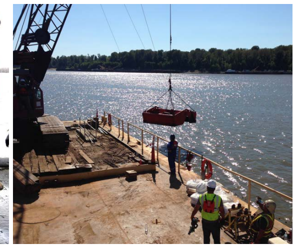

API Study on Detection and Recovery of Sunken Oil

Jacqueline Michel, Research Planning, Inc.
Mark Ploen, QualiTech
Jim Elliott, T&T Marine Salvage, Inc.
William Key

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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

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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

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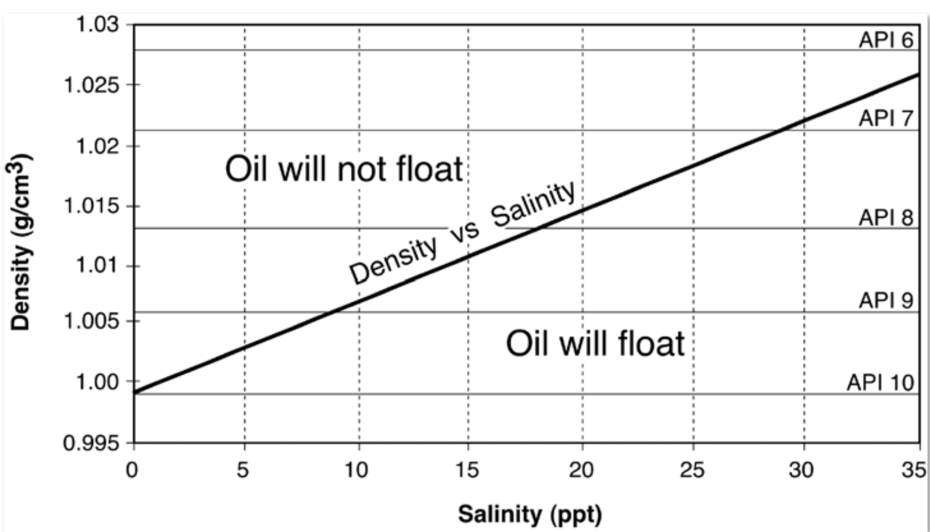

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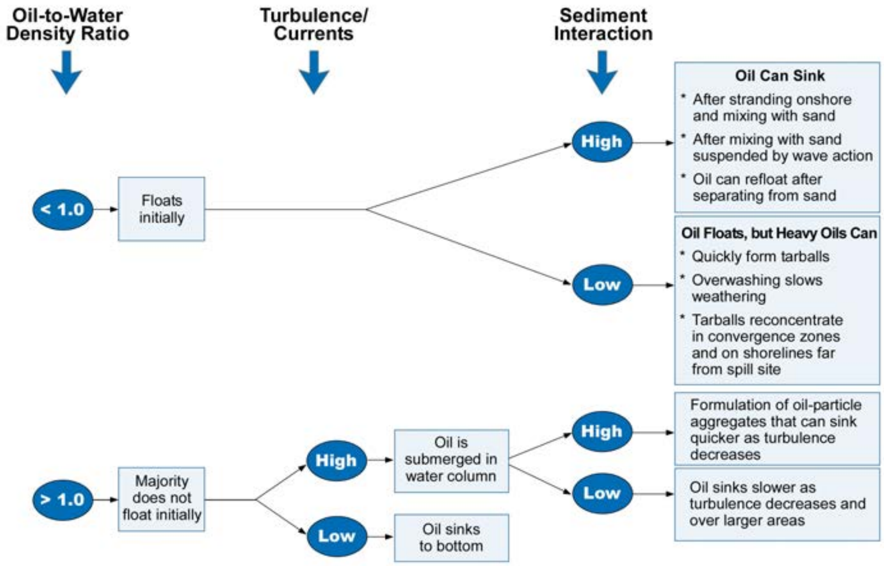
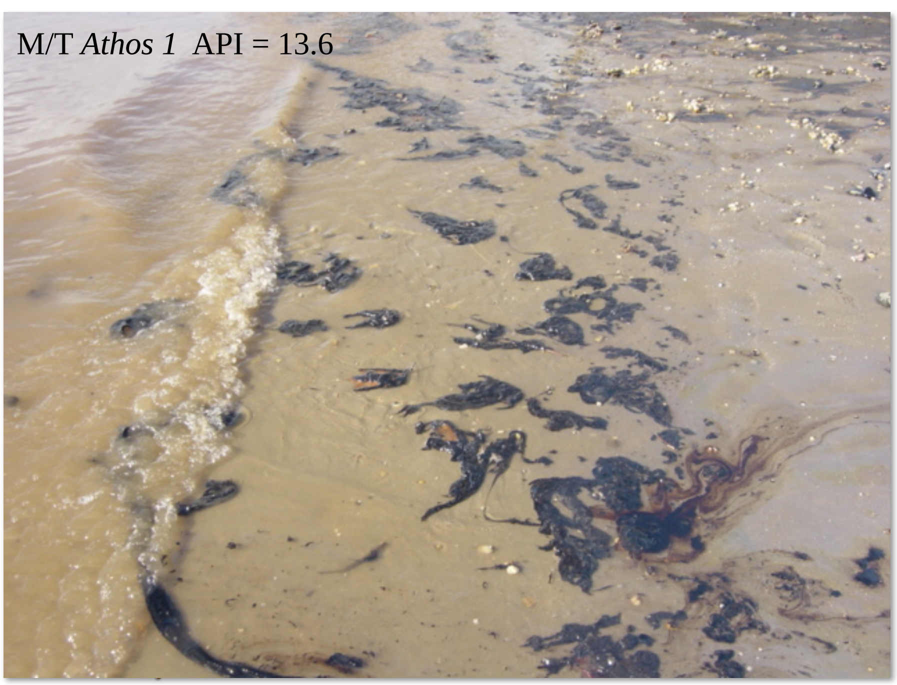

Oil-to-Water Density Ratio
Turbulence/ Currents
Sediment Interaction
< 1.0
Floats initially
High
Oil Can Sink
* After stranding onshore and mixing with sand
* After mixing with sand suspended by wave action
* Oil can refloat after separating from sand
Low
Oil Floats, but Heavy Oils Can
* Quickly form tarballs
* Overwashing slows weathering
* Tarballs reconcentrate in convergence zones and on shorelines far from spill site
> 1.0
Majority does not float initially
High
Oil is submerged in water column
High
Formulation of oil-particle aggregates that can sink quicker as turbulence decreases
Low
Oil sinks slower as turbulence decreases and over larger areas
Low
Oil sinks to bottom


M/T *Athos 1* API = 13.6

T/B *Morris J. Berman* API = 9.5

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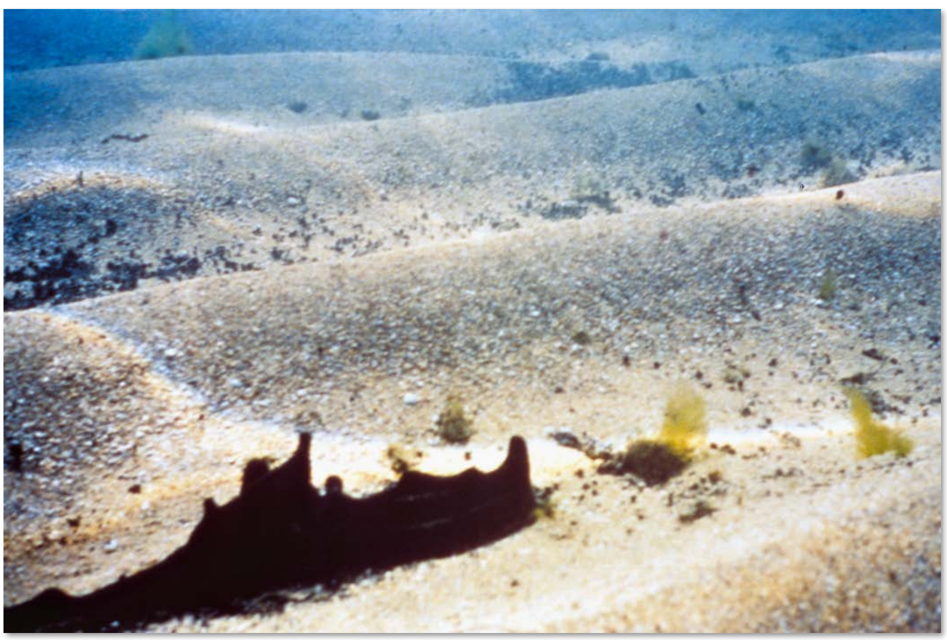
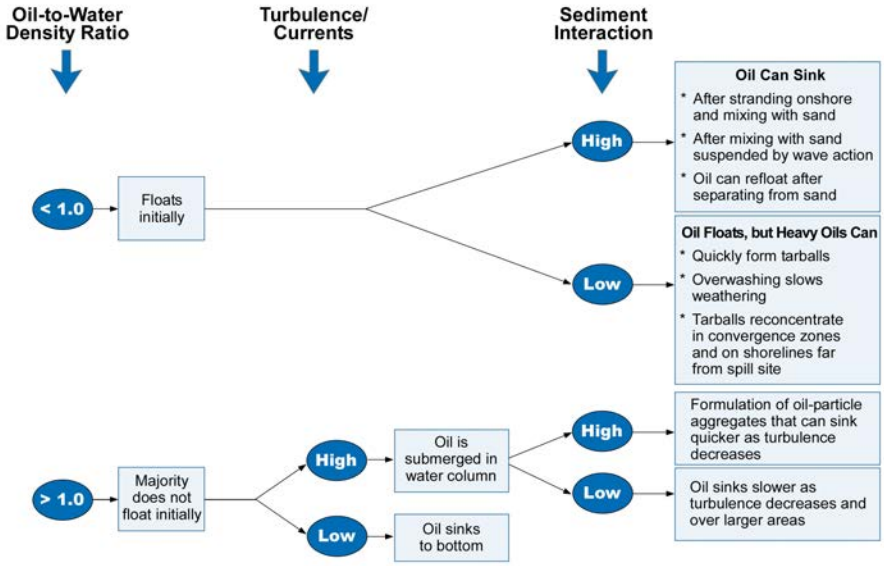
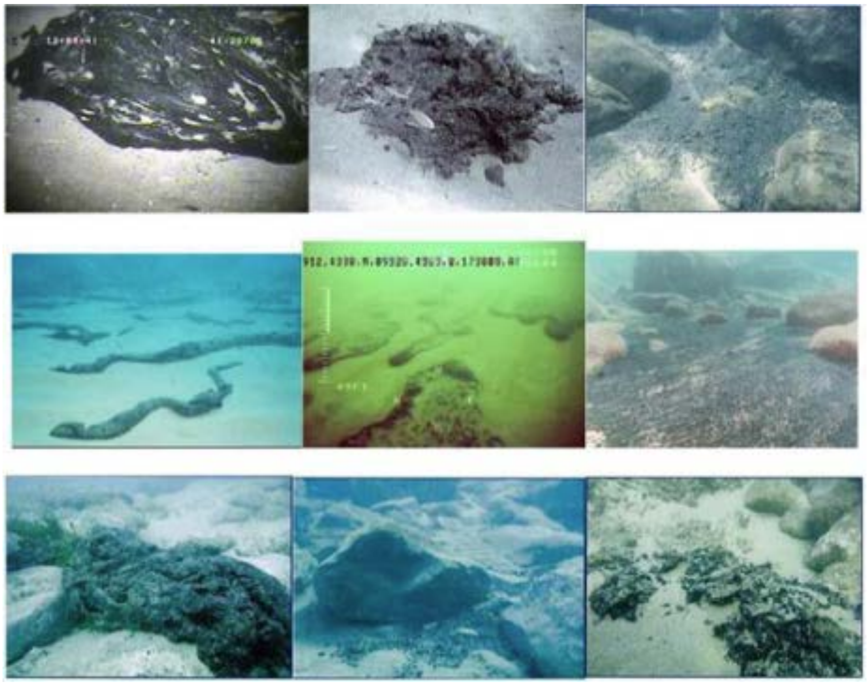
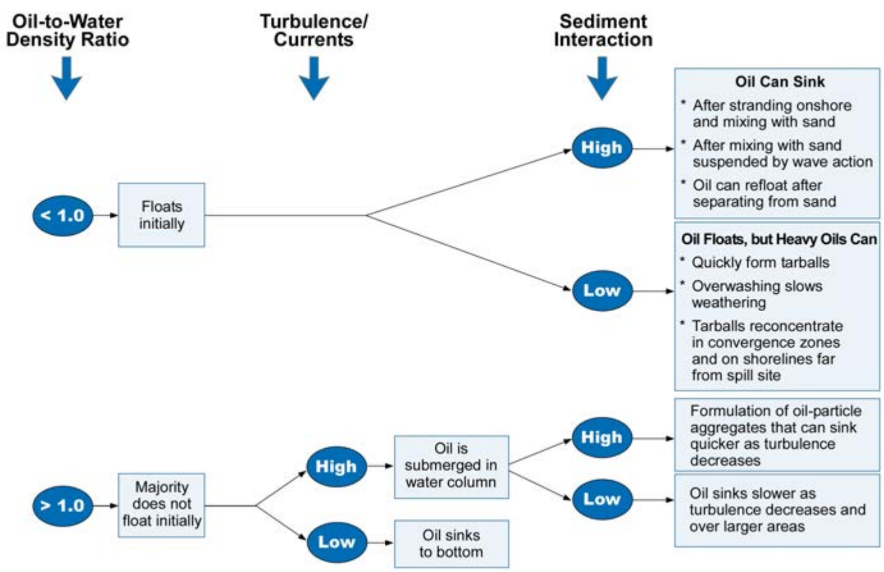


T/B *Morris J. Berman* API = 9.5







Oil-to-Water Density Ratio
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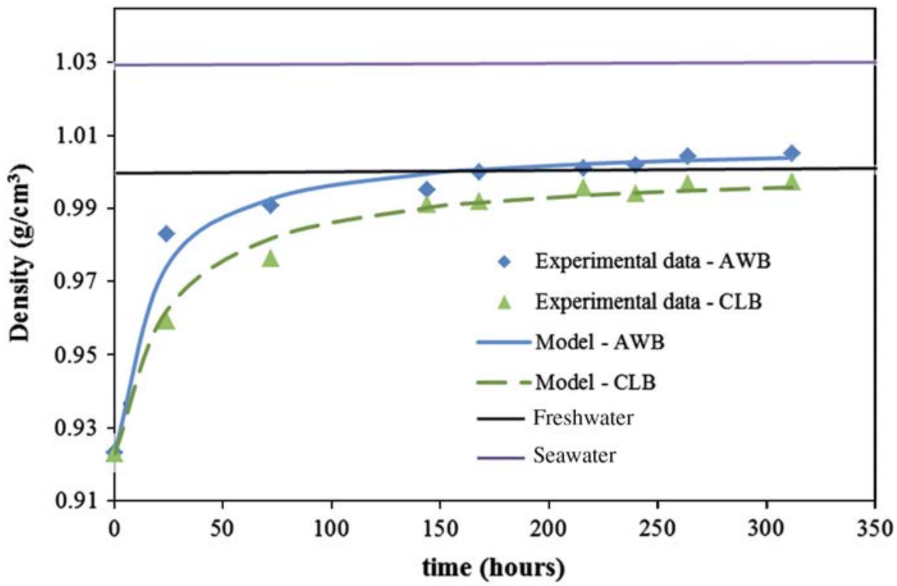
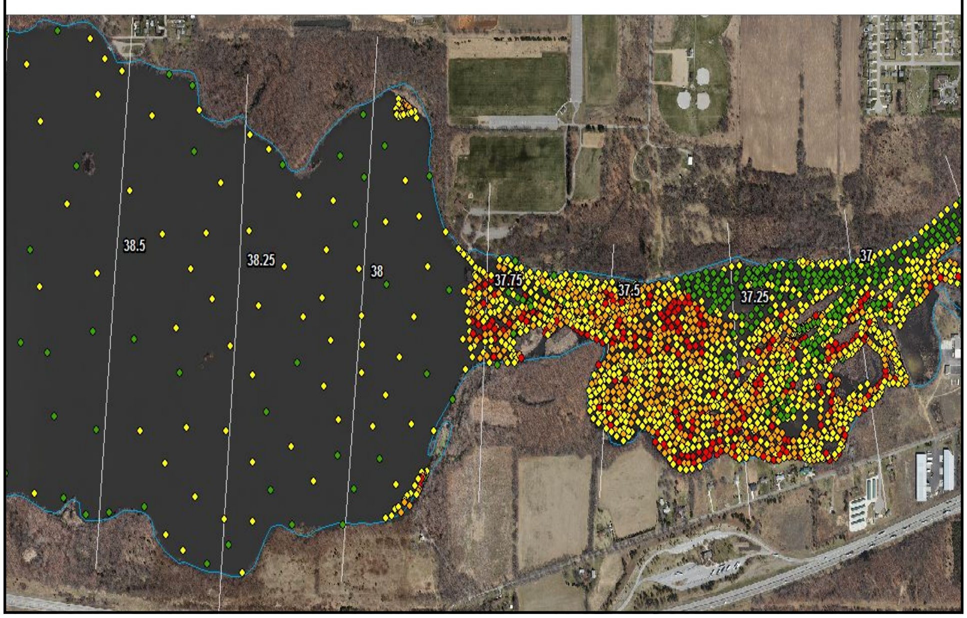
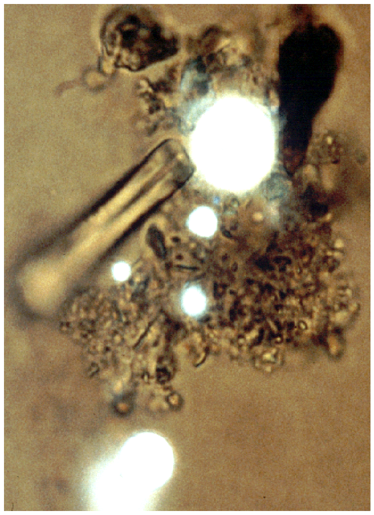
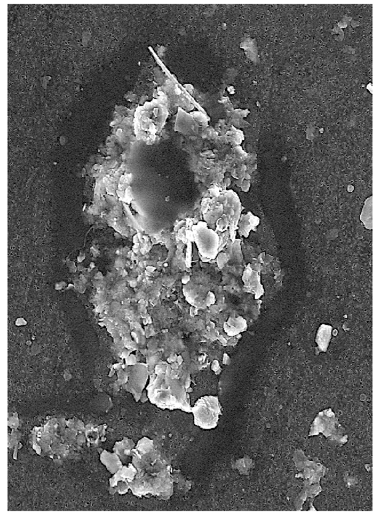


2012 Spring Submerged Oil Reassessment Poling Results at Morrow Lake Delta and Morrow Lake: Enbridge Pipeline Spill, Kalamazoo River







(Ken Lee, Canada Department of Fisheries and Oceans)

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

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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
- **2014**: Detection of Oil in Water Column: Prototype Tests
- **2016:** Mitigation of Oil in the Water Column: Concept Designs for:
  - Microbubbles to push submerged oil to the water surface for traditional oil recovery methods
  - Absorbent foam in nets
- **2016-2018**: Containment of Oil Moving Along the Bottom: Prototype Design and Field Tests

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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 (~2% sand = sinking)
- **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

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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; cannot detect buried oil; needs validation
- Growing experience in response community
- AND significant improvements in real-time data processing and calibration; ~~post-processing time~~

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Sonar Systems

Advantages	Disadvantages
Side Scan Sonar >350 kHz	
- Rapid area coverage - Readily available in offshore industry - Good bottom oil detection shown in *DBL-152* spill - Able to detect oil patch as small as 1 m^2	- Requires ground-truth for absolute validation of sonar data - Will not be able to detect buried oil
Multibeam Echo Sounder >350 kHz	
- Easy to deploy and provides pseudo-imagery of the bottom - Provides bathymetry maps showing low spots where sunken oil could collect	- Resolution is lower than side scan sonar making interpretation/detection of oil difficult
Sub Bottom Profiler 4-24 kHz Chirp	
- 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	- No applicability in detection of sunken oil on the surface - Data are difficult to interpret due to limitation in resolution of layering in the sub bottom region
3D Scanning Sonar	
- 3D mapping and tracking of submerged or subsurface oil - Real-time observation of sunken oil on the bottom for recovery operations	- Limited availability in the commercial offshore market

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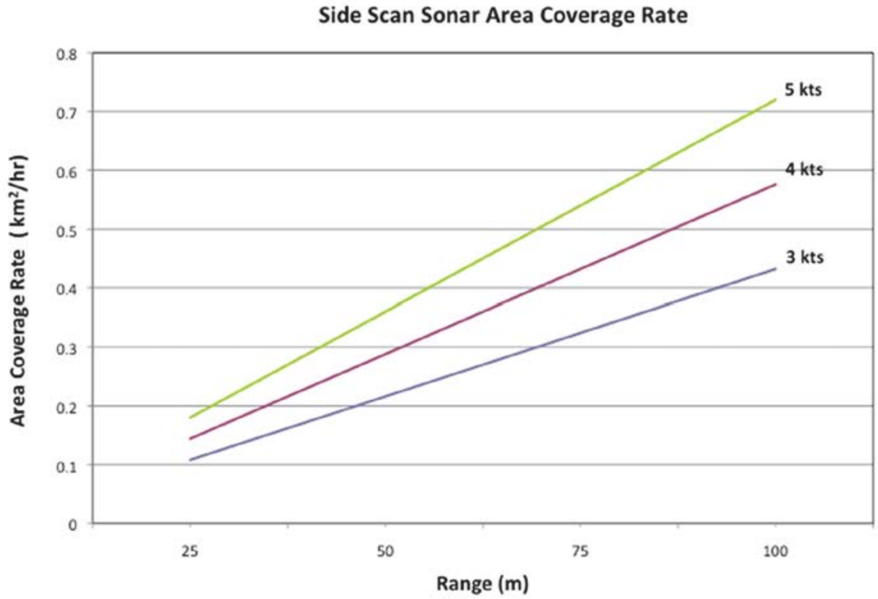

Detecting Oil on the Bottom: Visualization Systems

Advantages	Disadvantages
Digital Still Camera	
- Very high resolution images	- Discrete images do not provide continuous images of the sea bottom - Water turbidity limits effectiveness
Video Camera	
- 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	- Water turbidity limits effectiveness for imaging
Sediment Profile Imaging Camera	
- Provides digital images of near sub bottom for identification of sunken or buried oil mats	- 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
Acoustic Camera	
- 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	- Acoustic images have limited resolution when compared to optical images

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 *Mobiloil* spill in Columbia River; latest in 2015 during a spill of clarified slurry oil in the Mississippi River

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2004 *Athos*
Delaware Rr

Detection of Oil on the Bottom: Towed Sorbents

Advantages	Disadvantages
***Towed Sorbents (Heavy)*: Sorbents Attached To Multiple Chains Attached To a Header Bar**	
— Can be towed at up to 5 knots, though usually 3 to 4 knots, thus able to cover a large distance. — Area swept is about 8 ft. — Higher confidence that it maintains bottom contact. — Can vary the length of the trawl to refine spatial extent, to some degree. — Good positioning capability with onboard GPS; can load assigned tracks into the vessel navigation system. — Can be used in vessel traffic lanes.	— Requires larger vessel with crane or A-frame and pulley to deploy/retrieve. — Lots of concern about pipeline and debris snagging. — Cannot determine where along the trawl the oil occurred; no calibration with actual amount of oil on bottom. — Longer transects because of handling difficulty. — Highly dependent on wave conditions.
***Towed Sorbents (Light)*: Sorbents Attached To a Single Chain**	
— Manually deployed so can be used on smaller boats. — Can have very short trawls, if needed. — Can conduct continuous surveys without stopping, towed at 2 to 3 knots.	— Narrow swath (~1 ft) so less information on patchy oil. — Highly dependent on wave conditions. — 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.

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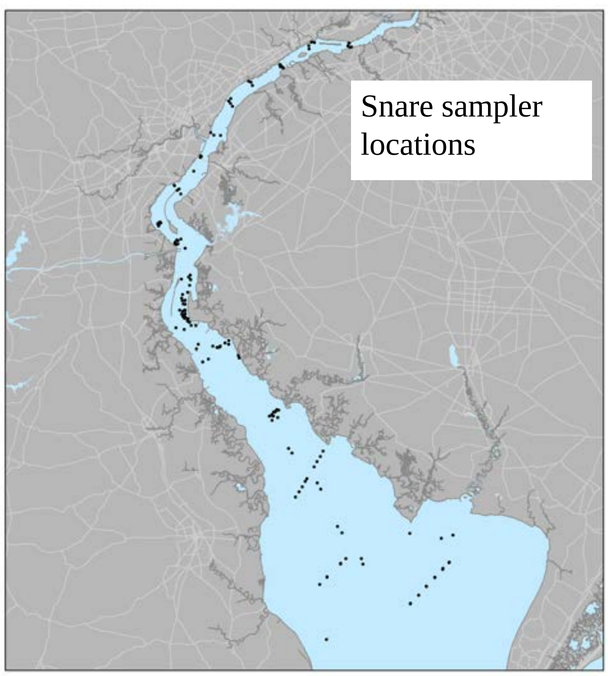
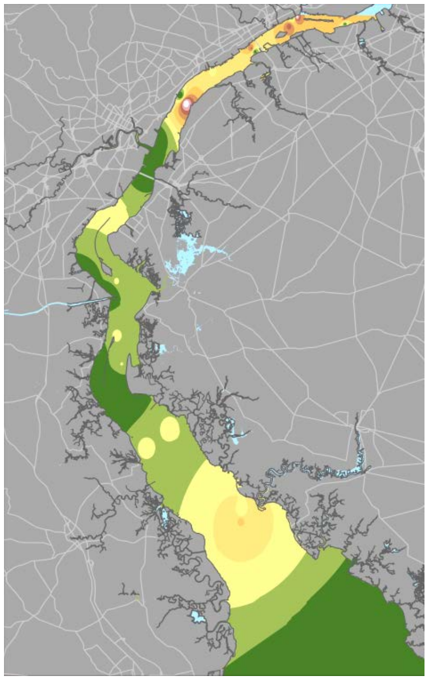
Snare Sentinels

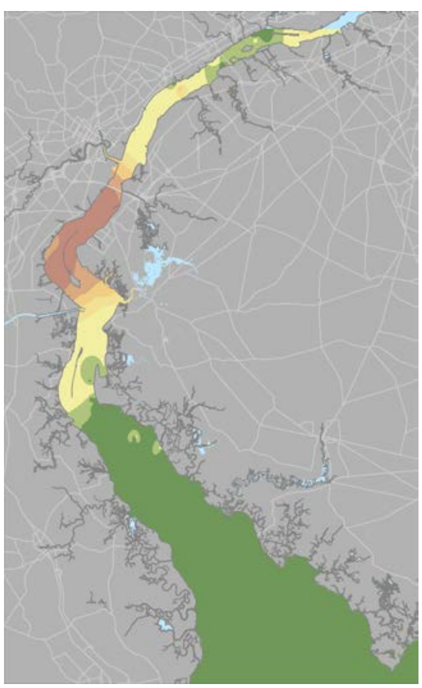

Snare sampler locations



Interpolated Snare Sampler Data

8-10 Dec 2004

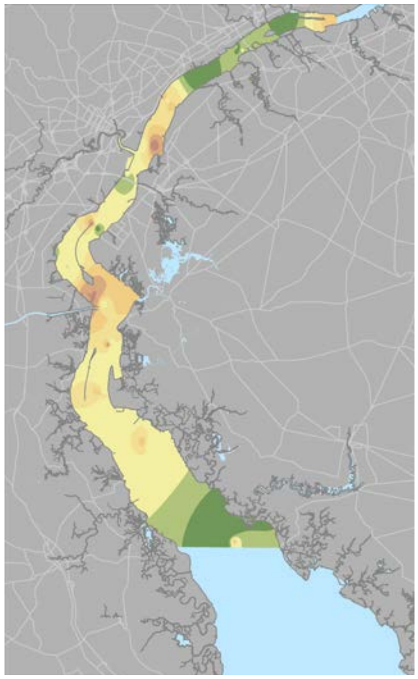
Reds = >10%
Yellows = 1-10%
Light Green = <1%



Interpolated Snare Sampler Data

11-14 Dec 2004

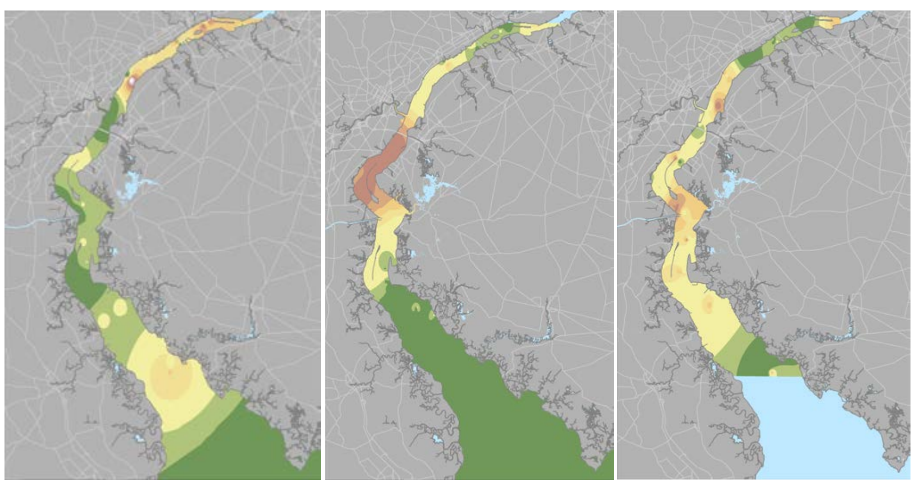
Reds = >10%
Yellows = 1-10%
Light Green = <1%



Interpolated Snare Sampler Data

15-18 Dec 2004

Reds = >10%
Yellows = 1-10%
Light Green = <1%



8-10 Dec 2004 | 11-14 Dec 2004 | 15-18 Dec 2004

Reds = >10% **Yellows** = 1-10% **Light Green** = <1%

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Detection of Oil on the Bottom: Stationary Sorbents

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

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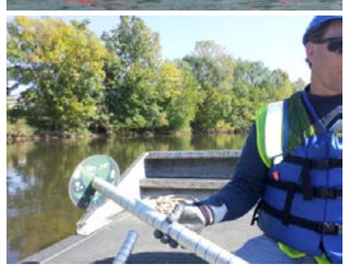
Detection of Oil on the Bottom: Visible Surveys from Surface/Air

- Water surface
- Wading-depth shovel pits (aka Snorkel SCAT)
- Poling
- Sticking



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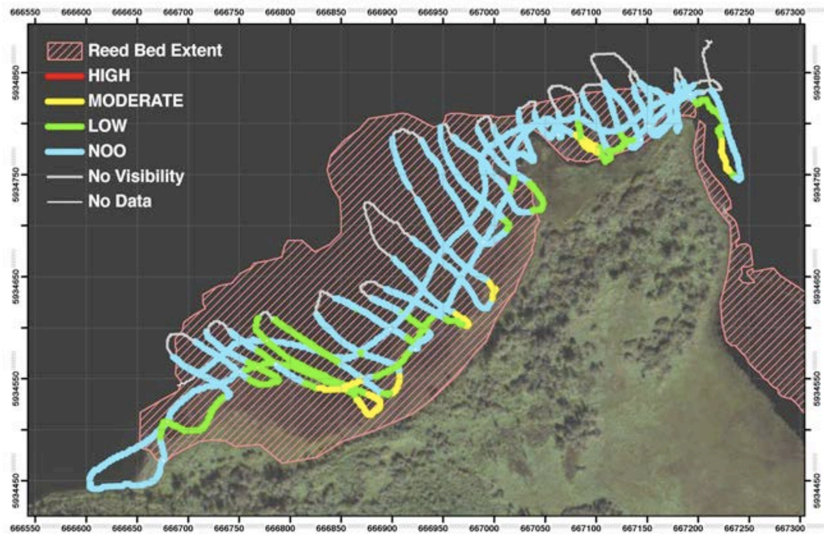
Lake Wabamun, Canada

Wabamun Lake Incident - 2006



NAD83 - UTM Zone 11
50 meter Grid

SE09 (Willow Point)

SCAT Reed Bed Survey
05 May 2006

Detection of Oil on the Bottom: Underwater Laser Fluorescence

Advantages	Disadvantages
Laser Fluorosensors	
— Highly sensitive to oil. — Generates few false positives once calibrated for the sunken oil. — Can be used during day or night.	— Cannot detect buried oil. — Detection ability decreases with water turbidity, distance from the target, and wave height. — Bright, backscattered light (such as from white sand) may saturate the input. — Only one prototype system available, and the latest model has not been tested.

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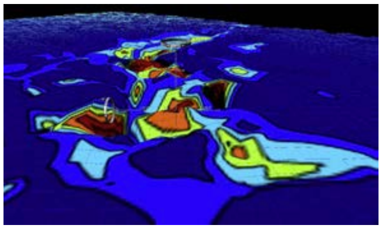
Detection of Oil on the Bottom: Water Column Sampling

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



Camilli et al. 2009. MPB.

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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

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Contaminated Water Diving

- Hazard Evaluation
- Medical Monitoring
- Site Safety Plan
- Diving Equipment
- Training
- Back-up Team
- Decontamination
- Record Keeping

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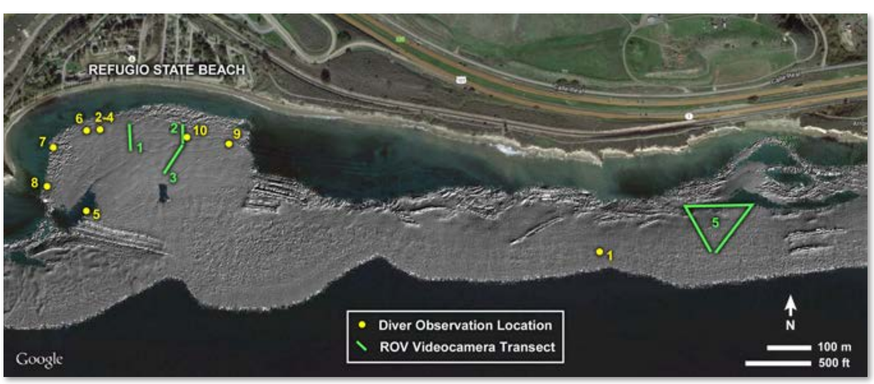
	Wading-Depth Manual Shovel Pits	Laser Fluorosensors
Description	A narrow blade shovel is used to dig shallow pits underwater, bringing the sediments to the surface for oil description.	Laser is used to excite the aromatic compounds in the oil to emit light with a unique pattern.
Availability of Equipment	Uses readily available equipment.	Only one prototype tested; latest model has not been tested.
Logistical Needs	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.	Unit must be towed close to the bottom; could be deployed on ROV as well.
Coverage Rate	Low: A team might be able to cover several hundred yd^2/hour once in the water, depending on access and spacing of pits.	Low; has a very narrow swath width.
Data Turnaround	Rapid to Moderate: If teams are supporting Operations, they can quickly delineate areas for removal and then re-survey to determine complete removal.	Unknown: Data can be visualized in real time. Uncertain time to process the data to generate geo-referenced maps.
Probability of False Positives	Low: Teams can be calibrated to consistently identify the oil vs. other materials. High if the oil is buried deeper than a shovel depth.	Low, once calibrated for the oil.
Operational Limitations	Many safety limits. Requires wading water depth, low waves and currents, light wind, no lightning, and warm water.	Detection decreases with water turbidity, distance from the target, and wave height. Bright light can interfere. Water depths accessible by boat.
Pros	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	Highly sensitive, few false positives; can be used day or night.
Cons	Narrow operational limits, slow coverage rate, and limited to depth of digging.	Cannot detect buried oil; not effective in turbid water; not proven operationally.

	Sonar Systems	Camera/ Video	Acoustic Camera	Diver Observations	Towed Sorbents	Stationary Sorbents	Visual Observations	Bottom Sampling	Manual Shovel Pits	Laser Fluorosensor	Water Column Sampling
Water Depth (ft)	10-1000	10-1000	10-1000	5-60	5-100	5-100	0-30	0-1000	0-5	10-100	5->1000
Water Visibility											
- > 30 ft	Green	Green	Green	Green	Green	Green	Green	Green	Red	Red	Green
- 5-30 ft	Green	Yellow	Green	Green	Green	Yellow	Yellow	Green	Red	Red	Yellow
- < 5 ft	Green	Red	Green	Yellow	Green	Red	Red	Green	Green	Green	Red
Availability	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow
Substrate Type											
- Sand	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
- Silty sand	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
- Mud	Green	Green	Green	Green	Green	Green	Yellow	Green	Yellow	Green	Green
Bottom Obstruction	Green	Green	Green	Yellow	Yellow	Green	Green	Green	Red	Green	Green
Oil Patch Size											
- < 0.1 ft^2	Red	Green	Yellow	Green	Yellow	Yellow	Yellow	Red	Yellow	Green	Yellow
- 0.1- 1 ft^2	Red	Green	Green	Green	Yellow	Yellow	Green	Red	Yellow	Green	Yellow
- > 1-10 ft^2	Yellow	Green	Green	Green	Green	Yellow	Green	Green	Green	Green	Yellow
- > 10 ft^2	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Green	Yellow
Oil Thickness	Yellow	Yellow	Red	Green	Yellow	Red	Yellow	Green	Green	Red	Red
Buried Oil	Yellow	Red	Red	Yellow	Yellow	Red	Red	Green	Green	Red	Yellow
Sensitive Habitat	Green	Green	Green	Green	Red	Green	Green	Yellow	Yellow	Green	Green
False Positives	Yellow	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Green
Coverage Rate	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Data Turnaround	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Green	Yellow	Yellow

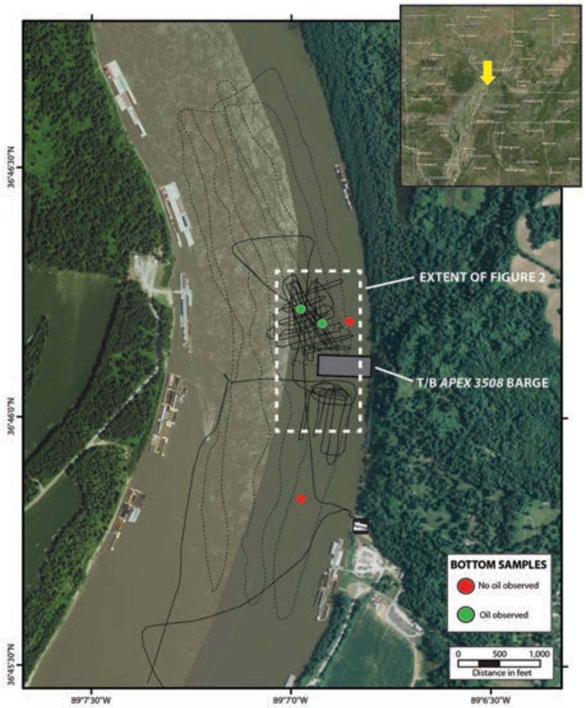
Detection of Oil on the Bottom

- Use multiple methods – Refugio Incident Example
  - MBES for bathymetry
  - ROV video of potential targets
  - Diver observations of potential targets



T/B *Apex 3508*

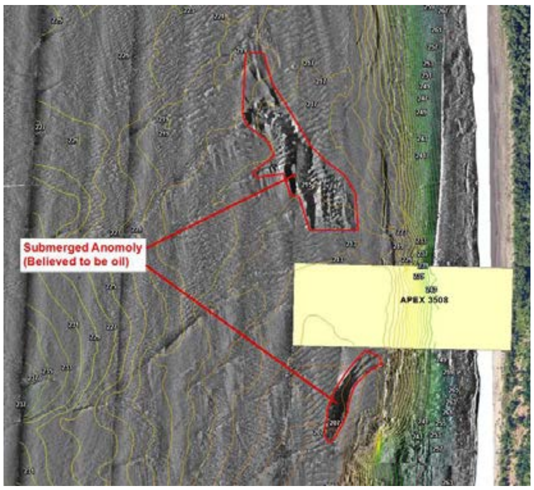
- 2 September 2015
- 2,870 bbl clarified slurry oil

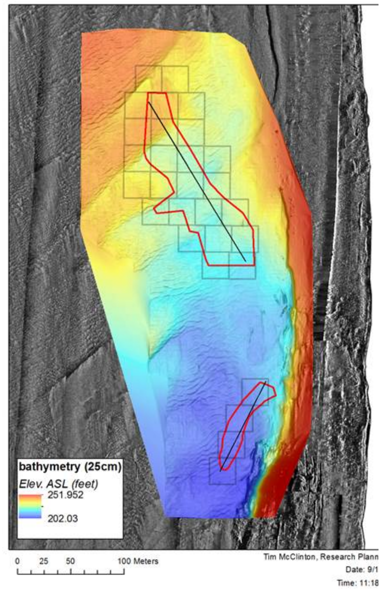


T/B *Apex 3508*

- 2,870 bbl clarified slurry oil
- API = -7.4
- Viscosity = 160,000 cSt

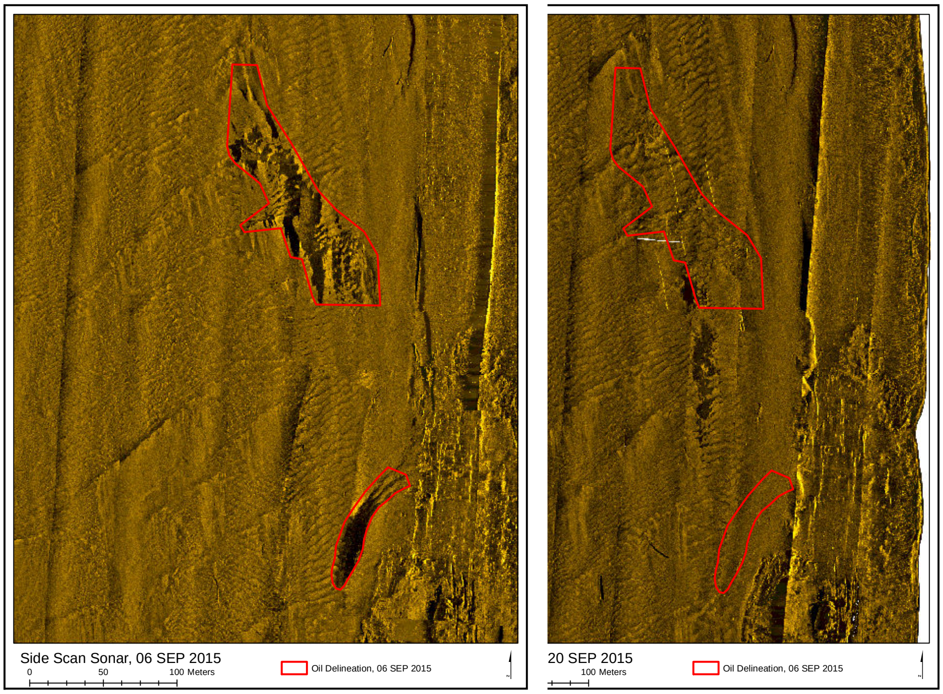
Detection: Side scan sonar and multibeam echo sounder





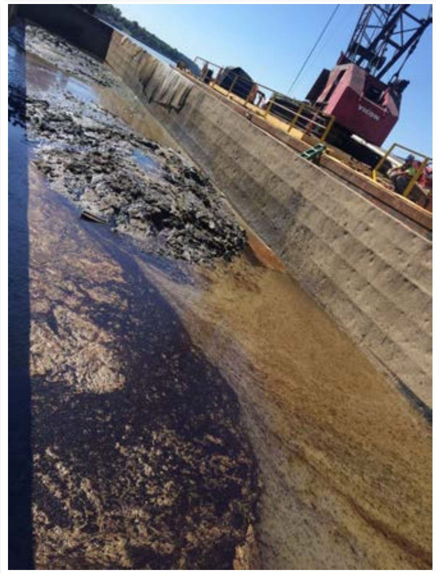
Confirmation by:

- V-SORs
- Coring
- Diver obs

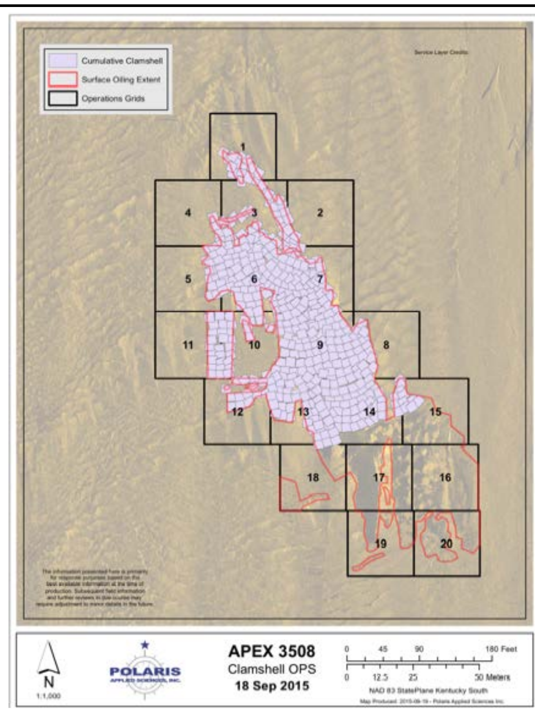


Recovery of Oil on Bottom:

- Suction Dredge
- Diver-Directed Pumping and Vacuuming
- Mechanical Removal
- Sorbent/V-SORs
- Trawls and Nets
- Manual Removal
- Agitation/Refloat



Solids Removed: 2,260 yd^3



Recovery of Oil on Bottom

Advantages	Disadvantages
Diver-directed Vacuuming	
— Vacuum trucks readily available. — Portable Vacuum Transfer Units (VTUs), while not as prolific as vacuum trucks, are available. — Ability to regulate flow. — Minimal mixing of recovered fluids and solids. — Ability to pass some solids (i.e. rocks and debris). — Can handle high viscosity. — Selective recovery provided diver has visibility.	— Rapid loss of effectiveness due to hose distance. — Large, heavy units. — Requires larger vessel or barge if unprotected water. — Small coverage area.
Diver-directed Pumping with Centrifugal Pump	
— Lightweight and portable. — Can pump long distances. — High head pressure, can pump several hundred feet up. — Easily modified to protect from rocks with a "rock box". — Ability to regulate flow. — Selective recovery provided diver has visibility. — Can introduce steam or hot water to reduce viscosity. — Ability to pass some solids (i.e. rocks and debris).	— Not readily available; must locate from dive or dredge contractor, some oil spill response organizations. — Generates large amounts of water and sediment requiring dewatering, handling of solids, and water treatment. — High rpm pump has the potential to create issues with turbulence, emulsification, and shearing. — Cannot handle viscous oil other than small amounts moved in large amounts of water. — Small coverage area.

Advantages	Disadvantages
Agitation/Refloat	
— Off the shelf items such as pumps and rakes can be used. — Aerators designed for waste water treatment or fish ponds can be modified for sunken oil recovery. — Selective recovery limiting associated recovered water and sediment.	— Slow and labor intensive. — Small coverage area. — Restricted to shallow water <8 feet and relatively low water velocity. — Suspended oil can remain mixed with the sediments and resettle to the bottom after agitation. — Mixes remaining oil deeper into the sediments. — 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. — Generates high turbidity that can spread downstream.

Recovery of Oil on Bottom: Decanting Systems

- Always *ad hoc*, under designed, lots of trial and error



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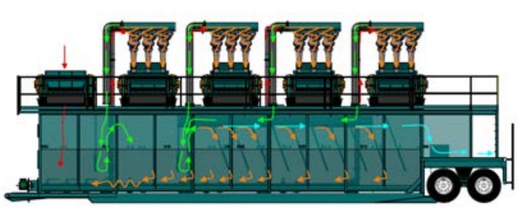
Recovery of Oil on Bottom: Decanting Systems

- 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




RPI QualiTech energy API

Sunken Oil R&D Needs

- Need new technologies for:
  detecting
  tracking
  containment
  modeling
  recovering
  decanting
  assessing
- But, they need to be "emergency" ready

RPI QualiTech energy API