Guidance for Dispersant Decision Making: Potential for Impacts on Aquatic Biota

Principal Investigator: Deborah French-McCay, PhD
Applied Science Associates
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Problem Statement

• Biologically/Ecologically-Driven Spill Response: Trade-off response decisions based on expected level of resource injury

Use of chemical dispersants

Quantify tradeoff
Investigative Approach

• Use oil fate and biological exposure modeling to quantify impacts
• Provide quantitative guidance for response decision makers
• Oil Spill Impact Guide (OSIG)
  • water volume adversely affected by dispersed oil and dissolved hydrocarbons
  • surface area impacted by floating oil
  • typical animal densities in shelf areas of US
Toxic Components of Oil (Additive Effects)

Aliphatics = (e.g., alkanes) - more volatile than soluble

Monoaromatic Hydrocarbons (MAHs)
- Benzene, Toluene, Ethylbenzene and Xylenes = BTEX - highly soluble, highly volatile, moderately toxic
- Alkyl-substituted Benzenes - soluble, less volatile, more toxic

Polynuclear Aromatic Hydrocarbons (PAHs)
- Naphthalenes (2-ring PAHs)
  - soluble, less volatile, more toxic
  - with more alkyl chains, less soluble but more toxic
- 3 ring PAHs: Phenanthrenes, Fluorenes, Dibenzothiophenes
- 4-ring PAHs - parent compounds bioavailable
- larger PAHs insoluble
Important Oil Fate Processes

- Water Surface
- Thick Oil
- Sediment Surface
- Sedimentation
- Entrainment
- Dispersant
- Wind
- Sheens
- Resurfacing
- Turbulent Dispersion and Dissolution
- Adsorption and Adherence to Particulates

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Biological Exposure Model

Organisms classified by behavior
- Wildlife
  - % of time on water surface
  - Habitats used
  - Feathers & fur
- Fish and Invertebrates
  - Swimming
  - Drift with currents
  - Stationary

Movements of organisms are tracked to calculate exposure of individuals

Impact a function of dose
- Wildlife
  - Area swept
  - Slick thickness
- Fish and Invertebrates
  - $\Sigma$ PAH Concentration (water, sediment pore water)
  - Exposure time
  - Temperature
Validation - Wildlife

**Exxon Valdez** (Prince William Sound)

- **Total Birds**
- **eagles**
- **murrels**
- **puffins**
- **guillemots**
- **murrelets**
- **other alcids**
- **gulls**
- **cormorants**
- **procellariids**
- **sea ducks**
- **grebes**
- **loons**

**log10 (# killed)**

**Model**

**Field**
Validation - Fish and Invertebrate Toxicity

- Oil bioassays
  (French McCay, 2002; Envir. Tox & Chem Vol. 10)
  - 24 data sets (2 to 91 species tested)
  - For all data sets: model not significantly different from observed

- North Cape Oil Spill (RI, Jan 1996):
  - Lobsters
  - Field estimate 9 million
  - Model estimate 8.3 million
    - (using best estimate of toxicity)
  - Strandings on beaches: 3 million

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Species Sensitivity Ranking -- PAHs in Crudes and Fuel Oils
Vertical Red Lines are Geometric Mean and Range for 95% of Species
(French McCay, 2002)

LC50 for >96hrs Exposure Time

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Biological Impacts: Equivalent Areas of 100% Loss

**Wildlife**
(Birds primarily)

Area swept by oil >10 \( \mu m \) thick multiplied by probability of encounter with water surface:

\[
\text{[Area Swept]} \times \text{[Probability]}
\]

**Water Column**
(Plankton)

Weighted sum of volumes affected at \( \lambda \)% loss:

\[
\sum \left[ \text{Volume} \times \frac{\lambda}{100} \right]
\]

Divide by mixed layer depth to calculate area affected
Previously Modeled Scenarios

- Hypothetical spills in open water
- Restricted to surface mixed layer: 10m, 20m
- Light Arabian crude
- Oil volume:
  - maximum volume of oil treated by a single sortie of a C-130 (100,000 gal = 326.3 MT = 378 m³, 20:1 oil:dispersant)
  - 80% efficiency
- Dispersant application scenarios:
  - No dispersant applied
  - Dispersant applied after weathered 8 or 16 hrs
- Wind speeds and associated turbulence conditions
  - 5 kts (2.5 m/s), 1 m²/s
  - 15 kts (7.5 m/s), 10 m²/s
- Background currents:
  - none
  - 0.25 kts (13 cm/s) downwind
  - 0.25 kts (13 cm/s) upwind
### Summary of Impacts - Area (km²)

Worst Case: 80% of 100,000 gal dispersed; no currents, 10m mixed depth

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>No Dispersant</th>
<th>With Dispersant</th>
</tr>
</thead>
</table>
| **5 kt** (2.5 m/s) | W: 197-209  
PA: 0  
PS: 0 | W: 83-100  
PA: 0.6-1.8  
PS: 7-15 |
| **15 kt** (7.5 m/s) | W: 391-425  
PA: 0  
PS: 0.03-0.20 | W: 68-108  
PA: 0.06-0.09  
PS: 1.4-2.2 |

- **W** = Wildlife
- **PA** = Plankton: Average Toxicity
- **PS** = Plankton: Sensitive Species
On-Going Project

- Other scenarios
- Matrix of model runs:
  - spills in open water
  - range of smaller oil volumes more likely to be dispersed
  - vary dispersant efficiency
  - vary key input variables determining impact
Products

- Results of model matrix:
  - areas and volumes impacted
  - #s of animals for representative densities
- Presented in tabular and chart format for can look up order of magnitude of likely impact
- Methods of interpolation between results for intermediate spill volumes
  - Visually off chart or table
  - Calculator in Excel
Model Run Matrix - Fates

- 2 Oil types: light and medium/heavy crude oil
- 2 Weather conditions
  - light wind and low turbulent mixing
  - high wind and high turbulent mixing
- 3 Temperatures
  - low (5°C), medium (15°C), and high (25°C)
  - affects weathering, uptake into biota, and toxicity
- Dispersant application
  - none
  - with three different efficiencies
- 5 Volumes - to allow curve-fitting of results
Model Run Matrix - Biological

- **Aquatic Toxicity**: 3 LC50s covering the range of ± two standard deviations (95%) of species response (French McCay, 2002)
  - mean [50 ppb dissolved PAH]
  - sensitive [5 ppb dissolved PAH]
  - insensitive [400 ppb dissolved PAH]

- **Wildlife**: Probability of oiling based on behavior and vulnerability
Model Results

• Water column impact
  • Volume where acute toxic effects would occur
    • equivalent volume for 100% mortality
    • multiply by mixed layer depth → area impact
  • Volume exceeding 1 µg/L total dissolved aromatics (sublethal and chronic effects)

• Area of water surface oiled
  • > Lethal dose to wildlife
    Probability of oiling varies by behavior group
  • >0.01 g/m² ~ approximate sheen thickness (socioeconomic impact)
SLAC, 5kt Wind: Area Where Wildlife Killed vs. Spilled Oil Volume

- Gallons
- Area (km²)

Legend:
- 25C, 0%
- 25C, 20%
- 25C, 50%
- 15C, 0%
- 15C, 20%
- 15C, 50%
- 5C, 0%
- 5C, 20%
- 5C, 50%
SLAC, 5kt Wind: Area Where Wildlife Killed vs. Oil Volume Not Dispersed

Area (km²) vs. Gallons

- 25°C, 0%
- 25°C, 20%
- 25°C, 50%
- 15°C, 0%
- 15°C, 20%
- 15°C, 50%
- 5°C, 0%
- 5°C, 20%
- 5°C, 50%
SLAC, 5kt Wind: Area Where Wildlife Killed vs. Oil Volume Not Dispersed

All Treatments:
\[ y = 0.1859x^{0.7034} \]
\[ R^2 = 0.99 \]
SLAC, 5kt Wind on DelMarVa Shelf: Birds Oiled vs. Oil Volume Not Dispersed

\[ y = 7.6857x^{0.7065} \]

\[ R^2 = 0.9899 \]
Wildlife Impact: Light Winds

# Oiled = [0.257 $V_s^{0.6759}$] [#/km$^2$] [Prob]

$V_s$ = Volume of oil not dispersed
Prob = Probability of being present on water surface
SLAC, 5kt Wind: Area Where Plankton Killed vs. Oil Volume Dispersed

15°C

Area (km²) of 10-m Deep Mixed Layer

Gallons Dispersed

\[ y = 3 \times 10^{-9}x^2 - 2 \times 10^{-5}x + 0.0123 \]

\[ R^2 = 0.9939 \]

\[ y = 8 \times 10^{-10}x^2 - 1 \times 10^{-5}x + 0.0244 \]

\[ R^2 = 0.9105 \]

\[ y = 0 \]

\[ R^2 = \text{N/A} \]
SLAC, 5kt Wind: Area Where Plankton Killed vs. Oil Volume Dispersed

\[ y = -4 \times 10^{-10} x^2 + 2 \times 10^{-5} x - 0.0171 \]

\[ R^2 = 0.8957 \]

\[ y = 0 \]

\[ R^2 = \text{#N/A} \]

\[ y = 0 \]

\[ R^2 = \text{#N/A} \]
Water Column (Plankton) Impact: Light Winds

# Killed = \[ f(V_d) \] [#/m^3] [z_{mix}]

\[ V_d = \text{Volume of oil dispersed} \]
\[ Z_{mix} = \text{surface mixed layer depth} \]
Products

• **Report** - describing the technical approach, assumptions and results of the modeling and guidance development

• **Field guide** (PDF format)
  • Summarize the results
  • Look-up tables with charts, for each oil type and environmental condition

• **Spreadsheet-calculator** for looking up and interpolating results
Use of Guidance Calculator

• User inputs
  • Environmental conditions
  • Oil type
  • Volume spilled
  • Volume/fraction dispersed and efficiency

• Calculator
  • Will interpolate from results of model matrix to in-between conditions
  • Based on regressions of results
Workshop

- Conduct a focused half-day workshop
- At or adjunct to a spill-response related meeting or conference
- Present the results of the study
- Discuss dispersant decision-making using the tool
Conclusions

• Guidance provides order of magnitude results
  • as an input to response decision-making
  • for scoping potential impacts and NRDA
  • for planning water column sampling

• Use of volumes and areas impacts
  • Allows analysis when animal densities unknown or uncertain
  • Multiply by estimated animal densities - scales proportionately