API Study on Detection and Recovery of Sunken Oil

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William Key
API Study Objectives

1. ID current best practices and alternative technologies to more effectively identify and recover *sunken oil*;

2. Establish a framework and priorities for ongoing R&D for the best potential alternative technologies

* = accumulation of bulk oil on the bottom of a water body
Types of Sunken Oil

- Oils that are heavier than water and mostly sink when spilled
- Oils that are lighter than water and sink after mixing with sediment
- Oils that become heavier than water due to formation of oil-particle aggregates under turbulent conditions, which eventually settle on the bottom of the waterbody in quiescent areas
Oil will not float

Density vs Salinity

Oil will float

Density (g/cm³)

Salinity (ppt)
Oil-to-Water Density Ratio

- **< 1.0**
  - Floats initially

- **> 1.0**
  - Majority does not float initially

Turbulence/Currents

- **High**
  - Oil is submerged in water column

- **Low**
  - Oil sinks to bottom

Sediment Interaction

- **High**
  - Oil can sink
    - After stranding onshore and mixing with sand
    - After mixing with sand suspended by wave action
    - Oil can refloat after separating from sand

- **Low**
  - Oil floats, but heavy oils can
    - Quickly form tarballs
    - Overwashing slows weathering
    - Tarballs recondense in convergence zones and on shorelines far from spill site

- **High**
  - Formulation of oil-particle aggregates that can sink quicker as turbulence decreases

- **Low**
  - Oil sinks slower as turbulence decreases and over larger areas
M/T Athos 1  API = 13.6
T/B Morris J. Berman  API = 9.5
T/B Morris J. Berman  API = 9.5
**Oil-to-Water Density Ratio**

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2012 Spring Submerged Oil Reassessment Poling Results at Morrow Lake Delta and Morrow Lake: Enbridge Pipeline Spill, Kalamazoo River
Recent Sunken Oil Summaries

- **IMO 2012**: Operational Guidelines on Sunken and Submerged Oil Assessment and Removal Techniques
- **BMT 2009**: Sunken and Submerged Oils – Behaviour and Response
- **AMSA 2006**: Analyses of Survey, Modelling and Remote Sensing Techniques for Monitoring and Assessment of Environmental Impacts of Submerged Oil During Oil Spill Accidents
- **Michel 2006**: Assessment And Recovery Of Submerged Oil: Current State Analysis
Recent USCG R&D Studies

• **2009**: Heavy Oil Detection (Prototypes) Final Report
• **2012**: Heavy Oil Recovery OHMSETT Test Report
• **2013**: Detection of Oil in Water Column: Sensor Design
38 Case Studies:

- **19 spills** – oil heavier than water and sank to the bottom or was suspended in the water column by strong currents
- **8 spills** - oil initially floated but a significant amount sank after stranding on sand beaches
- **6 spills** - oil initially floated but a significant amount then sank or submerged without stranding onshore
- **2 spills** - oil initially floated then became submerged and moved on the bottom with the currents, with little to no accumulation on the bottom
- **3 spills** - oil sank after burning or intense heating
Response Needs for Sunken Oil Spills

• Detection on the bottom
• Containment
• Recovery of oil on the bottom
• Detection/tracking of mobile oil moving along the bottom
Detecting Oil on the Bottom

1) Sonar systems
2) Underwater visualization systems
3) Diver observations
4) Sorbents
5) Laser fluorosensors
6) Visual observations by trained observers
7) Bottom sampling
8) Water-column sampling
Detecting Oil on the Bottom: Sonar Systems

• Lots of good capabilities: no water clarity limits, geo-referenced, good areal coverage rates, available technology

• Lots of limitations: detection limits for oil thickness, patch size; substrate effects; shallow water depth; needs validation

• Little experience in response community

• BUT significant improvements in real-time data processing and calibration; post-processing time

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RPI

QualiTech

energy
# Sonar Systems

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td><strong>Side Scan Sonar &gt;350 kHz</strong></td>
<td></td>
</tr>
<tr>
<td>- Rapid area coverage</td>
<td>- Requires ground-truth for absolute validation of sonar data</td>
</tr>
<tr>
<td>- Readily available in offshore industry</td>
<td>- Will not be able to detect buried oil</td>
</tr>
<tr>
<td>- Good bottom oil detection shown in <em>DBL-152</em> spill</td>
<td></td>
</tr>
<tr>
<td>- Able to detect oil patch as small as 1 m²</td>
<td></td>
</tr>
<tr>
<td><strong>Multibeam Echo Sounder &gt;350 kHz</strong></td>
<td></td>
</tr>
<tr>
<td>- Easy to deploy and provides pseudo-imagery of the bottom</td>
<td>- Resolution is lower than side scan sonar making interpretation/detection of oil difficult</td>
</tr>
<tr>
<td>- Provides bathymetry maps showing low spots where sunken oil could collect</td>
<td></td>
</tr>
<tr>
<td><strong>Sub Bottom Profiler 4-24 kHz Chirp</strong></td>
<td></td>
</tr>
<tr>
<td>- Provides potential for detection of oil mats in the shallow sub bottom region when used in conjunction with side scan sonar and multibeam echo sounders</td>
<td>- No applicability in detection of sunken oil on the surface</td>
</tr>
<tr>
<td></td>
<td>- Data are difficult to interpret due to limitation in resolution of layering in the sub bottom region</td>
</tr>
<tr>
<td><strong>3D Scanning Sonar</strong></td>
<td></td>
</tr>
<tr>
<td>- 3D mapping and tracking of submerged or subsurface oil</td>
<td>- Limited availability in the commercial offshore market</td>
</tr>
<tr>
<td>- Real-time observation of sunken oil on the bottom for recovery operations</td>
<td></td>
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</tbody>
</table>
# Detecting Oil on the Bottom: Visualization Systems

<table>
<thead>
<tr>
<th>Advantages</th>
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</tr>
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</table>
| **Digital Still Camera** | - Discrete images do not provide continuous images of the sea bottom  
- Water turbidity limits effectiveness |
| - Very high resolution images |  |
| **Video Camera** | - Water turbidity limits effectiveness for imaging |
| - Provides continuous color or b/w images of the sea bottom  
- Low light b/w cameras facilitate imaging in high turbidity conditions by eliminating requirement for light sources |  |
| **Sediment Profile Imaging Camera** | - Fouling of SPI window due to oil in water column or sunken oil on sea bottom  
- Samples only a very small area on the bottom |
| - Provides digital images of near sub bottom for identification of sunken or buried oil mats |  |
| **Acoustic Camera** | - Acoustic images have limited resolution when compared to optical images |
| - Provides acoustic imaging in very high turbidity water conditions  
- Could be deployed at a site to monitor sunken oil behavior over time or during events such as storms |  |
Detection of Oil on the Bottom: Towed and Stationary Sorbents

- Embarrassingly crude but simple
- Sorbent material attached to weights, dropped/dragged a short distance, then inspected for oil
- First use in 1984 at *Mobil* spill in Columbia River; latest in 2015 during a spill of clarified slurry oil in the Mississippi River
2008 Ohio River Spill
## Detection of Oil on the Bottom: Towed Sorbents

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Towed Sorbents (Heavy): Sorbents Attached To Multiple Chains Attached To a Header Bar</strong></td>
<td></td>
</tr>
<tr>
<td>— Can be towed at up to 5 knots, though usually 3 to 4 knots, thus able to cover a large distance.</td>
<td>— Requires larger vessel with crane or A-frame and pulley to deploy/retrieve.</td>
</tr>
<tr>
<td>— Area swept is about 8 ft.</td>
<td>— Lots of concern about pipeline and debris snagging.</td>
</tr>
<tr>
<td>— Higher confidence that it maintains bottom contact.</td>
<td>— Cannot determine where along the trawl the oil occurred; no calibration with actual amount of oil on bottom.</td>
</tr>
<tr>
<td>— Can vary the length of the trawl to refine spatial extent, to some degree.</td>
<td>— Longer transects because of handling difficulty.</td>
</tr>
<tr>
<td>— Good positioning capability with onboard GPS; can load assigned tracks into the vessel navigation system.</td>
<td>— Highly dependent on wave conditions.</td>
</tr>
<tr>
<td>— Can be used in vessel traffic lanes.</td>
<td></td>
</tr>
</tbody>
</table>

| **Towed Sorbents (Light): Sorbents Attached To a Single Chain** | |
| — Manually deployed so can be used on smaller boats. | — Narrow swath (~1 ft) so less information on patchy oil. |
| — Can have very short trawls, if needed. | — Highly dependent on wave conditions. |
| — Can conduct continuous surveys without stopping, towed at 2 to 3 knots. | — Concerns about it losing contact with the bottom with wave action. |
| | — Cannot determine where along the trawl the oil occurred. |
| | — No calibration with actual amount of oil on bottom. |
Snare sampler locations
Interpolated Snare Sampler Data

8-10 Dec 2004

- **Reds** = >10%
- **Yellows** = 1-10%
- **Light Green** = <1%
Interpolated Snare Sampler Data

11-14 Dec 2004

- **Reds** = >10%
- **Yellows** = 1-10%
- **Light Green** = <1%
Interpolated Snare Sampler Data

15-18 Dec 2004

Reds = >10%
Yellows = 1-10%
Light Green = <1%
8-10 Dec 2004
Reds = >10%
Yellows = 1-10%
Light Green = <1%

11-14 Dec 2004

15-18 Dec 2004
# Detection of Oil on the Bottom: Stationary Sorbents

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<tr>
<th>Advantages</th>
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</tr>
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<tbody>
<tr>
<td><strong>Stationary Sorbents – Detection of oil in the Water Column or Along the Bottom</strong></td>
<td><strong>Time and labor intensive for deployment, inspection, and replacement.</strong></td>
</tr>
<tr>
<td>— Proven to be effective at detecting oil at various depths in the water column and moving along the bottom.</td>
<td>— Can have high loss rates.</td>
</tr>
<tr>
<td>— Time-series data very useful to track trends, though requires a lot of data points to be meaningful.</td>
<td>— No calibration of the efficacy of oil adsorption and it might change over time.</td>
</tr>
<tr>
<td>— Can be re-deployed as needed as the oil migrates down current.</td>
<td>— Can not be deployed in active vessel traffic lanes.</td>
</tr>
<tr>
<td></td>
<td>— Low temporal data on when the oil was mobilized.</td>
</tr>
</tbody>
</table>
Detection of Oil on the Bottom: Visible Surveys from Surface/Air

- Water surface
- Wading-depth shovel pits (aka Snorkel SCAT)
- Poling
- Sticking
Detection of Oil on the Bottom: Underwater Laser Fluorescence

<table>
<thead>
<tr>
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<th>Disadvantages</th>
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<tbody>
<tr>
<td></td>
<td>Laser Fluorosensors</td>
</tr>
<tr>
<td>— Highly sensitive to oil.</td>
<td>— Cannot detect buried oil.</td>
</tr>
<tr>
<td>— Generates few false positives once calibrated for the sunken oil.</td>
<td>— Detection ability decreases with water turbidity, distance from the target, and wave height.</td>
</tr>
<tr>
<td>— Can be used during day or night.</td>
<td>— Bright, backscattered light (such as from white sand) may saturate the input.</td>
</tr>
<tr>
<td></td>
<td>— Only one prototype system available, and the latest model has not been tested.</td>
</tr>
</tbody>
</table>
Detection of Oil on the Bottom: Water Column Sampling

- Fluorometry – detects dissolved aromatic compounds in the overlying water
- Real-time mass spectrometer + concurrent acoustic navigation

Camilli et al. 2009. MPB.
Detection of Oil on the Bottom: Diver Observations/Video

- Water visibility/depth/wx limits
- Need divers anyway for validation
- Low areal coverage/poor quantification
- Contaminated-water diving expertise limited
Contaminated Water Diving

- Hazard Evaluation
- Medical Monitoring
- Site Safety Plan
- Diving Equipment
- Training
- Back-up Team
- Decontamination
- Record Keeping
<table>
<thead>
<tr>
<th></th>
<th>Wading-Depth Manual Shovel Pits</th>
<th>Laser Fluorosensors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>A narrow blade shovel is used to dig shallow pits underwater, bringing the sediments to the surface for oil description.</td>
<td>Laser is used to excite the aromatic compounds in the oil to emit light with a unique pattern.</td>
</tr>
<tr>
<td><strong>Availability of Equipment</strong></td>
<td>Uses readily available equipment.</td>
<td>Only one prototype tested; latest model has not been tested.</td>
</tr>
<tr>
<td><strong>Logistical Needs</strong></td>
<td>Can require a large team, depending on safety issues and access. Requires safety boat/crew at site, boats for access to sites with no land access.</td>
<td>Unit must be towed close to the bottom; could be deployed on ROV as well.</td>
</tr>
<tr>
<td><strong>Coverage Rate</strong></td>
<td>Low: A team might be able to cover several hundred yd$^2$/hour once in the water, depending on access and spacing of pits.</td>
<td>Low; has a very narrow swath width.</td>
</tr>
<tr>
<td><strong>Data Turnaround</strong></td>
<td>Rapid to Moderate: If teams are supporting Operations, they can quickly delineate areas for removal and then re-survey to determine complete removal.</td>
<td>Unknown: Data can be visualized in real time. Uncertain time to process the data to generate geo-referenced maps.</td>
</tr>
<tr>
<td><strong>Probability of False Positives</strong></td>
<td>Low: Teams can be calibrated to consistently identify the oil vs. other materials. High if the oil is buried deeper than a shovel depth.</td>
<td>Low, once calibrated for the oil.</td>
</tr>
<tr>
<td><strong>Operational Limitations</strong></td>
<td>Many safety limits. Requires wading water depth, low waves and currents, light wind, no lightning, and warm water.</td>
<td>Detection decreases with water turbidity, distance from the target, and wave height. Bright light can interfere. Water depths accessible by boat.</td>
</tr>
<tr>
<td><strong>Pros</strong></td>
<td>May be best option to detect buried oil in the surf zone; can work closely with Operations to achieve rapid removal after delineation of treatment area.</td>
<td>Highly sensitive, few false positives; can be used day or night.</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td>Narrow operational limits, slow coverage rate, and limited to depth of digging.</td>
<td>Cannot detect buried oil; not effective in turbid water; not proven operationally.</td>
</tr>
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Table 4-3 Matrix to assist in evaluation of technologies for detection, delineation, and characterization of sunken oil.

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<tr>
<td>10-1000</td>
<td>10-1000</td>
<td>10-1000</td>
<td>5-60</td>
<td>5-100</td>
<td>5-100</td>
<td>0-30</td>
<td>0-1000</td>
<td>0-5</td>
<td>10-100</td>
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Water Visibility
- > 30 ft  
  - 5-30 ft
  - < 5 ft

Availability

Substrate Type
- Sand
- Silty sand
- Mud

Bottom Obstruction

Oil Patch Size
- < 0.1 ft²
- 0.1-1 ft²
- > 1-10 ft²
- > 10 ft²

Oil Thickness

Buried Oil

Sensitive Habitat

False Positives

Coverage Rate

Data Turnaround
Detection of Oil on the Bottom

- Use multiple methods – Refugio Incident Example
  - MBES for bathymetry
  - ROV video of potential targets
  - Diver observations of potential targets
T/B Apex 3508

- 2 September 2015
- 2,870 bbl clarified slurry oil
T/B Apex 3508

- 2,870 bbl clarified slurry oil
- API = -7.4
- Viscosity = 160,000 cSt
Detection: Side scan sonar and multibeam echo sounder
Confirmation by:

• V-SORs
• Coring
• Diver obs
Recovery of Oil on Bottom:

- Suction Dredge
- Diver-Directed Pumping and Vacuuming
- Mechanical Removal
- Sorbent/V-SORs
- Trawls and Nets
- Manual Removal
- Agitation/Refloat
Solids Removed: 2,260 yd³
# Recovery of Oil on Bottom

<table>
<thead>
<tr>
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</tr>
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<tr>
<td><strong>Diver-directed Vacuuming</strong></td>
<td></td>
</tr>
<tr>
<td>— Vacuum trucks readily available.</td>
<td>— Rapid loss of effectiveness due to hose distance.</td>
</tr>
<tr>
<td>— Portable Vacuum Transfer Units (VTUs), while not as prolific as vacuum trucks, are available.</td>
<td>— Large, heavy units.</td>
</tr>
<tr>
<td>— Ability to regulate flow.</td>
<td>— Requires larger vessel or barge if unprotected water.</td>
</tr>
<tr>
<td>— Minimal mixing of recovered fluids and solids.</td>
<td>— Small coverage area.</td>
</tr>
<tr>
<td>— Ability to pass some solids (i.e. rocks and debris).</td>
<td></td>
</tr>
<tr>
<td>— Can handle high viscosity.</td>
<td></td>
</tr>
<tr>
<td>— Selective recovery provided diver has visibility.</td>
<td></td>
</tr>
<tr>
<td><strong>Diver-directed Pumping with Centrifugal Pump</strong></td>
<td></td>
</tr>
<tr>
<td>— Lightweight and portable.</td>
<td>— Not readily available; must locate from dive or dredge contractor, some oil spill response organizations.</td>
</tr>
<tr>
<td>— Can pump long distances.</td>
<td>— Generates large amounts of water and sediment requiring dewatering, handling of solids, and water treatment.</td>
</tr>
<tr>
<td>— High head pressure, can pump several hundred feet up.</td>
<td>— High rpm pump has the potential to create issues with turbulence, emulsification, and shearing.</td>
</tr>
<tr>
<td>— Easily modified to protect from rocks with a “rock box”.</td>
<td>— Cannot handle viscous oil other than small amounts moved in large amounts of water.</td>
</tr>
<tr>
<td>— Ability to regulate flow.</td>
<td>— Small coverage area.</td>
</tr>
<tr>
<td>— Selective recovery provided diver has visibility.</td>
<td></td>
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<tr>
<td>— Can introduce steam or hot water to reduce viscosity.</td>
<td></td>
</tr>
<tr>
<td>— Ability to pass some solids (i.e. rocks and debris).</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>— Off the shelf items such as pumps and rakes can be used.</td>
<td>— Slow and labor intensive.</td>
</tr>
<tr>
<td>— Aerators designed for waste water treatment or fish ponds can be modified for sunken oil recovery.</td>
<td>— Small coverage area.</td>
</tr>
<tr>
<td>— Selective recovery limiting associated recovered water and sediment.</td>
<td>— Restricted to shallow water &lt;8 feet and relatively low water velocity.</td>
</tr>
<tr>
<td></td>
<td>— Suspended oil can remain mixed with the sediments and resettle to the bottom after agitation.</td>
</tr>
<tr>
<td></td>
<td>— Mixes remaining oil deeper into the sediments.</td>
</tr>
<tr>
<td></td>
<td>— Only effective with liquid oils that are loosely adhered to the sediment and will re-float when separated from the sediment, and where complete containment of the resuspended oil is possible.</td>
</tr>
<tr>
<td></td>
<td>— Generates high turbidity that can spread downstream.</td>
</tr>
</tbody>
</table>
Recovery of Oil on Bottom:
Decanting Systems

• Always *ad hoc*, under designed, lots of trial and error
Recovery of Oil on Bottom: Decanting Systems

• Need guidelines and calculation tools
• Consider droplet size, flow rates, and oil behavior
• Advances in off-the-shelf systems
• Problems when used offshore—unstable platforms