OIL SPILL SCIENCE

SEA GRANT PROGRAMS OF THE GULF OF MEXICO

DISPERSANT USE AND IMPACTS AFTER THE DEEPWATER HORIZON OIL SPILL

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Chemical dispersants are one of the tools that responders can use when mitigating an oil spill. Dispersants can help reduce the amount of oil on the ocean's surface, protecting animals and coastal areas from oiling and response workers from direct contact with oil and its toxic fumes. The response to the 2010 Deepwater Horizon oil spill included the largest quantity of dispersants ever applied as well as the first use of dispersants at nearly 5,000 feet underwater. Since then, scientists have studied the effectiveness of and impacts from those dispersants and have made efforts to develop new, environmentally safe dispersants.

SYNTHESIS SERIES

The purpose of this publication is to exclusively reflect findings from synthesis activities supported by the Gulf of Mexico Research Initiative (GoMRI). GoMRI synthesis documents are the primary references for this publication. The summary may also include peer-reviewed publications and other reports cited in the GoMRI synthesis activities that help to provide foundation for the topic.

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DISPERSANTS IN OIL SPILL RESPONSE

Oil breaks down in many ways throughout the marine environment (**Figure 1**). Dispersants are typically used in marine spills to help remove large amounts of floating oil from the ocean's surface to protect response workers, animals, and coastal areas. Dispersants do this by breaking apart oil slicks into smaller oil droplets that mix more easily into water and stay submerged beneath the ocean's surface, which makes the oil available for **biodegradation** (**Figure 2**). Individual oil droplets have more surface area compared to a flat oil slick, making it easier for **microbes** to attach onto the droplet and use its carbon as an energy source.[1]

Dispersant formulations include **solvents** and **surfactants**, which can be found in everyday items such as food preservatives, soap, cleaners, medicine, and cosmetics. Solvents and surfactants help compounds that normally stay apart (such as oil and water) more readily mix and stay mixed together. Surfactant molecules have two distinct parts with different properties: one is attracted

Deepwater Horizon oil spill responders prepare to spray dispersants from airplanes to mitigate the effects of oil slicks. (US Coast Guard/Stephen Lehmann)

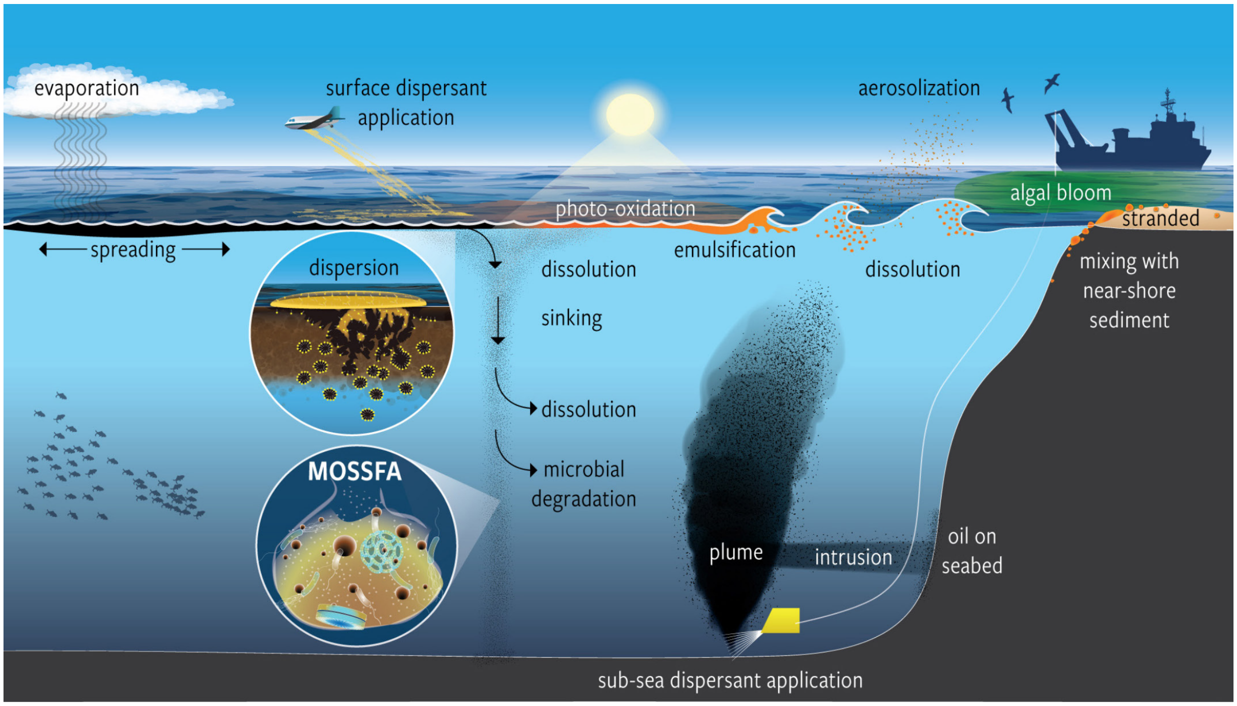

FIGURE 1. Oil breaks down in many ways throughout the marine environment. Dispersants help break oil slicks into smaller droplets that then mix into waters below the ocean's surface, making them more available for biodegradation by microbes and other processes. (Reprinted from Quigg et al., 2021)

to water and the other is attracted to oil. These two properties allow the surfactant to bind to oil and water at the same time, resulting in individual oil droplets with a coating that inhibits their reforming into a slick (**Figure 2**).

Dispersant application in oil spill response has been used more than 200 times worldwide since the 1970s.[a] Dispersant use takes place typically in larger offshore spills and can be used either along with other measures, such as recovering or burning oil at the surface, or alone if those measures are challenging to implement.[a]

For more details, refer to the Sea Grant publication ***Chemical dispersants and their role in oil spill response.***

DISPERSANTS AND THE DEEPWATER HORIZON SPILL

The dispersants used during the DWH spill response were Corexit 9527A and 9500A.[1] Responders sprayed more than one million gallons of these dispersants on oil slicks from airplanes 75 feet above the water in lines about 150 miles wide.[b,2] Dispersant application varied in the location and time it was applied, based on real-time response as oil slicks formed.[1] Responders sprayed no closer than two nautical miles from vessels and platforms and three nautical miles from shore (**Figure 3**).[b]

The response to the DWH oil spill also included the first ever use of dispersants deep below the ocean's surface, called Subsea Dispersant Injection (SSDI). Responders injected

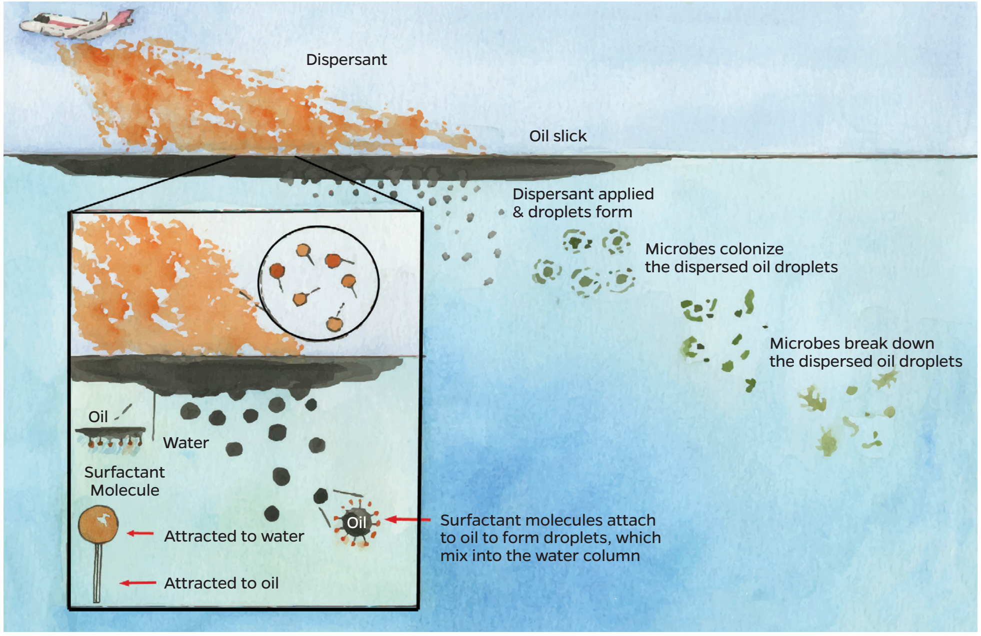

FIGURE 2. Dispersants include solvents and surfactants to help compounds that normally stay apart to mix and stay mixed together. When applied to a slick, dispersants break up oil into smaller droplets that mix in water below the surface making them available for biodegradation by marine microbes. (Anna Hinkeldey)

nearly 770,000 gallons of dispersants 5,000 feet below the surface through a tube inserted into the flow of oil and gas at the wellhead.[a,1] The intent was to extend the time that oil droplets stay floating beneath the surface so microbes could biodegrade the oil and reduce the amount of surface slicks that could harm humans, wildlife, and shorelines.[a] An advantage of SSDI was that responders could apply it around the clock, compared to the surface spraying that had to be done during daylight and in good weather.[b]

Dispersant effectiveness during the Deepwater Horizon oil spill

Answers about dispersant effectiveness during the DWH oil spill are not a straightforward yes or no because of unknowns introduced by the unique aspects of this complex incident. The DWH event was the largest offshore spill in history for which responders used greater volumes of dispersants than ever before and employed the first use of SSDI.[a,3] Decision makers had to quickly weigh the benefits and risks associated with all response measures, giving priority to reducing risks to humans working at the surface. In the case of dispersant use during the DWH incident, those decisions involved difficult tradeoffs such as impacts to deep-sea environments instead of coastlines.[4]

One way to determine dispersant effectiveness is to measure how small oil droplets are (or become) after dispersants have been applied. Scientists determined that droplets with a diameter of less than about 70 microns (roughly the width of a human hair) can stay suspended in salt water.[1] However, the type of measurement needed to understand the sizes of DWH oil and gas droplets before and after SSDI was not available.[a] Thus, scientists had to estimate droplet sizes with and without dispersants using high pressure experiments and modeling techniques (**Figure 4**).[5,6] Dispersants did effectively decrease oil droplet size, but the experiments produced conflicting results on how much SSDI reduced the formation of surface oil slicks.[a]

As the high-pressure flow of hot oil and gas (about 200° F) spewed into the cold deep ocean environment (39° F), it broke into tiny droplets and bubbles.[5,7] Some studies concluded that the SSDI effectively reduced surface slick formation while other studies found that the formation of surface slicks was about the same with or without SSDI.[b,2,7]

Another way to determine dispersant effectiveness is to measure the presence of **hydrocarbons** in the water, although delays in measurements while dispersants are sprayed from planes can affect accuracy.[b] An alternative is to measure the presence of the surfactant dioctyl sodium sulfosuccinate (DOSS), a key component of Corexit, which could indicate how quickly oil components dilute or break down in the ocean.[a] Scientists found high levels of DOSS in the oil plume near the wellhead but low or undetectable levels as they moved farther away from the spill site.[8] They could not directly connect the DWH oil spill to DOSS found in nearshore environments because DOSS is an ingredient in common household items that can enter coastal waters through wastewater systems and runoff.[9]

Even with dispersant use, surface oil slicks formed, which winds and currents pushed to land, affecting approximately 1100 to 1300 miles of

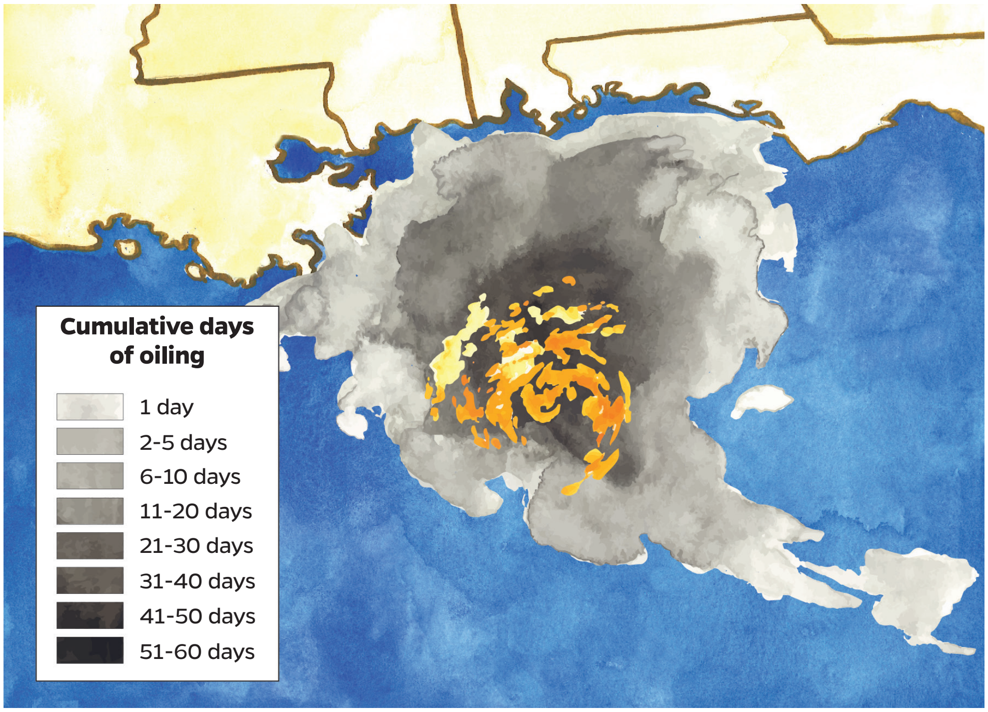

FIGURE 3. From May 15 to July 19, 2010, responders to the Deepwater Horizon oil spill applied chemical dispersants (shown in orange) on top of slicks to break them up into small oil droplets. The shades of gray reflect the total amount of days the area experienced oiling. (Anna Hinkeldey, adapted from Environmental Response Management Application)

FIGURE 4. To better understand the forces of oil and gas released from the Deepwater Horizon wellhead and how droplets formed and dispersed, scientists generated a variety of scenarios in laboratory experiments using an oil surrogate (droplets dyed pick). (Reprinted from Quigg et al., 2021)

shoreline.[10] A third of these shorelines were moderately to heavily oiled, including about 670 miles of the Louisiana coast.[10] A significant portion of oil droplets suspended in the underwater plume either rose to the surface and formed slicks farther away from the spill site or became attached to **marine snow** and sank to the seafloor.[11] Answering questions about outcomes for alternate oil spill response choices is difficult as many of the processes that affect oil spill fate are not yet included in large-scale spill prediction models.[4]

For more details, refer to the Sea Grant publication ***Persistence, fate, and effectiveness of dispersants used during the Deepwater Horizon oil spill.***

DISPERSANTS AND HUMAN HEALTH

As slicks formed during the DWH oil spill, **volatile organic compounds (VOCs)**—including benzene, associated with cancer formation—evaporated into the air. Their presence posed fire hazards and health concerns for cleanup workers and coastal communities.[7,12]

High-pressure experiments and modeling techniques suggest that the SSDI reduced the size of oil droplets and slowed their rise to the ocean's surface.[5,6] In doing so, air quality improved in the vicinity where cleanup work was being carried out, as attested by reports that the workers' respirator alarms, which monitored air quality, stopped going off.[a,7]

Some studies documented air quality, although more research is needed for a comprehensive understanding of risks. For example, scientists monitored air quality along coastlines from Florida to Texas and confirmed no airborne danger from the oil spill to those on shore.[b] A three-year study on responders working with dispersant-related equipment found that they may have experienced short-term negative health impacts on breathing, skin, and eyes.[13] Shortly after the spill started, initial measurements of VOCs near the spill site found them to be below the accepted levels of concern.[b] However, measurement methods were not systematic or from fixed locations, leading to limited data that were difficult to compare with results from laboratory experiments.[a] Recent advancements in analytical chemistry methods may make it possible for future studies on the effects of aerosolized and dispersed oil on human health to include a much wider analysis of oil chemicals than is currently typically done.[14]

Technological advancements since the DWH oil spill offer innovative means to gain insights into health risks from oil spills. For example, wave tank experiments measure VOCs and microdroplets that have entered the air from the interactions of waves, oil, and dispersed oil. Computer modeling techniques help scientists understand the impacts of oil and dispersant microdroplets that enter the air. Finally, techniques used in cigarette studies have applications for how human lung cells respond to oil and dispersants in the air.[15]

DISPERSANTS AND THE MARINE ENVIRONMENT

The SSDI contributed to underwater plumes of suspended oil and gas droplets that drifted with the currents. Scientists estimated that these oil plumes covered an area of approximately 360 square miles, making direct contact with marine life and **sediments** along the continental slope.[10]

Oil droplets in the underwater plume and near the ocean's surface

The main method that responders used to apply dispersants during the Deepwater Horizon oil spill was from small planes that sprayed dispersants as they flew over slicks. (U.S. Air Force/Tech. Sgt. Adrian Cadiz)

attached to floating clumps of sticky biological material, forming marine oil snow that then sank to the seafloor. These large influxes of oil led to unprecedented amounts of marine oil snow that became like a blizzard, transporting about 14% of DWH oil to the seafloor.[10] This cascade of sinking material became known as **Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA)**.[11] The influence of dispersants on marine oil snow formation and the fate and transport of MOSSFA is not well understood, although recent laboratory experiments are providing insights into these complex processes.[a]

Scientist detected oil and dispersants in material that settled on deep-water corals and seafloor sediments as well as in marshes, beach sands, sand patties, and tar mats.[1] Growing concerns arose about impacts from the **toxicity** of oil and dispersants on the marine food web, given that marine oil snow served as food for other organisms. However, isolating the impacts from dispersants alone is difficult when analyzing samples of marine life because dispersants were never used without oil present.[a]

After the DWH spill, scientists conducted laboratory experiments to learn more about the toxicity of dispersants in the marine environment. However, analysis of these laboratory results proved extremely difficult because of variations in experimental design such as dispersant concentrations, exposure times, and subsequent diluting of concentrations in repeated trials.[a] Scientific committees made recommendations to help address issues related to toxicity testing.[2] They include updates to existing experimental designs and the creation of a working group of experts to ensure data collected is better for modeling toxicity.

Extensive testing by federal and state agencies for oil spill contamination of seafood found that it was safe for public consumption.[16] Analysis of 10,000 seafood samples collected from affected areas that had been closed to fishing determined that concentrations of **polycyclic aromatic hydrocarbons (PAHs)**, a group of harmful compounds in oil, were at least two orders of magnitude below levels of public health concern. DOSS from dispersants was detected in less than 1% of samples, also below levels of concern.[16] The seafood safety study focused on PAHs. However, recent advancements in analytical chemistry make it possible, although expensive, to collect data on more than a thousand oil chemicals, leading to a better understanding of how oil and dispersed oil affect seafood and other marine organisms.[14]

For further details, refer to the publications ***Responses of aquatic animals in the Gulf of Mexico to oil and dispersants***, ***Microbes and oil: What's the connection?*** and ***The Deepwater Horizon oil spill's impacts on Gulf seafood.***

FUTURE DISPERSANT USE

Every oil spill is unique. Spill responders make decisions based on the best available scientific information, the prevailing conditions for each accident, the ecosystems that are at risk, and the availability of response tools, which for now include stockpiles of pre-approved dispersants.[4] As the oil and gas industry continue explorations in deep waters, having effective and safe cleanup tools ready to go are essential for response to future accidents.[a]

Some challenges that emerging dispersant technologies face include testing under realistic conditions, acceptance by industry and governmental agencies, and large-scale production and staging for use.[15] To move forward toward viable dispersant options, academic researchers have developed relationships with response agencies and industries that have testing and production-scale capabilities, forming collaborations that show promise for improving future oil spill response.[15]

More research is needed to improve the accuracy of models to compare spill response scenarios that include expected results as well as impacts from using, not using, or combining measures and technologies.[18] Studies also need to integrate ecological, biological, socioeconomic, and cultural considerations to build a comprehensive understanding about the fate and effects of oil and dispersants.[12] This understanding can then be shared with the organizations (government, industry, non-profit) involved with oil spill response leaders to inform their strategies.[a]

TECHNOLOGICAL ADVANCES IN DISPERSANT FORMULATIONS

Scientists have been developing new dispersants as potential alternatives to commercial dispersants, such as Corexit, to address the need for efficient spill remediation tools that are safe for humans and the environment.

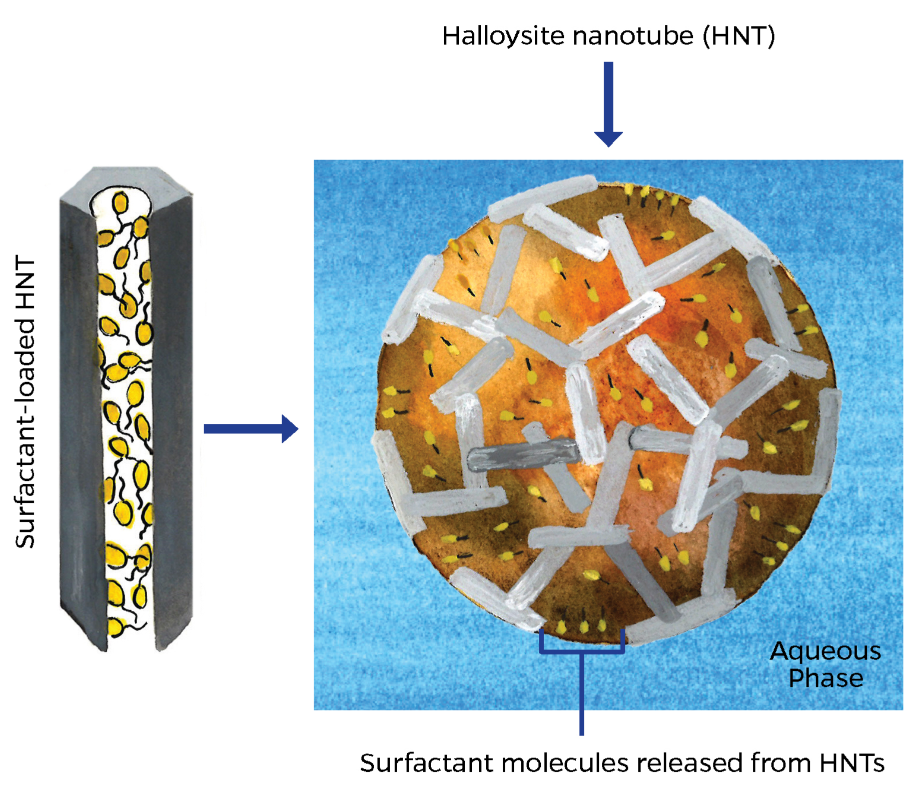

FIGURE 5. Scientists are studying the use of clay halloysite nanotubes (HNTs) as a new dispersant technology. The hollow nanotubes can be filled with surfactants that are slowly released when in contact with an oil slick and effectively disperse oil. These clay particles are economical, abundant, natural, and ecologically friendly. (Anna Hinkeldey, adapted from Owoseni et al., 2014)

A new formulation uses soybean lecithin, a natural and inexpensive substance, that when combined with another surfactant is as effective as Corexit.[b,15] Another potentially effective formulation is a floating gel-like surfactant (lecithin combined with other surfactants) that stays with a slick even when tossed around by waves.[15] A promising development is the use of natural clay particles whose hollow interiors are filled with surfactants that are then slowly released on a surface slick. They extend the time that oil droplets linger below the ocean's surface, hindering their ability to reform as slicks while promoting the growth of microbes and biodegradation (**Figure 5**).[b,17] For more details, refer to the Sea Grant publication ***Emerging surfactants, sorbents, and additives for use in oil spill clean-up.***

GLOSSARY

Biodegradation — The natural breakdown of a substance, especially by bacteria.

Hydrocarbon — A compound composed of carbon and hydrogen atoms. Most hydrocarbons naturally occur in crude oil and natural gas and are formed from decomposed organic matter.

Marine snow — A shower of material (a mix of sediment, fecal matter, mucus released from microbes, phytoplankton, and bits of decaying plants and animals) falling from the surface waters to the deep ocean that can trap oil droplets and carry them to the bottom.

Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA) — The creation of sticky clumps of oil droplets, bacteria, and other floating particles that eventually begin to sink and build up on the ocean floor.

Microbes — Very tiny organisms including bacteria, fungi, archaea, and protists. Some microbes (bacteria and archaea) are the oldest forms of life on earth.

Polycyclic aromatic hydrocarbons (PAHs) — A chemical group found in many sources, including but not limited to oil, tar, ash, coal, car exhaust, chargrilled animal fats, and smoke from burning oil or wood.

Sediments — 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.

Solvent — A liquid that acts to dissolve a substance into a solution, e.g., water is a solvent of salt.

Surfactants — Compounds that work to break up other materials. Soaps and detergents are surfactants.

Toxicity — The impact of certain chemicals on biological systems.

Volatile organic compounds (VOCs) — Gases released from certain solids or liquids, such as oil. Inhaling these compounds for a long period of time can be harmful to one's health.

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Publications resulting from the GoMRI-supported synthesis activities serve as the primary references for this work. Additional supporting literature, either cited in GoMRI synthesis papers or necessary for foundational information about the subject, is also included.

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Scientists and responders collaborate on oil spill research at the Ohmsett experimental facility in Leonardo, NJ. Here, they pour oil into a wave tank to test new dispersant formulations. (Florida Sea Grant/Monica Wilson)

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The GoMRI Research Board established Synthesis & Legacy committees to review 10 years of oil spill science findings. Look for Sea Grant extension publications on these GoMRI synthesis topics:

- Observing and modeling oil plumes and circulation
- Combined ecosystem modeling
- Combined oil spill modeling
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- Microbiology, genetics, and oil spills
- Dispersant-related impacts from oil spill response

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