

Detection of NFO Suspended in the Water Column and On the Bottom: Technologies and Data Gaps

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Detecting Oil on the Bottom

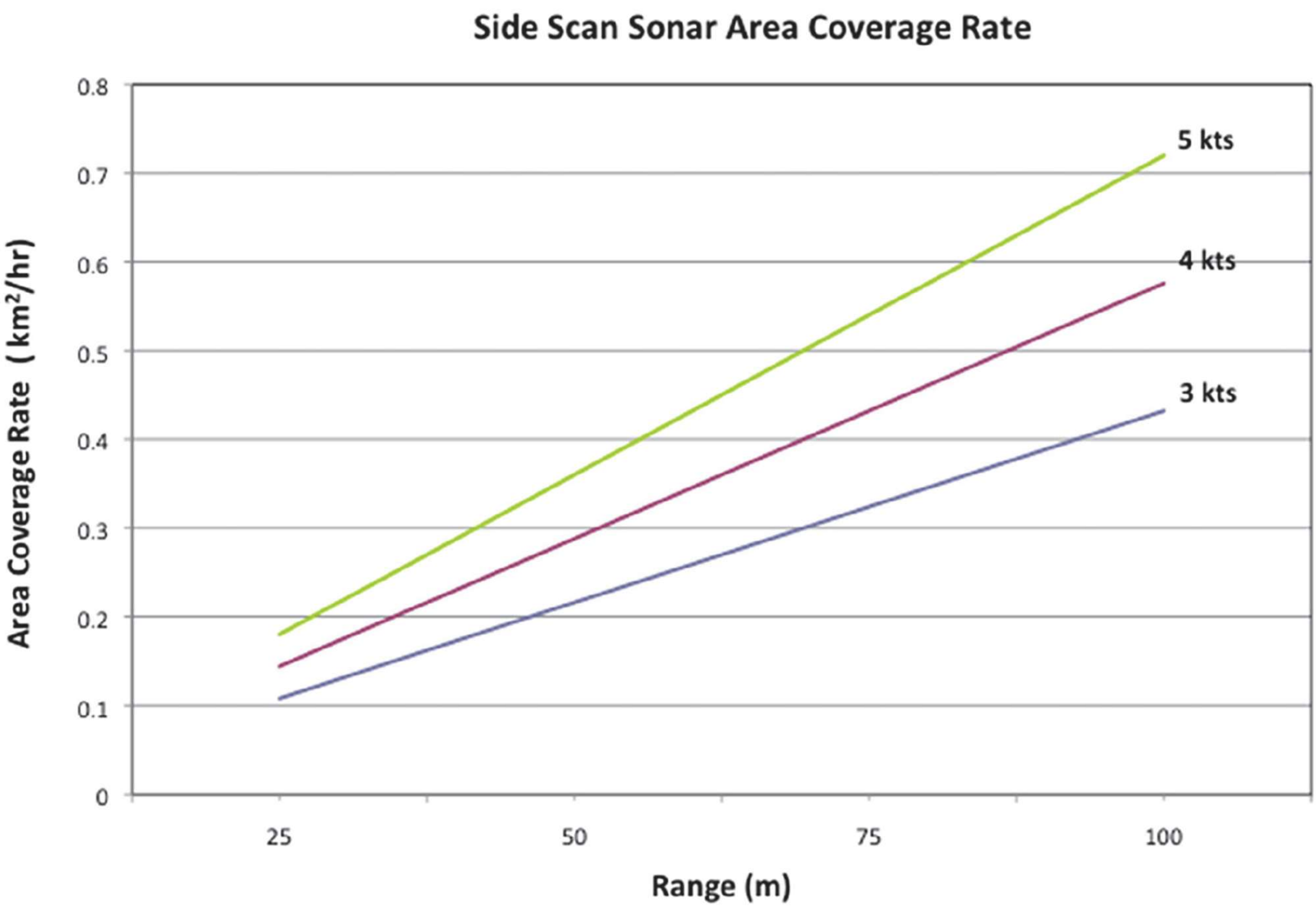
1) Sonar systems
2) Underwater visualization systems
3) Diver observations
4) Sorbents
5) Laser fluorosensors
6) Visual observations by trained observers
7) Bottom sampling
8) Water-column sampling

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~~

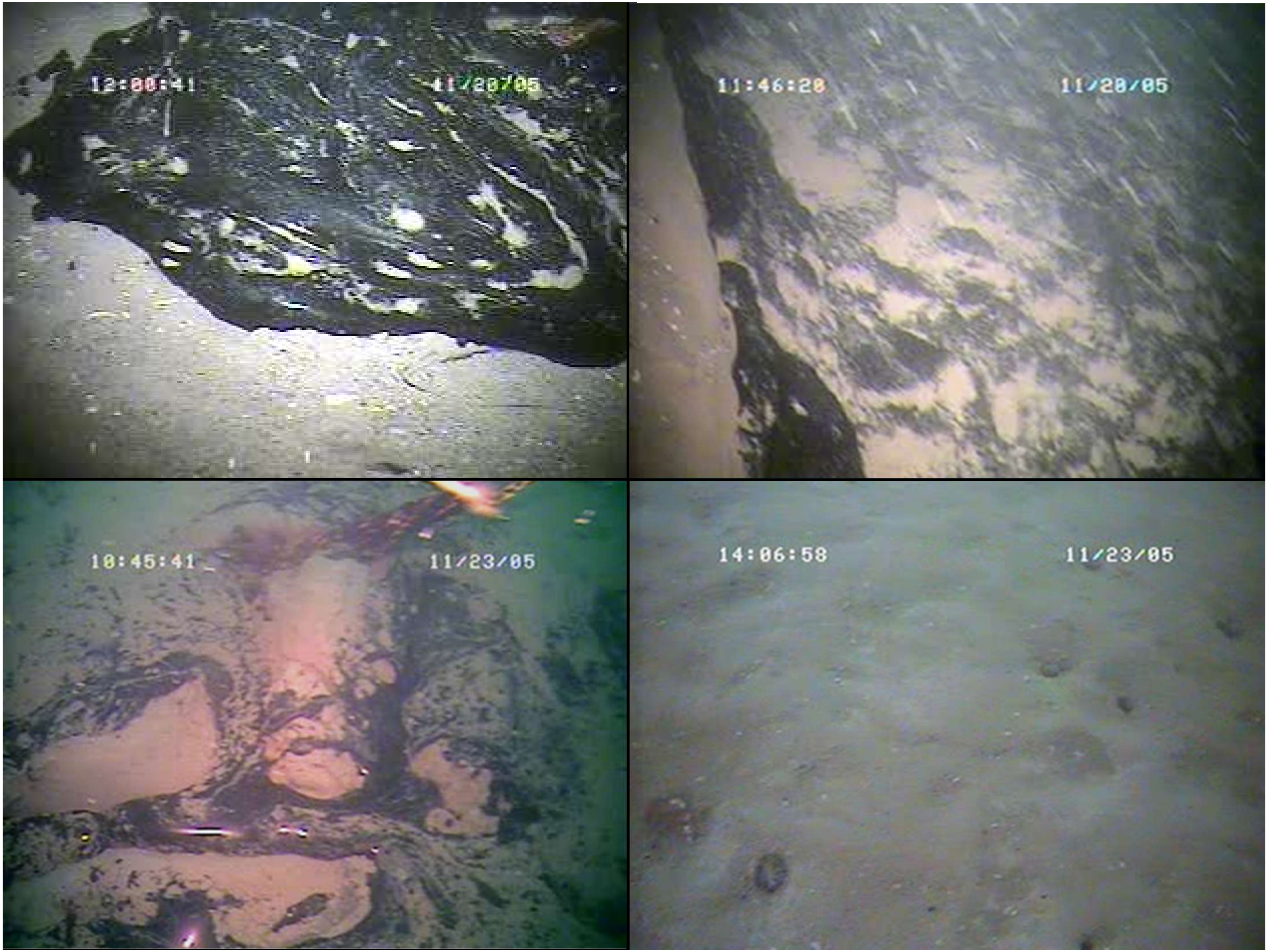
Sonar Systems

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


Side Scan Sonar Area Coverage Rate
5 kts
4 kts
3 kts
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
25
50
75
100
Area Coverage Rate (km²/hr)
Range (m)

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



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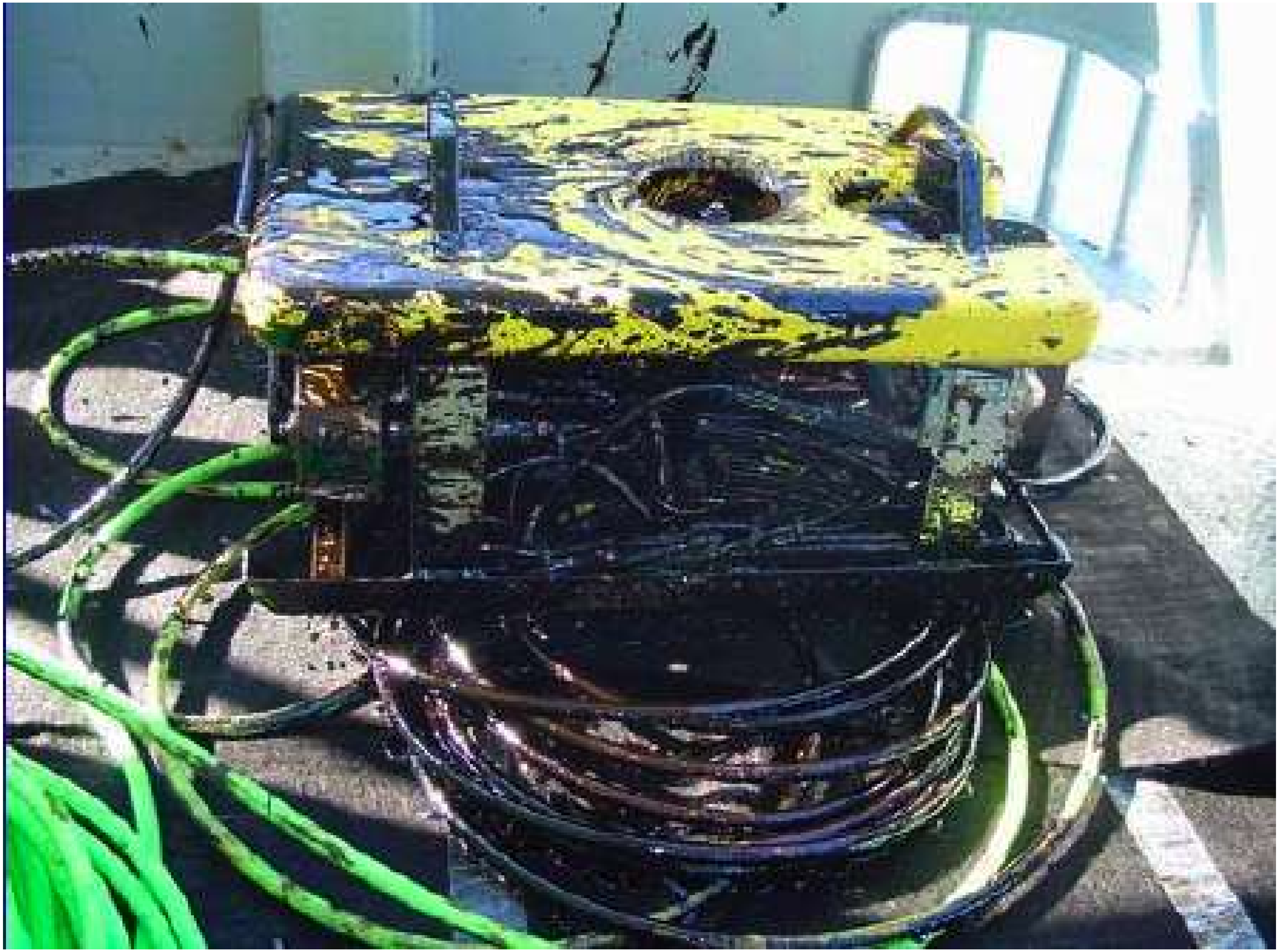


Detection of Oil on the Bottom: Towed and Stationary Sorbents

- 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

2004 *Athos*
Delaware Rr

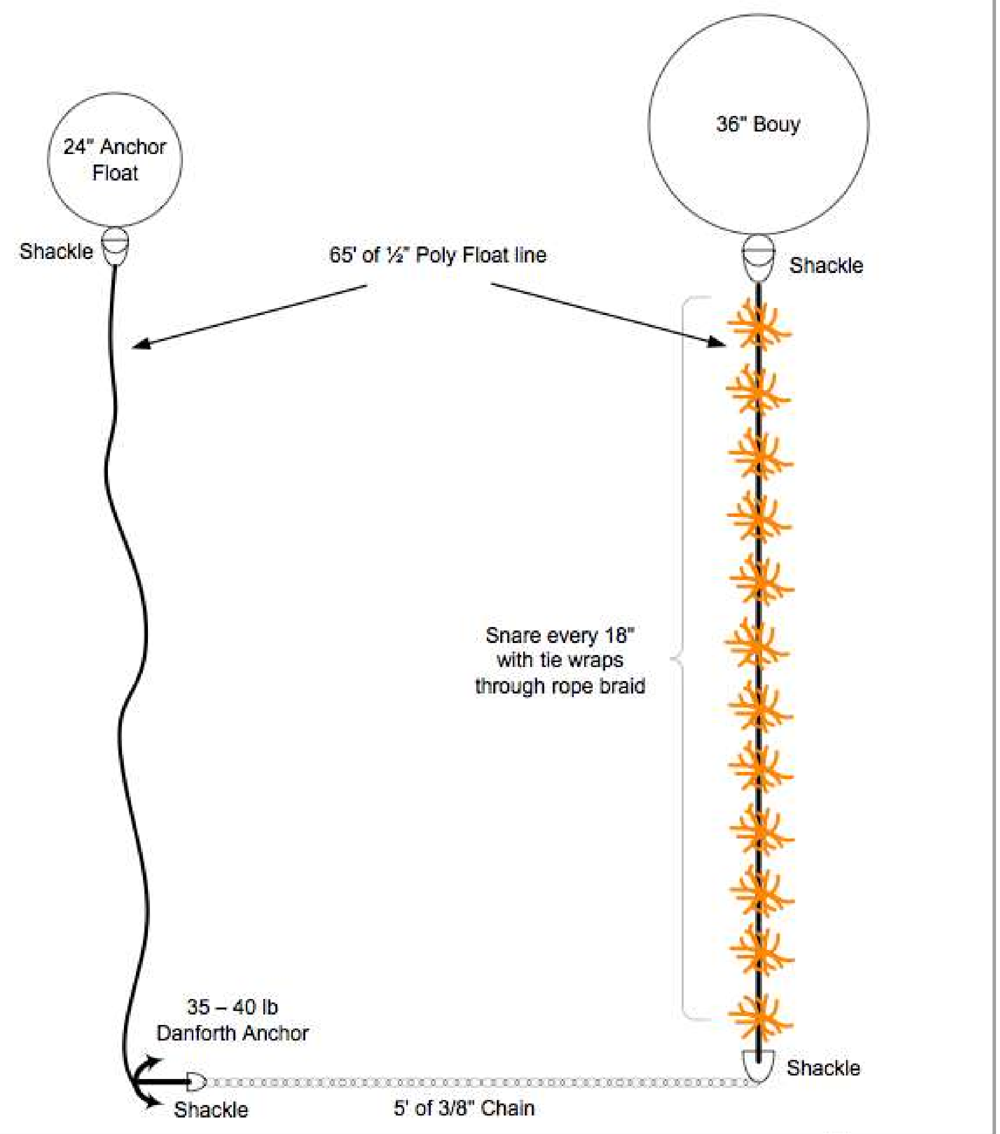
2008 Ohio
River Spill

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.

Oil in the Water Column

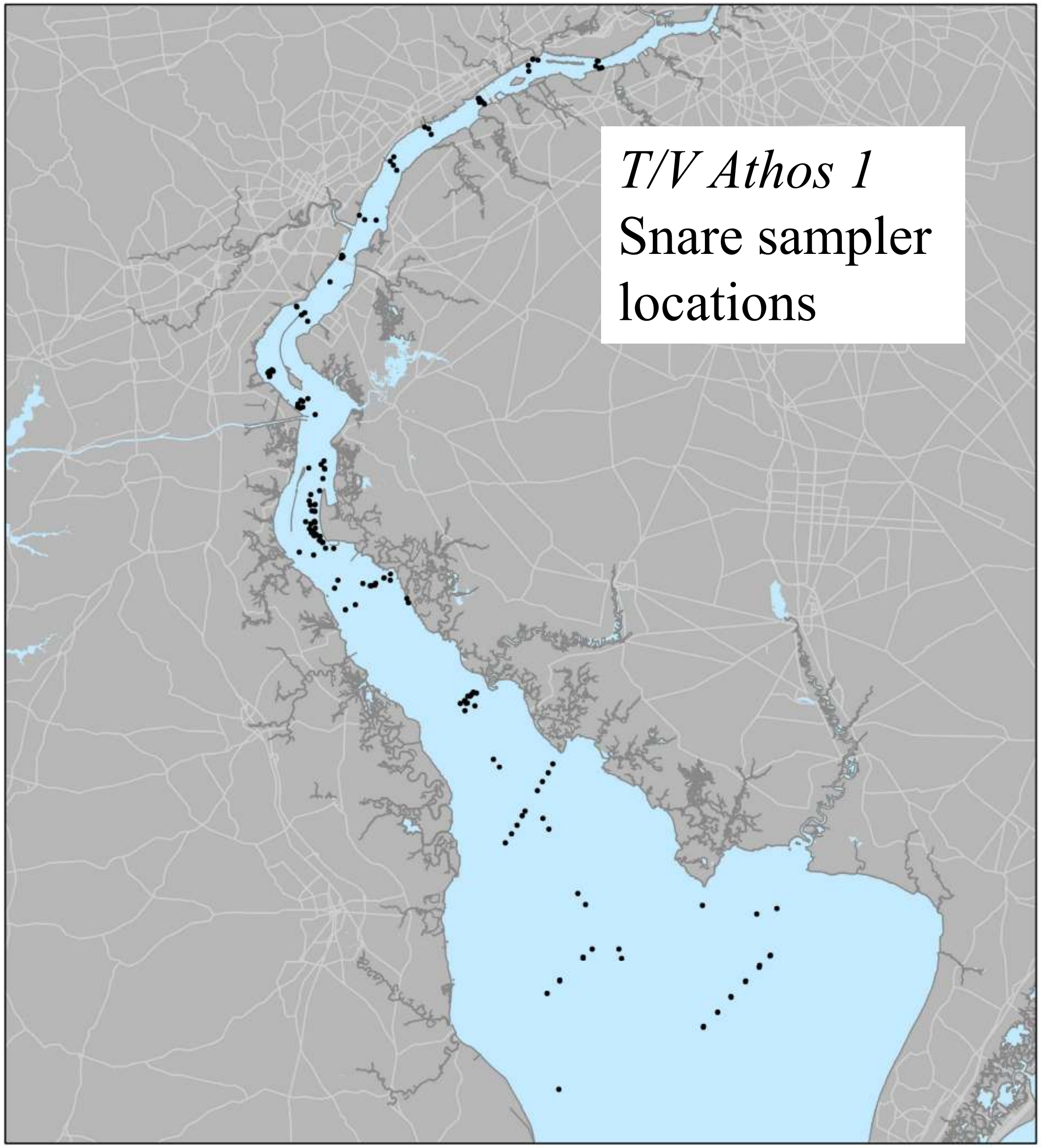
Snare Sentinels

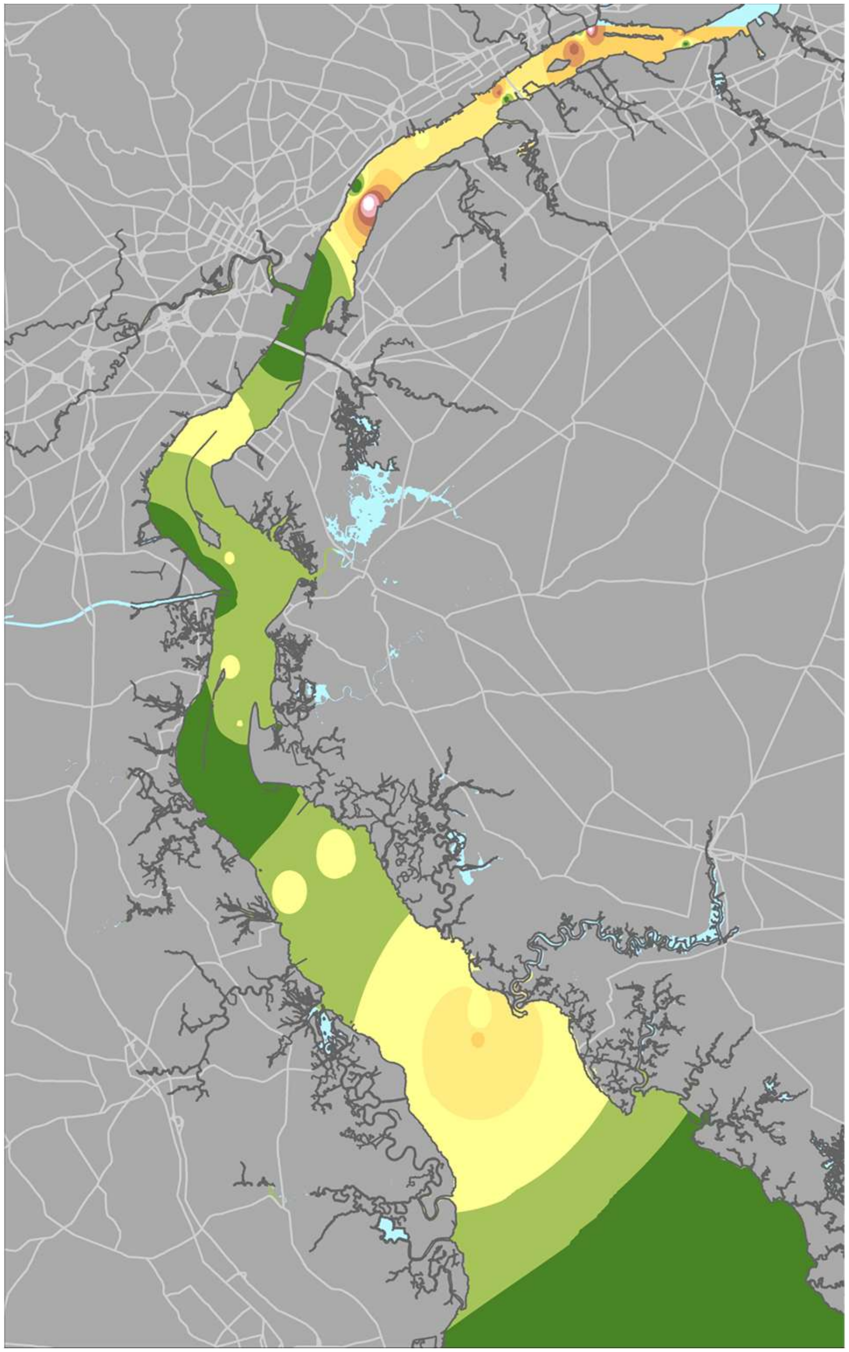


VERTICAL SNARE SAMPLING DETAIL

The O'BRIEN'S Group	Date: 11/22/05	Scale: No Scale	Dwg. By: MP


Snare Sentinels

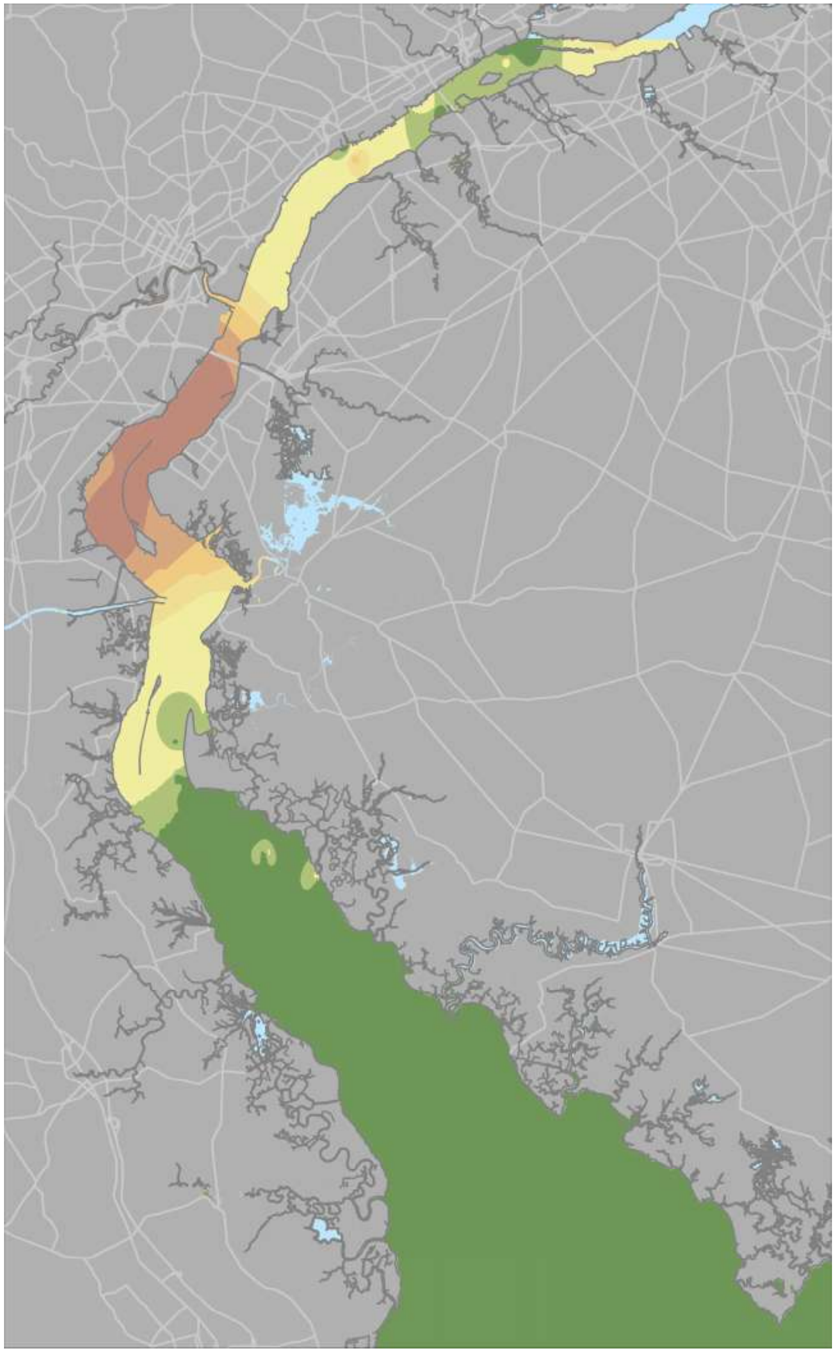

T/V Athos 1
Snare sampler
locations



Interpolated Snare Sampler Data

8-10 Dec 2004

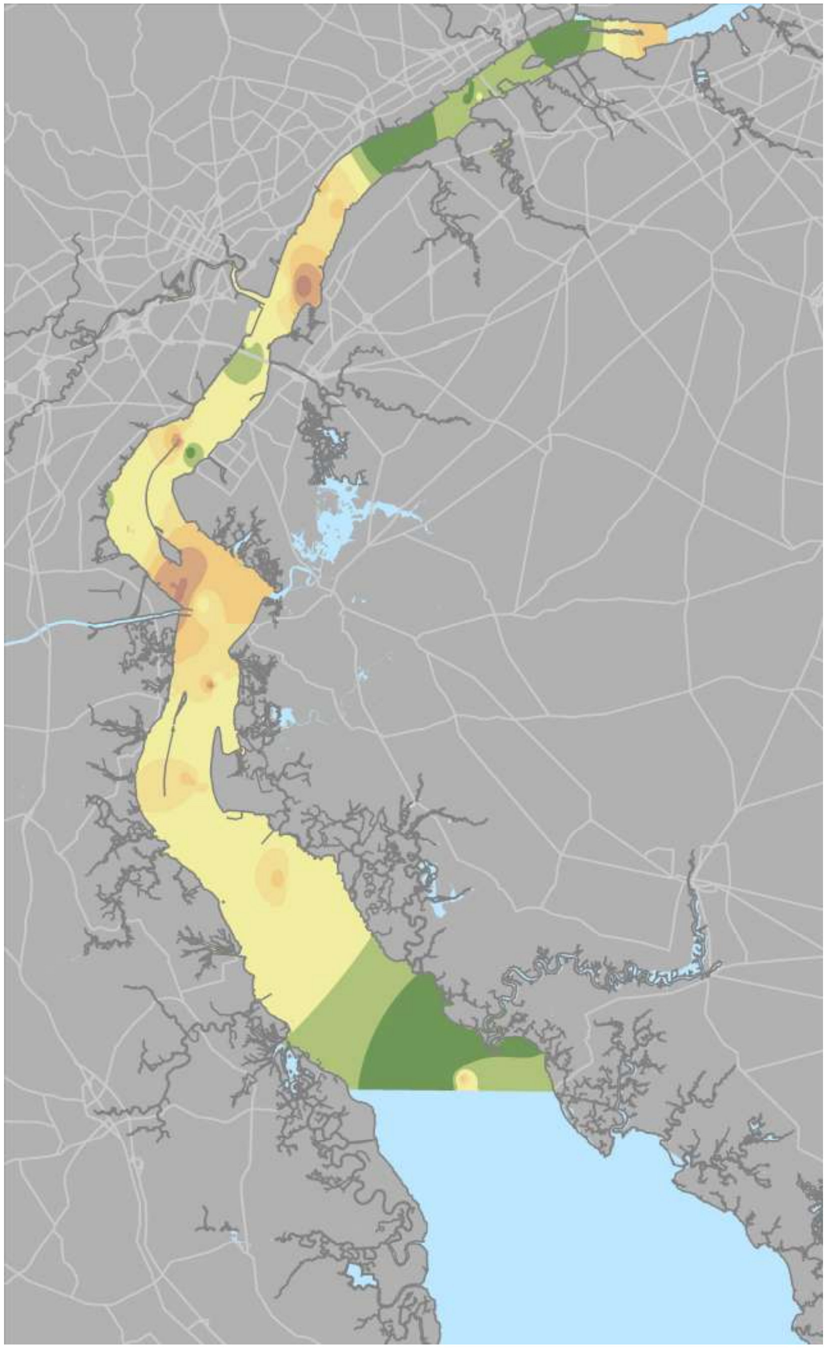
Reds = >10%
Yellows = 1-10%
Light Green = <1%



Interpolated Snare Sampler Data

11-14 Dec 2004

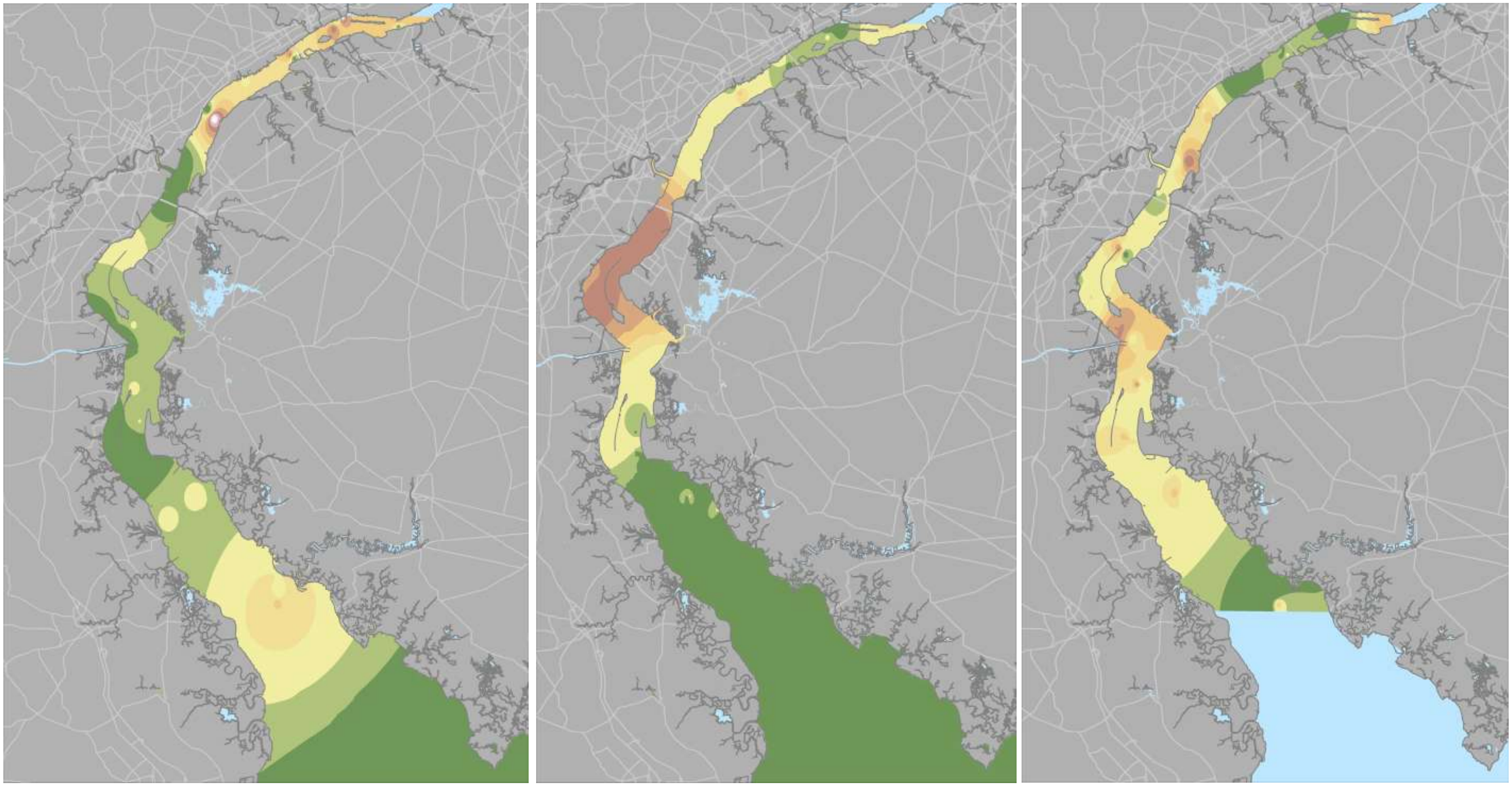
Reds = >10%
Yellows = 1-10%
Light Green = <1%



Interpolated Snare Sampler Data

15-18 Dec 2004

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



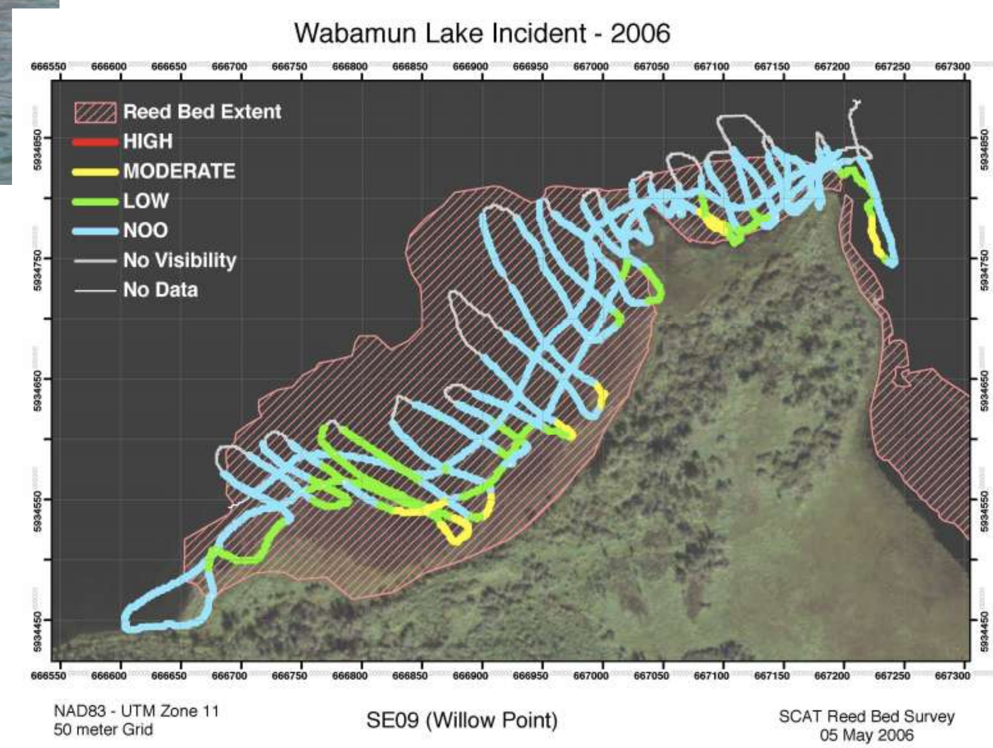
8-10 Dec 2004 | 11-14 Dec 2004 | 15-18 Dec 2004

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

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.

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

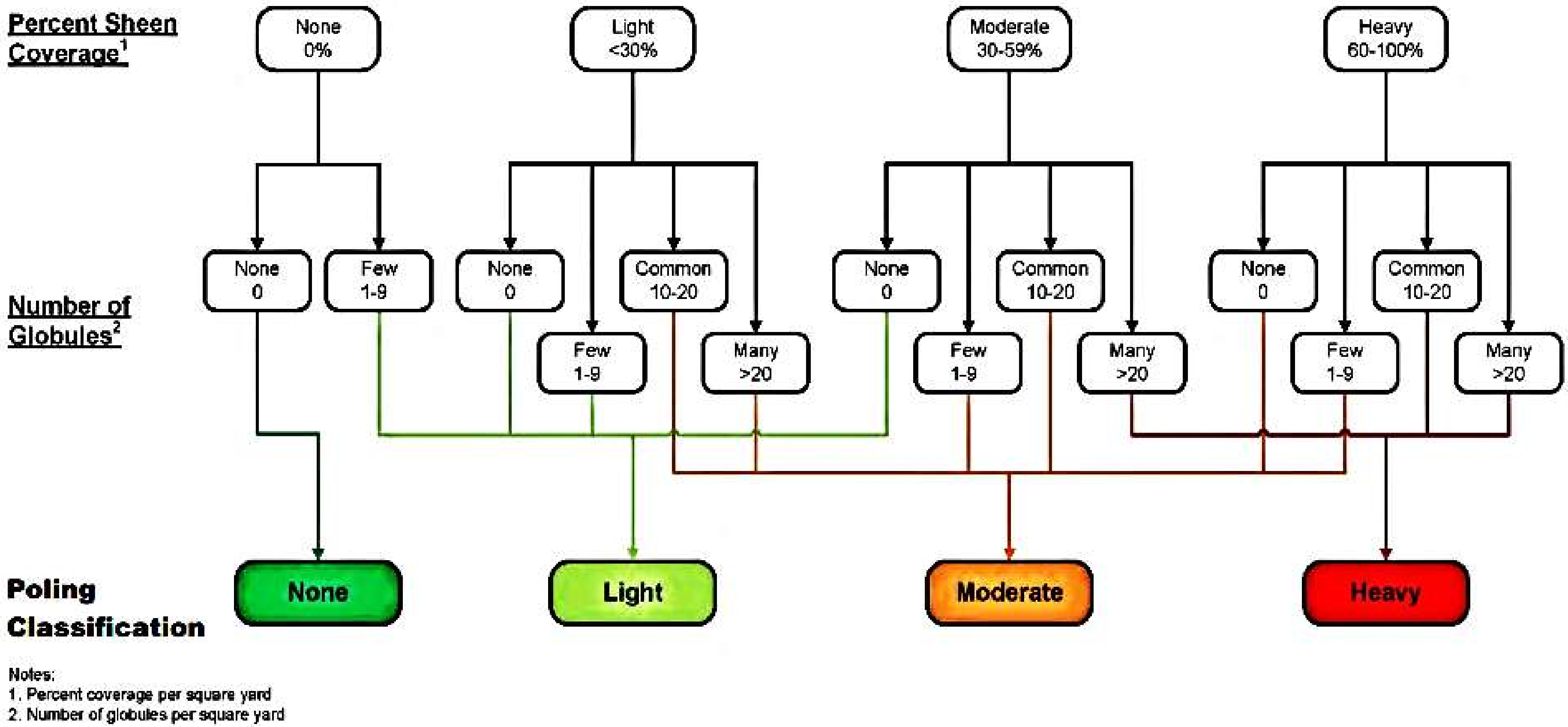


Detection of Oil on the Bottom: Bottom Sampling

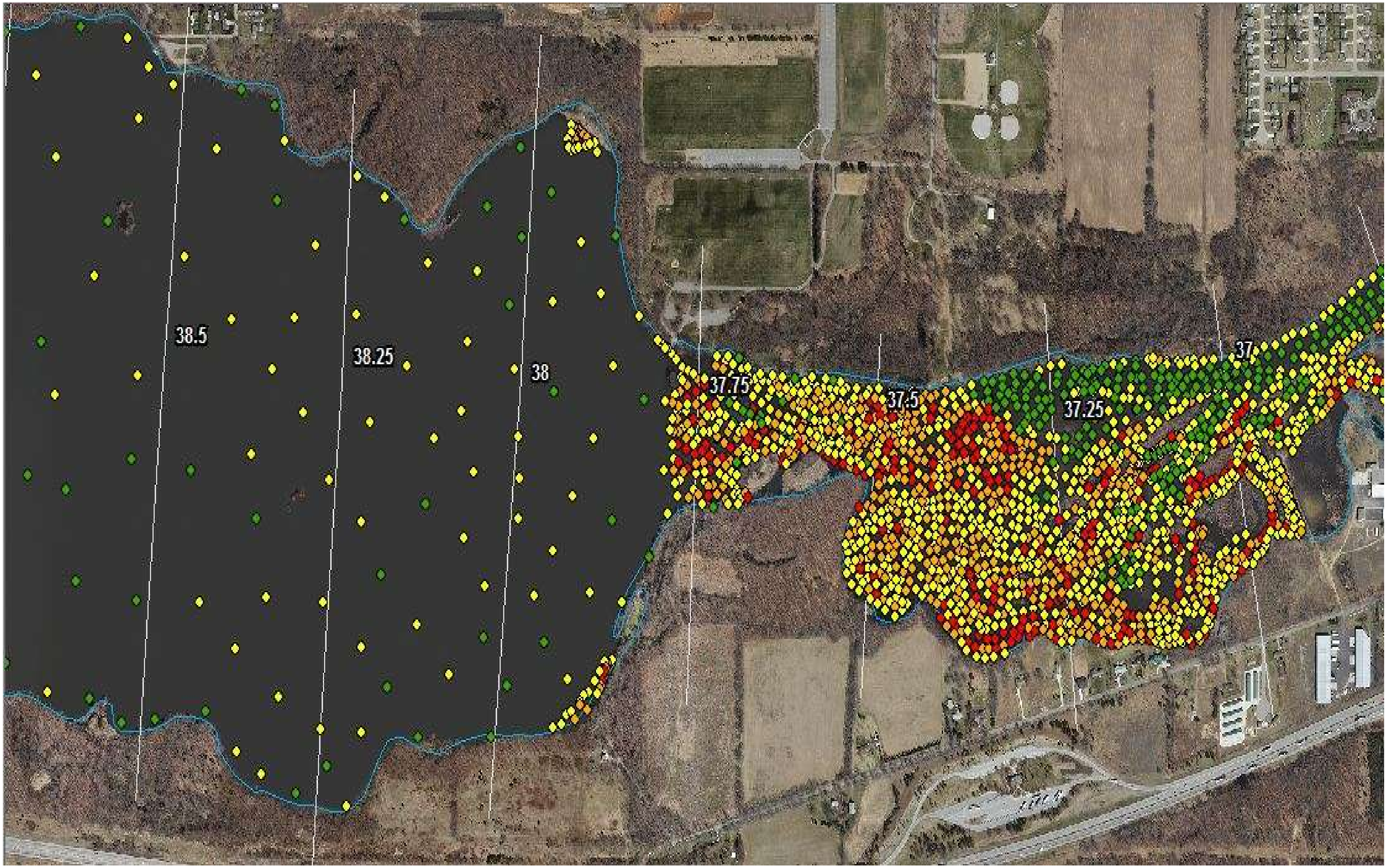
- Sediment grabs/cores
- Poling
- Wading-depth shovel pits (aka Snorkel SCAT)
- Sticking (asphalt)

Poling at Enbridge Pipeline Spill

Poling at Enbridge Pipeline Spill, Marshal, MI

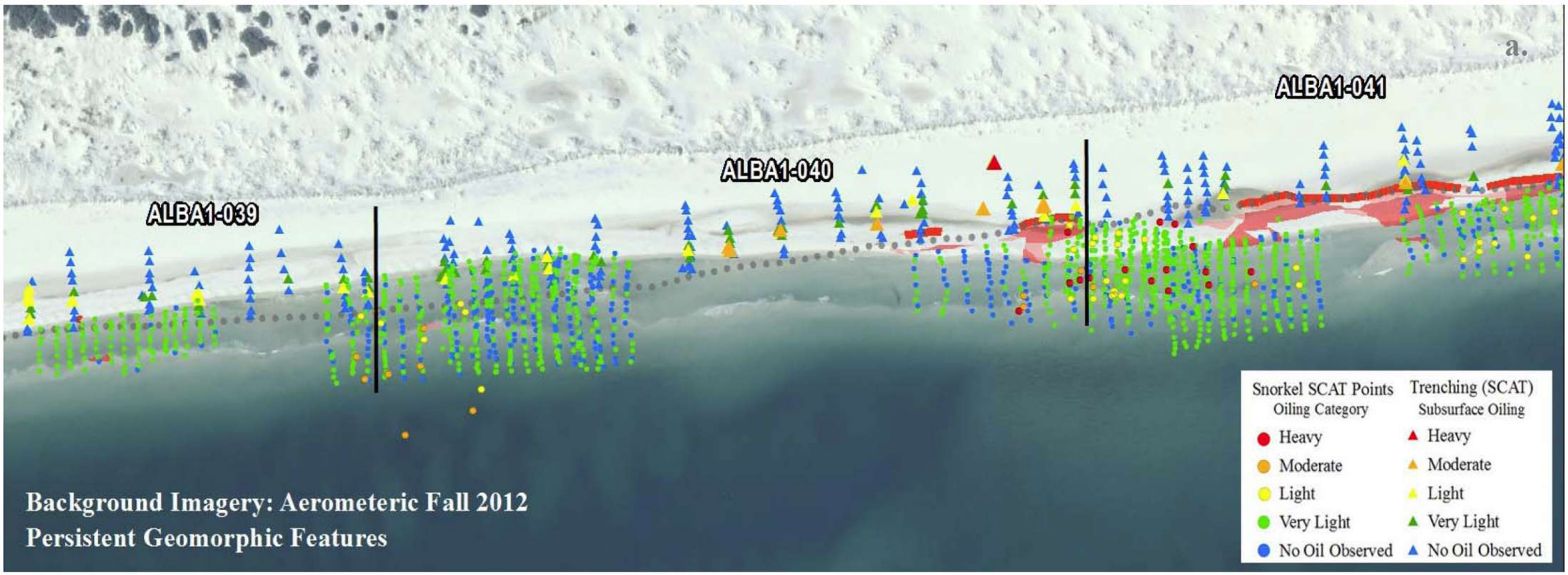


2012 Spring Submerged Oil Reassessment Poling Results at Morrow Lake Delta and Morrow Lake: Enbridge Pipeline Spill, Kalamazoo River



Wading-depth Shovel Pits (aka Snorkel SCAT)

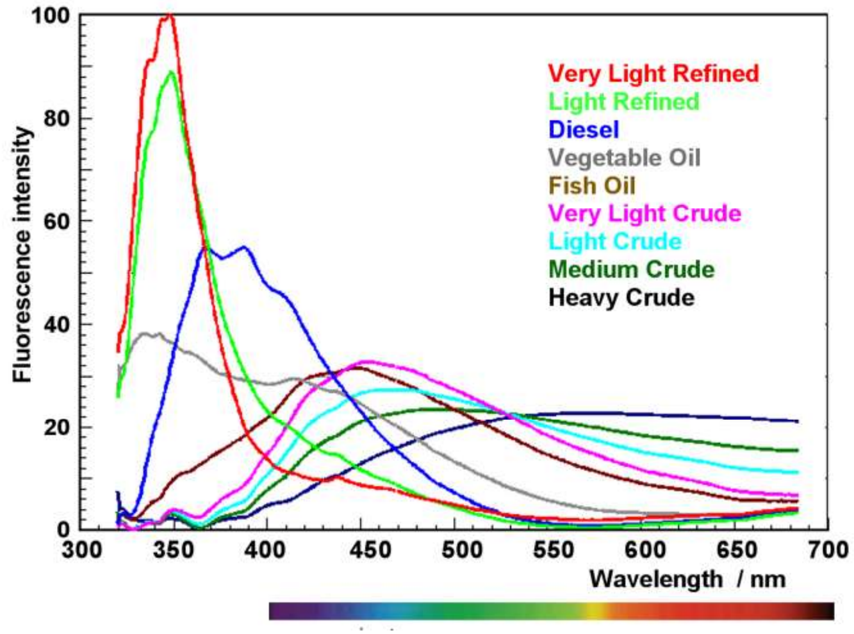
Wading-depth Shovel Pits (aka Snorkel SCAT)



Detection of Oil on the Bottom: Bottom Sampling

Advantages	Disadvantages
Bottom Sampling	
- Allows collection of samples to confirm the presence of oil, either visually or through chemical analysis - Can be effective in small areas for rapid delineation of a known patch of oil - Poling method indicated the relative risk of sheening of sunken oil	- Only point sample of a very small area - Not effective in patchy oiling conditions - Very slow and labor intensive - Even slower in deep water, rough sea conditions - Oil may be buried deeper than the sampler can penetrate into the bottom - Must use a statistically relevant sampling grid to be useful

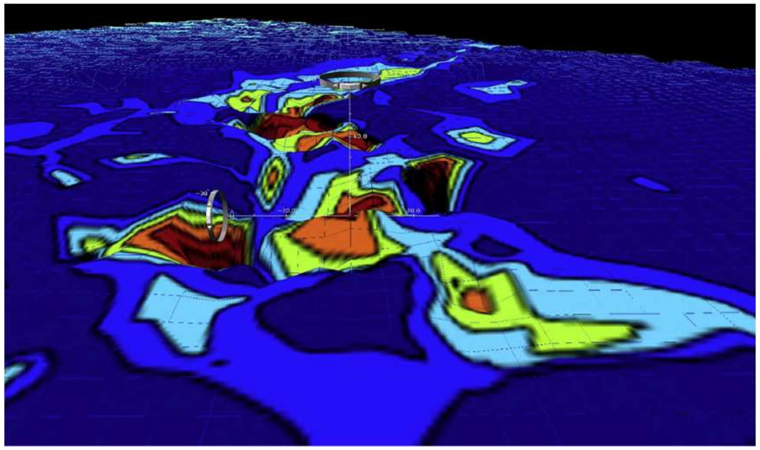
Detection of Oil on the Bottom: Underwater Laser Fluorescence



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.

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

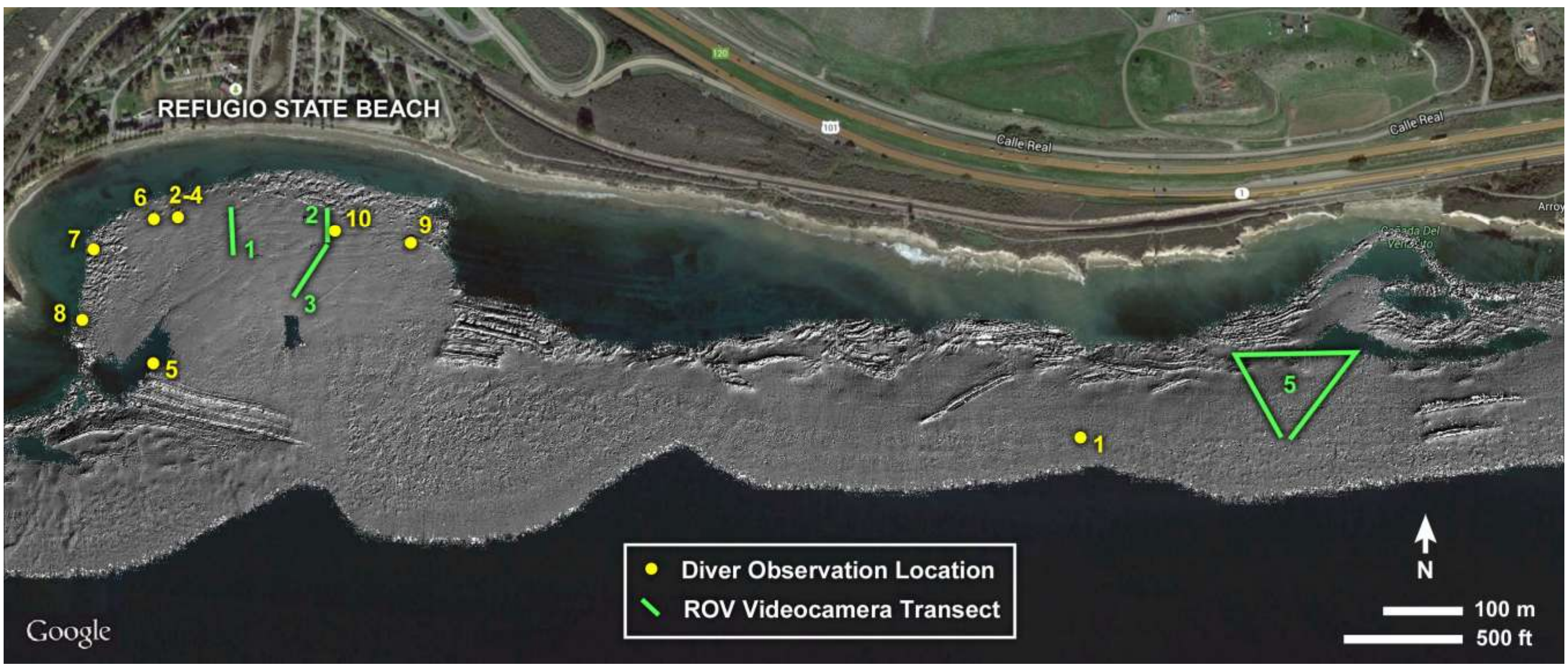
Sunken Oil Detection Techniques							
	Sonar System	Underwater Camera/ Video	Diver	Sorbents/ V-SORs	Surface Observa-tions	Bottom Sampling	Crab pots/ Nets
T/V *Alvenus*			X				
T/B *Apex 3508*	X		X	X		X	
T/B *Apex 3512*				X		X	
Apex Towing							
M/T *Athos 1*	X		X	X		X	
T/V Betelgeuse			X				X
T/B *Bouchard 155*					X		
T/B *DBL-152*	X	X	X	X			
Deepwater Horizon	X	X	X	X	X	X	
Degussa Eng. Carbons			X	X			
Detroit River			X				
T/V *Eleni V*					X		
T/B *EMC-423*	X		X				
Enbridge Pipeline				X		X	
T/V *Erika*	X		X			X	
T/V *ESSO Puerto Rico*				X			
Florida Mystery Spill			X				
T/V *Gino*	X	X					
M/C *Haven*	X	X	X			X	X
Honam Jade							X
T/V *Katina*					X		
M/V *Kuroshima*			X				
Lebanon		X	X				
Lake Wabamun		X		X	X	X	X
Lake Winona			X				
T/B *MCN-5*			X				
T/B *MM-53*			X				
T/V *Mobiloil*				X		X	X
T/B *Morris J. Berman*			X		X		
T/V *Nisa R3*			X				
T/V *Nissos Amorgos*					X		
T/V *Presidente Rivera*							X
T/V *Provence*				X			
SS *Sansinena*			X				
T/B *SFI 33*			X				
T/V *Thuntank 5*			X				
M/T *Velopoula*	X		X				
T/V *Volgoneft 248*			X			X	

	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											
- 5-30 ft											
- < 5 ft											
Availability											
Substrate Type											
- Sand											
- Silty sand											
- Mud											
Bottom Obstruction											
Oil Patch Size											
- < 0.1 ft^2											
- 0.1- 1 ft^2											
- > 1-10 ft^2											
- > 10 ft^2											
Oil Thickness											
Buried Oil											
Sensitive Habitat											
False Positives											
Coverage Rate											
Data Turnaround											

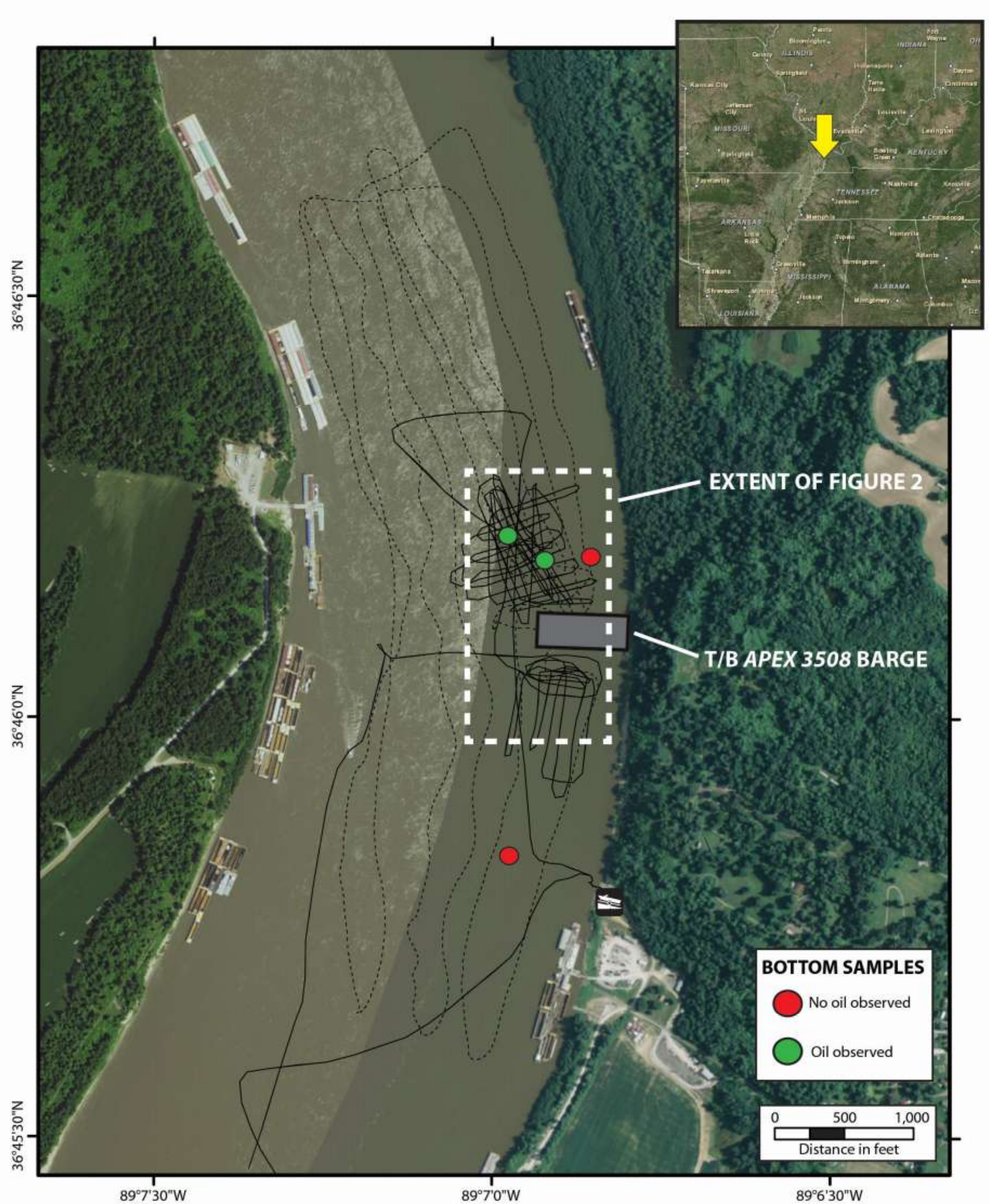
Detection of Oil on the Bottom

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



T/B *Apex 3508*

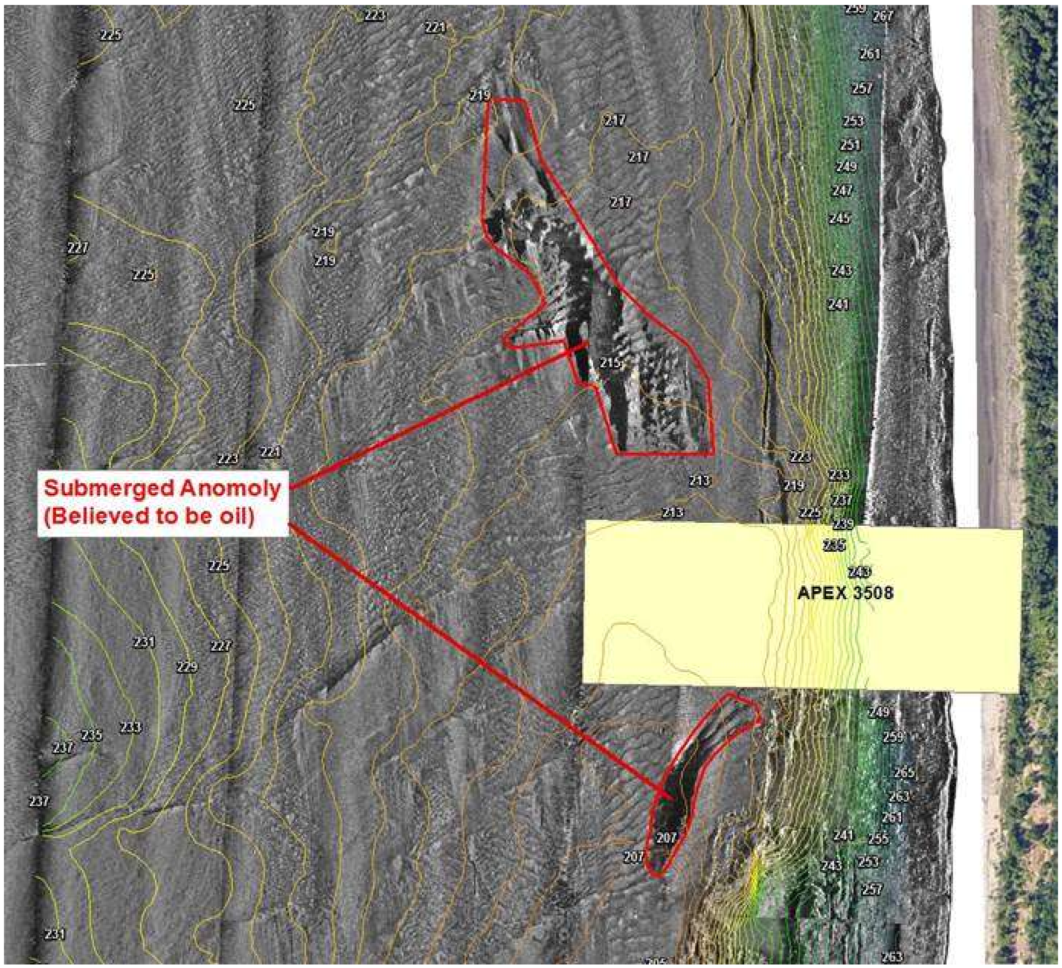
- 2 September 2015
- 2,870 bbl clarified slurry oil

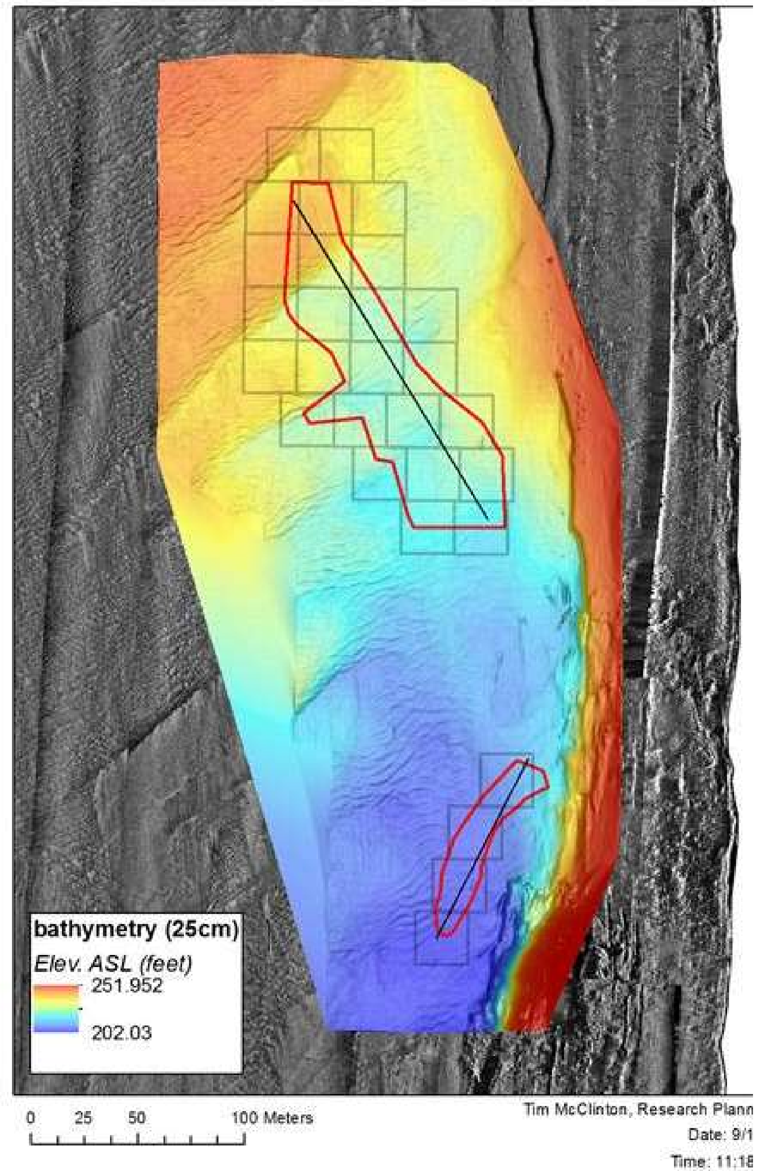


T/B *Apex 3508*

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

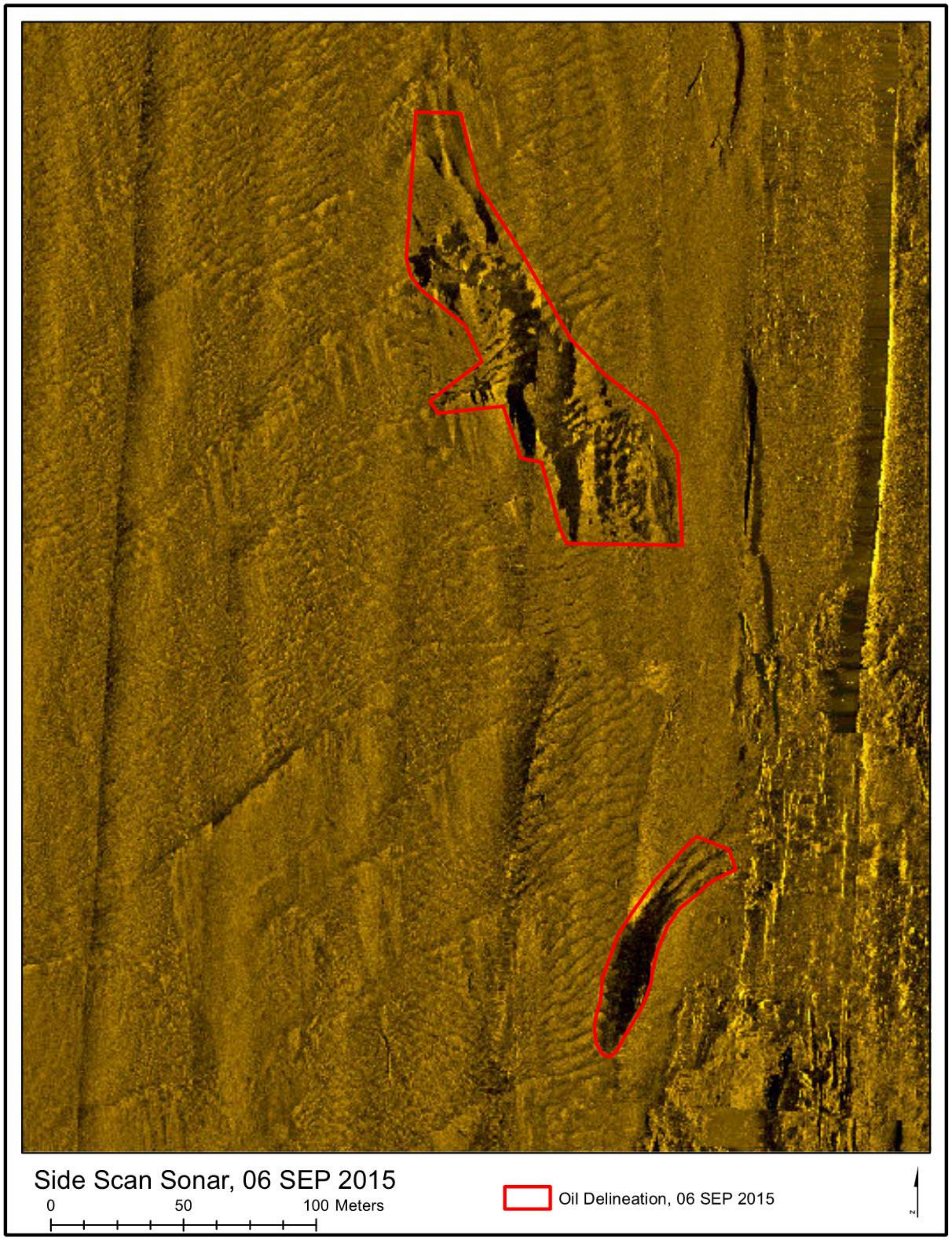
Detection: Side scan sonar and multibeam echo sounder

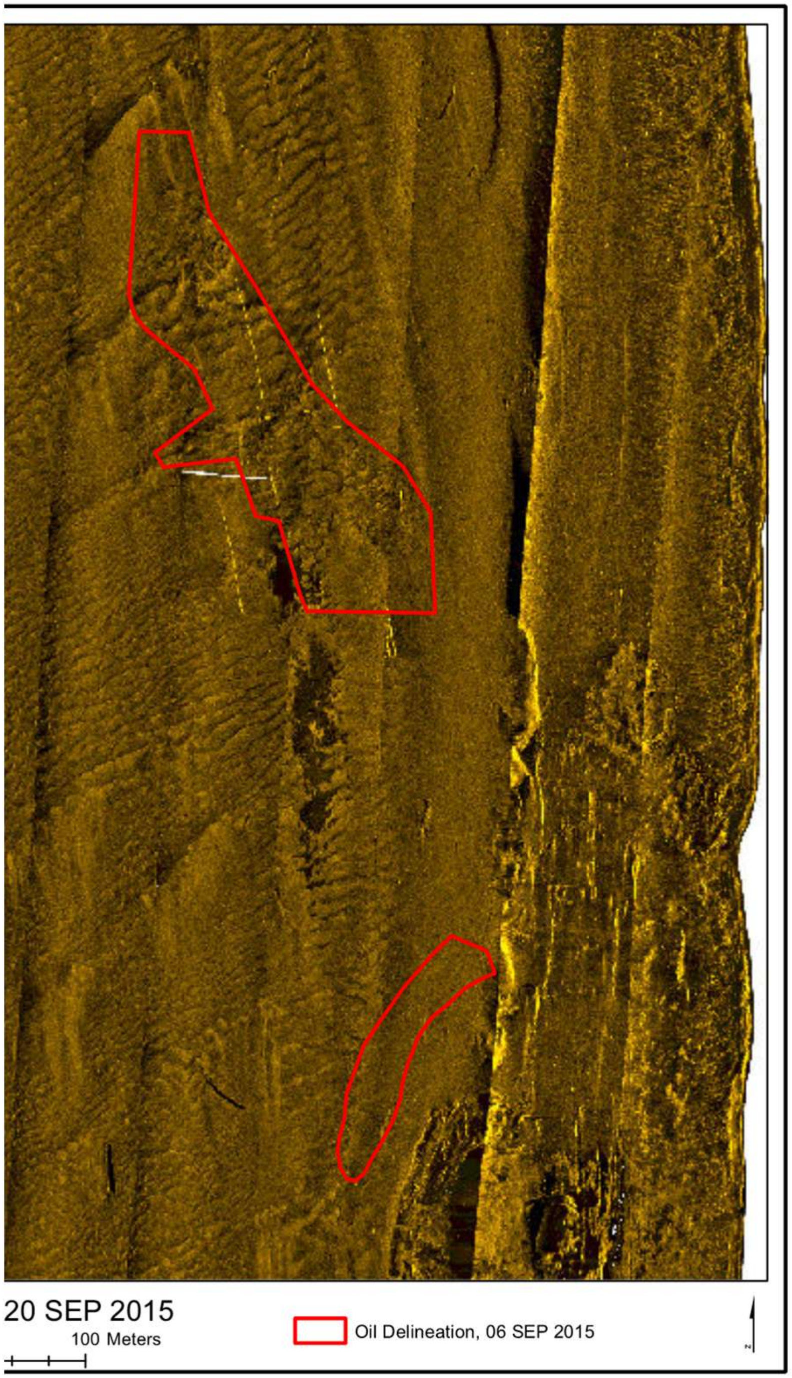




Confirmation by:

- V-SORs
- Coring
- Diver observations


Side Scan Sonar, 06 SEP 2015
0
50
100 Meters
Oil Delineation, 06 SEP 2015


20 SEP 2015
100 Meters
Oil Delineation, 06 SEP 2015

Detection/Quantification of Suspended Oil

Green = Most Effective; Yellow = Could Be Effective; Red = Least Effective; ? = Not Proven Yet

Response Technique	Water Habitats			
	Lake	Pond	Large River	Stream
Detection and Quantification				
Acoustic Sensor	Green	Green	Green	Green
Fluorometry	Green	Green	Green	Yellow
Optical Scattering	Green ?	Green ?	Green ?	Yellow ?
Mass Spectrometer	Green	Green	Green	Yellow
Induced Polarization	Green ?	Yellow ?	Green ?	Red ?
Sorbents	Yellow	Yellow	Yellow	Yellow
Nets	Yellow	Yellow	Yellow	Yellow
Underwater Still or Video Camera	Yellow	Yellow	Yellow	Yellow
Diver Observation	Green	Yellow	Green	Yellow

RPI QualiTech

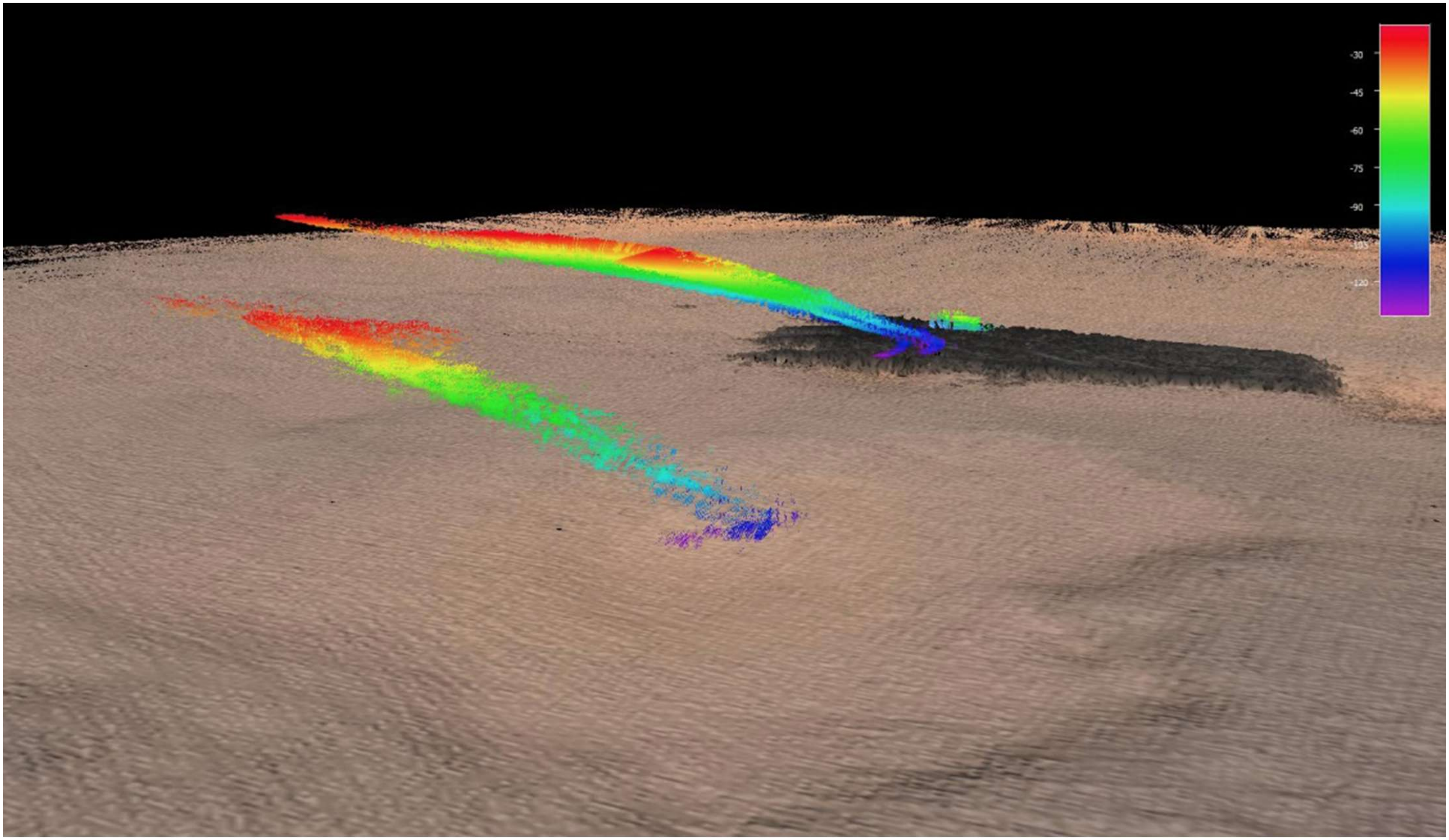
Considerations for Effectiveness of Submerged Oil
Detection and Quantification

- Minimum depth and width of a water body for deployment.
- Ability to quantify amount of oil present.
- Ability to detect oiled area, rather than at point locations that have to be interpolated to generate maps.

Water-Column Acoustic Sensors

Advantages	Considerations
Acoustic Sensor	
— Based on well-developed, commercially available technology that has been used in various aquatic applications — Can survey a wide area of a water column and generate 3D plume maps — Works in currents or tow speed up to 5 knots — No depth limitations; very compact and easily deployed on underwater vehicles — Proven in the field for subsurface oil releases	— Not able to conclusively discriminate petroleum hydrocarbons from other materials that can have a similar acoustic signature — Acoustic profiling at multiple frequencies generates a large amount of data that must be stored and processed — Real-time interpretation currently entails subjective analysis by a trained operator

Water-Column Acoustic Sensors



Fluorometry

Advantages	Considerations
Fluorometry	
— Based on well-developed, commercially available technology that has been used in various aquatic applications, including dispersed oil monitoring	— Uncertain how larger oil droplets or oil:particle aggregates affect detection and quantification
— Can provide geo-referenced oil locations in real time and at high spatial resolution	— Horizontal or vertical line transects only sample a small part of a water body
— With real-time results, can modify a survey area to locate oil boundaries and concentration areas	— Potential for fouling of the flow cell
— Other sensors can be added (e.g., temperature, dissolved oxygen)	— Collects data at single points along vertical and horizontal transects that have to be interpolated to generate 3D concentration maps, which can be difficult for plume that is constantly changing

Optical Scattering

Optical system that uses reflection and refraction of light by suspended oil droplets to determine mass and volume concentration, droplet size, and density of entrained oil.

Advantages	Considerations
Optical Scattering	
— Compact, inexpensive instruments are available — Showed promise during testing at Ohmsett; however, needs further testing under field conditions — Works in currents or tow speed up to 5 knots	— Collects data at single points along vertical and horizontal transects that have to be interpolated to generate 3D concentration maps, which can be difficult for plume that is constantly changing — Algorithms to determine particle size and density can be challenged by oil:particle aggregates of widely varying size and shape — Entails a specially trained team of operators and interpreters

Induced Polarization

An electrical current introduced into the water (a conductive medium), and measurement of the voltage difference enables detection of oil

Induced Polarization	
— Laboratory studies show ability to detect oil in water at concentrations of a few ppm — Collects data in 2D transects can be assembled quickly to generate a 3D map of an oil plume	— Only laboratory studies show effectiveness at detection of oil in the water column; no spill testing — Entails a specially trained team of operators and interpreters

Nets

Advantages	Considerations
Nets	
— Low-tech but uses readily available materials, so possible for rapid deployment without special teams — Could be installed at different positions and/or depths across a water body to cover a larger area than sorbents	— Time and labor intensive for deployment, inspection, and replacement — For towed nets, might not know on where along the tow oil was encountered — Can have issues with fouling by debris or snagging on bottom obstructions (if towed) — For stationary nets, low temporal information on when oil was present during the period of deployment — No calibration of efficacy of oil adsorption, particularly using local net materials and in currents >1-2 knots — More waste material for disposal once contaminated, even if part of the net is oiled

NFO Detection Data Gaps

- Better designs for towed sorbents to maximize contact with the bottom:
  - Experiments with video to observe behavior at different speeds, configurations, with a plow/scoop
  - Testing of various sorbents to increase effectiveness
- Ability to quantify the amount of oil present in the water column synoptically
- Ability to detect oiled area, rather than at point locations that have to be interpolated to generate maps
- There are promising technologies to increase spatial and temporal coverage in the water column, but need field testing prior to use during emergencies (it is hard to get funding for when NFO spills are relatively infrequent; no one wants to test a new technology during a spill emergency)