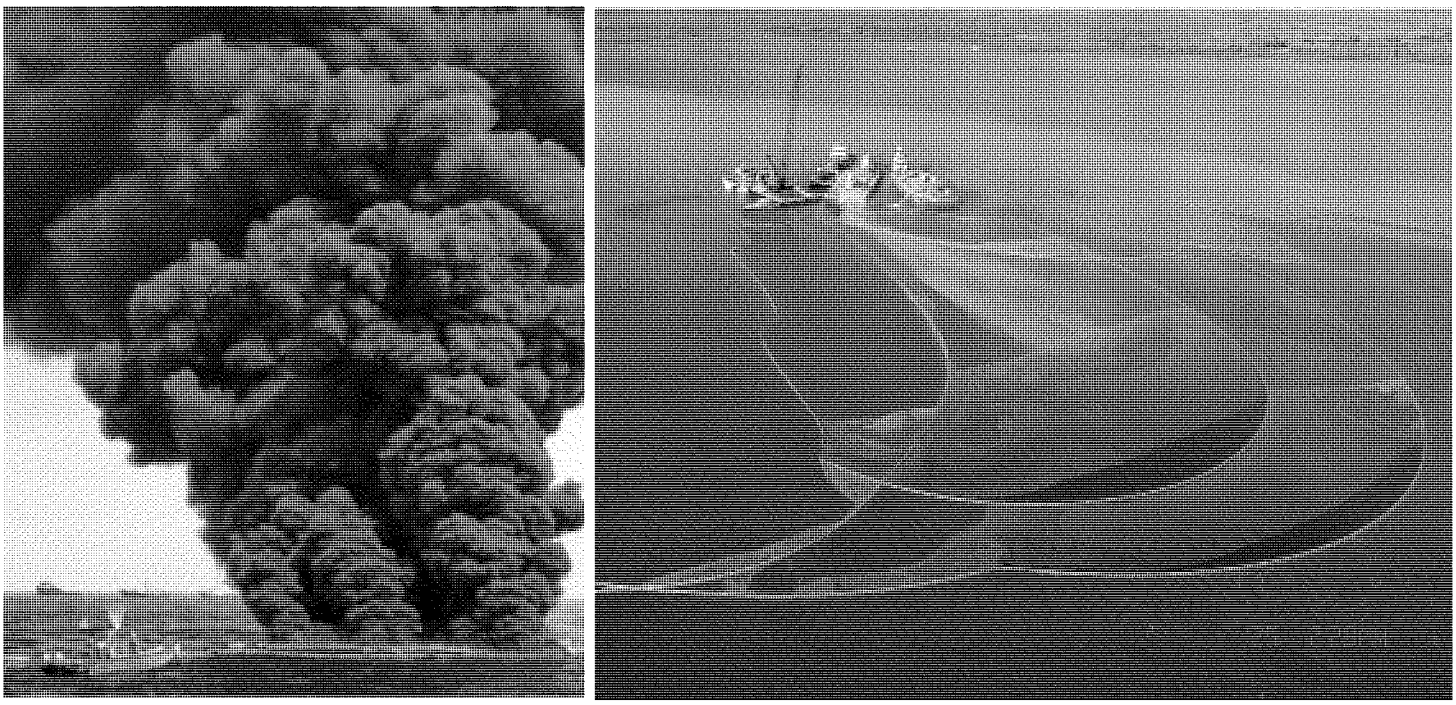
over time to use oil as food. In the process, they naturally remove oil from the environment. Smaller oil droplets are more available to these "oil-eating" microbes than large oil slicks (Figure 2).

WHEN DO RESPONDERS USE DISPERSANTS TO CLEAN UP OIL?

Responders consider trade-offs when determining the most effective cleanup method(s) that should be used during an oil spill.[7,8] Applying dispersants was just one of many strategies that emergency responders used during the Deepwater Horizon site during the spill. Other response activities included burning the oil at the water surface and mechanically recovering it using skimmers or other equipment.

Emergency responders typically use dispersants when other cleanup methods will not be effective. For example, the spill may be too large, the water may be too rough, or the spill may be too far away from land to use mechanical recovery equipment.[7] Under these conditions, responders may choose to apply dispersants to break up an oil slick. They may also choose to use dispersants because they can be deployed rapidly by aircraft, cutting down on the response time.[8]

Dispersants can prevent an oil slick from reaching the shoreline. This can reduce the oiling of coastal wildlife and sensitive habitats, such as coastal wetlands, mangroves, and beaches. Once these habitats are oiled, they are very difficult to clean without causing further damage to the area.[8]



Controlled burning (left) and skimming (right) are two response techniques used to remove oil from the water surface after an oil spill. (NOAA photos)

However, dispersants are not always effective. When oil is dispersed, it is removed from the water's surface and harder to clean up mechanically.[8] Dispersants may not work well on some types of oil and spraying them on patchy oil slicks can be inefficient.[7,8] They also do not work well under very windy conditions because they can drift in the wind during application or waves can wash them off the slick. When this happens, the dispersant cannot penetrate, mix with, and break down the oil.[7]

Applying dispersants beneath the water's surface, at the site of the wellhead, was a new technique used during the Deepwater Horizon oil spill. Agencies in charge of the response efforts approved the deep-water application of dispersants because it minimized human contact with dispersants. This technique also allowed for a quicker response time because dispersants could be applied at night and in foul weather.[1]

HOW DID AGENCIES REGULATE AND MONITOR DISPERSANT USE?

The **National Contingency Plan (NCP)** guidelines are used to regulate dispersant use. These guidelines outline which dispersants emergency responders can apply during a spill, where they can apply them, and how much they can apply.[9]

Emergency responders use **Special Monitoring of Applied Response Technologies (SMART)** guidelines to monitor dispersant use. SMART guidelines do not look at the effects or impacts of dispersed oil. Instead, they provide information about how to apply dispersants and how well they are working.[10]

Responders use the SMART monitoring program to determine if dispersants are effectively breaking up oil and, if so, how quickly.[4] The U.S. Coast Guard, National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (EPA), U.S. Centers for Disease Control and Prevention, and the U.S. Bureau of Safety and Environmental Enforcement are all part of the monitoring program.[4] During the Deepwater Horizon oil spill, trained observers flew over the oil slick to see if the dispersant was working to break up the oil. Sampling teams collected water samples to measure the amount of dispersed oil in the water column. Agencies used this information to modify how they were applying the dispersant.[4]

The U.S. EPA monitored the air quality and tested for two chemicals, 2-butoxyethanol and propylene glycol. Both of these chemicals are found in Corexit. In 2010, they collected air samples off the coast of Louisiana for four days after the aerial application of dispersants. Scientists took samples 30 minutes after dispersant application and did not find either chemical.[10] The U.S. EPA also collected onshore air quality samples along shoreline sites in Louisiana, Mississippi, Alabama, and Florida. They tested these samples for two dispersant chemicals that

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HOW MUCH IS TOO MUCH?

How a substance can affect you will depend on how harmful it is and how long and how often you are exposed to it. Every substance is poisonous at some level. Take water, for example. Although we need water to survive, drinking too much water can also kill us because it dilutes the concentrations of other nutrients that our body needs to function. Researchers determine how much of a substance is "toxic" by looking at the LC50, or median lethal concentration. The LC50 is the dose required to kill half of a population being tested. Scientists have conducted most of the tests on small fish or shrimp to determine how harmful chemicals found in dispersants are to animals. It is important to note that the LC50 will vary among different species, differing lengths of exposure time, and the other factors that might be affecting that species at the time.

Dispersant used during the Deepwater Horizon oil spill	*Toxicity level (LC50 or LD50) (ppm = parts per million; H = hour)*	*Potential health effects to humans based on animal tests*
Corexit 9500	Concentration in water: Copepod, *Acartia tonsa* ~ 34 ppm in 48H; Shrimp, *Artemia* spp. ~ 20 ppm in 48H	Repeated or prolonged exposure may cause eye and skin irritation, dry the skin leading to discomfort and dermatitis, or irritate the respiratory tract.
Corexit 9527A	Concentration in water: Turbot (flatfish) ~ 50ppm in 96H	May be harmful if swallowed, effect the liver and kidney, and/or damage or irritate the gastro-intestinal tract. Harmful if absorbed through skin or by inhalation. Repeated or prolonged exposure may irritate the respiratory tract or existing skin condition. Excessive exposure may cause central nervous system effects, nausea, vomiting, anesthetic, or narcotic effects.

TABLE 1. *The toxicity level and potential health effects of the two dispersants that emergency responders used during the Deepwater Horizon oil spill are shown above. For reference, 1 ppm is analogous to a single drop of water in a 5-gallon bucket that you might pick up from the home improvement store. The toxicity level and potential health effects were compiled from the Material Safety Data Sheets for each chemical.*

were most likely to be in the air in measurable amounts after spraying, 2-butoxyethanol and dipropylene glycol monobutyl ether. They found low levels of both chemicals in the air, but all were below levels that are likely to cause negative health effects. All of the data from these monitoring efforts are available on U.S. EPA's website at http://www.epa.gov/bpspill/dispersant-air-sampling.html.[12]

According to the U.S. Coast Guard's On-Scene Coordinator Report, the U.S. EPA and the U.S. Coast Guard were satisfied with how dispersants were used during the Deepwater Horizon oil spill. These agencies stated that dispersants had been an important tool for reducing the oil spill's impact and had prevented more damage to marshes, wetlands, beaches, and coast's economy. They also stated that the information collected during the spill supported continued application of dispersants.[4]

CAN DISPERSANTS HARM MARINE ANIMALS?

The dispersants that emergency responders use today are less harmful to the environment than the more toxic products used prior to 1970.[7] However, they still contain chemicals that can have a negative impact on aquatic life (Table 1 & 2).

The U.S. EPA was concerned that dispersants could hurt aquatic wildlife and so, in May 2010, they directed BP to scale back on the use of dispersants. To understand how dispersants could affect aquatic wildlife, the U.S. EPA conducted independent toxicity studies in the laboratory.[6]

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The U.S. EPA tested eight approved dispersants, including Corexit 9500, on two aquatic species: Gulf mysid, a small shrimp, and the inland silverside, a fish that resides in coastal waters in the Gulf of Mexico.[6] Corexit 9527 was not tested during these studies because the dispersant was no longer being used in response efforts.

The laboratory experiments showed that none of the dispersants, when tested alone, caused serious impacts to the shrimp or silversides. Corexit 9500 and another dispersant (JD-2000) were less toxic to silversides than the other dispersants that were tested.[6]

The U.S. EPA was also concerned about how oil mixed with dispersant could affect aquatic life. They conducted additional studies and found that Corexit 9500, when mixed with oil, was no more or less toxic than seven other dispersants that were tested.[6] Oil alone and oil mixed with each of the dispersants that were tested had similar toxicity to shrimp, except when oil was mixed with one of the dispersant tested (Nokomis 3-AA). The combination of oil and this type of dispersant was more toxic to the shrimp than oil alone.[6]

The extent of damage that dispersants, dispersed oil, and oil can have on aquatic life is still under debate. Some peer-reviewed research studies have found dispersants to be less toxic than oil alone, and other studies have shown that dispersants or oil plus dispersant are more toxic than oil alone.[7]

The On-Scene Coordinator Report

This report documents the response efforts during the Deepwater Horizon oil spill. It provides a timeline of the spill and the efforts to address the potential impacts to public health related to the spill. This report is available at http://masgc.org/assets/uploads/publications/873/2_coordinator_report_dwh.pdf.

A member of U.S. Coast Guard National Strike Force on an overflight mission, observing an airplane spraying dispersant. (NOAA photo)

WHAT STUDIES ARE STILL ONGOING?

Many questions remain about the impacts of dispersants and dispersed oil on the ecosystem, environment, and human health. The Gulf of Mexico Research Initiative (GoMRI) and other research programs are looking at alternative dispersant use and technology, how dispersants react with oil under various conditions, the environmental impacts of currently approved dispersants, and the impacts that dispersants have on human health.

CAS #	*Chemicals in Corexit 9500 and Corexit 9527A*	*Other substances that contain this chemical* [a,b,c]	*Potential health effects to humans based on animal tests*[d]
577-11-7	Di(2-ethylhexyl) sodium sulfosuccinate (DOSS)	Certain cosmetics, gelatin, chocolate powder, beverages, laxatives	Causes eye, skin, and respiratory tract irritation. May be harmful if absorbed through the skin or inhaled. Harmful if swallowed. May cause gastrointestinal irritation with nausea, vomiting, and diarrhea.
111-76-2	2-Butoxyethanol (Found in Corexit 9527A only, not Corexit 9500)	Certain cleaners, soaps, cosmetics, lacquers, paints	Causes eye and skin irritation. May be toxic to blood, kidneys, liver, and central nervous system. Repeated or prolonged exposure to the substance can produce target organs damage, including injury to red blood cells, kidney or the liver. May cause adverse reproductive effects, birth defects, or cancer. Severe over-exposure can result in death.
57-55-6	Propylene glycol	Cosmetics, preservatives in food, medicines	Causes mild eye, skin, respiratory, and gastrointestinal irritation. May affect the behavior or central nervous system, brain, metabolism, blood, respiration, cardiovascular system, endocrine system, urinary system, and liver. Prolonged or repeated inhalation may affect behavior, central nervous system, and spleen. May be toxic to central nervous system. May mutate genetic material or cause adverse reproductive effects and birth defects.
64742-47-8	Distillates, petroleum, hydrotreated light	Air fresheners, cleaners, paints, varnishes	Causes skin irritation. Repeated skin contact has resulted in irritation and skin cancer in animals. May cause drowsiness or dizziness. May be fatal if swallowed or enters airways.
29911-28-2	Dipropylene glycol monobutyl ether	Cleaners, degreasers, paints	The chemical, physical, and toxicological properties of this chemical have not been thoroughly investigated.
1338-43-8	Sorbitan, mono-(9Z)-9-octadecenoate	Skin cream, air freshener	Not classified as a hazardous substance or mixture.
9005-65-6	Sorbitan, mono-(9Z)-9-octadecenoate, poly(oxy-1,2-ethanediyl) derivatives	Baby bath, mouth wash, face lotion	Not classified as a hazardous substance or mixture.
9005-70-3	Sorbitan, tri-(9Z)-9-octadecenoate, poly(oxy-1,2-ethanediyl) derivatives	Insect spray, food additive	Not classified as a hazardous substance or mixture.

TABLE 2. *The chemicals that are found in Corexit 9500 and 9527A, the two dispersants that were used during the Deepwater Horizon oil spill. The Chemical Abstracts Service number (CAS) or unique identifier for each chemical substance, toxicity level based on tests on animal subjects, and the potential health effects are listed for each chemical. This information was provided by the Food and Drug Administration (a), U.S. Department of Health and Human Services (b), Agency for Toxic Substances and Diseases Registration (c), and Material Safety Data Sheets (d).*

More information about these ongoing studies can be found on GoMRI's website at http://gulfresearchinitiative.org. Other publications focusing on dispersants are on the Sea Grant Oil Spill Science Outreach website at www.gulfseagrant.org/oilspilloutreach.

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GLOSSARY

Corexit – a modern dispersant approved for use in US waters that was used to minimize the presence of surface oil slicks during the Deepwater Horizon oil spill.

Dispersants – chemicals that are used during oil spill response efforts to break up oil slicks and prevent floating oil from impacting sensitive ecosystems such as coastal habitats.

Microbes – very tiny organisms including bacteria, fungi, archaea, and protists. Some microbes (bacteria and archaea) are the oldest form of life on earth.

National Contingency Plan (NCP) – a federal document that outlines response efforts for oilspills and other hazardous substance spills.

Special Monitoring of Applied Response Technologies (SMART) – a cooperative monitoring program that is used during oil spill response efforts to determine if dispersant application is effective.

Surfactants – compounds that work to break up oil. Dispersants contain surfactants that break the oil slick into smaller droplets that can more easily mix into the water column.

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