2014 INTERNATIONAL OIL SPILL CONFERENCE

Quantifying Tradeoffs – Net Environmental Benefits of Dispersant Use

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ABSTRACT 300077:

Oil spill response often involves making decisions regarding dispersant usage; the potential tradeoffs of increasing exposure of water column biota to hydrocarbons in order to reduce surface and shoreline oiling needs to be carefully considered and justified. A modeling analysis using RPS ASA's Spill Impact Model Application Package (SIMAP) was performed to evaluate the likely water volume adversely affected by naturally- or chemically-dispersed oil, as well as the surface area impacted by floating oil, and summarized in guidance useful for response planners and decision-makers. Key inputs were varied: oil type, oil volume, environmental (e.g., wind speed, temperature) conditions, dispersant use, weathering state when dispersants are applied, and toxicity to aquatic biota. Model results, including water volume where acute toxic effects would occur and the area of water surface oiled (which would impact wildlife, as well as socioeconomic uses), are summarized in tabular form, as well as a software-tool for interpolation, to provide data for quantitative comparisons of tradeoffs. Findings show that for (effective) dispersant treatment of floating oil volumes up to 100,000 gal in a single location during a short period of time (<1 hr; e.g., by a dispersant plane sortie), the area of surface water where water column biota would be affected would be much less than that affected by floating oil thick enough to directly affect wildlife. Thus, even if large volumes of oil are dispersed, a net environmental benefit may be achieved due to reduction or prevention of exposure to floating and shoreline oil, especially if the dispersant applications are over a wide area or over time.

INTRODUCTION:

There is considerable uncertainty and debate about the efficacy of dispersant use (Fingas, 2002) and the impact tradeoffs resulting from floating versus dispersed oil (National Research Council (NRC), 1989, 2005). NRC (2005) summarized uncertainties with respect to impacts to water column organisms as being related to incomplete understanding of oil fate and toxicity (particularly sublethal and ecosystem-level implications), and called for additional laboratory or tank experimentation and field monitoring to increase scientific understanding and verify models. However, there is considerable information available to indicate the acute effects of spilled oil on wildlife (i.e., birds, marine mammals, sea turtles), shoreline habitats, and water column biota, which is utilized to evaluate potential impacts of dispersant use and inform spill response decision-making.

We do not address efficacy (feasibility and effectiveness) as part of this analysis, rather the tradeoffs related to potential impacts of effective dispersant use as compared to those of untreated oil. The results provide responders with guidance, including model estimates of water volume adversely affected (with respect to acute toxicity to aquatic biota) by dispersed oil and dissolved hydrocarbons, as well as the surface area impacted by floating oil.

Previous computer simulations using the oil fates and biological effects model SIMAP (Spill Impact Model Application Package; French McCay, 2003, 2004) were made of natural and chemically-treated dispersion of large oil slicks (~ 1.5 miles^2, 3.9 km^2), indicating that resulting plumes could persist for several days with polynuclear aromatic hydrocarbon (PAH) concentrations at levels acutely toxic to at least sensitive aquatic organisms (French McCay et al., 2006). The scenarios examined the highest potential oil volume that could be dispersed into the water column at a given location, i.e., the amount of oil that could be dispersed by a single sortie of a C-130 airplane [100,000 gal = 379 m^3 of crude oil] dispersed at 80% efficiency). Those results indicated that wildlife impacts, if oil were left floating, would occur in a much larger area than water column impacts in the surface mixed layer (~10-20 m deep), and area-based reductions of wildlife impacts would be much greater than increases in water column impacts, if dispersants are used to a maximum possible extent. While an area of water column impact would be expected from dispersant use at this large scale, the area where wildlife impacts would occur would be much larger if dispersants were not used (French McCay et al., 2006).

Modeling was also performed in support of the US Coast Guard (USCG) Programmatic Environmental Impact Statement (PEIS) for its changes to Vessel and Facility Response Plan oil removal capacity (Caps) requirements for tank vessels and marine transportation-related facilities (USCG, 2009). Those model results (French McCay et al., 2005) were based on dispersing 45-80% of large oil volumes (i.e., treating 2,500 bbl [397 m^3 = 105,000 gal] and 40,000 bbl [6,359 m^3 = 1,680,000 gal] of oil), again demonstrating potential (quasi-) worst-case impacts to water column biota. Comparisons of potential water column with wildlife, shoreline, and socioeconomic impacts, based on percentages of resources affected and recovery time, indicated that large-scale effective dispersant use on medium-large spills would reduce overall impact.

However, similar modeling of typical (smaller) oil volumes that might be dispersed in localized areas was not previously performed and no quantitative guidance was available for response decision-makers. Dispersant use on smaller oil volumes might be more palatable to stakeholders if it can be shown that water column effects would be negligible or small, especially relative to alternative impacts on wildlife and shorelines. Thus, a matrix of model scenarios was run for a range of smaller oil volumes in open unrestricted waters that would likely to be dispersed in any given location during an actual spill response. The objective was to estimate areas and resources impacted by floating oil, as compared to volumes of water made acutely toxic by both naturally- and chemically-dispersed oil.

METHODS:

Model

RPS ASA's SIMAP (French McCay, 2003, 2004, 2009), which quantifies concentrations of subsurface oil components (dissolved and particulate) as well as areas swept by floating oil of varying thicknesses, was run for hypothetical oil spills with and without dispersant use in a range of potential environmental conditions. The model algorithms in SIMAP (French McCay, 2002, 2003, 2004) were developed over the past three decades to simulate fate and effects of oil spills under a variety of environmental conditions. The three-dimensional physical fates model in SIMAP estimates distribution (as mass, areas and thicknesses of oil, and concentrations) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments (French McCay, 2004). Dispersant use is simulated by increasing the amount of oil entrained into the water and reducing the droplet size distribution of that entrained oil, as compared to natural wind- and wave- induced entrainment. The model does not calculate the effectiveness of a dispersant application (i.e., the fraction of treated oil that actually is entrained into the water), as this is determined not only by the dispersant and oil properties but by the logistical effectiveness of applying the dispersant on the oil, as well as environmental conditions. Rather, the model user defines efficiency of dispersant application as an assumed input.

The SIMAP biological effects model estimates short term (acute) exposure of biota of various behavior types to floating oil and subsurface contamination, resulting percent mortality, and sublethal effects on production (growth). Mortality for each wildlife behavior group is based on the area swept by surface oil over a threshold thickness that would oil an animal with a lethal dose, the probability of encounter with the oil on the water surface, and the probability of mortality once oiled. Toxicity to aquatic biota in the water and subtidal sediments is estimated from dissolved aromatic concentrations and exposure duration, using laboratory-based bioassay data for oil hydrocarbon mixtures (French McCay, 2002, 2009).

In this study, impacts are estimated by species group for wildlife and water column biota by comparing equivalent areas or volumes of 100% loss (the weighted sum of lesser percentage losses). The use of equivalent areas and volumes for 100% mortality as metrics is an innovative approach that allows quantitative comparisons to be made between impacts to surface-related and water column-related resources, without having to estimate species densities. Since densities of all biota are highly variable in time and space, in some cases potential end-users of model results have difficulty accepting assumed biological data. This approach avoids that controversy, getting to the issue at hand – evaluating tradeoffs between wildlife and water column impacts in determining the best course of action to minimize overall impacts to biological resources.

Modeling Matrix and Inputs

A generic offshore spill site was used in the simulations, as the areas and volumes impacted would be similar in all offshore open-water areas under the same environmental conditions. Below is the matrix design that includes 360 physical fate model runs, each with three biological exposure and toxic effects model runs, i.e., 1,080 exposure scenarios.

Oil Type and Properties

Two oil types were modeled: light (South Louisiana, SLA) and medium/heavy (Alaskan North Slope, ANS) crude. Oil properties for SLA (API=34.5, 65% boiling <380^{o}C) and ANS crude (API=29.9, 46.4% boiling <380^{o}C) are described in French McCay et al. (2005).

Volume of Oil Dispersed and Not Dispersed

Five spill volumes (3.8 – 379 m^3 = 1,000 – 100,000 gal) were run. The highest potential oil volume that could be treated with dispersant at a given location would be that potentially dispersed by a single sortie of a C-130 aircraft, which carries 19 m^3 (5,000 gal) of dispersant capable of dispersing 20 times as much oil in a highly-effective operation, i.e., 379 m^3 (100,000 gal) of oil. Higher volumes were not run as the affected areas would be separated in space and time, and therefore their impacts could be considered separately and as additive.

The volume of oil dispersed by an application of chemical dispersant was examined as a percentage of spilled oil volume being effectively treated (0% or no dispersant application, 20% of spill volume dispersed, or 50% of spill volume dispersed). The effectiveness range is considered realistic for dispersant applications at sea by the USCG (2009).

Weathering State of the Oil When Dispersed

In many cases, the time oil is left to weather on the surface of the water before dispersant is applied is a direct result of response time. Two weathering times (12 and 24 hours post spill) were included to represent two potential response times. In actual spills, response times will often be longer than these, such that the oil would be more weathered than in the model cases examined here. Thus, these results are conservatively high as to the water column contamination that would be expected from a typical dispersant application.

Wind Speed

Wind is an important force leading to natural dispersion via wind-driven waves and entrainment into the water column. Two wind speeds were modeled to represent light (0 – 6 m/s [0 – 12 kts]) and moderate (6 – ~13 m/s [12 – ~25 kts]) winds. Because wind speed can have a large influence on floating oil, the results from this guidance should not be applied in situations where wind conditions are greater than ~13 m/s. Payne et al. (2007) and French McCay et al. (2007) found that dye tracking of subsurface transport indicated that surface dispersed oil and dissolved components would be rapidly mixed vertically into the surface mixed layer, and relatively little would mix deeper than the mixed layer on the time scale (hours) where toxicity may exist after surface oil is entrained. Thus, it was assumed that dispersed oil mixes to the bottom of a 10-m mixed layer, but no farther subsequently (a conservative assumption).

Temperature

Temperature is another important variable as volatilization, uptake rate into biota, and toxicity are all greatly enhanced at higher temperature. Three temperatures were used to cover the range of temperatures found in US waters: low (5ºC), medium (15ºC), and high (25ºC).

Other Environmental Factors

Other environmental factors have less affect on model results (French McCay et al., 2006). The salinity assumed is that typical of open ocean: 32 psu. Effects of small scale horizontal current shear were not modeled; only locally-forced wind-driven currents (i.e., characterized by vertical shear in the wave-mixed layer) were included. To the degree that a subsurface dispersed oil plume is sheared and diluted, water concentrations and toxic effects will likely be reduced.

The diffusion of subsurface oil and dissolved components is dependent on the horizontal and vertical dispersion coefficients, which determine the amount of mixing during simulated small-scale motions: those turbulent eddies and motions at spatial and temporal scales smaller than the grid-cell size and time step used in the hydrodynamic model producing the advective (current) field. We employ Thorpe's (1995) vertical diffusion rate algorithm (a function of wind speed) and a conservatively low horizontal dispersion coefficient of 1 m^2/sec (Okubo, 1971) in the mixing layer for all simulations.

Toxicity

Mortality is a function of duration of exposure – the longer the duration of exposure, the lower the (lethal) effects concentration (see review in French McCay, 2002; also Unger et al., 2007). The LC50 is the lethal concentration to 50% of exposed organisms. The incipient LC50 ($LC50_\infty$) is the asymptotic (and minimal value of the) LC50 reached after infinite exposure time (or long enough that that level is approached). Percent mortality is a log-normal function of concentration, with the LC50 the center of the distribution.

French McCay (2002) found that the value of $LC50_\infty$ ranges from 5-400 μg/L for 95% of species and life stages exposed to dissolved PAH mixtures for over 96 hrs, with the average species at ~40-50 μg/L. In the modeling matrix, three separate model runs were made using each of three $LC50_\infty$ values: 5, 50 and 400 μg/L (ppb). For each run and $LC50_\infty$ assumption, fractional mortality rates of fish, invertebrates, and their eggs and larvae were computed in exposed water volumes as a function of temperature, concentration, and time of exposure.

Analysis of Results

The key model results from these runs are the volume of water where acute toxic effects would occur (which would impact subsurface organisms, particularly plankton) and the area of water surface oiled (which would impact wildlife, as well as socioeconomic uses). Potential water-column impacts, assuming each of the range of toxicity values characterizing 95% of species noted above, were summarized as equivalent water volumes of 100% loss, i.e., percent mortalities for each water volume affected were summed (weighed by the volume) to estimate a total equivalent volume for 100% mortality.

Similarly, areas of impact to wildlife of various percentage losses were summed to calculate equivalent areas of 100% impact for birds, marine mammals and sea turtle species and/or behavior groups. The oiled areas also indicate the potential area for socioeconomic impacts. The total impact for a spill with a specific response, defined by volume spilled and percentage of that volume chemically dispersed, is the sum of impacts for the volume of oil not dispersed plus those for the volume of oil effectively dispersed.

RESULTS:

The matrix of model runs was designed to cover the variables that are most likely to generate variability in the results: wind speed, weathering time, and volume of spill. Higher wind speeds create more natural entrainment and thus dispersion of floating oil. However high entrainment does not always mean a significant reduction in surface area oiled; spillets can resurface behind the main slick as the wind pushes it beyond where the oil was originally entrained and the oil is swept over a greater surface area of the water. The weathering of oil on the water surface allows for toxic components to evaporate off without causing impacts in the water column. Therefore, the longer oil sits on the surface the smaller is the water volume impacted when the oil is eventually dispersed into the water. Higher wind speeds and temperatures increase the rate of evaporation of toxic components. Finally, the volume of the spill, and the volume that is dispersed, greatly affects the impact. The non-dispersed volume accounts for wildlife impact while the dispersed volume accounts for water column injuries.

Overview of Findings Based on Model Results

Impacts, estimated as equivalent areas or volumes of 100% loss (the weighted sum of lesser percentage losses), may be compared to estimate relative impacts to wildlife versus fish and invertebrates for spill response purposes, as well as in ecological risk assessments. Model results for SLA crude, a light oil, are summarized here in a series of charts showing the magnitudes of impacts and trends with volume and other variables. Complete results for the other oil and environmental variables can be found in the full report (French McCay and Graham, 2010).

Wildlife Impacts

In light winds, modeled at 2.6 m/s (5 kts) but applicable for 0-6 m/s (0-12 kts; breaking waves increase natural dispersion rate at >6 m/s), the area where wildlife would be oiled with a lethal dose if present increases with volume spilled (Figure 1) and not dispersed (Figure 2).

From Figure 1, it is apparent that the wildlife impact increases with volume of oil, but the rate of change of impact lessens with increasing oil volume. The effect of temperature is small at this wind speed, primarily by affecting the loss rate via evaporation such that area swept is slightly less at higher temperature. If the results are plotted against volume of oil that is not effectively chemically dispersed, all the data overlay each other such that a single curve describes the trend, regardless of temperature and efficiency of the dispersant application (not shown; see French McCay and Graham, 2010).

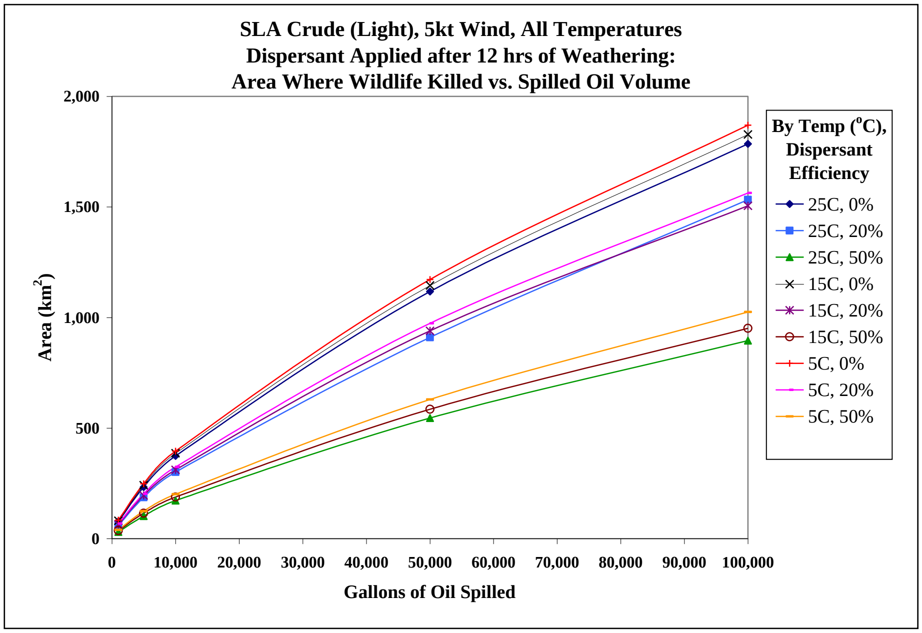

Figure 1. Area impacted versus oil volume (1,000 gal = 3.8 m^3) for SLA crude in 2.6 m/s (5 kt) winds. The swept area of impact is where a lethal dose would affect wildlife, if present.

In high winds, modeled at 7.7 m/s (15 kts) but applicable for 6 – ~13 m/s (12 to ~25 kts), the area where wildlife would be oiled with a lethal dose if present is a function of oil volume spilled (not shown; see French McCay and Graham, 2010) and volume not dispersed (Figure 2). The results are much more variable at the higher wind speed because the effects of temperature and wind speed on evaporation rate become apparent. The largest area of impact occurs at the coolest temperatures whereas the lowest impact occurs at high temperatures, regardless of amount spilled, because of high evaporation rates (Figure 2).

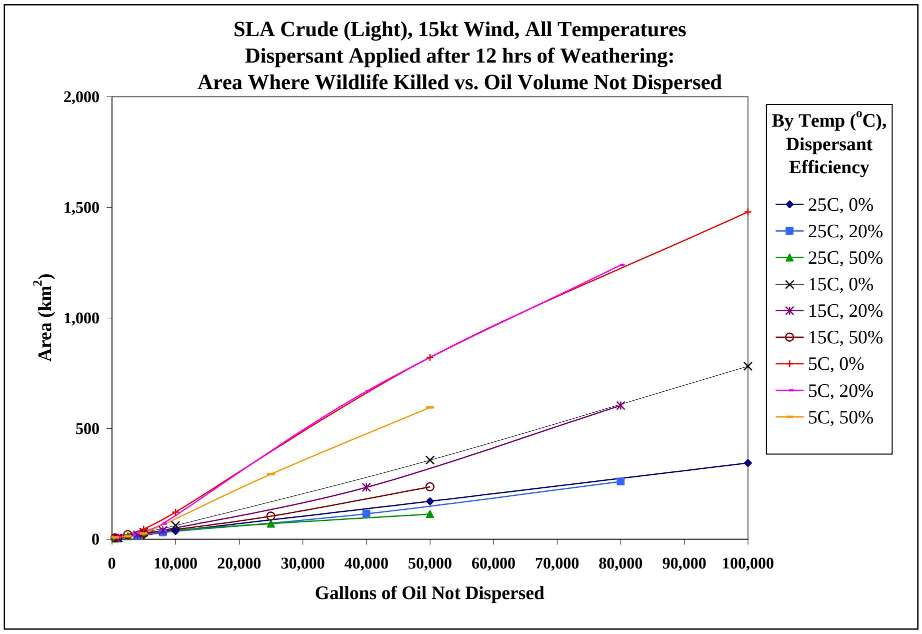

Figure 2. Area impacted versus oil volume not dispersed (1,000 gal = 3.8 m^3), for SLA crude in 7.7 m/s (15 kt) winds. The swept area of impact is that where a lethal dose would affect wildlife, if present.

In light winds, the difference between oil types is small, with the heavier oil (ANS crude) having a larger area of impact than lighter oil (SLA crude). This is because of the higher percentage of the oil evaporated over time for the lighter crude, which contains a larger percentage of volatiles. The difference between the oil types is more apparent at the higher wind speed (not shown; see French McCay and Graham, 2010). If dispersant was applied after a longer weathering time, there was a slightly higher wildlife impact (see French McCay and Graham, 2010), for a given amount of floating oil remaining after dispersant application.

Water Column Impacts

For water column impacts, the amount of oil dispersed is the major factor contributing to toxicity in the water column. Figure 3 shows the area (of a 10-m deep mixed layer) where water column biota (e.g., plankton), if present, would be exposed to a lethal dose of dissolved aromatic hydrocarbons as a function of oil volume chemically dispersed into the water at warm water temperature (25ºC) and in light winds (2.6 m/s). Across all temperatures, the impact to aquatic biota increases with volume of oil dispersed. The effect of temperature is strong because both uptake by biota and toxicity are functions of temperature. Impacts are greatly reduced at lower temperatures; only the most sensitive species (LC50 5 ppb [i.e., LC50$_\infty$ = 5 ppb]) sustain quantifiable impacts at cool water temperature (5ºC).

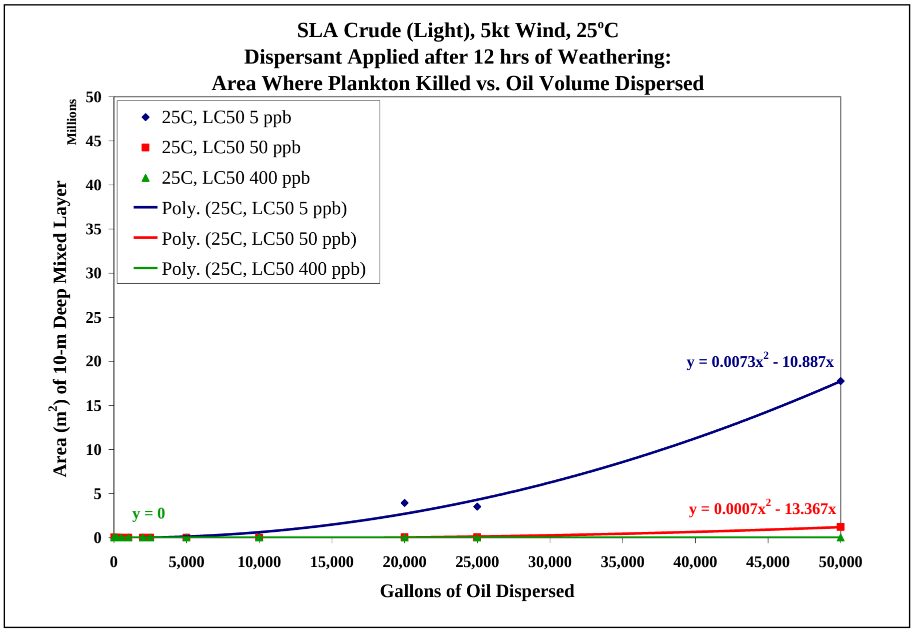

Figure 3. Polynomial curve fit to area of a 10-m deep mixed layer impacted versus volume of oil dispersed (1,000 gal = 3.8 m^3), for SLA crude in 2.6 m/s (5 kt) winds and 25ºC. The impact area is that where a lethal dose would affect plankton for each LC50.

There is also a large variation in response with sensitivity to oil hydrocarbons, i.e., as indicated by the range of LC50s describing 95% of species tested (French McCay, 2002). As a result the impacts to aquatic biota at the same concentrations (subsurface plume dynamics) can be negligible for insensitive species (LC50 400 ppb) and relatively large for sensitive species (LC50 5 ppb), particularly at higher temperatures (Figure 3). Figure 4 shows the area (of a 10-m deep mixed layer) where water column biota (e.g., plankton), if present, would be exposed to a lethal dose of dissolved aromatic hydrocarbons as a function of oil volume chemically dispersed into the water at 25ºC under high winds of 7.7 m/s (15 kts). As with light-wind conditions, the impact areas for a given oil volume dispersed decrease substantially as temperature decreases. Across all temperatures, the impact to aquatic biota increases with volume of oil dispersed, and the rate of change of impact increases with increasing oil volume. For these dispersed oil volumes, impacts to insensitive species are very low at moderate and cool temperatures; however the impact potential for average and sensitive species is higher at these temperatures as the high wind speed entrains the oil before evaporation has reduced the toxicity. Thus, there is a large effect of species sensitivity, and higher wind speed increases the impact to sensitive more than less sensitive species (Figure 4, 3).

The difference in toxicity to the most sensitive species at the highest temperatures between oil types is small at low wind speeds but measurable at high winds (not shown; see French McCay and Graham, 2010). The lighter oil (SLA) creates a slightly larger impact area at higher volumes of dispersed product because of its lower viscosity which results in smaller entrained droplets and therefore higher dissolution rates. Even though natural dispersion and entrainment increase the area of impact as compared to impacts at light wind speeds, there is a noticeable reduction in impact if the oil is dispersed after 24 instead of 12 hours (not shown; see French McCay and Graham, 2010).

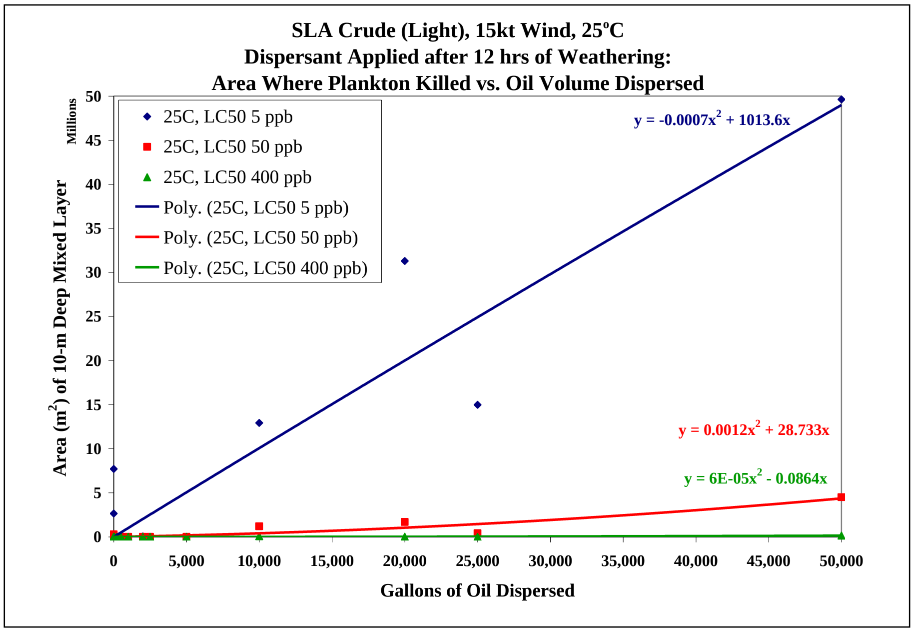

Figure 4. Polynomial curve fit to area of a 10-m deep mixed layer impacted versus volume of oil dispersed (1,000 gal = 3.8 m^3), for SLA crude in 7.7 m/s (15 kt) winds and 25ºC. The impact area is that where a lethal dose would affect plankton for each LC50.

Impact Tradeoffs: Wildlife versus Water Column Biota

In order to examine the tradeoffs between impacts to wildlife and water column biota, comparisons were made between the equivalent areas where 100% mortality would occur, assuming average sensitivity of water column biota to dissolved aromatic hydrocarbons. Presented here are the results for spills of 379 m^3 (100,000 gal) of the SLA crude. These and comparisons for 189 m^3 (50,000 gal) spills for both oils can be found in Appendix A of the full report (French McCay and Graham, 2010). Spills of volumes smaller than 189 m^3 (50,000 gal) produced minimal impacts on water column organisms of average sensitivity to PAHs regardless of dispersant effectiveness assumed or environmental conditions (i.e., volumes impacted by < 19 m^3 (5,000 gal) of entrained oil were not measurable at the model resolution used for species of average sensitivity); therefore, no comparison is needed.

In light winds (2.6 m/s [5 kts]) and high water temperature (25ºC), a spill of 379 m^3 (100,000 gal) that is not dispersed impacts close to 1,800 km^2 for wildlife and does not measurably impact the water column (“plankton”; Figure 5). If 20% of the slick is dispersed after 12 hours of weathering, the area of wildlife impact (caused by the full volume of oil before 12 hrs and the remaining 80% of the oil after 12 hours) is reduced to 1,550 km^2 and increased to 0.05 km^2 for plankton. At 50% dispersal, the area of wildlife impact had been reduced by half of the original impact while plankton has increased by two orders of magnitude to about 1.2 km^2. If the oil is left to weather until 24 hours after the spill before dispersant application, the impact to wildlife is slightly lower (because the oil remaining after partial dispersal has slightly less volume due to the higher loss to evaporation), while there are ~zero impacts (at the resolution of the model, ~0.01km^2) to the water column biota (of average sensitivity to PAHs), regardless of percentage dispersed. In cooler waters the impact to wildlife is similar while impact to the water column biota is reduced from 1.2 km^2 at 25ºC to 0.14 km^2 at 15ºC and ~zero at 5ºC.

At higher wind speeds, natural dispersion and evaporation change the relationships between impacts (Figure 6). Surface area swept is much lower under the higher winds than the low winds (compare Figure 6 to Figure 5) because natural entrainment disperses the oil. Evaporation rate is also considerably higher at 7.7 m/s (15 kts) than at 2.6 m/s (5 kts), and this effect is even stronger at higher temperatures. Thus, the surface area where wildlife would be oiled is much less in warmer temperatures than cooler ones. At high water temperatures (25ºC), dispersing 50% of the surface slick after 12 hours of weathering reduces the impact area from 340 to 150 km^2 (Figure 6); however, there is a large increase in area of impact for plankton (and other water column biota). Natural dispersion impacts 0.3 km^2 while additional chemical dispersal of 50% increases the area of impact to 4.5 km^2. At cooler temperatures the impact to plankton holds a similar pattern but is not nearly as high (15ºC: 0-0.7 km^2; 5ºC: 0-0.1 km^2).

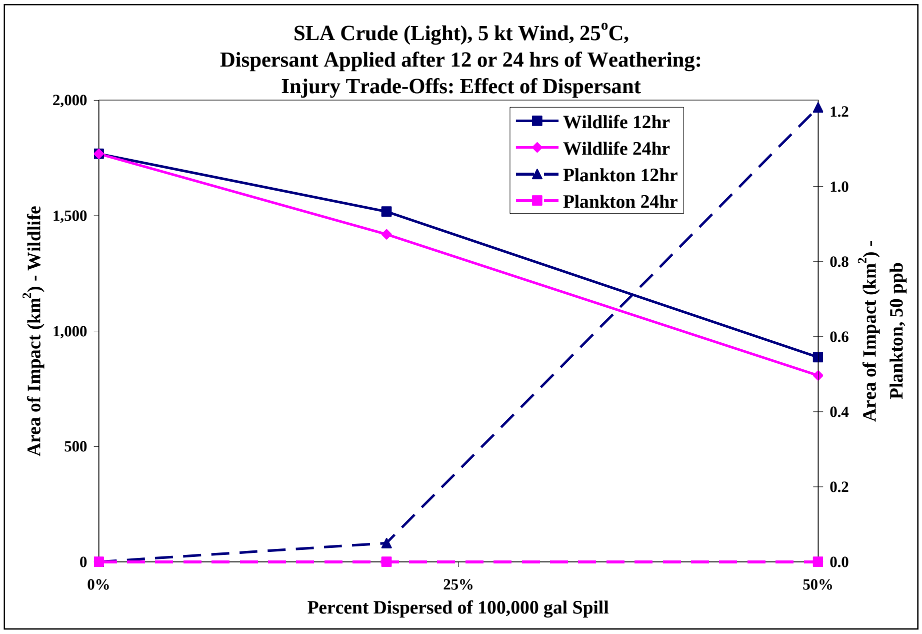

Figure 5. Area impacted versus percent dispersed for SLA crude in 2.6 m/s (5 kt) winds and 25º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

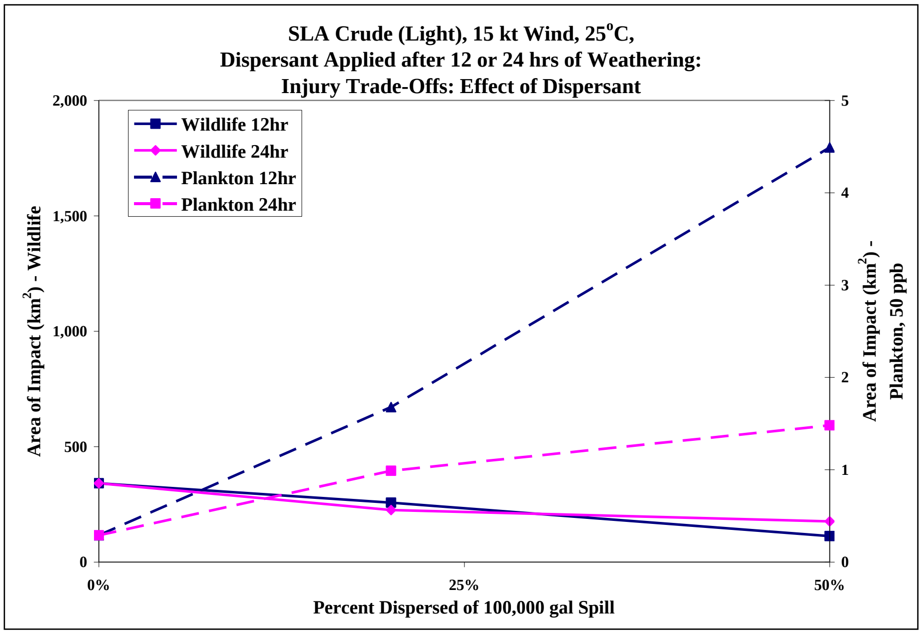

Figure 6. Area impacted versus percent dispersed for SLA crude for 7.7 m/s (15 kt) winds and 25° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

Increasing the weathering time before dispersant is applied also reduces the impact to plankton. Dispersing after 24 hours reduces the plankton impact from 4.5 km^2 to 1.5 km^2 while the impact to wildlife remains similar (Figure 6).

Complete Model Results and Oil Spill Impact Guide

The complete set of results, i.e., mass balance of oil during the simulations and impacts to wildlife and water column biota, can be found in the full report (French McCay and Graham, 2010). Additionally, the results compiled during this project were used to create an Oil Spill Impact Guide (OSIG) which uses regression analysis to estimate impacts of spills at volumes in between those volumes modeled. The calculator was designed to be used by first responders and help them make an educated decision about whether or not to apply dispersant. This calculator, a Microsoft Excel-based tool, is freely available by request to the authors; the full report contains instructions on its use (French McCay and Graham, 2010).

DISCUSSION:

Following an oil spill, decision makers must rapidly consider various response options as to the expected improvement, degradation and eventual recovery of the environment. Dispersants are a “tool” in the responder’s “toolbox” that should be considered among other options for how to best respond to a spill. Many areas off the US coast have been designated as “Pre-approval Zones” for dispersant application to floating oil during oil spill response, but in these and other areas the “Go” decision to apply dispersants remains controversial because of uncertainty about efficacy and impact tradeoffs of floating versus dispersed oil (NRC, 2005).

An effective application of dispersant would reduce exposure of wildlife and shoreline habitats, but with the potential tradeoff that the dispersed oil may cause impacts to water column organisms. The model results address the range of volumes where dispersant would be applied in any given location (3.8 – 379 m^3 = 1,000 – 100,000 gal) with various potential efficiencies (0%, 20%, 50%). Impacts for dispersed oil volumes up to 19 m^3 (5,000 gal) were below the level detectable for water column biota of average sensitivity. For sensitive water column biota, this threshold was 2 m^3 (500 gal). Thus, as a general conclusion, the tradeoff with respect to wildlife versus water column biota is in favor of dispersant use for oil volumes < 2 m^3, while remaining protective of 97.5% of species. Dispersing more than these volumes of oil in a single location during a short period of time (< 1 hour) could have impacts on some biota in the surface mixed layer, depending on winds, degree of current shear, weathering state, temperature, and sensitivity of the aquatic biota exposed (i.e., toxicity). However, the volume and area of surface water where water column biota would be affected would be much less than the area where wildlife would be affected by floating oil. Furthermore, the model results showed that dispersant application on spills of < 19 m^3 (5,000 gal) produced non-measurable impacts on water column organisms of *average* sensitivity to dissolved PAHs, regardless of dispersant effectiveness assumed or environmental conditions. Thus, if the dispersant applications are spread out over wide areas or over time, such that each localized application does not exceed 2 m^3 (to protect 97.5% of species) or 19 m^3 (to protect the average species) of oil dispersed, water column impacts can be held low while still accomplishing a reduction of impacts due to the floating oil.

In an actual incident, the potential benefits and risks of dispersant use depend on the density and sensitivity of biota present in the affected area. In addition to considering acute effects, long-term effects should be considered for areas where exposure is sustained. Populations of long-lived species, such as birds and marine mammals, and complex shoreline or benthic habitats, typically recover at much slower rates from the impact of an oil spill than populations of species with a higher turnover rates such as zooplankton.

In conclusion, we expect that the research and lessons learned from this effort will contribute to international efforts aimed at developing decision-support tools, and provide needed information related to spill response, specifically with respect to dispersant use.

ACKNOWLEDGEMENTS:

Funding was provided by the NOAA/UNH Coastal Response Research Center (CRRC, Grant number NA04NOS4190063). We greatly appreciate the comments and suggestions provided by the technical reviewers: Troy Baker (NOAA OR&R), Nancy Kinner (CRRC), Amy Merten (CRRC), Charlie Henry (NOAA OR&R), Chris Barker (NOAA OR&R), Jordan Stout (NOAA OR&R), Kurt Hansen (USCG Research and Development Center), Bruce Hollebone (Environment Canada), and Daniel Hahn (NOAA OR&R). We would especially like to thank Kathy Mandsager of CRRC for her support throughout this project on contracting and logistics.

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