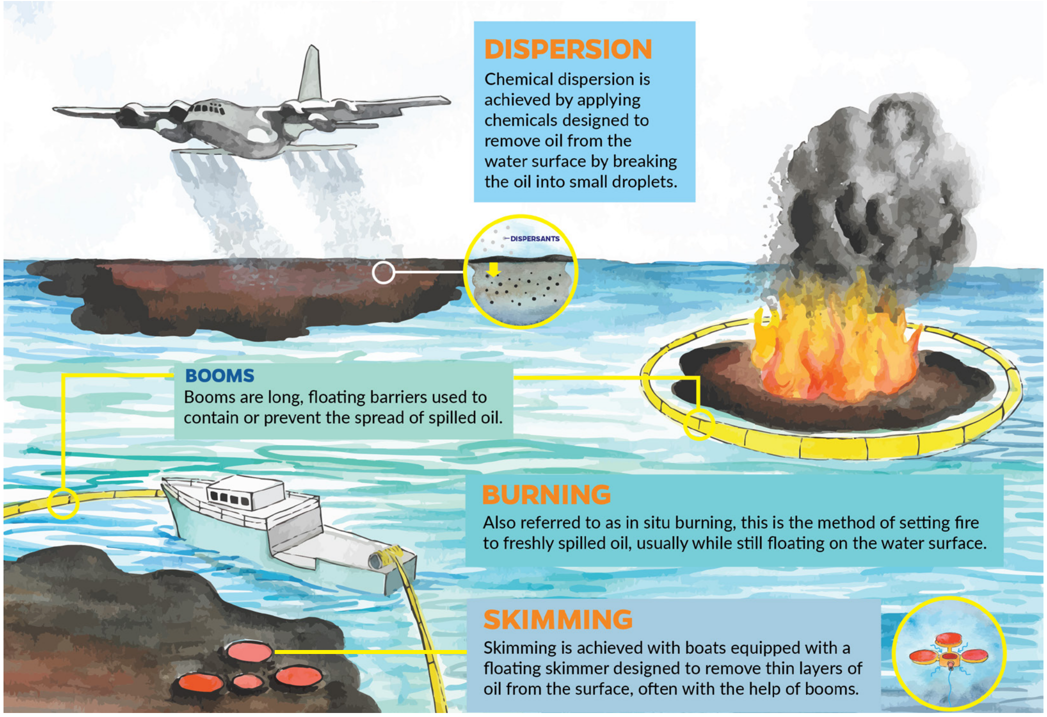
OIL SPILL SCIENCE
SEA GRANT PROGRAMS OF THE GULF OF MEXICO

OIL ON THE WATER: INSIGHTS INTO OIL SPILL RESPONSE

Emily Maung-Douglass, *Christine Hale, Melissa Partyka, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson*

An oil spill occurs offshore and emergency responders are called to the scene. Their goal is to protect people and natural resources. To do so, they must select the best set of clean-up tools and techniques for the situation at hand. They consider many factors, including but not limited to human and animal welfare, weather and sea conditions, geography, and type of oil.



DISPERSION
Chemical dispersion is achieved by applying chemicals designed to remove oil from the water surface by breaking the oil into small droplets.

BOOMS
Booms are long, floating barriers used to contain or prevent the spread of spilled oil.

BURNING
Also referred to as in situ burning, this is the method of setting fire to freshly spilled oil, usually while still floating on the water surface.

SKIMMING
Skimming is achieved with boats equipped with a floating skimmer designed to remove thin layers of oil from the surface, often with the help of booms.

Booms, chemical dispersion, burning, and skimming are just a few of the techniques that may be used by emergency responders during oil spill clean-up. Emergency responders carefully consider a number of factors, such as human safety, wildlife, and environmental conditions when selecting response tools to use. (Anna Hinkeldey, adapted from NOAA)

THE BEST DEFENSE IS A WELL-PLANNED OFFENSE

The main goal of oil spill response is to protect people and natural resources to the best extent possible. How do emergency responders stay coordinated when faced with an oil spill? Even before an oil spill occurs, emergency response professionals gather at local and regional levels, often multiple times per year. Attendees at these Regional Response Team and Area Committee meetings represent agencies from several sectors, including local, state,

THE SEA GRANT and GOMRI PARTNERSHIP

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine, and Great Lakes resources in order to create a sustainable economy and environment. There are 34 university–based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10–year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization, and remediation technologies. GoMRI is led by an independent and academic 20–member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

Sea Grant
Texas • Louisiana • Florida
Mississippi-Alabama
gulfseagrant.org

GULF OF MEXICO
RESEARCH INITIATIVE
gulfresearchinitiative.org

and federal government, industry, and sometimes non-governmental organizations. Topics of discussion include response techniques, lessons learned from previous spills, and planning for future spills. Responders also discuss documents – known as Contingency Plans – used for guidance on response options.[1] Area Committees also participate in training exercises to prepare for a multitude of oil spill scenarios.

ASSESSING AND RESPONDING TO THE SPILL

The foremost concern of emergency response workers is human safety, followed by protecting natural resources. Responders try to reduce any damage from the spill by predicting where oil may end up in the environment and determining the best strategies to protect animals and habitats.[2] Action must be taken quickly, as spilled oil can spread rapidly with winds and currents, coat aquatic life, and impact habitats such as wetlands. There are many types of response tools, each with their own applications. They may be used alone but are often used in concert with one another (**Cover image**; **Table 1**).[2] For example, booms may be used to restrict the movement of oil and to deflect oil away from sensitive areas.[4] Once the oil is corralled with a boom, emergency responders may remove the oil from the water using methods, such as skimmers, **sorbents**, **solidifiers**, or in situ burning.[5-7]

Each spill is unique and each tool has its own set of limitations and considerations (**Table 1**). Therefore, no 'one-size-fits-all' response technique can be used for every spill. Emergency responders take multiple factors into account when selecting response strategies.[2,8,9] For example, the type of oil involved helps guide the selection of response tools since **light** and **heavy oils** may each be more easily cleaned using specific strategies. Further, environmental and spill conditions – such as wind, waves, ice, debris, and oil volume – create challenges during response and may make it difficult to use certain clean-up strategies.[9-12] Responders must weigh the environmental trade-offs of each response option in the context of the situation – including doing nothing – to reduce harm to animals and habitats (**Table 1**).

WHO IS IN CHARGE?

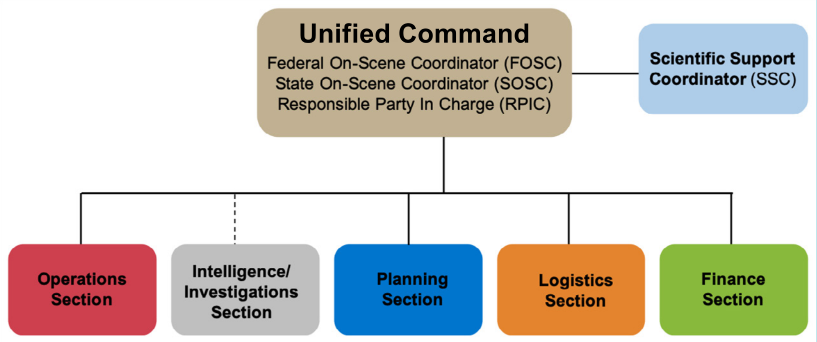


FIGURE 1. *The Incident Command System (ICS) has many players. Together they work toward the common goals of protecting human safety and natural resources. Depending on the nature of the incident, an intelligence/investigations section may be included as well. (adapted from NOAA, 2013)*

To respond to an oil incident in a coordinated way, an incident command system (ICS) is used (Figure 1).[2,3] Unified Command (UC) is formed within the flexible structure of the ICS. In UC there are at least three distinct groups represented which must include the federal government (U.S. Coast Guard Federal On-Scene Coordinator, FOSC), the state government (State On-Scene Coordinator, SOSC), and the responsible party (Responsible Party Incident Commander, RPIC).[3] Depending on the nature of the incident, additional groups may be represented in the UC, such as tribes.[3] Working together as a unit, UC makes decisions regarding how to achieve desired outcomes. Other personnel support UC in many areas, including operations, planning, logistics, finance, and in some situations, intelligence/investigations.[3] A scientific support coordinator (SSC) also acts as the lead scientific advisor, supporting the U.S. Coast Guard FOSC and informing scientific decision making.[3] The SSC has a suite of duties and may work with a scientific support team (SST) to achieve them. The duties include but are not limited to reporting the environmental hazards associated with the oil involved, sharing the forecasted movement of oil in the environment, gathering scientific information from various sources to aid in creating response plans, and evaluating the environmental impacts and outcomes of potential clean-up methods.[3] In coastal and offshore spills, the National Oceanic and Atmospheric Administration (NOAA) fulfills the SSC duties, while the U.S. Environmental Protection Agency (EPA) is the SSC for inland spills.

TABLE 1. *Emergency responders consider a number of factors when choosing tools to combat an oil spill. Recovered oily waste from booms, skimmers, solidifiers, sorbents, or any other source must be disposed of at appropriate waste facilities.*[2]

Berms—Physical barrier constructed from sediments that prevent oil from entering shoreline habitats.[39,40]

- Berms require large amounts of **sediment** from other locations.[39,40]
- Construction can be costly.[40]
- Berms are unlikely to stay in place in the long term.[40]
- Stirred up sediments can decrease water quality and negatively impact aquatic life.[40]

Booms—Plastic, metal, or sorbent barriers that float on the water's surface, preventing oil from spreading into surrounding waters or sensitive habitats.[4]

- Used sorbent booms require proper oil disposal and fire-resistant booms can be cumbersome, expensive, and break down quickly during use.[2,11]
- Waves can cause the oil to 'jump' over or under the boom.[9]
- Booms can come ashore in event of unexpected extreme weather and damage onshore habitats, like wetlands.[41] Anchors remaining in the water can create boat hazards (NOAA, personal communication, March 2020).

Dispersants—Chemical mixtures that allow oil and water to mix, creating tiny oil droplets from oil slicks, speeding up the breakdown of oil by microbes, sunlight, and evaporation.[42]

- Many formulations of dispersant exist.[20,42]
- Dispersants may protect air quality by reducing the volatile oil-based compounds released into the air.[42]
- Laboratory studies indicate mixtures of oil and dispersant increase exposure of aquatic life to oil-based compounds and can cause negative effects to the organisms.[20,22,23,43]
- They are best used during early days of a spill, while oil is still fresh.[42]

Diversions—Sending a river from its natural course, allowing large discharges of freshwater to flush oil away from shore to protect sensitive habitats.[40]

- Diversions are not a standardly used method (NOAA, personal communication, March 2020).
- They may result in large losses of organisms sensitive to salt-levels like oysters because of extended exposure to freshwater.[40,44,45]

In situ burning—Setting an oil slick on fire at the site of the spill, which can remove up to 95% of oil from the water, converting it mainly into carbon dioxide and water.[6,10,11,46]

- Oil slicks must be at least 0.04 inches thick – about the thickness of a dime.[11]
- Burning releases gases, oil-based compounds, and particles into the atmosphere, and residues to the seafloor.[6,10,11,46]
- Some oil-based compounds can pose a human health hazard – policies and guidelines restrict in situ burning to situations and locations that will not place people at risk.[10,46]
- Burning cannot be used under heavy wind and waves since these conditions tend to form oil-water emulsions.[10]
- Burning must be done soon after a spill occurs since it is not possible to ignite emulsions containing more than 25% water.[11]
- Fire-resistant booms contain the fire and aid in achieving the needed oil thickness by concentrating oil into a given area.[11]

Skimmers—Mechanical devices that remove oil from the water's surface.[7,9]

- Multiple types exist.[7] Some act like a dam, trapping oil, while others work by suction. Others have a rotating surface – such as a drum or belt – that attracts oil, which is then scraped off into a collection container.[31]
- Skimmers minimally impact the environment.[2]
- Skimmers can be slow and ineffective when dealing with thick, viscous, or weathered/emulsified oil; diesel and gasoline; or heavy wind/wave conditions.[9]
- Recovery of oil from the water can depend on the thickness of oil layer present.[12]
- Marine debris can jam the skimmer, complicating clean-up efforts.[31]

Solidifiers—Semi-solid, porous material that is attractive to oil and creates a solidified mass that responders can physically remove from the water.[5]

- Solidifiers may be stuffed into booms or sprinkled on surface of water.[5]
- Solidifiers will not leak the absorbed oil but may sink after mixing with oil.[5]

Sorbents—Products made from both natural and manmade materials that attract and soak up oil to remove it from the water.[8, 47]

- Sorbents can hold between 3 to 70 times their weight in oil.[8, 47]
- Sorbents may be stuffed into booms or crafted into absorbent pads to scatter onto the water's surface.[8]
- Lighter, thinner oil tends to leak from during removal from water due to the added weight of the recovered oil.[8]

SPECIAL MONITORING OF APPLIED RESPONSE TECHNOLOGIES (SMART)

Protecting humans and minimizing damage to natural resources are the highest priorities for emergency responders.[13] The Special Monitoring of Applied Response Technologies (SMART) is a collaborative program – made up of the U.S. Coast Guard, National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (EPA), Centers for Disease Control and Prevention (CDC), and Bureau of Safety and Environmental Enforcement (BSEE) – to help ensure that these needs are met when certain response techniques such as dispersants and in situ burning are used.[13] During an active spill, teams collect real-time data, such as air and water samples, from the field to monitor spill conditions.

INNOVATIONS AND NEW DIRECTIONS IN RESPONSE

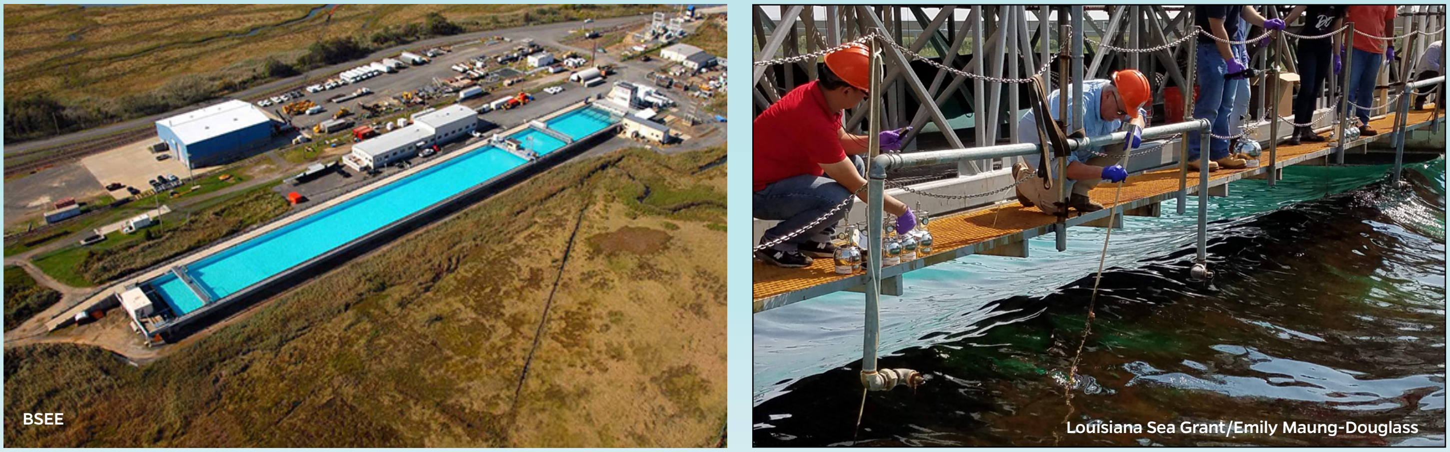
The design of response tools themselves can present challenges for response and opportunities for innovation.

Booms

There are several styles of boom, such as those stuffed with sorbents meant to absorb oil and those made from plastic or metal meant to deflect oil, often away from sensitive habitats.[4,16] Using a single boom is not always effective at containing a spill.[16] By pairing together different types of booms, any oil that ‘jumps’ the initial boom may be contained or absorbed by a secondary boom (**Figure 3**). Towing strategies and configurations of multiple boom systems have been a focus of research to enhance collection and deflection of oil, depending upon the situation.[17] Additionally, modifications of the four basic types of fire-resistant boom – stainless steel, ceramic, water-cooled, and thermally resistant fabric – are continually developed by industry.[17]

Dispersants

Dispersants are a continual focus of research. The first dispersants debuted in 1967 and were industrial degreasers, chemically different from the dispersants


BSEE

Louisiana Sea Grant/Emily Maung-Douglass

FIGURE 2. *Researchers take oil and water samples from the wave tank at Ohmsett during oil spill response testing.*

TESTING OIL SPILL RESPONSE TECHNOLOGIES

The United States does not allow intentional oil spills in the environment for any purpose, including testing new response technologies. In the U.S., BSEE is developing Technology Readiness Levels (TRLs) to make development of experimental oil spill technologies as smooth, direct, and cost-effective as possible.[14] Emergency responders and oil spill scientists in the U.S. run test scenarios at facilities, like ***Ohmsett***, a government facility with a wave tank over 660 feet in length that holds 2.6 million gallons of seawater (Figure 2).[15] At this facility, scientists from academia, industry, government, and other organizations test oil spill clean-up technologies under a variety of simulated spill conditions, including heavy waves and ice (**Figure 2**).

FIGURE 3. *Sorbent booms (shown on left) soak up oil from the water's surface and may be paired with another type of boom, like containment boom (in yellow). (U.S. Fish and Wildlife Service)*

in use today.[18,19] Those early dispersants were highly toxic, killing much of the aquatic life on the rocky shorelines where they were applied.[18] In contrast, the main dispersant used during Deepwater Horizon oil spill was Corexit 9500A, which has low toxicity.[20,21] However, dispersants do increase the availability of oil-based compounds in the water, which can cause negative impacts to aquatic life.[20,22,23]

> *Dispersant use continues to be regulated via the National Contingency Plan.[1] Its application is not permitted near shorelines, vessels, or people.[24] Dispersants have been used rarely in the U.S. and not since the Deepwater Horizon oil spill in 2010.*

Ongoing research is examining how clay minerals like halloysite can be combined with a **surfactant** found in existing dispersants, such as Corexit 9500A. The clay minerals act as cargo vessels for surfactant molecules, delivering them in a targeted way to the surface of microscopic oil droplets. This technique reduces the amount of dispersant needed.[25] Scientists are also developing combinations of food-grade surfactants that create smaller oil droplets than current dispersant technologies.[26,27] The smaller oil droplets created are more easily broken down by oil-eating microbes than larger droplets.[26]

In situ burning

In the past, responders ignited oil on the water's surface from nearby vessels.[17] In recent years, the development of aircraft-delivered ignition devices has enhanced in situ burning operations. These ignition devices are gels specially engineered to sustainably burn at temperatures of 1472°F for several minutes.[17] This provides just enough heat to ignite even heavy oils which are often hard to clean up.

While the design of fire-resistant booms used to contain oil for an in situ burn are continually being improved, they can be cumbersome, expensive, and broken-down quickly during use.[11,17] For this reason, surface collecting agents (SCAs) – an alternative to fire-resistant booms – are a hot topic in in situ burning research, though they have existed for some time (see sidebar).

SURFACE COLLECTING AGENTS (SCAs) AKA 'CHEMICAL HERDERS'

When applied at the outer edge of an oil slick, SCAs work at the molecular level to 'herd' oil to a smaller area (**Figure 4**).[28] This may enable emergency responders to mechanically recover the oil with skimmers or remove it through in situ burning. The latter is possible because SCAs can create a layer of oil thick enough to sustain an in situ burn.[29,30] In cold climates, SCAs could be valuable as well since ice acts as a physical barrier, making deploying booms difficult.[29] As of 2019, two chemical surface collecting agents – ThickSlick 6535 and OP-40 – are listed on the National Contingency Plan Product Schedule but have never been used in active spill situations.[1,30]

Skimmers

Scientists continue to investigate new ways to increase the efficiency of skimmer design, mechanics, and other response tool pairings.[31,32] Currently, oil recovery is fast when a thick oil layer is present but relatively slow when only a thin layer exists.[12] Additionally, it is difficult to remove all of the oil from the skimmer surface – it often transfers from the skimmer back into the water.[31] To overcome these issues, scientists developed a skimmer with a grooved surface that improves the removal of oil from the water by as much as 33% over traditional skimmers.[31] This modified design works with a wide range of oil types and nearly all the oil on the skimmer can be recovered for disposal. Another method under research increases oil removal efficiency by using a high-tech solidifier to absorb oil in the water and collect it via skimmer.[32]

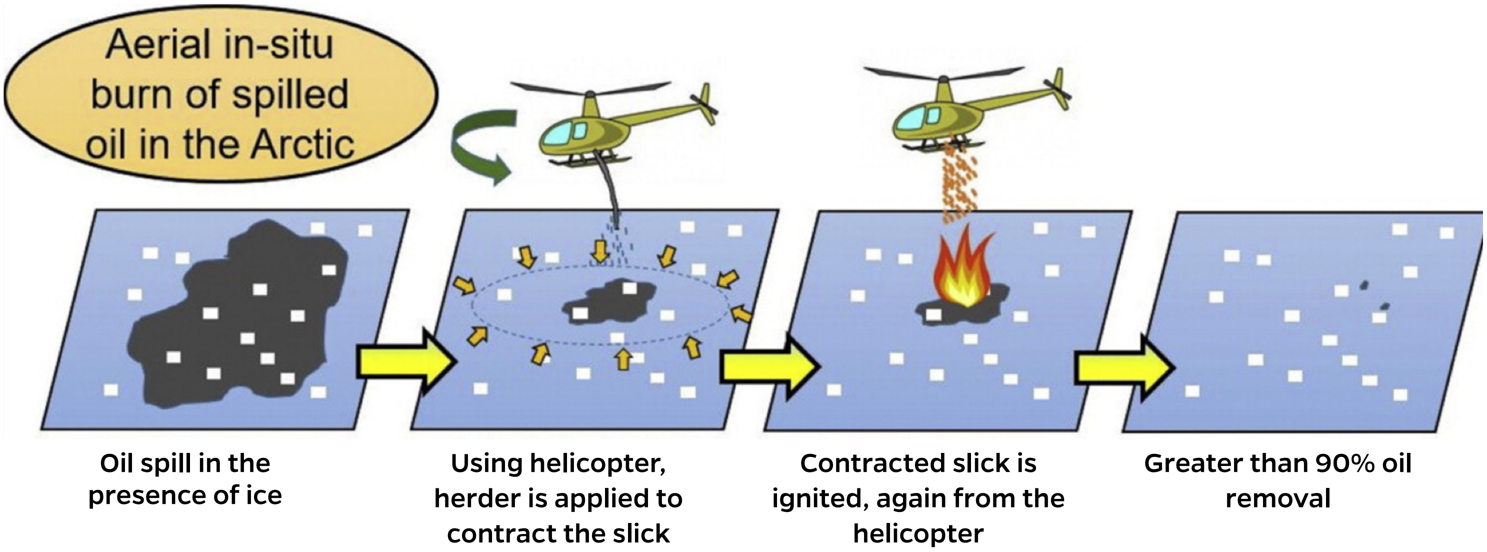


FIGURE 4. *Surface collecting agents (SCAs) – also known as herding agents – can help to thicken an oil slick by herding it into a smaller area. Once the desired oil thickness is achieved, as much as 95% of the oil can be removed from the water via in situ burning. SCAs can also be used to assist skimmers in removing oil from the water. (Reprinted from Aggarwal et al., 2017)*

Sorbents and solidifiers

Sorbents may be made from a variety of materials, both natural and human-made. These often include human-engineered modifications of pre-existing materials such as mixtures of plastics or natural fibers chemically modified to retain less water and more oil.[33,34] The development of aerogels – springy sorbents like those found in diapers – from recycled paper waste are another innovation.[35] These sorbents have an excellent ability to soak up oil but have the added advantage of being biodegradable. In the realm of solidifiers, 'gelators' derived from natural materials like sugar are a focus of innovation.[36-38] Gelators bond with oil to form a gel that can be removed from the water. Naturally-derived gelators are attractive because of their ability to break down in the environment and low toxicity.[38]

WHERE DO WE GO FROM HERE?

The Gulf of Mexico Research Initiative (GoMRI) and others continue to develop an understanding of oil spills. To learn more, visit the GoMRI website at www.gulfresearchinitiative.org. Visit the Gulf Sea Grant program website at http://gulfseagrant.org/oilspilloutreach to view our other publications, about dispersants, sorbents, oil, and other topics.

GLOSSARY

Dispersants — Chemicals that are used during oil spill response efforts to break up oil slicks and limit floating oil from impacting sensitive ecosystems such as coastal habitats.

Heavy oil — Oil, whether crude or refined, that does not flow easily due to its chemical composition.

Light oil — Oil, whether crude or refined, that flows easily due to its chemical composition.

Sediment — Natural materials (including rocks, minerals, and remains of plants and animals) broken down by weathering and erosion, and then transported and deposited to a new location by wind, water, or ice or gravity.

Sorbents — Materials used to absorb oil during oil spill clean-up operations.

Solidifiers — Porous materials that physically bond with oil, causing the oil to solidify for removal during oil spill clean-up operations.

Surfactants — Compounds that work to break up oil. Dispersants contain surfactants that break the oil slick into smaller droplets that can more easily mix into the water column.

REFERENCES

1. U.S. EPA. (2015). Code of federal regulations: Title 40 - Protection of the environment: Part 300 – National oil and hazardous substances pollution contingency plan. Retrieved from ***www.govinfo.gov/content/pkg/CFR-2015-title40-vol28/xml/CFR-2015-title40-vol28-part300.xml***
2. NOAA. (2013). Characteristics of response strategies a guide for spill response planning in marine environments. Retrieved from ***https://response.restoration.noaa.gov/sites/default/files/Characteristics_Response_Strategies.pdf***
3. U.S. Coast Guard. (2014). United States Coast Guard incident management handbook – Incident command system (ICS). Retreived from ***https://www.atlanticarea.uscg.mil/Portals/7/Ninth%20District/Documents/USCG_IMH_2014_COMDTPUB_P3120.17B.pdf?ver=2017-06-14-122531-930***
4. U.S. EPA (2017a). Booms. Retrieved from ***https://epa.gov/emergency-response/booms***
5. National Response Team Science & Technology Committee. (2007). NRT-RRT Factsheet: Application of sorbents and solidifiers for oil spills. Retrieved from ***www.epa.gov/sites/production/files/2013-09/documents/nrt_rrt_sorbsolidifierfactsheet2007finalv6.pdf***
6. Stout, S. A., & Payne, J. R. (2016). Chemical composition of floating and sunken in-situ burn residues from the Deepwater Horizon oil spill. *Marine Pollution Bulletin, 108*(1-2), 186-202.
7. U.S. EPA. (2017b). Skimmers. Retrieved from ***https://epa.gov/emergency-response/skimmers***
8. U.S. EPA. (2016). Sorbents. Retrieved from ***https://archive.epa.gov/emergencies/content/learning/web/html/sorbents.html***
9. Li, P., Cai, Q., Lin, W., Chen, B., & Zhang, B. (2016). Offshore oil spill response practices and emerging challenges. *Marine Pollution Bulletin, 110*(1), 6-27.
10. NOAA. (1997). Oil spill - Behavior, response and planning: August 18 - 22, 1997. Retrieved from ***https://response.restoration.noaa.gov/sites/default/files/open-water-response_ISBatPST_1997.pdf***
11. Mullin, J. V., & Champ, M. A. (2003). Introduction/overview to in situ burning of oil spills. *Spill Science & Technology Bulletin, 8*(4), 323-330.
12. McKinney, K., Caplis, J., DeVitis, D., Van Dyke, K. (2017). Evaluation of oleophilic skimmer performance in diminishing oil slick thickness. Bureau of Safety and Environmental Enforcement. Retrieved from ***www.bsee.gov/sites/bsee.gov/files/osrr-oil-spill-response-research/osrr-1072aa.pdf***
13. NOAA. (2019). SMART. Retrieved from ***https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/smart.html***
14. Bureau of Safety and Environmental Enforcement. (2016). OSRR-1042-Technology readiness level (TRL) definitions for oil spill response technologies and equipment. Retrieved from ***www.bsee.gov/research-record/osrr-1042-technology-readiness-level-trl-definitions-for-oil-spill-response***
15. Ohmsett. (2019). Ohmsett: About the Ohmsett facility. Retrieved from ***www.ohmsett.com/facility.html***
16. Dave, D. & Ghaly, A. E. (2011). Remediation technologies for marine oil spills: A critical review and comparative analysis. *American Journal of Environmental Sciences, 7*(5), 423-440.
17. Fingas, M. (2011). *Oil spill science and technology.* Gulf Professional Publishing.
18. Southward, A. J., & Southward, E. C. (1978). Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the Torrey Canyon spill. *Journal of the Fisheries Board of Canada, 35*(5), 682-706.
19. Nalco. (2005). Material safety data sheet: Corexit 9500®. Retrieved from ***http://masgc.org/assets/uploads/publications/873/6_msds_corexit_9500.pdf***
20. Hemmer, M. J., Barron, M. G., & Greene, R. M. (2011). Comparative toxicity of eight oil dispersants, Louisiana sweet crude oil (LSC), and chemically dispersed LSC to two aquatic test species. *Environmental Toxicology and Chemistry, 30*(10), 2244-2252.
21. Lively, J. A. A., & McKenzie, J. (2014). Toxicity of the dispersant Corexit 9500 to early life stages of blue crab, *Callinectes sapidus. Bulletin of Environmental Contamination and Toxicology, 93*(6), 649-653.
22. Bosker, T., van Balen, L., Walsh, B., Sepúlveda, M. S., DeGuise, S., Perkins, C., & Griffitt, R. J. (2017). The combined effect of Macondo oil and corexit on sheepshead minnow (*Cyprinodon variegatus*) during early development. *Journal of Toxicology and Environmental Health, Part A, 80*(9), 477-484.
23. Barron, M. G., Krzykwa, J., Lilavois, C. R., & Raimondo, S. (2018). Photoenhanced toxicity of weathered crude oil in sediment and water to larval zebrafish. *Bulletin of Environmental Contamination and Toxicology, 100*(1), 49-53.
24. Regional Response Team 6. (2001). RRT-6 FOSC Dispersant pre-approval guidelines and checklist. Retrieved from ***www.glo.texas.gov/ost/spill-response-resources/rrtvi/rrt6.pdf***
25. Owoseni, O., Nyankson, E., Zhang, Y., Adams, D. J., He, J., Spinu, L., . . . & John, V. T. (2016). Interfacial adsorption and surfactant release characteristics of magnetically functionalized halloysite nanotubes for responsive emulsions. *Journal of Colloid and Interface Science, 463*, 288-298.
26. Athas, J. C., Jun, K., McCafferty, C., Owoseni, O., John, V. T., & Raghavan, S. R. (2014). An effective dispersant for oil spills based on food-grade amphiphiles. *Langmuir, 30*(31), 9285-9294.
27. Riehm, D. A., Neilsen, J. E., Bothun, G. D., John, V. T., Raghavan, S. R., & McCormick, A. V. (2015). Efficient dispersion of crude oil by blends of food-grade surfactants: Toward greener oil-spill treatments. *Marine Pollution Bulletin, 101*(1), 92-97.
28. Garrett, W. D. & Barger, W. R. (1972). *Control and confinement of oil pollution on water with monomolecular surface films* (U.S. Navy Naval Research Laboratory Memorandum Report 2451).
29. Aggarwal, S., Schnabel, W., Buist, I., Garron, J., Bullock, R., Perkins, R., . . . Cooper, D. (2017). Aerial application of herding agents to advance in-situ burning for oil spill response in the Arctic: A pilot study. *Cold Regions Science and Technology, 135*, 97-104.
30. Bullock, R. J., Perkins, R. A., & Aggarwal, S. (2019). In-situ burning with chemical herders for Arctic oil spill response: Meta-analysis and review. *Science of the Total Environment, 675*, 705-716.
31. Broje, V., & Keller, A. A. (2006). Improved mechanical oil spill recovery using an optimized geometry for the skimmer surface. *Environmental Science & Technology, 40*(24), 7914-7918.
32. Nam, C., Li, H., Zhang, G., Lutz, L. R., Nazari, B., Colby, R. H., & Chung, T. M. (2018). Practical oil spill recovery by a combination of polyolefin absorbent and mechanical skimmer. *ACS Sustainable Chemistry & Engineering, 6*(9), 12036-12045.

33. Teli, M. D., & Valia, S. P. (2013). Acetylation of Jute fiber to improve oil absorbency. *Fibers and Polymers, 14*(6), 915-919.

34. Saleem, J., Ning, C., Barford, J., & McKay, G. (2015). Combating oil spill problem using plastic waste. *Waste Management, 44*, 34-38.

35. Nguyen, S. T., Feng, J., Ng, S. K., Wong, J. P., Tan, V. B., & Duong, H. M. (2014). Advanced thermal insulation and absorption properties of recycled cellulose aerogels. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 445*, 128-134.

36. Jadhav, S. R., Vemula, P. K., Kumar, R., Raghavan, S. R., & John, G. (2010). Sugar-derived phase-selective molecular gelators as model solidifiers for oil spills. *Angewandte Chemie International Edition, 49*(42), 7695-7698.

37. Vibhute, A. M., Muvvala, V., & Sureshan, K. M. (2016). A Sugar-based gelator for marine oil spill recovery. *Angewandte Chemie International Edition, 55*(27), 7782-7785.

38. Motta, F. L., Stoyanov, S. R., & Soares, J. B. (2018). Application of solidifiers for oil spill containment: A review. *Chemosphere, 194*, 837-846.

39. Lavoie, D., Flocks, J. G., Kindinger, J. L., Sallenger, A. H., Jr., & Twichell, D. C. (2010). *Effects of building a sand barrier berm to mitigate the effects of the Deepwater Horizon oil spill on Louisiana marshes* (U.S. Geological Survey Open-File Report 2010–1108). Retrieved from **https://pubs.usgs.gov/of/2010/1108/**

40. Martínez, M. L., Feagin, R. A., Yeager, K. M., Day, J., Costanza, R., Harris, J. A., . . . & Moreno-Casasola, P. (2012). Artificial modifications of the coast in response to the Deepwater Horizon oil spill: quick solutions or long-term liabilities? *Frontiers in Ecology and the Environment, 10*(1), 44-49.

41. Zengel, S., & Michel, J. (2013). *Deepwater Horizon oil spill: Salt marsh oiling conditions, treatment testing, and treatment history in northern Barataria Bay, Louisiana - Interim Report October 2011* (U.S. Dept. of Commerce, NOAA Technical Memorandum NOS OR&R 42). Retrieved from ***http://response.restoration.noaa.gov/deepwater_horizon***

42. National Academies of Sciences, Engineering, and Medicine (NASEM). (2019). *The use of dispersants in marine oil spill response*. Washington, DC: The National Academies Press. Retrieved from ***www.nap.edu/catalog/25161/theuse-of-dispersants-in-marine-oil-spill-response***

43. Kuhl, A. J., Nyman, J. A., Kaller, M. D., & Green, C. C. (2013). Dispersant and salinity effects on weathering and acute toxicity of South Louisiana crude oil. *Environmental Toxicology and Chemistry, 32*(11), 2611-2620.

44. Powers, S. P., Grabowski, J. H., Roman, H., Geggel, A., Rouhani, S., Oehrig, J., & Baker, M. (2017). Consequences of large-scale salinity alteration during the Deepwater Horizon oil spill on subtidal oyster populations. *Marine Ecology Progress Series, 576*, 175-187.

45. Deepwater Horizon Natural Resource Damage Assessment Trustees. (2016). Deepwater Horizon oil spill: Final programmatic damage assessment and restoration plan and final programmatic environmental impact statement. Retrieved from ***www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan***

46. DeMarini, D. M., Warren, S. H., Lavrich, K., Flen, A., Aurell, J., Mitchell, W., . . . Hays, M. D. (2017). Mutagenicity and oxidative damage induced by an organic extract of the particulate emissions from a simulation of the Deepwater Horizon surface oil burns. *Environmental and Molecular Mutagenesis, 58*(3), 162-171.

47. Zhu, K., Shang, Y. Y., Sun, P. Z., Li, Z., Li, X. M., Wei, J. Q., . . . & Zhu, H. W. (2013). Oil spill cleanup from sea water by carbon nanotube sponges. *Frontiers of Materials Science, 7*(2), 170-176.

ACKNOWLEDGMENT

Special thanks to the many external reviewers who contributed to the betterment of this oil spill science outreach publication.

SUGGESTED CITATION

Maung-Douglass, E., Hale, C., Partyka, M., Sempier, S., Skelton, T., Swann, L., and Wilson, M. (2020). Oil on the water: Insights into oil spill response. GOMSG-G-20-004.

OIL SPILL SCIENCE OUTREACH TEAM

Dani Bailey
Texas Sea Grant College Program
danielle.bailey@tamu.edu

Emily Maung-Douglass
Louisiana Sea Grant College Program
edouglass@lsu.edu

Missy Partyka
Mississippi-Alabama Sea Grant Consortium
m.partyka@auburn.edu

Stephen Sempier
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

Tara Skelton
Mississippi-Alabama Sea Grant Consortium
tara.skelton@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant Consortium
ladon.swann@usm.edu

Monica Wilson
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

Sea Grant
Texas • Louisiana • Florida
Mississippi-Alabama

GULF OF MEXICO
RESEARCH INITIATIVE

NOAA

Sea Grant
LOUISIANA

This work was made possible in part by a grant from The Gulf of Mexico Research Initiative, and in part by the Sea Grant programs of Texas, Louisiana, Florida and Mississippi-Alabama. The statements, findings, conclusions and recommendations do not necessarily reflect the views of these organizations.

GOMSG-G-20-004 December 2020