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Deepwater Horizon Oil Spill: The Fate of the Oil

Updated October 4, 2011

Congressional Research Service
https://crsreports.congress.gov
R41531

CRS REPORT
Prepared for Members and
Committees of Congress

Summary

The April 20, 2010, explosion of the *Deepwater Horizon* offshore drilling rig led to the largest oil spill in U.S. waters. Federal government officials estimated that the deepwater well ultimately released (over 84 days) over 200 million gallons (or 4.9 million barrels) of crude oil. Although decreasing amounts of oil were observed on the ocean surface following the well's containment on July 15, 2010, oil spill response officials and researchers have found oil in other places. A pressing question that has been raised by many stakeholders is where did the oil go?

On August 4, 2010, the federal government released an estimate of the oil spill budget for the *Deepwater Horizon* incident. On November 23, 2010, the federal government released a peer-reviewed "Technical Document" that further explained how the estimates were derived, and in some cases, modified the initial estimates. The oil budget estimates divide the released oil into seven categories, accounting for the following percentages of the total oil released. These categories generally fall into three groups:

1. Human intervention: direct recovery from the well (17%), in situ burning (5%), skimmed (3%), chemically dispersed (16%).
2. Natural Processes: naturally dispersed (13%), evaporated or dissolved (24%).
3. Other (22%): refers to the oil remaining after subtracting the above estimates from the total estimated release; possible fates include remaining in the water column, settling to the sea floor, mixing with sediment, ingested by microbes, or collected during shore cleanup activities.

Direct observation and measurement of the fate of the vast majority of the estimated 200 million gallons of oil presents a considerable challenge. In some cases, the estimates used to calculate these percentages contain considerable uncertainty. Even assuming that approximately half of the oil has been removed from the Gulf ecosystem through direct recovery, burning, skimming, or evaporation, the fate of the remaining ("other") oil is unknown.

It is debatable whether the fate of the remaining oil will ever be established conclusively, because multiple challenges hinder this objective: the complexity of the Gulf system, resources required to collect data, and varied interpretations over the results and observations. Moreover, as time progresses, determining the fate of the oil will likely become more difficult. Regardless, the question of oil fate will likely be answered through an incremental process. Researchers are continuing to study various components of the Gulf, specifically damages to natural resources. Some of these efforts may provide clues to the oil's fate.

Because evaluating the actual fate of the oil may take time and may prove difficult, perceptions of the oil's fate may influence congressional interest and action, with consequences for the affected stakeholders. The perception of the spill's fate may be influenced by multiple factors, including oil spill assessments, the group that prepared the assessment, and the manner in which the assessment is presented. If policymakers have the perception that the oil has degraded with minimal impacts to the environment, attention to the oil spill's consequences and associated impacts may wane. On the other hand, a perception that a substantial volume of oil remains and poses a threat to the environment could result in continuing pressure on Gulf industries and livelihoods.

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Introduction

On April 20, 2010, the *Deepwater Horizon* oil drilling rig was reportedly nearing completion of a deepwater oil well (owned by BP) when an uncontained release of hydrocarbons (oil and natural gas) caused explosions and fire, resulting in 11 crew member fatalities. The incident produced the largest oil spill that has occurred in U.S. waters, eclipsing the magnitude of the 1989 *Exxon Valdez* spill after four to five days. The spill spanned approximately 84 days, and following several attempts, responders gained control of the oil discharge on July 15, 2010. Based on the most recent estimate from the federal government's Flow Rate Technical Group,[1] the deepwater well ultimately released more than 200 million gallons (or 4.9 million barrels) of crude oil (see "Well Flow Rate Estimates" below).[2] The uncertainty range of this estimate (+/-10%) is equivalent to two *Exxon Valdez*-size spills in either direction.[3]

Following the well's containment, satellite data began to reveal decreasing daily quantities of oil on the ocean's surface. (See **Appendix** for a snapshot of satellite analyses from selected days during the spill.) According to the federal government's GeoPlatform database, August 20, 2010, was the first day since the spill's start in which no oil was observed on the ocean's surface.[4] After several days without observed oil on the ocean surface, the satellite analyses were discontinued on August 25, 2010.

Although decreasing amounts of oil were observed on the ocean surface following the well containment, oil spill response officials and researchers have found oil in other places. A pressing question raised by many stakeholders is where did the oil go?

Assessing the oil's fate is the primary objective of this report. For the purposes of this report, the term *fate* refers to the oil itself, not its actual or potential impacts on the Gulf ecosystems or organisms. The impact of the 2010 Gulf spill is still being assessed and will likely continue to be assessed for years to come.[5]

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[1] U.S. Department of the Interior, Press Release, "U.S. Scientific Teams Refine Estimates of Oil Flow from BP's Well Prior to Capping," August 2, 2010, at http://app.restorethegulf.gov/release/2010/08/02/us-scientific-teams-refine-estimates-oil-flow-bps-well-prior-capping.

[2] As will be discussed, an estimated 17% of this oil did not enter the Gulf environment, but was directly recovered from the wellhead by BP.

[3] Several non-governmental groups have subsequently produced estimates that are comparable to the federal government's calculation. See Timothy J. Crone et al., "Magnitude of the 2010 Gulf of Mexico Oil Leak," *Science Express*, September 23, 2010. A Wood's Hole Oceanographic Institution team also produced a similar estimate, described in National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *The Amount and Fate of Oil*, Staff Working Paper, released October 6, 2010, at http://www.oilspillcommission.gov.

[4] See the GeoPlatform interactive mapping and database tool at http://www.geoplatform.gov/gulfresponse/index.html. To track the observed oil data, click "View Interactive Map." Use the "layers" tab and select "BP Deepwater Horizon Oil Spill" and then "Satellite, Radar, and Aerial Images of the Spill."

[5] For further reading, see e.g., CRS Report R41407, *Deepwater Horizon Oil Spill: Highlighted Actions and Issues*, by Curry L. Hagerty and Jonathan L. Ramseur; CRS Report R41396, *The 2010 Oil Spill: Natural Resource Damage Assessment Under the Oil Pollution Act*, by Kristina Alexander; CRS Report R41485, *Reorganization of the Minerals Management Service in the Aftermath of the Deepwater Horizon Oil Spill*, by Henry B. Hogue.

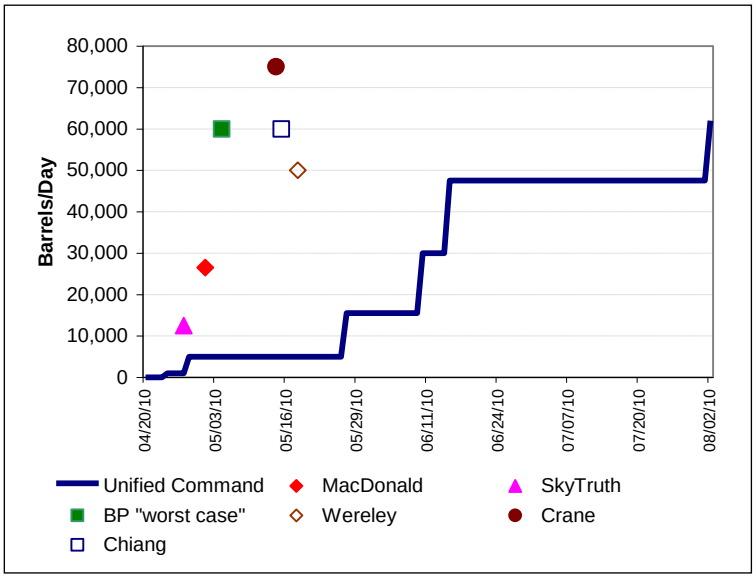
Well Flow Rate Estimates

Throughout the oil spill response, the estimated flow rate received considerable attention and generated considerable controversy. **Figure 1** illustrates the Unified Command's flow rate estimate over time, culminating in an August 2 estimate of 62,000 barrels per day.[6] For comparison purposes, **Figure 1** identifies other estimates that were offered during the response and the general time frame in which they were made. These additional estimates come from independent scientists and an environmental advocacy group, as well as a worst-case scenario BP provided responders. A staff paper from the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling documents this chain of events.[7]

The flow rate estimates and associated issues[8] are beyond the scope of this report. For the purposes of this report, the ultimate flow rate estimate is an important piece of information, because it determines the magnitude of the spill volume. The uncertainty in the flow rate estimate affects the uncertainty in the magnitude of various oil fates. In addition, the underestimated flow rate may have played a role in the degree to which the oil was monitored.[9]

Figure 1. Flow Rate Estimates during Response

Comparison of Selected Estimates



Source: Prepared by CRS; estimates and timeline from National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *The Amount and Fate of Oil*, Staff Working Paper, released October 6, 2010, at http://www.oilspillcommission.gov.

Notes: Details regarding the sources of the above estimates are provided in the Commission publication (cited above). In some cases, the estimates were presented as a range. For example, the Chiang estimate was between 20,000 and 100,000 barrels/day. In such cases, the middle point of the range was used in the figure.

[6] U.S. Department of the Interior, Press Release, "U.S. Scientific Teams Refine Estimates of Oil Flow from BP's Well Prior to Capping," August 2, 2010, at http://app.restorethegulf.gov/release/2010/08/02/us-scientific-teams-refine-estimates-oil-flow-bps-well-prior-capping.

[7] The Amount and Fate of Oil, Staff Working Paper, released October 6, 2010, at http://www.oilspillcommission.gov.

[8] Issues may include (1) the relationship between flow rates and potential Clean Water Act penalties (see CRS Report R41370, *Federal Civil and Criminal Penalties Possibly Applicable to Parties Responsible for the Gulf of Mexico Oil Spill*, by Robert Meltz); and (2) possible impacts of underestimated rates on response efforts (see National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Stopping the Spill: The Five-Month Effort to Kill the Macondo Well, Staff Working Paper, released November 22, 2010).

[9] For example, if the early flow rates had indicated a greater volume of oil was not reaching the ocean surface, might responders have initiated a more comprehensive subsea monitoring program?

Because evaluating the actual fate of the oil may take time and may prove difficult, perceptions of the oil's fate may influence congressional interest and action, with consequences for the affected stakeholders. These perceptions may be influenced by multiple factors, including oil spill assessments and their methods, the group that prepared the assessment (and perceived biases of the group), and the manner in which the assessment is presented. If policymakers have the perception that the oil has degraded with minimal impacts to the environment, attention to oil spill's consequences and associated impacts may wane. On the other hand, a perception that a substantial volume of oil remains and poses a threat to the environment could result in continuing pressure on Gulf industries and livelihoods.

The fate of the oil may be of interest to policymakers for other reasons, including oversight of oil spill response performance and assessment of the government's capability to monitor oil spills in the environment.

Factors that Impact an Oil Spill's Fate

Multiple factors play a role in determining the fate of oil released into a marine environment. These include the chemical composition of the oil, a complex collection of natural processes and pathways, the location of the spill or discharge, and human intervention.

Composition of the Oil

The chemical composition of oil plays a critical role in how it reacts in an environment. The 2010 Gulf spill involved crude oil, which is not a homogenous material, but contains a mixture of chemical compounds that interact differently when exposed to the environment. According to a 2003 National Research Council report,[10] evaporation can remove about one-third of the volume of a medium crude oil slick within the first day of a release. However, other components of the crude oil may persist for much longer. For instance, the fraction of crude oil that is water soluble can persist for weeks to years.[11] Other portions of spilled crude oil often form into tar balls, which are persistent and may be transported great distances from the release site. The crude oil released during the 2010 spill is relatively lighter than other crude oil, and thus may evaporate more readily.

Natural Processes

When oil enters a marine environment it encounters an array of natural processes that transport the oil from its point of origin and alter its physical and chemical makeup. These combined physical and chemical changes are often described as "weathering." The altered materials will be incorporated into the planet's various natural systems: water, soil, air, or living organisms.[12] The time involved in these changes can range from a matter of minutes and hours for some crude oil components to years (possibly decades)[13] for other components. **Figure 2** illustrates the processes and pathways involved.

[10] National Research Council, Oil in the Sea III: Inputs, Fates, and Effects, (hereinafter NRC Report, 2003) National Academies Press, 2003.

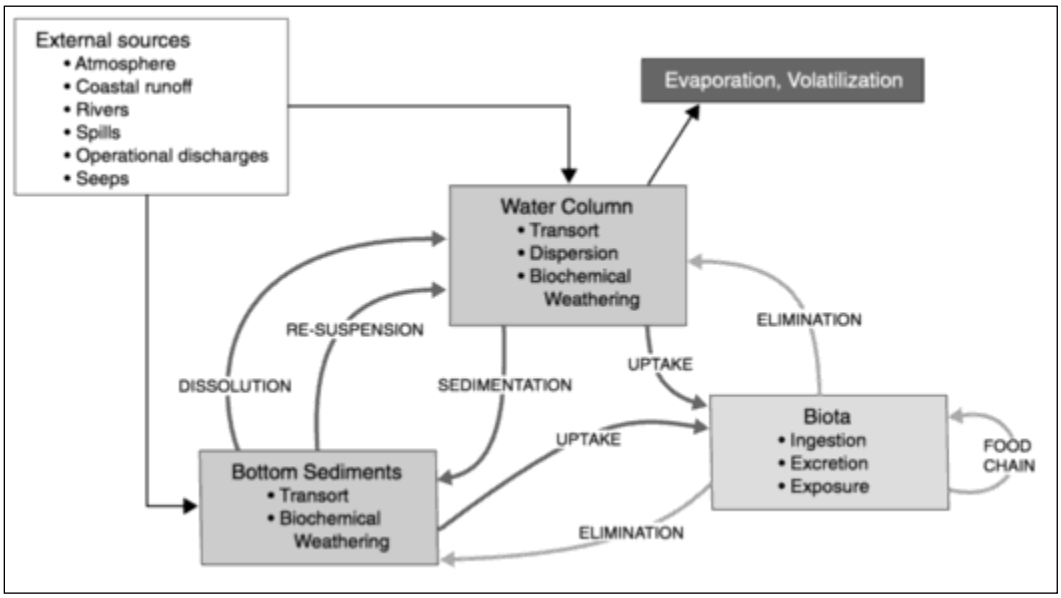
[11] This fraction includes a wide range of polycyclic aromatic compounds (PAH), which appear to pose the greatest toxicity to the environment. NRC Report, 2003, p. 114.

[12] For a more detailed discussion, see NRC Report, 2003, Chapter 4 ("Behavior and Fate of Oil").

[13] See e.g., Daniel Esler et al., "Cytochrome P4501A Biomarker Indication of Oil Exposure in Harlequin Ducks up to

Figure 2. Fate of Oil in a Marine Environment

Processes and Pathways



Source: Reproduced from National Research Council, Oil in the Sea III: Inputs, Fates, and Effects, National Academies Press, 2003, Figure 4-1. This document provides a comprehensive discussion of these processes/pathways.

Location of Spill

The location of an oil release plays a significant role in determining the oil's fate. Various attributes of an affected marine environment will influence the degree to which natural processes (identified above) interact with the introduced oil. For example, warmer water temperatures will generally expedite some natural processes, such as evaporation, biodegradation, and dissolution.[14]

Severe weather events, which are common during the Gulf's hurricane season, could also influence an oil spill's fate. For example, a storm event may transport oil to sensitive locations or cause settled oil to become resuspended in the water column. Moreover, in the *Deepwater Horizon* incident, severe weather events can impede human response activities or allow oil to breach manmade barriers (e.g., booms).

The 2010 Gulf spill presented a unique combination of location factors that likely played a part in the oil's fate. First, the origin of the release occurred at a water depth of approximately 5,000 feet. According to the 2003 National Research Council report, this type of scenario introduces a number of complications compared to oil released at the surface (e.g., from a tanker spill). Although some research has found that the majority of oil from a deepwater release will reach the surface in several hours, the resulting surface slick may be thinner (compared to a typical surface spill), because some of the oil will be naturally diffused and dispersed as it rises to the surface.[15] Second, the oil well blowout was a multi-day event, discharging the oil into the Gulf waters at a

20 Years after the Exxon Valdez Oil Spill," *Environmental Toxicology and Chemistry*, Vol. 29, No. 5, published online January 2010, pp. 1138–1145.

[14] For further discussion, see NRC Report, 2003.

[15] NRC Report, 2003, p. 108, citing a 2001 study: Johansen et al., "DeepSpill—Field Study of a simulated oil and gas blowout in deep water," *Proceedings Intern. Marine Environmental Modeling Seminar*. New Orleans, LA, 2001.

rapid rate. Some have surmised that this high-speed discharge increased the rate at which the oil naturally dispersed. Third, some initial scientific studies have suggested that microbial organisms, which essentially eat certain oil components, may play a part in controlling the oil's ultimate fate (discussed below).

Human Intervention

In the 2010 Gulf spill, responders employed a combination of mechanical removal (e.g., booming and skimming), *in situ* burning, and surface and sub-surface chemical dispersant application to remove the oil from the open waters of the Gulf. These applications yield different consequences for the oil's fate. Mechanical removal essentially takes a portion of the surface oil out of the environment. *In situ* burning removes the oil from the marine environment, but may transfer some of the pollution risk to the air. Particulate matter (PM) from in situ burning is "considered by most health professionals to be the main combustion product to investigate and monitor."[16] During the oil spill, EPA monitored for PM at the shoreline and found the levels to be consistent with Gulf Coast summertime levels.[17]

Use of chemical dispersants in response to the Gulf spill has received considerable attention. Dispersants are chemical agents that enhance the breakup of an oil slick into small oil droplets that mix with the water column. Dispersant application does not reduce the amount of oil entering the environment; instead, dispersants alter the physical properties of oil, changing its transport, fate, and potential effects.[18] In general, a decision to use dispersants poses trade-offs for oil spill responders. The objective of dispersant use is to minimize the amount of surface oil that reaches shoreline habitats, where it threatens a wide range of animals and plants. The downside is that dispersants increase water column organisms' exposure to oil. As stated in a 2005 National Research Council study, "[d]ispersant application thus represents a conscious decision to increase the hydrocarbon load (resulting from a spill) on one component of the ecosystem (e.g., water column) while reducing the load on another (e.g., coastal wetland)."[19]

Federal responders authorized the use of approximately 1.8 million gallons of dispersants in the Gulf. Approximately 42% of this dispersant volume was applied at the point where oil was escaping the wellhead, an unprecedented sub-surface application. Excepting a relatively minor application on July 19, dispersant use halted when the well was sealed on July 15.[20] While dispersants have proven effective in breaking up the oil, impacts from the chemically dispersed oil (and the chemical dispersants) are unknown.[21]

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[16] Nir Barnea (National Oceanic and Atmospheric Administration), "Health and Safety Aspects of In-situ Burning of Oil," at http://response.restoration.noaa.gov/book_shelf/655_health.pdf.

[17] See EPA, "Air Data from the Gulf Coastline," at http://www.epa.gov/bpspill/air.html#aqi.

[18] For a more comprehensive discussion, see National Research Council, *Oil Spill Dispersants: Efficacy and Effects* (National Academies Press, 2005).

[19] Ibid.

[20] EPA, The Federal Government Response: Dispersant Use in the BP Oil Spill, at http://www.restorethegulf.gov/sites/default/files/imported_pdfs/external/content/document/2931/835583/1/Fact%20Sheet%20Dispersants%20july%2029%202010-1.pdf.

[21] EPA conducted some laboratory tests on the dispersants used in the Gulf spill. Of the eight dispersants evaluated (on the two test species), EPA found that the dispersants alone were less toxic than the dispersant-oil mixture. For more information, see EPA's Toxicity Testing of Dispersants, at http://www.epa.gov/bpspill/dispersants-testing.html.

The Federal Government's Oil Budget Estimates

On August 4, 2010, the National Incident Command (the spill response leadership team of the federal government) made public an estimate of the oil spill budget for the *Deepwater Horizon* incident.[22] The release of the estimate received considerable media attention and was accompanied by a press conference, attended by key Administration personnel: Thad Allen (National Incident Commander), Jane Lubchenco (Administrator of the National Oceanic and Atmospheric Administration, NOAA), Carol Browner (Director of the White House Office of Energy and Climate Change Policy), and Robert Gibbs (White House Press Secretary).

A number of questions were raised about the August 4 estimates, in part because of limited detail about how the estimates were developed (see "Criticism of the August 2010 Oil Budget Estimates" below). On November 23, 2010, the federal government released a peer-reviewed "Technical Document" that further explained how the estimates were derived; in some cases, the November document modified the August estimates. The Technical Document explained that the oil budget estimates were and will continue to be used for operational and response purposes, not to track the final fate of the spilled oil.[23] Although the November Technical Document stresses this point in its text, the August oil budget estimates appear to have been used exactly for this latter purpose.

[22] The release includes two documents, both made public August 4, 2010: "Deepwater Horizon MC252 Gulf Incident Oil Budget: Government Estimates through August 01 (Day 104)" and "BP Deepwater Horizon Oil Budget: What Happened To the Oil?"

[23] The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team, *Oil Budget Calculator: Deepwater Horizon-Technical Documentation*, November 2010.

Criticism of the August 2010 Oil Budget Estimates

After the government released its initial oil budget estimate, some scientists questioned specific aspects of the analysis; others criticized the way in which the estimates were presented by high-level administration officials. This chain of events is documented in a staff working paper prepared by the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling.[24]

One of the primary critiques of the oil budget was that it offered precise figures (to the barrel) for various estimates. These fixed amounts give the impression that the estimates carry more certainty than is the case. Similarly, the budget documents do not provide uncertainty ranges for various estimate categories, some of which may have considerable error bars (as shown in the November release). As a possible demonstration of the uncertainty, a group of scientists with the Georgia Sea Grant program estimated substantially lower amounts for the evaporation category.[25]

Another critique of the August oil budget was the way in which certain oil fate categories were initially described during interviews and press conferences, arguably giving the impression that large percentages of the oil budget were of little concern. For example, the categories of naturally dispersed, chemically dispersed, and evaporated/dissolved were initially grouped together and described as "gone" in some verbal communications.[26] However, the National Commission working paper charts a progression of statements from Administration officials, which over time, included more caveats and clarifications. Some of these caveats and clarifications were present in the August oil budget document from the start. For example, the August oil budget stated that "until it is biodegraded, naturally or chemically dispersed oil, even in dilute amounts, can be toxic to vulnerable species."[27]

Oil Budget Categories

The August and November oil budget estimates describe the oil as being in one of seven categories, which can be placed into three groups: human intervention, natural processes, and other. The estimates below are from the November 2010 oil budget document, which are based on calculations made July 14, 2010 (**Figure 3**).

[24] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *The Amount and Fate of Oil*, Staff Working Paper, released October 6, 2010, at http://www.oilspillcommission.gov. President Obama established the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling on May 22, 2010. The commission is tasked with providing recommendations on how to prevent—and mitigate the impact of—any future spills that result from offshore drilling. The commission's final report is due to the President by January 12, 2010.

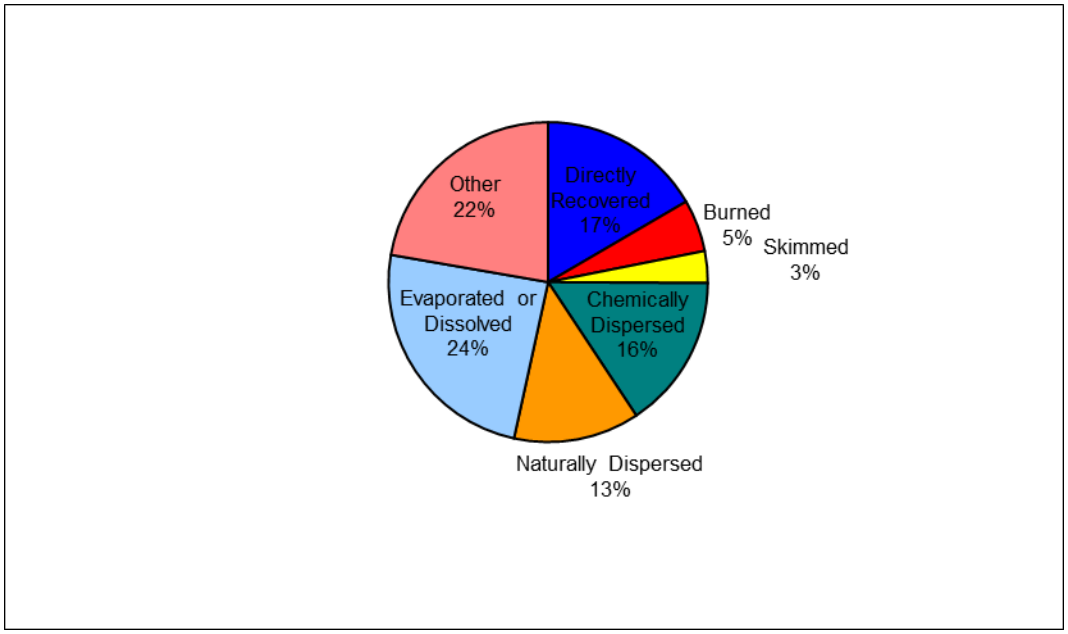
[25] Chuck Hopkinson, Outcome/Guidance from Georgia Sea Grant Program: Current Status of the BP Oil Spill, August 17, 2010.

[26] Recounted in the National Commission Working Paper.

[27] National Commission, Working Paper, pp. 20-23.

Figure 3. Federal Government's Oil Budget

Based on the "Expected" Estimates Calculated July 14, 2010



Source: Reproduced by CRS using estimates provided the Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team, Oil Budget Calculator: Deepwater Horizon-Technical Documentation, November 2010.

Human Intervention

- **Direct recovery from wellhead:** This refers to the direct capture of oil from the discharging well and its pipeline transport to surface level vessels. Of the seven categories, this quantity—820,000 barrels (~34 million gallons)—is the only category based on direct measurement and is thus the most precise figure, accounting for 17% of the total estimated release.
- **Burned:** The Oil Budget estimates that responders burned 260,000 barrels (~11 million gallons) of oil *in situ*—5% of the total estimated release. The Oil Budget states that the authors used American Society for Testing and Materials (ASTM) burn rate standards in their calculations, with different rates for non-emulsified and emulsified oil.[28]
- **Skimmed:** Although the estimate of skimmed oil is based on an actual measurement—barrels of oil/water mixtures collected—the estimate is a "rough calculation" due to the uncertainty of net oil in the oily water. Measurements of oil-water ratios were not available, so the oil budget authors based skimmer performance on sea conditions, nature of the oil, and past experience.[29] The oil budget estimate is 160,000 barrels (~6.7 million gallons)—3% of the total

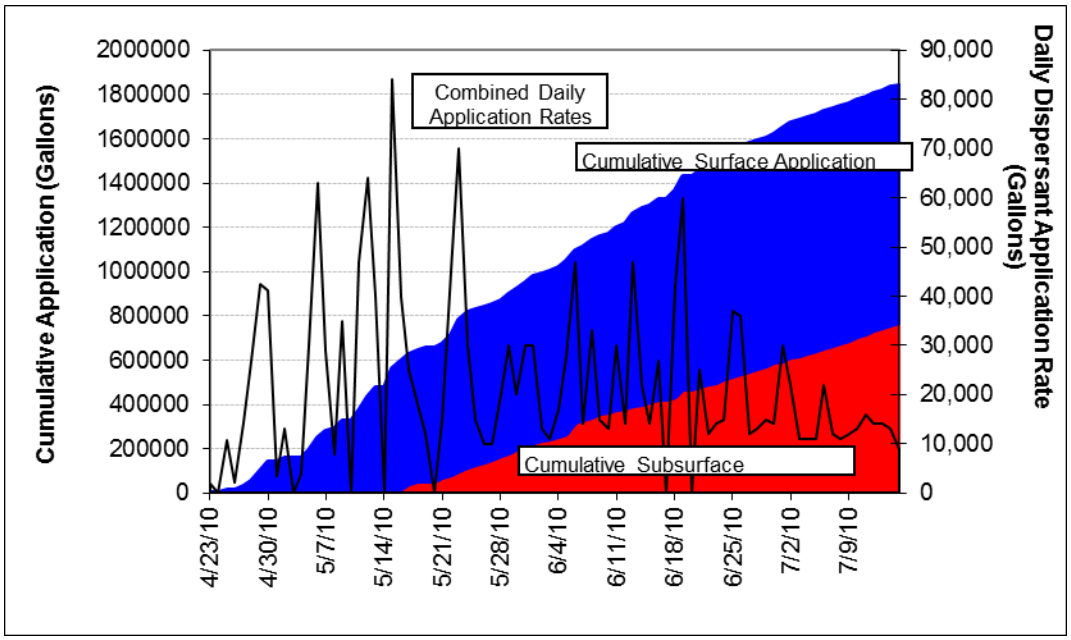
[28] An EPA document suggests the burned estimates are more uncertain than presented in the oil budget documents. According to EPA, responders conducted 411 controlled burn events, combusting an estimated 222,000 to 313,000 barrels of oil (or 9.3 million to 13.1 million gallons), at http://www.epa.gov/research/dioxin.

[29] The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team, *Oil Budget Calculator: Deepwater Horizon-Technical Documentation*, November 2010, p. 33.

estimated release. Although oil spill recovery rates average approximately 15%,[30] "historically, recovery from major spills has amounted to only a few percent, if there was any recovery at all."[31]

- **Chemically dispersed:** The budget estimates that 770,000 barrels (~32 million gallons) of oil were dispersed through the application of 1.8 million gallons of surface and sub-surface chemical dispersants (**Figure 4**)—16% of the total estimated release. This estimate represents a near doubling (88%) compared to the August document, by far the most the most significant modification. The authors note that the original estimate was conservative, and now represents the low end of the estimate range. The range of uncertainty for chemically dispersed oil dwarfs the uncertainties for other categories (**Figure 5**). The Technical Document states: "Estimating effectiveness of these dispersant operations was the most difficult challenge in constructing the Budget Calculator, given the present state of oil response technology."[32] In particular, experts could not reach an agreement on the underlying assumption for subsurface application.

Figure 4. Surface and Subsurface Chemical Dispersant Application During the 2010 Gulf Oil Spill



Source: Prepared by CRS with data from daily "Current Operations" updates, available at http://www.restorethegulf.gov/.

Natural Processes

- **Naturally dispersed:** The budget estimates that 630,000 barrels (~26 million gallons) of the oil were naturally dispersed—13% of the total estimated release

[30] National Research Council, *Spills of Non-Floating Oils*, National Academy Press, 1999.

[31] Office of Technology Assessment, *Coping with an Oiled Sea*, 1990.

[32] The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team, *Oil Budget Calculator: Deepwater Horizon-Technical Documentation*, November 2010, p. 25.

(**Figure 3**).[33] The authors define dispersed oil as droplets smaller than 100 micron (approximately the diameter of a human hair). The Technical Document's discussion of the natural dispersion calculation suggests this estimate is based on several assumptions. Although the Technical Document data used to generate the uncertainty ranges in **Figure 5** showed no uncertainty range for the "naturally dispersed" category, the text of the Technical document discusses an uncertainty factor for both natural subsurface and natural surface dispersion.[34] The reason for this apparent omission is not specified.

- **Evaporated or dissolved:** The budget estimates that 1.2 million barrels (~50 million gallons) of oil evaporated or dissolved—24% of the total estimated release (**Figure 3**). The authors state that they achieved this estimate by applying an evaporation rate specific to the type of oil released to the amount of oil estimated to have reached the surface (and not removed through *in situ* burning). Although the evaporation and dissolution processes are lumped together, the evaporation process likely dominates this grouping. According to a 2003 National Research Council report, medium crude oil can lose up to 40% of its volume within a few days. By contrast, "dissolution accounts for only a small portion of oil loss."[35] However, the Oil Budget Technical Document indicates that dissolution likely played a larger role in the Gulf spill than typical surface spills: "because of the nature and depth of the release, dissolution of oil into the water column was a significant weathering factor."[36]

Other

The "other" category is essentially the portion that remains after subtracting the above category measurements/estimates from the total amount of oil estimated to have released. Such a calculation yields 1.1 million barrels (~46 million gallons)—22% of the total estimated release (**Figure 3**). This category includes "oil on or just below the surface as light sheen and weathered tar balls, washed ashore or collected from shore, or buried in sand and sediments and may resurface through time."

Inherent Uncertainty

Most of the estimated categories of the oil's fate contain some degree of uncertainty, because the estimates are not based on direct measurement or observation.[37] Instead, the oil budget analysts employed formulas and assumptions based on "theoretical considerations and expert knowledge from past incidents."[38]

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[33] This is a 3% decrease from the August estimate. Although not explained, the decrease is likely due to the increase in chemically dispersed oil. See pp. 5-6 of the Technical Document.

[34] See p. 23 and p. A1.9.

[35] NRC Report, 2003, pp. 90-93.

[36] The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team, *Oil Budget Calculator: Deepwater Horizon-Technical Documentation*, November 2010, p. 16.

[37] "There are very few variables in the overall set of theoretical equations which are actually populated by real measurements, observations, or even observation-based estimates …. it cannot be stressed enough that it is not appropriate to use the results in post-spill evaluations of impact or response actions." Peer review comments in Appendix 10 of Technical Document, p. A10.24.

[38] Technical Document, p. iv.

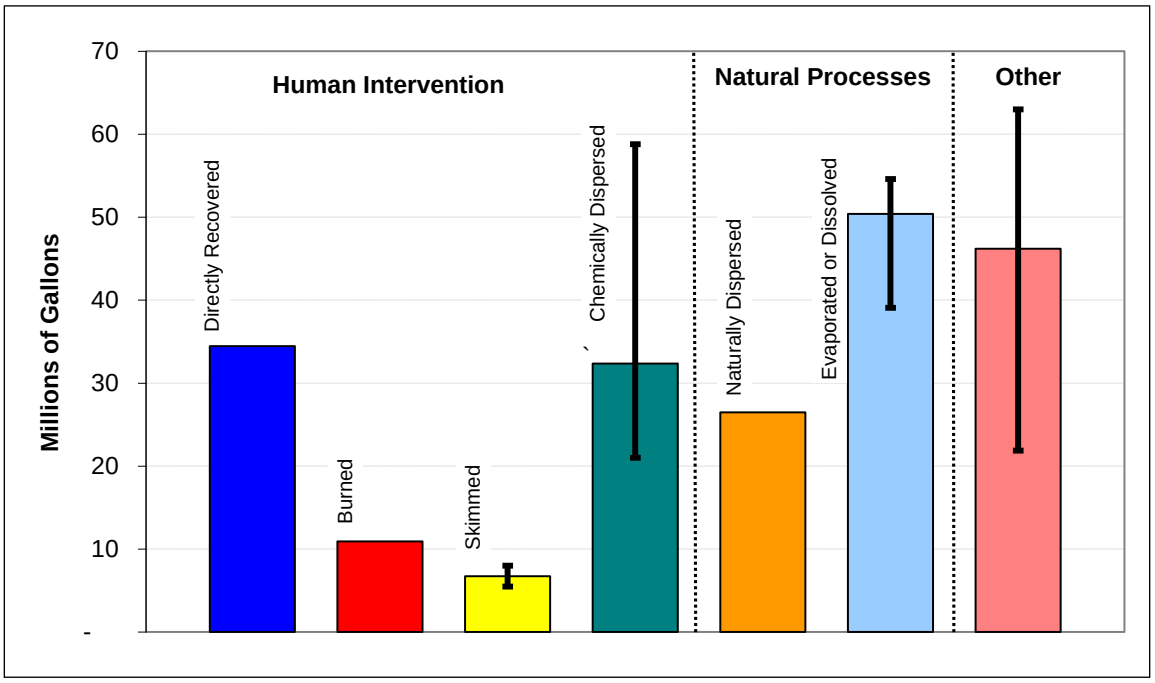
Although the uncertainty behind the estimates was not stressed in the August document, the November Technical Document underscores the uncertainties in multiple instances. The document points out the estimates represent a snapshot in time and are likely to change with new information, stating "the final mass balance calculation of the Deepwater Horizon Spill lies somewhere in the future, to be produced only after all the appropriate and necessary studies will have been completed."[39]

The November Technical Document includes uncertainty ranges for some of the various categories. These are illustrated in **Figure 5**. The columns illustrate the "expected" case estimates. The uncertainty bars represent the range between the best and worst case scenarios.

Some may question the usefulness of releasing the estimates to the public, considering (1) the level of uncertainty (particularly the magnitude—tens of millions of gallons) and (2) the stated purpose of the oil budget being solely for oil spill responders. A potential concern of making the estimates public is that the estimates may be misapplied, leading to false perceptions of the oil's fate. Others may counter that the government should share data/information when it is available. This debate is beyond the scope of this report, but it may be an issue policymakers should consider for future oil spill responses.

Figure 5. Federal Government Oil Budget Estimates and Ranges of Uncertainty

Based on July 14, 2010, Estimates



Source: Prepared by CRS using estimates provided the Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team, Oil Budget Calculator: Deepwater Horizon-Technical Documentation, November 2010, p. 39.

Notes: The columns illustrate the "expected" case estimates. The uncertainty bars represent the range between the best and worst case scenarios. Although the data (from Figure 12) used to generate the uncertainty ranges above showed no such range for the "naturally dispersed" category, the text of the Technical document discusses an uncertainty factor for both natural subsurface and natural surface dispersion.

[39] Ibid., p. 2.

What Happened to the *Remaining* Oil?

Even assuming that approximately half of the oil has been removed from the Gulf marine environment through direct recovery, burning, skimming, or evaporation,[40] a substantial portion of oil—over 100 million gallons—remained in the Gulf as of the Oil Budget estimate. Where is the remaining oil and what is its physical and chemical state?

Some data and ongoing studies offer some clues that could provide a partial and preliminary answer. One of the more comprehensive of these studies was released December 17, 2010, by the Unified Command's Operational Scientific Advisory Team (OSAT).[41] This report (hereinafter referred to as the "OSAT report") provides results from samples collected from May through October 2010 in the Gulf's nearshore, offshore, and deepwater areas.[42] Although the purpose of the sampling data was to provide responders with detailed information about the location of recoverable oil,[43] the results (discussed below) offer further pieces of information concerning the oil's fate.

Oiled Shorelines

Although many of the response activities were intended to prevent oil from reaching shorelines, oil eventually contaminated hundreds of miles of Gulf state shorelines. This oil falls into the "other" category of the government's oil budget.

According to NOAA shoreline survey data, the maximum extent of shoreline oiling involved almost 1,100 miles of shoreline. As of October 2011, that figure has decreased to 481 miles.[44] **Figure 6** compares the extent of shoreline oiling in October 2010 with oiling in October 2011. The comparison is not ideal, because researchers surveyed more shoreline miles in the 2011 dataset. Regardless, the comparison shows a decline in the total number of oiled shoreline miles, particularly for the "heavy" category. However, many would argue that a considerable amount remains compared to the previous year.

Although the hundreds of miles of oiled shoreline might appear to account for a considerable amount of oil, CRS is not aware of an authoritative source that quantifies this oil (in terms of volume). Such a quantification is important in determining the extent to which the beached oil contributes to the "other" category. The November Technical Document states: "no estimates were made of the percentage of oil in [oiled shoreline debris] so it is not possible to give a

[40] Evaporated oil may remain in the atmosphere for some period of time. The 2003 NRC states that "relatively little work has been conducted on the basic physics and chemistry of oil spill evaporation" (p. 90).

[41] Federal oil spill response leaders formed the Operational Science Advisory Team (OSAT) on August 18, 2010, to provide "situational data and analysis for use in directing the on-going response operations." The OSAT is composed of personnel from the National Oceanic and Atmospheric Administration; the Coast Guard; EPA; the Bureau of Ocean Energy Management, Regulation, and Enforcement; the U.S. Geological Survey; and BP. The December 17 OSAT report is available at http://www.restorethegulf.gov/sites/default/files/documents/pdf/OSAT_Report_FINAL_17DEC.pdf.

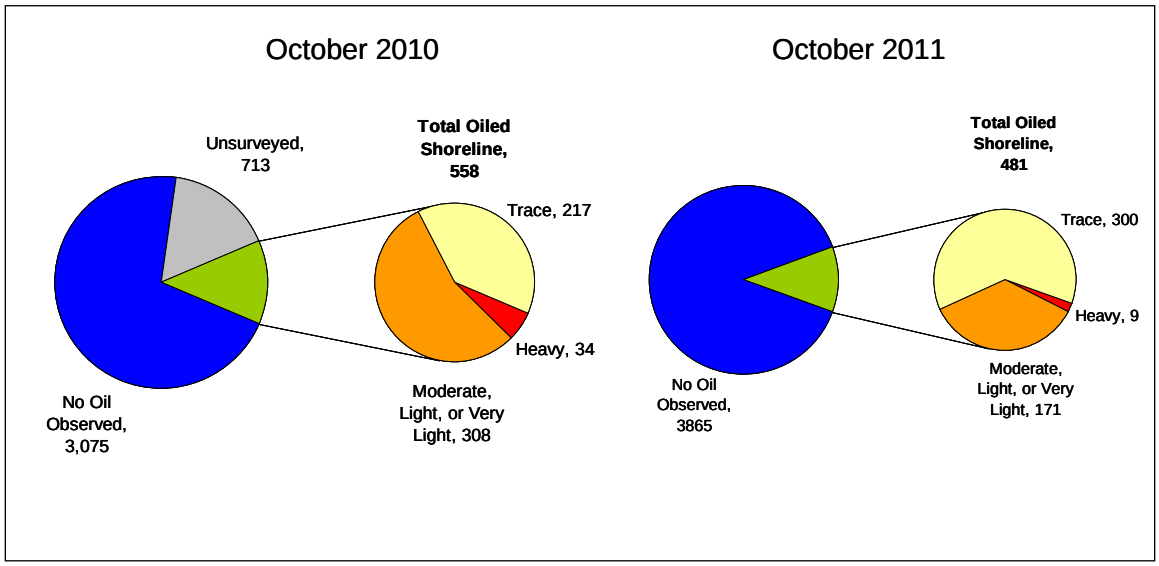
[42] The nearshore sampling zone includes waters and sediments inshore of 3 nautical miles (9 nautical miles for the Florida panhandle); the offshore zone includes waters and sediments seaward of 3 nautical miles until a water depth of 200 meters; the deepwater zone includes waters and sediments seaward of 200 meters.

[43] Based on the report the Coast Guard Federal On-Scene Coordinator (Rear Admiral Paul Zukunft) determined that "there is no actionable oil [i.e., amenable to removal action] in the water or sediments of the offshore or deepwater zones." See Memorandum from Zukunft to Parker, December 17, 2010, preceding the OSAT report.

[44] Data from personal communication (October 3, 2011) with NOAA Office of Response and Restoration officials.

reliable estimate of this amount. Based upon past spills, the oil content of collected debris mass is only a few percent."[45]

Figure 6. Miles of Oiled Shoreline for Gulf of Mexico States



Source: Prepared by CRS; data from personal communication with NOAA Office of Response and Restoration officials.

Note: The NOAA data separate the moderate, light, and very light categories. These categories are combined in the above pie charts.

Water Column

In the immediate weeks following the *Deepwater Horizon* incident, independent researchers began to disclose findings of potential underwater plumes of weathered oil near the spill source. Some of the initial evidence generated some controversy and was met with skepticism.[46] However, a different research team subsequently reported evidence of an undersea plume, which NOAA confirmed was linked to the *Deepwater Horizon* incident.[47]

Peer-reviewed papers followed, documenting further evidence of subsea plumes. For example, in an August report in *Science*, a team from Woods Hole Oceanographic Institution described a plume[48] southwest of the well site that was over 35 kilometers long at a depth of approximately

[45] The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team, *Oil Budget Calculator: Deepwater Horizon-Technical Documentation*, November 2010.

[46] See e.g., NOAA Administrator's Press Release discussing the findings from the *Pelican* research vessel, which documented irregular dissolved oxygen levels. "Media reports related to the research work conducted aboard the R/V Pelican included information that was misleading, premature and, in some cases, inaccurate." May 17, 2010, press release at http://www.restorethegulf.gov/release/2010/05/17/statement-noaa-administrator-jane-lubchenco-ongoing-efforts-monitor-subsea-impact.

[47] Robert Haddad and Steven Murawski (NOAA), *Analysis of Hydrocarbons in Samples Provided from the Cruise of the R/V WEATHERBIRD II, May 23-26, 2010*, released June 8, 2010, at http://www.noaanews.noaa.gov/stories2010/PDFs/noaa_weatherbird_analysis.pdf.

[48] Characteristics of the plume material have been described in different ways. According to the Woods Hole team (Interview with Richard Camilli and Christopher Reddy): "visually, these water samples look like clean springwater and have no smell." However, a different research team extracted samples from a *suspected* plume in the same vicinity

3,300 feet.[49] In an interview the researchers point out that the earlier efforts—the research that was greeted with skepticism—may have identified the same plume.[50]

The Administration established a Joint Analysis Group (JAG), including officials from NOAA and EPA, to facilitate cooperation and coordination regarding subsea monitoring in the Gulf. The JAG has issued several reports on collected data in the Gulf.[51] The most recent JAG report (August 16, 2010) reviewed data collected through August 9, 2010.[52] This report documented diminished dissolved oxygen (DO) levels, which serve as a proxy measure for subsurface dispersed oil (i.e., subsea plumes). The decreased DO levels where found in areas where plumes have been observed by other scientists.

The OSAT report provided water column sampling results collected in the nearshore, offshore, and deepwater zones. The data indicate that during June and July 2010, some of the collected samples[53] exceeded EPA's polycyclic aromatic hydrocarbon (PAH) water quality chronic benchmarks for aquatic life.[54] In some cases, the exceeded concentrations were at least one order of magnitude higher (i.e., a factor of 10) than the benchmark. Water column samples collected after August 3, 2010, did not contain concentrations exceeding the benchmarks for PAHs.[55]

Some may interpret the OSAT sampling data in different ways. Regarding the fate of the oil, the OSAT water column sampling results provide limited insights. (But this is expected, considering the purpose of the OSAT report is to support response decisions of the Unified Command.) A key limitation of the report is the absence of pre-spill data. Although some of the data indicate concentrations of oil in the water column before the oil spill occurred (thus providing some background information), more extensive pre-spill data are needed to indicate the degree to which samples with detectable PAH levels are typically found in the Gulf. Moreover, one would need to determine the percentage of samples with detectable PAH levels that are "consistent"[56] with the oil from the BP well. This analysis was performed only on samples that exceeded the PAH aquatic life benchmarks.

Sediment and Sea Floor

Although oil spilled or released at a subsea location generally rises to the surface, some fraction of the oil could instead sink, after mixing with suspended solids in the water column.[57] Studies

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that did have an oil sheen and an oily odor (Samantha Joye, "Trust Your Senses," Gulf Oil Blog, University of Georgia, May 30, 2010, at http://gulfblog.uga.edu).

[49] Richard Camilli et al., "Tracking Hydrocarbon Plume Transport and Biodegradation at Deepwater Horizon," *Science Express*, August 19, 2010.

[50] Interview with Richard Camilli and Christopher Reddy (Woods Hole Oceanographic Institution), *Science* Magazine podcast, August 20, 2010.

[51] See Joint Analysis Group website, at http://ecowatch.ncddc.noaa.gov/JAG/index.html.

[52] Joint Analysis Group (JAG), *Review of Preliminary Data to Examine Oxygen Levels In the Vicinity of MC252#1 May 8 to August 9, 2010*, at http://ecowatch.ncddc.noaa.gov/JAG/index.html.

[53] The percentage varied depending on location, but did not exceed 2% of *all the collected samples* (May–October). The percentage would likely be higher if measured against the samples collected only in June/July, but the report did not include this particular breakdown.

[54] For more information on this measure, see EPA's discussion at http://www.epa.gov/bpspill/water-benchmarks.html.

[55] This date was deemed a milestone in the OSAT report. According to the report, "the last overflight observation of potentially recoverable oil on the ocean surface was made on August 3, 2010."

[56] The OSAT report used this term to refer to oil samples thought to have originated from the BP well. The process used to make this determination is described in Appendix D of the OSAT report.

[57] Ian R. MacDonald (Professor of Oceanography, Florida State University), Testimony before the National

regarding the fate of the 1979 Ixtoc[58] oil spill indicate that a substantial portion—25%, according to one estimate—of the oil settled to the bottom of the Gulf.

Some sampling of sea floor sediments suggests that some of the oil from the 2010 Gulf spill may be resting on the ocean floor. For example, in early September, a university research vessel extracted sediment samples near the well site that had a layer of oil on the top sediment layer. Although the researchers could not definitively link the oil to the spill, according to their initial observations, the oil layer did not resemble oily deposits from natural seeps.[59] However, the November Technical Document appears to discount the September findings, stating that "ongoing sampling programs have not confirmed the claim of extensive oil being present on the bottom of the Gulf from Deepwater Horizon."[60] A key word in this sentence is *extensive*, because the OSAT sampling suggests (discussed below) that some portion of the oil may have settled in various sea floor locations.

The OSAT report provided sediment sampling results for the (1) nearshore, (2) offshore, and (3) deepwater zones.

OSAT Nearshore Sediment Results

Similar to the water column samples, a percentage of the nearshore sediment samples had PAH levels above aquatic life benchmarks. These elevated PAH levels occurred in the early weeks (June–July 2010) of the spill; no samples above benchmark levels were observed after August 3, 2010, that were consistent with oil from the BP well. As nearshore sampling concluded in October, all sediment samples were below a pre-spill reference level. According to the OSAT report this indicates "that pre-impact average concentrations had been reached."

In addition to the quantitative sampling program, the OSAT report described nearshore qualitative sampling (e.g., snares and sorbent pads used to determine the presence of oil) that found oil in locations in which "tar mat formations" (described as submerged, sedimented oil) had previously been observed by shoreline cleanup assessment teams (SCAT). The report concluded that a sampling data gap existed in nearshore waters of less than 10 feet, stating that a specific OSAT team has been established to further evaluate this concern.

OSAT Offshore Sediment Results

Few offshore samples were collected in the early months (May–July 2010), limiting the analysis of the offshore zone. The offshore samples (collected between August and October) did not demonstrate PAH concentrations above benchmarks, and most of the samples were at or below a pre-spill reference level.

Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, September 27, 2010.

[58] On June 3, 1979, the Ixtoc I exploratory well in the Bay of Campeche, Mexico, in 167 feet of water, blew out. A resulting explosion and fire destroyed the platform, which sank to the seafloor and damaged the drilling pipe and well casing. This incident led to the largest oil spill in North American waters (at that time): an estimated 140 million gallons (more than 3 million barrels). The release was ultimately contained—290 days later—by pumping mud into geologically linked wells, a strategy similar to the relief well approach employed in the 2010 Gulf oil spill. See Arne Jamelov and Olof Linden. "Ixtoc I: A Case Study of the World's Largest Oil Spill." *Ambio*, v. 10, no. 6, 1981, pp. 299-306.

[59] See Samantha Joye, Gulf Oil Blog, University of Georgia, Department of Marine Sciences, September 5, 2010, at http://gulfblog.uga.edu/2010/09/focusing-in-on-oil/.

[60] Oil Budget Technical Document, p. 9.

OSAT Deepwater Sediment Results

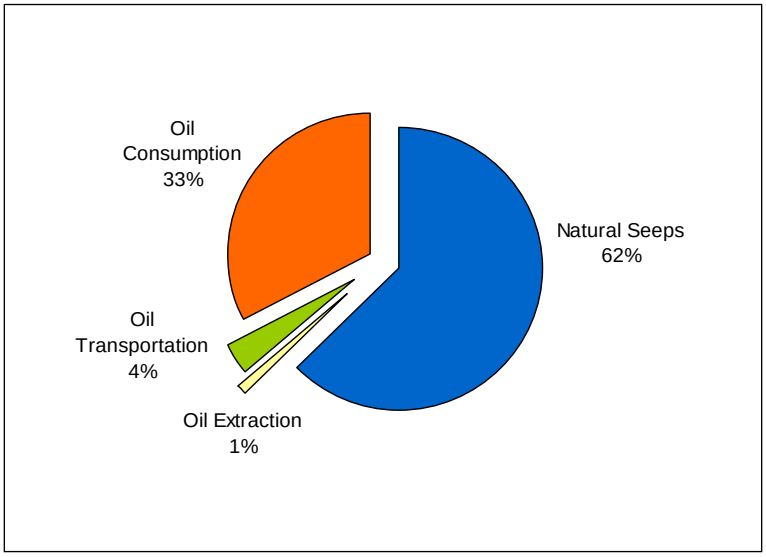
No deepwater samples were collected until mid-August. Of the water column and sediment samples collected, the deepwater sediment samples had the highest percentage (~6%) exceeding PAH chronic aquatic life benchmarks.[61] All of these higher concentrations were within three kilometers of the wellhead.

Biodegradation

Microbial organisms likely played a role in the oil's fate. The Gulf has natural oil seeps, which have existed for eons and support a community of oil-eating bacteria. As illustrated in **Figure 7**, the majority of oil in U.S. waters comes from natural seeps—geologic openings on the ocean floor. Well-known natural seeps are found in the Gulf of Mexico and off the coast of southern California, regions with extensive oil exploration and production. Although the seeps release large volumes of oil each year, the surrounding ecosystem can adapt, and even thrive, because the rate of release is relatively slow.[62] A 2003 study estimated that the natural seep volume in North American waters ranges from 24 million to 71 million gallons each year.[63]

Figure 7. Estimates of Percentage Contribution of Oil into North American Coastal Waters, by Major Source Categories

Based on Average Annual Releases, 1990-1999



Source: Prepared by CRS with data from the National Research Council (NRC) of the National Academies of Science, 2003, *Oil in the Sea III: Inputs, Fates, and Effects*, p. 69.

Notes: Extraction includes platform spills, produced waters, and atmospheric deposition. Transportation includes spills from tanker/barges, pipelines, coastal facilities, and atmospheric deposition. Oil consumption includes river and urban runoff; oil spills from cargo ships; operational discharges from commercial vessels and recreational craft; and atmospheric deposition. For further details of these inputs, see NRC Report, 2003.

[61] Of 127 deepwater sediment samples, seven had PAH levels above aquatic life benchmarks. OSAT report, p. 39.

[62] NRC report, 2003, p. 2.

[63] The "best estimate" (included in **Figure 7**) is 47 million gallons (ibid., p. 69).

Several scientific studies have examined the impacts of these organisms in relation to the Gulf spill.[64] Although some scientists concluded that microbes played a substantial role,[65] others questioned this assessment.[66] In an August 2010 paper from a Woods Hole research team, the authors contended that the subsurface plume had "persisted for months without substantial biodegradation."[67] A different August 2010 paper from researchers at the Lawrence Berkley National Laboratory suggested otherwise. This paper documented results indicating

> that a variety of hydrocarbon-degrading populations exist in the deep-sea plume [the same plume studied by the Woods Hole team] and that the microbial communities appear to be undergoing rapid dynamic adaption in response to oil contamination. These results also imply that there exists a potential for intrinsic bioremediation of oil contaminants in the deep-sea, and that oil-degrading communities could play a significant role in controlling the ultimate fates of hydrocarbons in the Gulf.[68]

An August 2011 study from another Woods Hole research team supports this notion, at least for surface water activity. The team analyzed data collected from the surface waters during the spill (June 2010).[69] The team initially hypothesized that the microbes would be unable to process (eat) the discharged oil due to limited nutrients, particularly phosphate, in the offshore environment. Although the limited phosphate did appear to hinder microbial growth, the microbes digested the oil "at an unprecedented rate." The researchers concluded that "this rate was potentially great enough to keep pace with the flux of oil reaching the surface from the Macondo well."

Conclusions

A complete and definitive answer to the question of the *remaining* oil is unknown at this juncture. The most recent authoritative assessment—the November Oil Budget document—contained estimates based on calculations made in July 2010. At the time of these calculations, a substantial portion of the oil had been effectively removed from the Gulf environment through human interaction. However, a greater portion remained, in some form, in the Gulf. Months later, it is unknown what happened to the oil that remained.

It is debatable whether the fate of the remaining oil will ever be established conclusively. Multiple challenges hinder this objective: the complexity of the Gulf system; resources required to collect data; and varied interpretations over the results and observations. Moreover, as time

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[64] See Bethanie Edwards *et al*., "Rapid Microbial Respiration of Oil from the Deepwater Horizon Spill in Offshore Surface Waters of the Gulf of Mexico," *Environmental Research Letters*, Vol. 6, August 2011; National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Testimony during September 27-28 Meeting (Panel II); Terry C. Hazen et al., "Deep-Sea Oil Plume Enriches Indigenous Oil-Degrading Bacteria," *Science Express*, August 24, 2010; Richard Camilli et al., "Tracking Hydrocarbon Plume Transport and Biodegradation at Deepwater Horizon," *Science Express*, August 19, 2010; Joint Analysis Group, *Review of Preliminary Data to Examine Oxygen Levels in the Vicinity of MC252#1 (May 8 to August 9, 2010)*, August 16, 2010.

[65] See e.g., Ronald Atlas and Terry Hazen, "Oil Biodegradation and Bioremediation: A Tale of the Two Worst Spills in U.S. History," *Environmental Science and Technology*, Vol. 45, pp. 6709-6715, June 23, 2011.

[66] See Ian R. MacDonald, (Florida State University), National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Testimony during September 27-28 Meeting (Panel II).

[67] Richard Camilli *et al*., "Tracking Hydrocarbon Plume Transport and Biodegradation at Deepwater Horizon," *Science Express*, August 19, 2010.

[68] Terry C. Hazen et al., "Deep-Sea Oil Plume Enriches Indigenous Oil-Degrading Bacteria," *Science Express*, August 24, 2010.

[69] Bethanie Edwards *et al*., "Rapid Microbial Respiration of Oil from the Deepwater Horizon Spill in Offshore Surface Waters of the Gulf of Mexico," *Environmental Research Letters*, Vol. 6, August 2011.

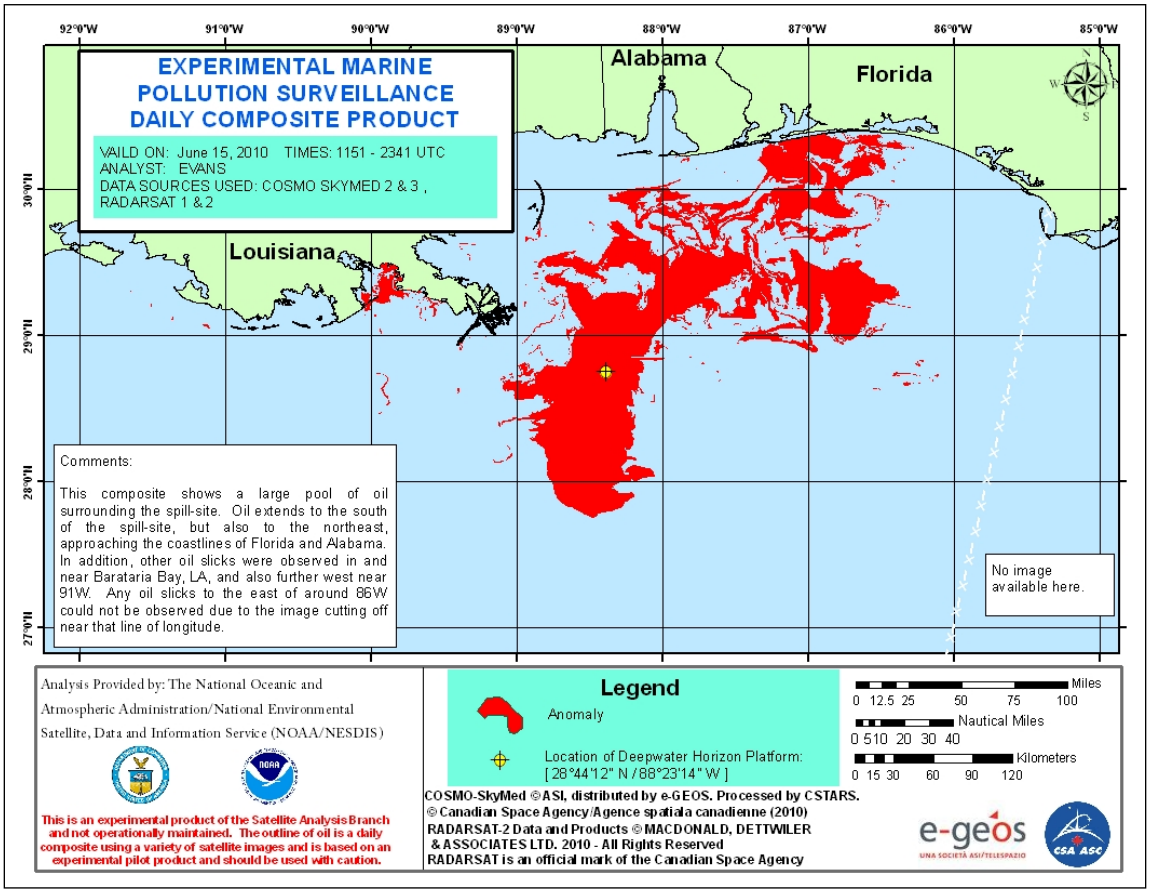
progresses, determining the fate of the oil will likely become more difficult. Regardless, the question of oil fate will likely be addressed through an incremental process.[70] Researchers are continuing to study various components of the Gulf, specifically damages to natural resources. Some of these efforts may provide clues to the oil's fate.

[70] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *The Amount and Fate of Oil*, Staff Working Paper, released October 6, 2010, p. 24.

Appendix. Selected Satellite Images of *Deepwater Horizon* Oil Spill

Figure A-1. NOAA Satellite Analysis of Gulf Oil Spill

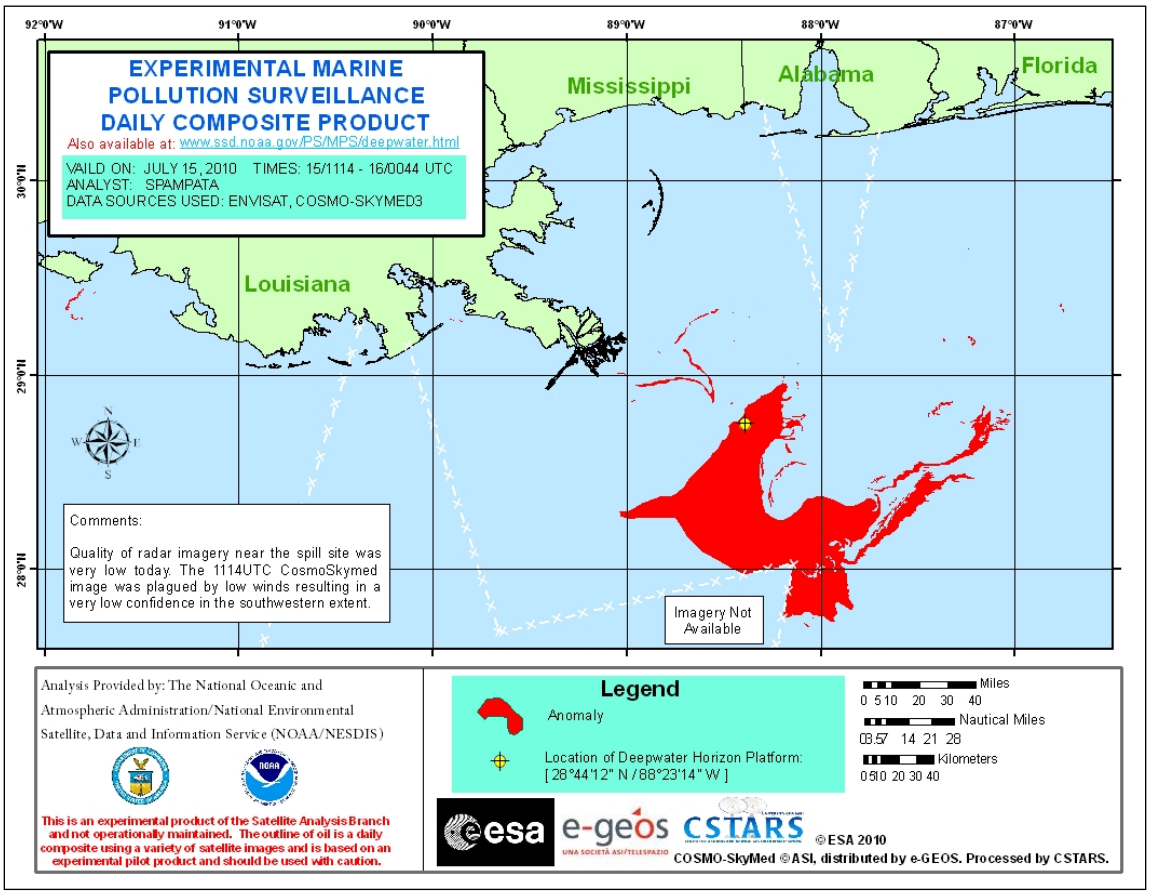
June 15, 2010



Source: National Oceanic and Atmospheric Administration, GeoPlatform.gov, at http://www.geoplatform.gov/gulfresponse.

Figure A-2. NOAA Satellite Analysis of Gulf Oil Spill

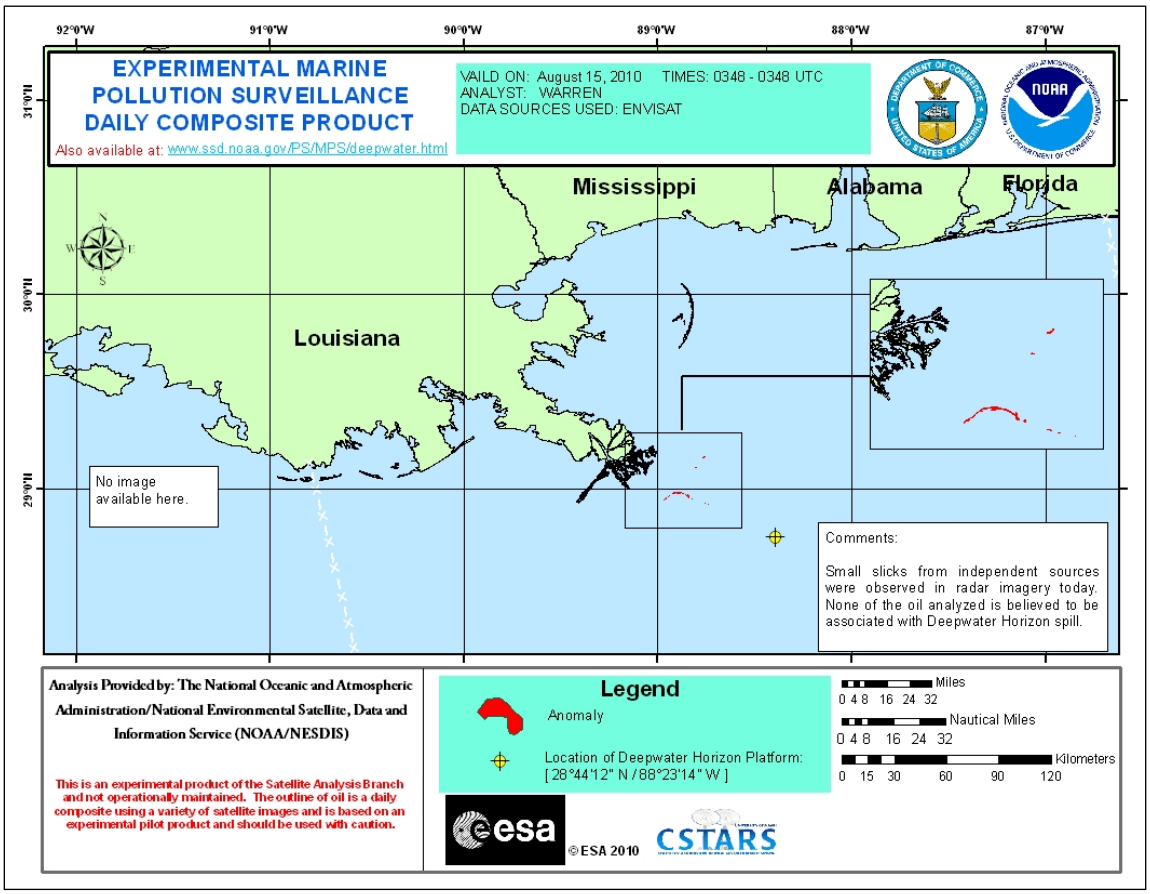
July 15, 2010



Source: National Oceanic and Atmospheric Administration, GeoPlatform.gov, at http://www.geoplatform.gov/gulfresponse.

Figure A-3. NOAA Satellite Analysis of Gulf Oil Spill

August 15, 2010



Source: National Oceanic and Atmospheric Administration, GeoPlatform.gov, at http://www.geoplatform.gov/gulfresponse.

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