




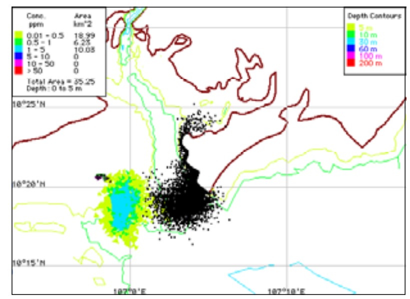

Research & Development Needs For Making Decisions Regarding Dispersing Oil

Coastal Response Research Center
Durham, New Hampshire
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Coastal Response Research Center

UNIVERSITY OF NEW HAMPSHIRE

Forward

Use of dispersants in the U.S has been controversial for decades. The National Academy of Science (NAS) published its first review of the topic on 1989. Subsequently, the Oil Petroleum Act of 1990 (OPA 90) noted the need for national and regional guidelines to address their use during spills. As a result, some regional response teams have "pre-approved" dispersant use in waters beyond the three mile limit and exceeding 30 feet in depth. More recently, the U.S. Coast Guard has considered changes to regulations regarding dispersant application, but these may not be released until 2007 after many delays. The NAS agreed to revisit the dispersants question, examining the existing information and ongoing research on the efficacy and effects of dispersants as an oil spill response measure in the U.S. The resulting NAS report was released in May 2005. Two of the many findings/recommendations of the report were the lack of adequately peer-reviewed research on dispersants and the need for an integrated plan to guide future research endeavors and funding.

The Coastal Response Research Center, a partnership between the National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration (ORR) and the University of New Hampshire (UNH), develops new approaches to spill response and restoration through research and synthesis of information. The Center's mission requires it to serve as a hub for research, development, and technology transfer to the oil spill community. During the summer of 2005, the Center helped form the Dispersants Working Group (DWG), consisting of fourteen entities that fund research. The DWG membership agreed to participate in formulating an integrated research plan; the first step of this plan was to convene a research needs workshop on the efficacy and effects of dispersants. The Center hosted this workshop in September 2005 in Durham, NH. Dr. Carol-Ann Manen, the NOAA Co-Director of the Center who retired in March 2006, Kimberly Newman, and Kathy Mandsager were all actively involved in the planning and convening of this workshop. This report, written for the Center by Drs. Jacqueline Michel (Research Planning, Inc.) and Amy Merten (NOAA ORR Management) and approved by the DWG, summarizes the funding of approximately 35 individuals who attended the workshop. It outlines the broad research topics that will be the basis for RFPs on dispersants for the next three to five years.

I hope you enjoy reading the report and exploring the topics. If you have any comments, please contact the Center. The Center looks forward to many more similar endeavors during the coming years where it can be of service to the oil spill community and the nation.

Sincerely,

Nancy E. Kinner, Ph.D.
UNH Co-Director
Professor of Civil/Environmental Engineering

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I. Introduction

Use of chemical dispersants in U.S. waters as a major response tool has been a controversial issue for decades. This is partly due to the legacy of first generation "dispersants" which consisted of misapplications of degreasers and other solvents with high aquatic toxicities (NRC, 1989; 2005). The newer formulations of dispersants are less toxic to marine organisms, and often are orders of magnitude less toxic than the toxic fractions in the oil itself. The remaining factors perpetuating the controversy include questions regarding the effectiveness (efficiency) of dispersant use relative to other cleanup methods, and the long-term fate and effects of dispersed oil, especially in near-shore environments (NRC, 2005).

Dispersants are chemical compounds (surfactants) with lipophilic and hydrophilic groups designed to reduce the oil-water interfacial tension and enhance physical dispersion into the water column by breaking an oil slick into small, dispersant-coated oil droplets (NRC 1989, 2005). The primary function of a dispersant is to remove the oil from the surface of the water to prevent it from stranding on a shoreline and reduce the risk of oiling birds and mammals using the surface layer. Dispersants do not reduce the mass of oil in the environment; they simply move it to a different environmental compartment, and in doing so, shift the risk of impacts to water column and offshore benthic organisms. Thus, in order to make sound decisions on whether to use dispersants, one must use a risk-based paradigm to evaluate tradeoffs and decide whether the overall environmental benefits of dispersant use outweigh the environmental costs from utilizing this response option.

Dispersants have been and remain a high research priority in the U.S. In 1989, the first National Research Council (NRC) report, "Using Oil Spill Dispersants on the Sea," was published in response to significant research conducted, nationally and abroad. The 1989 study was commissioned to: evaluate whether dispersants were effective, identify possible impacts of dispersants and dispersed oil on marine and coastal environments, and provide guidance on the appropriate locations to consider dispersant use. This report and the establishment of Interagency Coordination Committee on Research and Technology (Title VII) of the Oil Pollution Act of 1990 (OPA) fueled further research to meet the recommendations of the report and establish zones in which dispersant use could be considered. Much of this worked focused on open water, and the establishment of dispersant pre-approval zones in the U.S. for marine waters greater than 10 m deep and offshore greater than 3 miles, where the risk of using dispersants was easier to accept due to large dilution effects.

However, most of the spills that occurred in U.S. waters from 1990 – 1999 were within 3 miles of shore and less than 10,000 gallons (NRC, 2005). Cleaning oil from shorelines is costly in both economic and environmental terms. As a result, there is a desire to consider greater use of dispersants in near-shore environments to protect sensitive shorelines from floating oil (e.g., coastal marshes, mudflats, and mangroves). In these environments, cleanup techniques themselves often contribute to damage (e.g., foot traffic) and must be minimized. In near-shore environments, the uncertainties and complexities associated with the use of dispersants increase rapidly, and there is less time to make decisions to use dispersants and deploy resources before a portion of the spill comes in contact with the shoreline.

Difficult decisions can be debated and made in a pre-spill setting, where the consequences of using dispersants are evaluated against all of the other options available, including no response. These difficulties are demonstrated by the considerable efforts spent conducting Ecological Risk Assessment (ERA) workshops (Kraly et al., 2001) sponsored by the U.S. Coast Guard (USCG). In these workshops, local stakeholders are asked to consider all of the resources potentially at risk given a particular spill response method. Ultimately, participants must use their best judgment in considering tradeoffs among local resources using existing toxicity data to develop "consensus-based criteria" to evaluate where and when dispersant use may be appropriate in near-shore environments. This process has not been critically evaluated in terms of its effectiveness in improving decision-making, nor has it always been successful. However, it has increased awareness and been educational.

The ERA process also provided impetus for the USCG to consider requiring dispersant capabilities. Currently, the USCG is in the regulatory process of requiring vessels and facilities to have dispersant capabilities for Group II – IV fuels (USCG, FR NPR USCG-2001-8661, 2002). This rule requires owners to demonstrate the ability to perform a tiered response to combat a portion of a spill using dispersants. The promulgation of this rule is expected to occur in Spring 2007. It could increase the use of dispersants in U.S. pre-approved zones and heighten the need for considerations of dispersant use outside of pre-approved zones.

In addition to policy and regulatory shifts, the demarcation of dispersant pre-approval zones in Area Committee Plans, and the infusion of the ERA process, during the 1990s there was a major effort to standardize oil and dispersed oil toxicity testing protocols through an interdisciplinary collaboration (Singer et al., 2000). The effort advocated developing environmentally relevant exposures (i.e., spiked instead of constant) and measuring exposures instead of relying on nominal concentrations. The effort applied standardized techniques for producing water-accommodated fractions (WAFs) and chemically enhanced fractions (CE-WAFs) of oil to improve inter-comparisons among studies.

In 2004, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Minerals Management Service (MMS), the USCG, and the American Petroleum Institute (API) commissioned the NRC to conduct a follow-up study to evaluate the state of knowledge on dispersants, and to focus specifically on identifying research needs for better understanding the consequences of dispersant use in the near-shore and estuarine environments. In May 2005, the NRC published, "Understanding Oil Spill Dispersants: Efficacy and Effects." The NRC's major, overarching recommendation was that, "NOAA, the Environmental Protection Agency (EPA), the Department of the Interior (including MMS and USGS [U.S. Geological Survey]), USCG, relevant state agencies, industry, and appropriate international partners should work together to establish an integrated research plan, which focuses on collecting and disseminating peer-reviewed information about key aspects of dispersant use in a scientifically robust, but environmentally meaningful context."

In rapid response to the 2005 NRC report, and with support from the affected oil spill response community, the Coastal Response Research Center (CRRC) convened a strategy meeting in early July 2005 of U.S. representatives from federal and state agencies and the private sector that conduct and fund research on dispersants and dispersed oil. CRRC, a partnership between

NOAA and the University of New Hampshire (UNH), focuses on research to advance the knowledge, technology, and practice of spill response and restoration. There are several reasons why CRRC was well-positioned to lead the response to the NRC report's overarching recommendation. First, CRRC possesses one of the largest sources of R&D funding available for oil spill response and restoration in the U.S. Second, with the connection to the University of New Hampshire, CRRC could ensure that research is conducted to the highest standards of peer-review, as recommended by the NRC. Third, and perhaps most importantly, the CRRC does not have a stake in the past research or policies and could therefore provide third-party objectivity to developing an integrated framework for the next generation of science needed to improve spill response and the use of dispersants. The meeting participants agreed to form the "Dispersant Working Group." Membership of this group is shown in Appendix A. In less than two months after the release date of the report, the Dispersant Working Group had assembled, agreed to coordinate dispersant-related R&D programs but still acting autonomously, and started efforts to develop a coordinated, prioritized research plan to address the critical knowledge gaps identified in the NRC report.

The first major effort of the Dispersant Working Group was to sponsor a targeted research needs workshop. On September 20 - 21, 2005, CRRC hosted the "Research and Development Needs for Making Decisions Regarding Dispersing Oil" workshop at the University of New Hampshire (Durham, NH). The workshop participants were selected by the Dispersant Working Group and consisted of a diverse group from all sectors, including academia, industry, international, national and state governments, and non-governmental agencies (See Appendix B for the list of participants). The CRRC invited individuals who could analyze the NRC report, further delineate gaps and next steps, and had expertise or experience with oil spills and dispersant use. The overall workshop objective was to work together to establish an integrated research plan that focused on collecting and disseminating peer-reviewed information about key aspects of dispersant use in a scientifically robust, but environmentally meaningful context. This report serves as: The synthesis of the research priorities identified at the workshop; a working document for funding entities to use to sponsor future research; and an information dissemination tool for the oil spill response community. The report provides language for the preparation of study plans for future funding mechanisms or research proposals.

II. Workshop Organization and Structure

The CRRC workshop used the major topic recommendations from the 2005 NRC Study on Dispersant Efficacy and Effects to serve as the basis of discussion. The major topic areas for research recommended by the NRC report were arranged into six R&D categories: 1) chemical effectiveness of dispersant formulations; 2) operational effectiveness parameters; 3) hydrodynamic understanding, and integration of data needed to develop modeling capabilities to predict and evaluate dispersant effectiveness; 4) short- and long-term toxicity of dispersants and dispersed oil; 5) long-term fate, including emphasis on biodegradation; and 6) development of relevant exposure regimes.

The workshop was organized along the two categories of the NRC report - "Efficacy and Effects" using the six main R&D topics as "breakout" discussion themes. Prior to the workshop, the participants were selected to establish equal representation of expertise in efficacy and effects. There was also a concerted effort to distribute affiliations and expertise across breakout groups to maximize exchange and reduce parochialism. During the workshop, the groups were subdivided again so there were two “Efficacy” groups and two “Effects” groups. During each breakout session, the “Effects” groups discussed the same R&D topic, and the “Efficacy” groups discussed the same topic. This duplication was used to determine that a range of priorities was truly identified. After each breakout session, all groups were reconvened. Each group reported on their discussions and priorities for the given topic. For each major research idea or need presented several factors were identified: The overall research topics; an example title; objectives; guidelines for development of studies; issues and problems that could affect feasibility; and the topic’s application to the decision-making process. The main body of this report reflects this format.

Overall, the priorities that were recommended by the participants were complementary to the NRC recommendations, but go several steps further. There were common action items identified across the groups:

- Expansion of data-mining and literature syntheses for efficacy and effects
- Improvement in designing studies and analytical protocols to allow better inter-comparisons among studies
- A return to bench-scale testing to fill basic gaps that still exist
- Better field monitoring methods and technologies at spills of opportunities
- Development of integrated models to assist decision makers on dispersant use during planning and emergency response

This report is the result of a multi-stakeholder effort and provides the Dispersant Working Group with a prioritized template of potential research topics to more effectively use the limited funds available for research. The results also provide an integrated research planning tool to improve understanding of dispersant effectiveness, fate, and effects, and facilitate future decision making. This report provides the spill response community with an abbreviated work plan to inform the development of requests for proposals and other funding mechanisms. It also provides the research community with information to facilitate proposal writing, develop experimental designs, and improve the efficiency and relevance of future research.

III. Workshop Results

The workshop results are organized into a table for each of the three major topics under the two main categories, thus there are six tables. Tables 1-3 contain summaries of recommended R&D activities for Efficacy: 1) six topics on “Chemical Parameters that Influence Overall Effectiveness”; 2) six topics on “Operational and Hydrodynamic Parameters that Influence Overall Effectiveness”; and 3) two topics on “Modeling Integration of Chemical, Operational and Hydrodynamic Parameters.” Tables 4-6 contain summaries of recommended R&D activities for Effects with: 4) five topics on “Fate of Oil and Dispersed Oil in the Water Column and Other Habitats”; 5) four topics on “Realistic Exposure Regimes/Toxicity Testing”; and 6) five topics on “Integration to Make Short- and Long-Term Prediction of Effects.”

Table 1. EFFICACY TOPIC 1: Chemical Parameters that Influence Overall Effectiveness.

1A. Research Topic	Literature synthesis on physical and chemical properties of oils that determine the overall effectiveness of dispersant application
Objectives	Use existing data to develop tools to predict dispersibility as a function of composition and weathering; identify data gaps and recommend future studies, including bench-scale and wave tank tests, that should be conducted to support development of inputs to models that can predict the window of opportunity over which dispersant use will be effective
Guidelines	Synthesis should include good graphical products that will be useful to decision makers
Issues/Problems	Coordinate with responders and decision makers to identify what empirical tools would be most useful
Application to the Decision-Making Process	Improve ability to predict the window of opportunity for effective dispersant application

1B. Research Topics	Refining existing datasets to correlate physical and chemical properties of different types of oil with dispersibility
Objectives	Identify properties that determine dispersibility of a given oil; Develop "groupings" of oil properties that help define the dispersibility of unstudied oils
Guidelines	Build on existing syntheses
Issues/Problems	Need good statistical expertise in the assessment because there are complex, multivariate interactions to be quantified
Application to the Decision-Making Process	Provide necessary input data for models; should facilitate the decision-making process by providing more realistic predictions of an oil's dispersibility

1C. Research Topics	Protocols for creating weathered oil/emulsions
Objectives	Develop methods to create consistent and representative test oils for effectiveness testing as an oil weathers at sea; understand how weathering affects dispersibility
Guidelines	Compare simple to more complex methods; simple is best, but need to confirm that simple methods produce weathered oils/emulsions that are representative of natural conditions
Issues/Problems	Methods should be tested for oils with different emulsification properties; test oils should be as representative as possible of at-sea oil slicks, thus rheological and chemical properties of oil samples representative of past spills (both spills of opportunity and field tests) should be collected and characterized
Application to the Decision-Making Process	Not a direct influence; important component of other protocols and test systems to produce realistic results
1D. Research Topics	Development of standard oils with known dispersibility over a range of variables, for use in comparison with other oils

Table 1. EFFICACY TOPIC 1: Chemical Parameters that Influence Overall Effectiveness (cont.).

Objectives	Provide data for decision makers to better predict the dispersibility of a less-studied oil by comparison of its properties with a series of well-studied standard oils
Guidelines	Standard oils need to be in broad categories; they must have been field or tank tested to provide the most realistic results
Issues/Problems	Selection of oils should be based on regional priorities and reflect knowledge that characteristics of oils from source fields can change over time as a field is developed or depleted
Application to the Decision-Making Process	Improve current ability to predict the effectiveness of dispersant application for a specific oil

1E. Research Topics	Development and intercomparison studies of methods for measuring droplet size distributions and energy dissipation rate in different dispersant effectiveness test systems
Objectives	Develop protocols and sensor systems for measuring droplet-size distributions in bench-scale tests, wave tank tests, and field applications; evaluate methods and develop standard protocols to measure energy dissipation rates during dispersant effectiveness testing in bench-scale and wave tank systems
Guidelines	Should include a synthesis of the literature on horizontal and vertical energy dissipation rates for upper sea-surface turbulence under a variety of sea conditions, and inter-related scales under which dispersant use might be considered. Must be synthesized so that testing system conditions can be correlated with typical values at sea
Issues/Problems	Multiple protocols may be needed for different testing systems
Application to the Decision-Making Process	Improve the value of test results because they will be correlated to real field conditions

1F. Research Topics	Design and implement a research program to fill identified data gaps in chemical dispersant effectiveness testing
Objectives	Generate data needed to better understand and predict dispersant effectiveness in the field
Guidelines	Should include energy dissipation rates, droplet size distributions, different dispersant types and dosages, and other measurements that are important to assess effects, based on the results of the literature synthesis and using standard protocols and methods
Issues/Problems	Should be a coordinated program consisting of bench-scale testing followed by a focused wave tank testing program built on more realistic mechanisms of energy input and weathered oil
Application to the Decision-Making Process	Improve ability to predict the window of opportunity for effective dispersant application

Table 2. EFFICACY TOPIC 2: Operational and Hydrodynamic Parameters that Influence Overall Effectiveness.

2A. Research Topics	Determination of the factors that represent realistic operational conditions for wave tank test systems
Objectives	Define and achieve operational effectiveness; establish realistic wave tank test conditions; be able to correlate energy characteristics of wave tanks with realistic sea conditions
Guidelines	Review on-going work-plans at existing wave tanks; consider the capabilities of existing tanks; operational factors to be tested include impact velocity, dispersant: oil ratio, oil thickness, and wave dynamics and effects of currents (or lack thereof) in dispersant effectiveness
Issues/Problems	Slick control for reproducibility; need to improve mass balance calculations
Application to the Decision-Making Process	Used by researchers to correlate bench-scale and wave tank test results to field energies; will provide improved information on which to choose platform and dosage and better predict effectiveness

2B. Research Topics	Improving models of dispersed oil transport in the upper mixed layer
Objectives	Conduct a literature search for data and methods to measure key hydrodynamic properties of the upper mixed layer (into which dispersed oil moves); correlate wave and current dynamics to energy dissipation rate; define layer below turbulent mixing, but above pycnocline/thermocline
Guidelines	Literature search should focus on the issues of dispersed oil transport
Issues/Problems	Unsure if the data exist; scale of available data might not be useful for dispersed oil modeling needs; data will vary widely by setting (i.e., freshwater, estuaries, open ocean)
Application to the Decision-Making Process	Improves the physical transport components of models

2C. Research Topics	Update SMART monitoring protocols
Objectives	Identify data gaps and weaknesses in existing protocols; update existing protocols to incorporate new technologies; extend use of results through distribution via accessible databases/websites
Guidelines	Upgrade existing methods, do not re-invent the whole program
Issues/Problems	Requires coordination among agencies; may not be R&D; concerns about the costs of maintaining staff to implement the higher monitoring tiers
Application to the Decision-Making Process	Enhances assessment of dispersant efficacy with real-world data

Table 2. EFFICACY TOPIC 2: Operational and Hydrodynamic Parameters that Influence Overall Effectiveness (cont.).

2D. Research Topics	Assessment of the effects of dispersant application on subsequent mechanical recovery of undispersed oil
Objectives	Determine the ability of mechanical methods to recover oil that has been treated with chemical dispersants, but not effectively dispersed
Guidelines	Should provide information on choice of mechanical equipment after dispersant use to recover remaining floating oil
Issues/Problems	Should address effects of dispersant dosage, oil type, equipment type, and temporal changes in the oil
Application to the Decision-Making Process	Will inform decisions about consequences of attempting dispersant application on marginally dispersible oil or dispersant use in low mixing energy situations

2E. Research Topics	Optimizing the operational effectiveness of dispersant applications
Objectives	Identify and conduct appropriate research to understand how operating characteristics affect dispersant application and effectiveness
Guidelines	Should be a coordinated effort that considers evaporative processes, chemical composition at the oil slick surface, effective droplet size range, spray systems, swath definition, wind effects, sea state, and wind restrictions
Issues/Problems	Most operational factors can only or best be evaluated during field applications; such tests will be expensive and representative of only the actual field conditions; may be able to garner some data from spills of opportunity where dispersants are used or have been used
Application to the Decision-Making Process	Will improve operational decisions regarding application parameters

2F. Research Topics	Evaluation of new technologies for monitoring dispersant effectiveness in the field
Objectives	Test and evaluate sensor systems to measure field effectiveness of dispersant applications as indicated by water column measurements at various depths
Guidelines	Parameters of interest include: quantitative measurement of amount of oil dispersed; dissolved and particulate oil concentrations in the water column; synoptic measurements of oil over space and time; droplet-size distributions; oil/SPM interactions
Issues/Problems	Systems should be cost-effective
Application to the Decision-Making Process	Will provide operational data to support continued dispersant application and concentration data for model validation and effects assessment

Table 3. TOPIC 3: Modeling Integration of Chemical, Operational and Hydrodynamic Parameters.

3A. Research Topics	Workshop on requirements for integrating oil toxicity and biological data with oil fate and transport models
Objectives	Provide cross-training of modelers and scientists in disciplines of physical, toxicological, and population models so that they jointly agree on necessary standards; identify additional research needed to improve models
Guidelines	Issues to be addressed include: How good do the answers have to be (validation standards); where should fate models be improved; what are important scales for assessing impacts (spatial and temporal); and what bioassay data should be incorporated into models
Issues/Problems	Physical, chemical, biological, toxicological, and operational uncertainties have to be identified and quantified
Application to the Decision-Making Process	First step towards developing good, integrated models to support decision-making

3B. Research Topics	Improved models to predict dispersant effectiveness and oil fate
Objectives	Incorporate results of earlier effectiveness projects into integrated models to predict effectiveness of dispersant applications; includes model development, calibration, and validation
Guidelines	Model development to include improved surface turbulence algorithms, relationship between energy dissipation rate and droplet size distributions, and operational application parameters. Model output to include: Time series maps of droplet-size distributions; total dissolved and particulate hydrocarbons/PAH; Should build on data from tank tests, dispersant application tests, lab studies on dispersant effectiveness for different oils, and environmental effects
Issues/Problems	Should be an open code so the entire modeling community can benefit from the research
Application to the Decision-Making Process	Improved models will inform tradeoff analyses during preplanning and real-time response decisions

Table 4. EFFECTS TOPIC 1: Fate of Oil and Dispersed Oil in the Water Column and Other Habitats.

1A. Research Topics	Understanding the interactions of chemically dispersed oil droplets with suspended particulate matter (SPM) and how these processes affect the rate of oil biodegradation and ultimate fate of dispersed oil
Objectives	Develop a coalescence model and model inputs to predict the interaction of chemically dispersed oil and SPM and the influences of oil/SPM agglomerates on biodegradation kinetics, composition of sedimented oil, and the ultimate fate of dispersed oil droplets
Guidelines	Must be able to predict the size and composition of oil/SPM aggregates and the buoyancy of the aggregates
Issues/Problems	Need to better understand the interaction of multiple variables including SPM type (mineral, organic, biological), SPM size and density, oil type, oil droplet size, surfactant type, salinity, energy, and characteristics of the aggregates; need to develop the inputs to models that can predict the interaction of dispersed oil and SPM under realistic field conditions
Application to the Decision-Making Process	Will address concerns that dispersed oil will interact with SPM and be deposited on the seafloor, increasing the risk of exposure to benthic communities; will provide better information on biodegradation rates of sedimented oil, particularly in areas of high SPM (e.g., estuaries and the surf zone)

1B. Research Topics	Assessment of the degree, rate, and consequences of surfactant leaching from surface slicks and chemically dispersed oil droplets
Objectives	Provide data on how the rates of surfactant leaching from dispersed oil droplets affect oil droplet/SPM interactions, coalescence of individual oil droplets (and thus the re-surfacing rate), and biodegradation rates; assess how surfactant leaching from treated floating slicks may be determine the effectiveness of the initial oil dispersion
Guidelines	Studies should be conducted at realistic oil-to-water ratios and under different energy regimes
Issues/Problems	Studies should consider oil type, oil droplet size, surfactant type, surfactant application method; results should be reported as rates appropriate to a scalable model
Application to the Decision-Making Process	Will address concerns about how long dispersant application under calm conditions may be effective; will provide better data on fate of dispersed oil, particularly in areas of high suspended sediments

Table 4. EFFECTS TOPIC 1: Fate of Oil and Dispersed Oil in the Water Column and Other Habitats (cont.).

1C. Research Topics	Reconciliation of the differences between the empirical evaporation approach and traditional pseudo-component approach
Objectives	Improve algorithms to predict evaporation rates of surface slicks and chemical composition of dispersed oil
Guidelines	None
Issues/Problems	Studies need to resolve the issue of whether slick thickness should be considered in evaporation algorithms
Application to the Decision-Making Process	Important to better predict the loading and fate of oil components of concern (particularly the low molecular weight components that pose the greatest acute toxicity) in dispersed oil as it mixes into the water column and interacts with suspended particulate matter

1D. Research Topics	Quantification of the biodegradation kinetics of dispersed oil
Objectives	Better predict the kinetics of biodegradation of dispersed hydrocarbons and persistent PAHs in dispersed oil; develop inputs into a dispersed oil fate model
Guidelines	Conduct studies at realistic oil-to-water ratios that represent those that follow significant dilution of the dispersed oil plume
Issues/Problems	Need to address the broad spectrum of constituents, with emphasis on the more persistent, high molecular weight PAHs; should review results of past studies to identify weaknesses in previous test protocols
Application to the Decision-Making Process	Will answer significant questions about whether, and at what rates, dispersed oil degrades in the water column

1E. Research Topics	Improve, verify, and validate oil spill trajectory and fate models
Objectives	Improve the ability to model the trajectory and fate of dispersed oil
Guidelines	Be prepared to use spills of opportunity to verify models
Issues/Problems	Concerned that some of the better models are proprietary
Application to the Decision-Making Process	Improved and validated models will reduce concern of stakeholders that current models are inadequate

Table 5. EFFECTS TOPIC 2: Realistic Exposure Regimes/Toxicity Testing.

2A. Research Topics	Develop methods for collection and analysis of samples of dissolved phase and particulate/oil-droplet phase PAH in environmental samples
Objectives	Measure dissolved-phase PAH and particulate/oil-droplet phase PAH as a function of time and space at spills of opportunity or field tests for comparison to PAH thresholds measured in toxicity tests and predicted in models
Guidelines	Should include environmental monitoring guidance manual with sampling and analytical methods and quality assurance protocols and data quality objectives to ensure cost effectiveness and maximum use of the data
Issues/Problems	Will need detailed plans, including pre-positioning of sufficient equipment and human resources, for rapid deployment at spills
Application to the Decision-Making Process	These data are needed to develop appropriate toxicity testing methods and validate oil fate and effects modeling

2B. Research Topics	Monitoring dispersed oil concentrations at spills of opportunity
Objectives	Improve operational monitoring at spills to be able to document spatial and temporal concentrations of dispersed oil (dissolved and particulate)
Guidelines	Review emerging technologies to improve operational monitoring at spills; need ability to measure both dissolved-phase PAH and particulate/oil-droplet phase PAH as a function of time and space for comparison to PAH thresholds measured in toxicity tests and predicted in models
Issues/Problems	Waiting for a spill of opportunity is high risk-may not get spill in specific years of funding; Tier 3 SMART addresses some of these requirements, but lacks detailed protocols and a team for implementation at spill emergencies
Application to the Decision-Making Process	Field data will be important for validation of all model components

Table 5. EFFECTS TOPIC 2: Realistic Exposure Regimes/Toxicity Testing (cont.).

2C. Research Topics	Literature synthesis of dispersed oil toxicity studies
Objectives	Provide data summaries of dispersed oil toxicity studies for use in current risk assessments and to identify data gaps and recommend future studies
Guidelines	Data summaries should be presented in formats appropriate to current risk assessment approaches (e.g., ERA workshops); but also to support integrated models
Issues/Problems	Need to consider inconsistencies in dilution methods, exposure regimes, oil measurement methods and analytes (dissolved vs. particulate, nominal vs. measured, TPH vs. PAH), and endpoints
Application to the Decision-Making Process	Peer-reviewed literature synthesis will greatly improve the quality of risk assessments and direction of future research

2D. Research Topics	Standard methods for toxicity testing of dispersed oil appropriate for coastal regimes
Objectives	Develop standard methods for toxicity testing of dispersed oil appropriate for coastal regimes (e.g., near-shore CROSERF)
Guidelines	Convene a working group to review existing methods and develop new ones for toxicity testing; issues include realistic concentrations and durations (exposures) of dissolved and particulate PAH, measurement of actual concentrations of both, selection of and techniques for measuring ecological endpoints (lethal and sublethel acute effects and chronic effects), photo-toxicity, and appropriate species and life stages
Issues/Problems	Need to better estimate the relative contribution of dissolved and particulate oil/PAH
Application to the Decision-Making Process	Data are essential to assessment of impacts to water column resources during tradeoff analysis in near-shore settings

Table 6. EFFECTS TOPIC 3: Integration to Make Short and Long Term Prediction of Effects.

3A. Research Topics	Synthesis of existing dispersed oil toxicity data to support risk-based decision making for use of dispersants at spills
Objectives	Conduct synthesis of existing data on toxicity of dispersed oil, with data summaries presented in formats appropriate to current risk assessment approaches
Guidelines	Consider data on oil, dispersants, and dispersed oil for chronic and acute toxicity; data summary format should consider something like NOAA's SQUIRT or Table 2-3 in the NRC (2005) report
Issues/Problems	Many problems with existing data, such as reporting the oil as TPH vs. different components; summary should have strong statistical basis and be peer-reviewed; more discussion is needed to define role of chronic effects
Application to the Decision-Making Process	Will greatly improve trade-off evaluation by providing clear, peer-reviewed summaries of toxicity data

3B. Research Topics	Effects of dispersed oil on wildlife
Objectives	Determine thresholds at which dispersed oil in the water column affects birds and fur-bearing mammals
Guidelines	Studies should compare dispersed and undispersed oil; endpoints should include effects of dispersant and dispersed oil on water-proofing of fur and feathers and thermoregulation
Issues/Problems	Studies should be performed at realistic exposure conditions; may need to consider effects of leaching of the surfactant
Application to the Decision-Making Process	Important for evaluating the environmental tradeoffs that assume dispersant use reduces impacts of oil on wildlife

3C. Research Topics	Effects of short-term exposure to dispersed oil
Objectives	Focused short-term toxicity tests (identified gaps based on literature synthesis and using new standard methods)
Guidelines	Include elements for: phototoxicity; dissolved and particulate PAH fractions; standardized chemistry; and standardized endpoints (lethal, sublethal, and long-term)
Issues/Problems	Will need to develop protocols for estimating relative contribution of dissolved vs. particulate oil phases to toxicity
Application to the Decision-Making Process	Will produce short-term exposure results for evaluating impacts of dispersed oil

Table 6. EFFECTS TOPIC 3: Integration to Make Short and Long Term Prediction of Effects (cont.).

3D. Research Topics	Long-term effects of short-term exposures to dispersed oil
Objectives	Focused long-term toxicity tests (identified gaps based on the literature synthesis and using new standard methods) and realistic exposure scenarios.
Guidelines	Include elements for delayed effects such as length/weight, abnormalities, enzymatic effects, reproduction, genetic abnormalities, and behavioral impacts (e.g., mating, flight, feeding)
Issues/Problems	Will need to develop protocols for estimating relative contribution of dissolved vs. particulate oil phases to toxicity
Application to the Decision-Making Process	Will produce data on the long-term effects for evaluating impacts of dispersed oil

3E. Research Topics	Integration of fate and toxicity models with population models to predict short- and long-term effects of dispersant application
Objectives	Evaluate existing population models for applicability to episodic oil exposures and effects
Guidelines	Extrapolate from existing population and existing data.
Issues/Problems	How to extrapolate from toxicity tests to population- or community-level impacts is a difficult issue
Application to the Decision-Making Process	Will provide more quantitative analysis of consequences of dispersant use

IV. Synthesis of Workshop Results into Suggested Research Topics

The workshop results can be synthesized into the following suggested research topics. It is expected that these topics will be considered by funding agencies and organizations.

Development of Protocols for the Generation of Weathered Oil and Emulsions for Meso-Scale Testing of Dispersant Effectiveness

The two most important weathering processes affecting the dispersability of oil released at sea are evaporation and the formation of stable water-in-oil emulsions because they affect an oil's viscosity over time. The viscosity of stable emulsions can be as much as three orders of magnitude greater than the starting oil. Past bench-scale research has identified that the oil properties that are most important in determining the type of emulsions formed include the asphaltene and resin content, as well as the initial viscosity of the oil. Although bench-scale tests have been valuable in determining empirical factors controlling the chemical effectiveness of dispersants, they cannot simulate field conditions. Wave tank tests offer the ability to incorporate more realistic field conditions into the experimental design and test hypotheses regarding factors that can affect operational effectiveness. One of the criticisms of past wave tank tests has been that the test oils were artificially weathered by evaporation of the volatile compounds. Such test oils have not undergone the complex weathering processes that occur on oil slicks at-sea. For example, one of the factors that may be important for oils weathered at sea may be formation of a highly viscous skin that may affect penetration of dispersant droplets. Studies should focus on development and testing of standardized protocols for the generation of weathered oil and emulsions for such tests. To assure that the test oils are as representative as possible of at-sea oil slicks, rheological and chemical properties of oil samples representative of past spills (spills of opportunity and field tests) should be collected and characterized.

Development of Protocols for Measuring Droplet-Size Distributions of Dispersed Oil

Understanding the effectiveness of chemical dispersants, as well as the possible long-term fate and transport, requires measurement of droplet-size distribution of the dispersed oil. Droplet-size distribution is affected, initially, by turbulent shear and size fractionation due to differential rise velocities and by the effectiveness of the dispersant in reducing oil-water surface tension. Production of droplet-size distributions in experimental systems that are correlated to real field conditions will provide information on the droplet formation mechanisms and thus improve the value of the test results to predict when dispersant use will be effective. Studies should develop protocols and sensor systems for measuring droplet-size distributions in bench-scale tests, wave tank tests, and field applications.

Intercomparison of Energy Dissipation Rate Measurements

One of the most important factors in dispersant effectiveness testing is the energy dissipation rate, which is a measure of mixing energy. This parameter varies widely among experimental systems. Discrepancies in the results obtained with various systems are often attributed to differences in mixing energies. Correlation of laboratory-scale and meso-scale experiments with conditions in the open ocean can be facilitated through an understanding of turbulence regimes in all three systems. Furthermore, one of the biggest uncertainties in computer modeling of oil spill behavior comes from obtaining appropriate horizontal and vertical diffusivities. Dispersant effectiveness tests should measure the rate of dispersion and droplet-size distributions over a range of energy dissipation rates to characterize the functional relationship between these variables. Studies are needed to evaluate methods and develop standard protocols to measure energy dissipation rates during dispersant effectiveness testing in bench-scale and wave tank systems. The objective is to be able to generate data to correlate the relationship between energy dissipation rates that dominate common experimental systems to typical values at sea. Another objective is to determine the feasibility of correlating the relationship between energy dissipation rates that dominate in common experimental systems to typical micro-scale turbulence values in surface waters of the ocean. Studies should include a synthesis of the literature on horizontal and vertical energy dissipation rates for upper sea-surface turbulence under a variety of sea conditions and inter-related scales under which dispersant use might be considered. Characteristics and environmental variables such as wave heights, wave frequency, and local currents should be factored into these assessments.

Weathering Processes Controlling the Chemical Effectiveness of Oil Spill Dispersants: Part 1. Literature Synthesis of Past Chemical Dispersant Effectiveness Studies

Significant research has been conducted to test for chemical dispersant effectiveness on a range of oils under different test conditions. However, it is currently not possible to predict, within a specified confidence range, the extent to which a specific oil under given field conditions might be dispersible and stable. Additional research is needed to develop physical-chemical models to predict dispersant effectiveness over time for a specific spill scenario. The first step in developing model inputs is to conduct a synthesis of the existing literature on the physical and chemical properties that determine the overall field effectiveness of dispersant application once an oil starts to weather. Studies should identify factors that determine the dispersibility of a given oil once spilled and develop groupings of oil properties that help define and predict dispersibility. Easy to interpret graphical products that will be useful to the general user should be developed. The synthesis should be used to develop empirical tools for predicting dispersant effectiveness on a specific oil over time under a range of spill conditions. Coordination should occur with responders regarding empirical tools that would be most useful. Data gaps should be identified and future studies recommended, including bench-scale and wave tank tests, to be conducted to support development of inputs to models that can predict the window of opportunity over which dispersant use will be effective.

Weathering Processes Controlling the Chemical Effectiveness of Oil Spill Dispersants: Part 2. Chemical Dispersant Effectiveness Tests

Following the literature synthesis described in Part 1, the next step is to conduct the necessary bench-scale and wave tank tests to fill in the identified data gaps. Such tests should follow new standard protocols being developed for formation of emulsified test oils, measurement of droplet-size distributions, and measurement of energy dissipation rate under different test operating conditions. Ideally, a coordinated research plan would be proposed, with initial bench-scale tests to characterize the relationships between energy dissipation rate, droplet-size distribution, and chemical effectiveness of dispersant use on oil and weathered oil emulsions over a range of conditions. The results of the bench-scale tests would then be evaluated, and a focused program developed for wave tank tests designed to address identified data requirements using more realistic mechanisms of energy input and emulsions with properties that closely represent those of oils weathered at-sea. The wave tank tests would be conducted at an appropriate range of energy dissipation rates that adequately represent the conditions for a selected set of spill scenarios. The tank test methods should include the proposed approaches to measure dispersant effectiveness and determine the mass balance of each test run. The bench-scale and wave tank test results should be analyzed to identify those properties that affect dispersant effectiveness and could be used in predictive models.

Effectiveness of Mechanical Recovery on Chemically Treated, but Undispersed Oil

One of the concerns about use of chemical dispersants is that mechanical recovery will be reduced for oil that has been treated with dispersants, but not effectively dispersed. Dispersant application often continues until it is determined to be no longer effective, so treated, undispersed oil will often be present. This assessment could be conducted as a follow-on to wave tank tests to minimize costs. Issues of concern that could be addressed include effects of dispersant dosage, oil type, mixing energy applied during dispersant tests, mechanical equipment choices following dispersant use, and temporal changes. The study results would be useful in evaluating the consequences of dispersant application on marginally dispersible oil or during marginal mixing energy conditions.

Workshop on Approaches for Modeling of the Fate and Effects of Dispersed Oil

Oil spill models are powerful and necessary tools for supporting decision makers during pre-planning, emergency response, and post-spill assessment. Models to predict dispersed oil fate and effects need to be improved, verified, and validated. The first step in this process is to determine the modeling requirements, in terms such as the spatial and temporal scale of impacts and oil exposure measurements needed (e.g., dissolved and particulate; specific analytes). The modeling approaches selected for a specific application depend greatly on how good the answers have to be and the physical, chemical, biological, toxicological, and operational uncertainties that have to be considered. This initial assessment is needed particularly if models are to meet the needs of planning and real-time decision making in complex near-shore settings. The goal of the modeling workshop is to provide an opportunity for trajectory modelers to share with those in other disciplines (e.g., chemists, biologists) current approaches in estimating fate of dispersed oil, and identify where uncertainties and gaps exist. One workshop outcome would be a better understanding of what levels of concern are necessary and realistic for extrapolating from exposure and toxicity to operational decisions. A second outcome would be the identification of additional research needed to improve the models.

Effects of Dispersed Oil on Wildlife

One of the key assumptions made in the tradeoff analysis is that dispersants used on floating oil slicks will reduce impacts to surface-dwelling organisms such as birds and fur-bearing marine mammals. However, there are few data on the potential impacts of the dispersed oil plume on water-proofing of fur and feathers and thermoregulation of birds and aquatic mammals. Studies are needed to determine the thresholds at which dispersants (misapplied or drifted from the target slick) and dispersed oil in the water column could affect birds and mammals with fur.

Literature Synthesis on Dispersed Oil Toxicity Studies

There have been numerous studies of the toxicity of dispersants and dispersed oil using laboratory, meso-scale, and field methods. Yet, it is difficult for decision makers to use these data in risk assessments because of many inconsistencies in toxicity measurements and reporting. A synthesis of the existing literature is needed to: 1) support current risk assessment approaches; 2) identify data gaps; and 3) make recommendations for additional studies to fill the gaps. The format of the data summaries in the synthesis will be the key to its usefulness;

Workshops on Developing New Protocols for Dispersed Oil Toxicity Assessment

In response to recommendations for improved toxicity testing in the NRC (1989) report on dispersants, a university-government-industry group was formed, called the Chemical Response to Oil Spills Environmental Research Forum (CROSERF). Through a series of workshops, this group successfully developed and tested toxicity test protocols appropriate for open-water conditions. Based on the recommendations of the NRC (2005) report and this workshop, a new series of workshops is needed to develop protocols for future toxicity studies to address: 1) the relative contribution of dissolved and particulate oil to toxicity; 2) photo-enhanced toxicity; 3) appropriate exposure conditions for near-shore settings; 4) appropriate endpoints including sublethal and long-term effects; 5) and representative species.

Studies to Support Development of a Dispersed Oil/Suspended Particulate Matter (SPM) Coalescence Model

One of the biggest concerns about using dispersants in near-shore water with high SPM concentrations is that dispersed oil will interact with SPM and be deposited on the seafloor, increasing the risk of exposure to benthic communities to sedimented oil. Oil/SPM coalescence is affected by multiple factors including: SPM type (i.e., mineral, organic, biologic); SPM size and density; oil type; oil droplet-size; surfactant type; salinity; energy; and aggregate characteristics. Studies are needed to develop the inputs to models that can predict the interaction of oil and SPM under realistic field conditions. Studies are also needed to determine the rate of biodegradation of oil and PAHs in oil/SPM agglomerates and the ultimate fate of dispersed oil droplets.

Surfactant Leaching: Rates and Effects on Dispersed Oil Behavior and Fate

There are little published data on the potential leaching of surfactants from floating oil and dispersed oil droplets at realistic oil-to-water ratios and under turbulent conditions that might be encountered in the field. Surfactant leaching from treated floating slicks may be an important factor in determining the effectiveness of the initial oil dispersion. Surfactant leaching from dispersed oil droplets may influence the potential for coalescence of individual oil droplets (and thus the re-surfacing rate) and interactions and coalescence with SPM. A better understanding of both processes is needed to better predict the behavior and fate of dispersed oil.

Innovations in Monitoring of Dispersant Applications

Monitoring of dispersant applications is always desired to support evaluation of the effectiveness and effects of the application. The protocols currently used in the U.S. (Special Monitoring of Applied Response Technologies - SMART) only provide qualitative information on whether the dispersant application is working. Innovative monitoring methods to collect data are needed to provide: Quantitative measurement of the amount of oil dispersed; dissolved and particulate oil concentrations in the water column; more synoptic measurements of oil over space and time; droplet-size distributions; energy dissipation rates; and oil/SPM interactions.

V. Workshop Summary

During the last session of the workshop, all of the workshop participants convened to reach consensus on a summary of the discussions of the four different workgroups.

A. Dispersant Efficacy Summary

The discussions on R&D needs for better understanding dispersant efficacy were organized around six broad topics: 1) data mining and gap analysis; 2) protocol development; 3) conduct of additional testing; 4) analysis of results and development of new tools; 5) field measurements; and 6) technology development.

> **Data Mining and Gap Analysis:** Literature synthesis studies are needed: 1) on the factors that influence the effectiveness of dispersants on different oils as they weather; 2) to develop empirical predictive tools; 3) to identify and prioritize data gaps; and 4) to inform future studies to fill the highest priority gaps. Currently, dispersant effectiveness for a given spill is based on professional judgment. The goal is to be able to predict effectiveness within a specified level of confidence using more quantitative methods, starting with empirical tools and eventually using physical/chemical models. Because of the lack of information on the energy dissipation rates among test systems and at-sea conditions, a literature synthesis is needed.
>
> **Protocol Development:** New protocols are needed to provide consistency and comparability among test systems in the recommended new bench-scale and wave tank studies. New protocols identified as of highest priority include: 1) preparation of weathered and emulsified oils to be used in test systems; 2) measurement of droplet-size distribution for dispersed oil; 3) measurement of mixing energy dissipation rates; and 4) methods to scale energy dissipation rates among test systems. These protocols should be incorporated into the design of additional tests, as outlined in Table 2.
>
> **Additional Testing:** Additional testing was discussed for all three levels of test systems, *Bench-scale tests* are needed to refine data and fill in the identified data gaps, and meet the needs for developing better predictive tools. A matrix approach was proposed where multiple oils would be tested under a range of weathering conditions that could be systematically compared to past studies. Focused *wave tank studies* are needed to provide

data on dispersant efficacy under a range of realistic conditions that should be based on the results of the literature synthesis and include cold water conditions. Wave tank studies should test and refine the new protocols. *Field tests* are the best methods to measure operational effectiveness, focusing on spills of opportunity rather than planned tests.

Analysis of Results and Development of New Tools: The ultimate goal is to be able to use existing and new data to develop integrated models to predict the efficacy of dispersant application within a specified level of confidence for a specific spill based on chemical, hydrodynamic, and operational factors. Workshops are needed to ensure that the new models meet user expectations and that users understand model limitations. Such models should be developed using open code so that all users will benefit. These models would be used in planning and emergency response. However, empirical tools are also needed because data are not always available to run models. Empirical tools have a role in generating data for less-studied oils or conditions.

Field Measurements: Field data are needed for models and to predict efficacy (such as droplet-size distribution and energy dissipation rates) and to validate model results. Protocols are needed for sample collection and analysis.

Technology Development: Because of the difficulty of data collection during emergency response, new technologies are needed to improve field measurements. Use of new sensors and remotely operated vehicles should be explored to infuse new ideas into the oil spill research community.

B. Dispersant Fate and Effects Summary

The discussions on R&D needs for better understanding dispersed oil fate and effects were organized around six broad topics: 1) dispersed oil/SPM interactions; 2) surfactant leaching issues; 3) exposure regimes and endpoints for toxicity testing; 4) monitoring approaches; 5) dispersed oil effects on birds and mammals; and 6) development of integrated models.

Dispersed Oil/SPM Interactions: Improved understanding of the mechanisms and fate of dispersed oil/SPM and interactions with the bottom sediments and shorelines were identified as high priority areas. Studies are needed to support development of oil/SPM coalescence models that predict rates of sorption to particles, degradation of bulk oil and individual PAHs, and the ultimate fate of the contaminant-sorbed particles.

Surfactant Leaching Issues: Studies are needed to predict the rate of surfactant leaching from surface slicks and dispersed oil droplets. Studies are also needed to assess the effects of surfactant leaching on oil/SPM interactions (particularly in the surf zone), oil-bottom sediment interactions, oil-droplet recoalescence, and oil degradation rates.

Exposure Regimes and Endpoints for Toxicity Testing: Literature synthesis studies are needed to: summarize the data for use in risk-based decision-making; identify and prioritize data gaps; and inform future studies to fill the highest priority gaps. A multi-stakeholder technical workgroup should be convened to develop testing standards for dispersed oil bioassays. This workgroup would hold workshops to develop: 1) protocols for exposure regimes appropriate for near-shore dispersant use that will allow estimation of the relative contribution dissolved and particulate oil to toxicity, development of appropriate exposure conditions, and consideration of photo-toxicity for light-sensitive species; and 2) appropriate endpoints (acute and sublethal, including the long-term consequences of short-term exposures), species, and life stages. Toxicity studies are needed to implement the recommended protocols.

Monitoring Approaches: Monitoring of the effects of dispersant applications is desired, but the limitations and costs of having teams and resources on standby are significant. Therefore, innovative approaches are needed for collection of desired data including dissolved and dispersed oil concentrations in the water column, droplet-size distributions, and energy dissipation rates over space and time. These data would validate and improve models to predict the spatial and temporal concentrations of the dispersed oil plume.

Dispersed Oil Effects on Birds and Mammals: Studies are needed to determine the concentrations of dispersant and dispersed oil below which there is no effect on diving birds (feathers) and mammals (fur). The exposure pathway is to disperse oil droplets in the water column, and the effect is on decreasing water-proofing of fur and feathers which leads to hyperthermia.

Development of Integrated Models: Integrated models are needed to predict the fate and effect of dispersed oil for both planning and emergency response. Effects modeling should include toxicity effects and recovery rates of affected populations. Note: CRRC will convene a workshop to address this topic, September 26 – 28, 2006, Durham, NH.

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Dispersant Working Group
Membership

Appendix A

List of Dispersant Working Group Membership as of September 2005

Dispersant Working Group Membership

AK Department of Environmental Conservation – *Leslie Pearson*

American Petroleum Institute – *Robin Rorick, Tom Purcell*

BP – *David Fritz*

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Cook Inlet Regional Citizens Advisory Council – *Susan Saupe*

Coastal Response Research Center – *Nancy Kinner, Carol-Ann Manen*

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Prince William Sound Oil Spill Recovery Institute – *Nancy Bird*

Prince William Sound Regional Citizens' Advisory Council – *John French*

TX General Land Office – *Robin Jamail*

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Appendix B

List of Workshop Participants

Coastal Response Research Center
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September 20-21, 2005
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September 20-21, 2005
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