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Application of Sonar For Oil Spill Response

Acoustic Detection, Evaluation and Monitoring of Sunken Oil Spills

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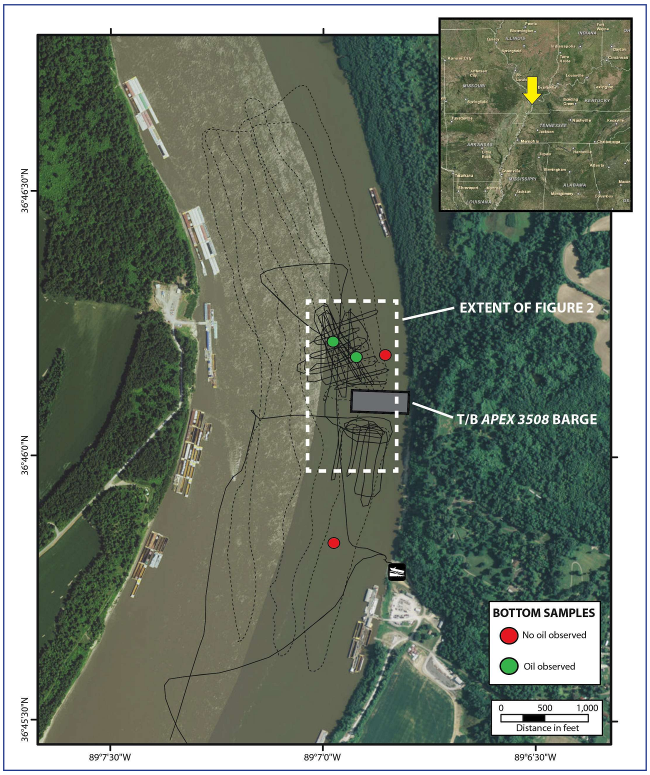
The majority of oil spill response strategies are focused on floating oil. However, in certain situations, specifically releases of heavy petroleum products (e.g., very heavy crude oil, slurry oil, heavy fuel oil), there is an increased risk of oil sinking and accumulating on the bottom. If the density of the oil is greater than that of the receiving water, the oil will submerge in the water column (if turbulence or currents are high) or sink to the bottom (if turbulence or currents are low). Oil that initially floats can increase in density as the oil weathers or mixes with sediment and become submerged or sink. A floating oil can mix with sand in the surf zone or after stranding on a beach, then sink offshore. Turbulence can entrain the oil in the water column, where the oil can interact with suspended sediments and organic matter, forming oil-particle aggregates that can become heavier than the receiving water and settle out as turbulence and currents decrease. Because sunken oil can be remobilized or buried by changes in currents or wave action, there is a need for rapid detection and recovery.

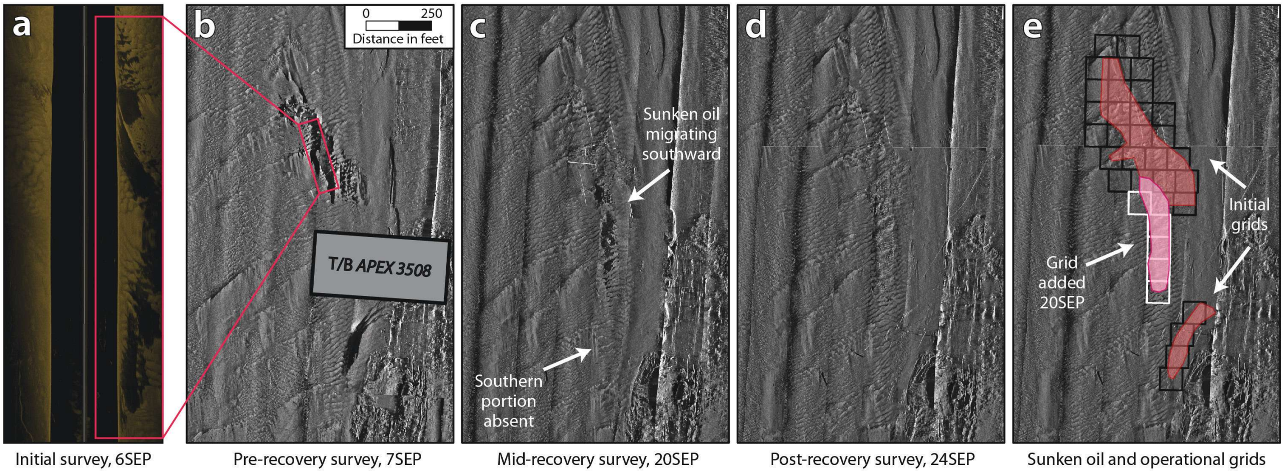


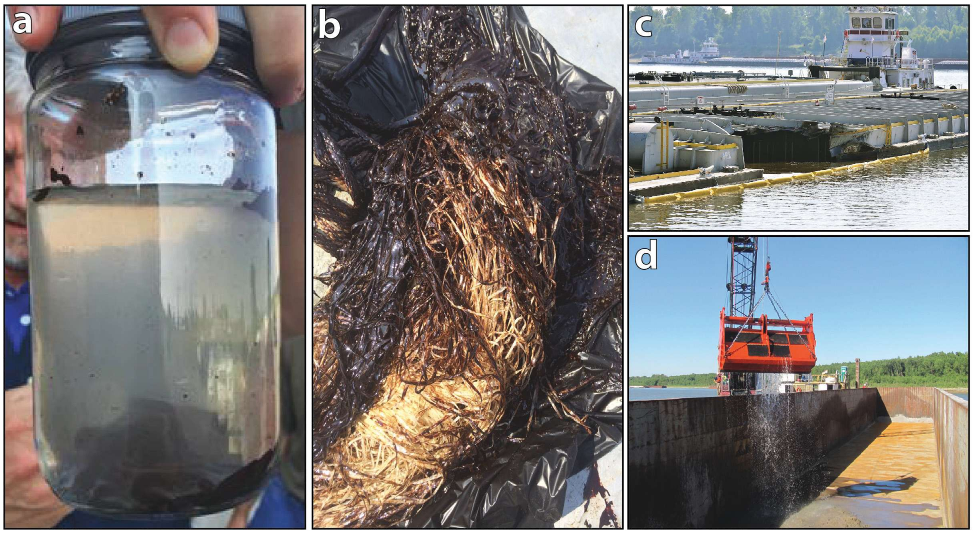
Setting of the T/B Apex 3508 *incident on the Lower Mississippi River. The thin black lines are tracklines of initial SSS surveys.*

Identification and mapping of sunken oil has historically been difficult due to logistical challenges and a significant gap in the scale and extent of bottom observations. Diver observations and underwater cameras provide the most detailed perspective, but operations are slow, labor-intensive and provide limited spatial coverage, as well as limited effectiveness under low-visibility conditions. Sorbents dragged along the bottom are often used, but there is no calibration between the amount of oil on the sorbent and on the bottom. Bottom sampling is slow and only provides data for a very small area. Sonar instruments can quickly and easily map large areas in a range of environmental conditions, but require specialized knowledge to operate and interpret the data and verification of acoustic signatures with bottom observations or samples. In a fast-paced spill emergency, immediate surveys are essential for sunken oil detection and recovery; therefore, a coordinated effort combining all appropriate methods is crucial. During a recent riverine spill incident, scientists working with NOAA in support of the U.S. Coast Guard were faced with this challenge.

T/B *Apex 3508* Sunken Oil Response, Assessment

On September 2, 2015, a collision occurred between northbound and southbound barges on the Mississippi River near river mile marker 938 (in the vicinity of Columbus, Kentucky). The collision compromised the watertight integrity of the #3 starboard tank of T/B *Apex 3508*, causing the release of 2,870 barrels (120,540 gallons) of clarified slurry oil (CSO) into the river. CSO is a heavy oil byproduct of the petroleum refining process. The CSO being transported by the T/B *Apex 3508* had a specific gravity of 1.14 (API gravity of -7.4), properties which suggested a high probability of sinking. The U.S. Coast Guard and the NOAA scientific support team were mobilized for spill assessment and response, operating out of an Incident Command Post in nearby Paducah, Kentucky. No oil was observed on shorelines downstream of the collision location; aerial overflights indicated only isolated light sheening. A "tailgate test" was performed using samples of the CSO and river water, which confirmed that the CSO substance sank nearly immediately





(Top) Acoustic backscatter images acquired with SSS during the T/B Apex *incident; lower backscatter is shown by darker colors.(Bottom) Images from the T/B* Apex *incident: a) tailgate test with CSO and river samples; b) bottom sample with oil; c) damage to T/B* Apex *barge; d) environmental clamshell.*

in a cohesive mass upon contact with the water. In addition, river levels and currents were relatively low, increasing confidence that the CSO had sunk quickly upon discharge.

A technical workgroup was organized to identify, locate and recover the sunken oil. Time being of the essence, the team contracted a vessel of opportunity from local emergency management authorities. The small vessel was equipped with an off-the-shelf Humminbird 1199 side scan sonar (SSS) system. Unlike bathymetric sonars, SSS systems produce images of the acoustic reflectivity of the bottom, which are used to infer subaqueous geology, sediment types and habitats. In general, rougher and harder materials (exposed rock, debris) reflect acoustic energy more effectively, resulting in a higher return to the sonar and a brighter signature in the SSS imagery; softer and smoother materials (sunken oil, submerged vegetation, mud) tend to absorb more acoustic energy than they reflect, resulting in darker signatures in SSS imagery. Due to the angle of the sensors, SSS imagery is also susceptible to geometric distortions (higher returns on facing slopes, lower returns on opposite slopes) and "shadows" behind objects that rise into the sensor's field of view. These image artifacts often require a combination of expert interpretation and bottom sampling to verify acoustic signatures.

The NOAA team conducted a series of preliminary surveys with the off-the-shelf system to locate anomalies in acoustic backscatter that suggested the presence of sunken oil. Backscatter imagery was viewed and interpreted in real time via a heads-up display. The system was operated in 455- and 800-kHz modes for backscatter image evaluation and comparison. The 800-kHz setting produced very grainy imagery, presumably due to the amount of suspended sediment within the water column (visibility of about 6 in.); therefore, the SSS was operated in 455-kHz mode for the remainder of the operation. This mode provided two 86° swaths corresponding to a combined range of approximately 200 to 250 ft.

The initial SSS surveys were conducted in the area of the barge collision and up to 6 mi. downstream of the incident location. Two acoustic anomalies were identified and completely mapped in the vicinity of the collision location. Both anomalies were low-reflectivity areas (dark image returns) that contrasted with the surrounding riverbed predominated by sand and silt. The anomalies appeared to superimpose the riverbed morphology (sand waves less than 1.5 ft. high) and displayed feathering on the downstream edges aligned with the direction of the river current (less than 2 kt.). The northern anomaly stretched approximately 1,000 ft. southeastward from the presumed collision location to where the T/B *Apex 3508* was secured. The southern anomaly was approximately 650 ft. long and extended southward from beneath the barge.

To investigate these acoustic signatures, sorbent materials were dropped at several locations chosen from the SSS imagery. These samples confirmed a heavy accumulation of oil at the bottom. Divers were contracted to conduct riverbed habitat surveys for endangered freshwater mussel species and to provide additional validation of the sonar anomaly, which also confirmed the presence of oil on the river bot-

"Identification and mapping of sunken oil has historically been difficult due to logistical challenges."

tom. With confirmation in hand, both acoustic anomalies were interpreted to be sunken oil that pooled in between riverbed sand waves, with thinner accumulations possibly being remobilized by river bottom currents. Later, analyses would show that the northern anomaly was consistent with discharge at the impact location, while the southern anomaly was likely the result of an additional discharge, possibly as the T/B *Apex 3508* was moved for lightering operations.

The preliminary SSS surveys were extremely useful for decreasing the geographic extent of the operation area; however, the images were relatively coarse in resolution and confined to a proprietary data format. Therefore, a commercial hydrographic surveyor was contracted to produce precisely navigated, motion-corrected, high-resolution bathymetric maps and SSS imagery of the area. Bathymetric data were collected with an Innerspace single-frequency (200 kHz) single-beam echosounder (SBES); high-resolution SSS imagery was collected with a Klein 3900 dual-frequency SSS, operated in 445-kHz mode. SBES and SSS data were collected and processed using HYPACK acquisition software. The resulting bathymetric maps had a horizontal resolution of 1 ft., enabling complete interpretation of SSS imagery and precise delineation of the sunken oil on the riverbed. The areas identified as sunken oil had a total surface area of 76,400 sq. ft.

Sunken Oil Recovery

Tactics for recovery of the sunken oil were reviewed and evaluated against the spill conditions. A barge-based environmental clamshell dredge, which reduces the amount of water that requires treatment, was chosen as the recovery method. The clamshell bucket was used in conjunction with HYPACK Dredgepack software and navigated via real-time kinematic GPS and motion and pressure sensors that enable operators to precisely position the bucket to pinpoint the area of material removal.

The areas of sunken oil were divided into grids of 82 by 82 ft. (25 by 25 m) to track and quantify the recovery process. After consultation with local, state and federal authorities, the recovery endpoint for each grid cell was set at less than 10 percent detectable oil in subsequent SSS surveys. This endpoint was chosen with careful consideration of the SSS detection ability and the spatial averaging (gridding) required to produce the SSS imagery. Depending on the pixel resolution of SSS imagery, the value of each pixel is an average of a number of the surrounding pixels; therefore, a minute area of sunken oil has the potential of appearing much larger in processed SSS imagery.

Recovery operations commenced on September 15 at the northern end of the operational area. Initial observations of recovered dredge material as it was placed in a hopper barge indicated heavy oil concentrations from areas where SSS imagery indicated sunken oil. As recovery progressed, observations also indicated that oil was not present, at least in obvious quantities, outside of the areas where SSS imagery indicated sunken oil.

Before transitioning to the southern end of the operational area, a second SSS survey was conducted on September 20 to assess recovery progress. The resulting SSS imagery indicated that recovery had been largely successful in the northern removal area, with all grid squares meeting cleanup endpoints. A comparison of SSS imagery from presumably non-oiled areas to areas in which removal had taken place showed no obvious differences in acoustic signatures. In addition, the SSS images from September 20 suggested that a portion of the sunken oil had migrated approximately 250 ft. downstream since initial SSS surveys. The northern removal area was therefore expanded to the south to include this area. Sorbent materials were placed downstream of the southern removal area and monitored to detect further spread of the oil. Trace amounts of oil were observed in these materials, likely due to the disturbance created by clamshell dredge activities.

Noteworthy in the September 20 SSS imagery was the absence of a southern oiled area. Nevertheless, when recovery operations were conducted in this area, observations of the dredged material indicated the presence of oil. The lack of an acoustic sig-

> *"SSS is becoming one of the tools in the response toolbox for heavy oil spills."*

nature might have been due to a thinner accumulation or burial of the oil by sediments.

In total, approximately 1,350 clamshell dredge cycles recovered about 3,300 cubic yards of oil and sediment from the river bottom within the operational area. Following the completion of recovery operations, it was estimated that oil recovery rates exceeded 75 percent of the total amount of oil discharged, not including any CSO in the water fraction that was removed during decanting of the dredge hopper barge.

Implications and Considerations

The acquisition and analysis of SSS imagery were essential for identifying sunken oil and monitoring the progress of recovery operations during the T/B *Apex 3508* incident. However, it was the combination of methods that made the sunken oil recovery operation successful. Prompt SSS surveys filled a critical gap between first responders and the incident command structure, allowing for rapid deployment of additional resources and recovery planning. If a spill of heavy oil occurs, it is strongly recommended that SSS surveys be considered as an immediate priority. These methods are clearly scalable and applicable to marine and freshwater oil spills in different settings. However, it is important to note the optimal conditions of the T/B *Apex 3508* incident—weak river currents, low water levels, clear weather window, relatively small operational area, and very heavy oil that sank immediately into large accumulations on the bottom. In contrast, a January 2016 CSO spill on the Mississippi River occurred during a major flood with currents greater than 7 kt. Under these conditions, the 135 barrels of oil released in the river submerged but did not sink near the release site and no oil was detected using SSS. While further field research is required to properly document the detection limits of SSS for sunken oil detection, in addition to standardizing procedures for future oil spill incidents, this technology is becoming one of the tools in the response toolbox for heavy oil spills.

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