# Worst Case Discharge Analysis (Volume I)

U.S. Department of the Interior Bureau of Safety and Environmental Enforcement (BSEE)

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# Executive Summary

The Bureau of Safety and Environmental Enforcement's (BSEE) Oil Spill Preparedness Division (OSPD) is responsible for developing and administering regulations that oversee industry's preparedness to contain, recover, and remove oil discharges from offshore facilities. As required by the Federal Water Pollution Control Act and the Oil Pollution Act of 1990, these regulations require the operators of these offshore facilities to submit an Oil Spill Response Plan (OSRP) that identifies the procedures and contracted spill response resources necessary to respond, to the maximum extent practicable, to their worst case discharges (WCD). In the case of most offshore exploration or production facilities, their WCD scenario will be the maximum foreseeable daily flow of oil from their facility, commonly referred to as a "well blowout."

Offshore oil well blowouts[1] that cause large-scale oil spills are rare events. Most blowout accidents release a relatively small amount of oil into the environment before the well is brought under control by operators or the well is sealed by natural processes (known as "bridging over").[2] This report begins with a summary of historical information on offshore blowouts and a general discussion of some of the factors that may influence the nature and potential consequences of blowouts. While there have been several large blowouts worldwide since exploration of the offshore and outer continental shelf (OCS) began more than 50 years ago, there have been only two major offshore exploration and production-related spills in U.S. waters — the Santa Barbara Channel Alpha Well 21 Platform "A" blowout in 1969[3] and the Gulf of Mexico Deepwater Horizon MC252 blowout in 2010.[4] With the depletion of nearshore resources, the oil and gas industry is moving farther offshore, into deeper waters, and potentially into the more extreme environments to meet U.S. and global energy needs. These new frontiers of oil and gas resource development present new safety and oil spill response challenges.

This report is the first volume of a two-volume study entitled *Oil Spill Response Plan Equipment Capabilities Review*. Volume I, *Worst Case Discharge Analysis*, presents regional profiles regarding the range and type of WCDs associated with U.S. offshore drilling, and illustrates their potential for impacting the environment through oil spill fate and transport modeling. Volume II, *Oil Spill Response Equipment Capabilities Analysis*, presents a series of related analyses, including spill modeling using different response countermeasures, to reduce the potential for impacts, and develop recommendations for oil spill response plan requirements.

### *Regional WCD Profiles*

To better understand where these frontier oil and gas development activities are occurring and how they may be affecting the nature and potential of WCD scenarios, profiles were developed for each OCS

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[1] In this study, the term "blowout" refers to a loss of well control in which there is a release of oil to the environment. The term "blowout" is sometimes, in other studies and contexts, used to describe losses of well control in which there is no release of oil to the environment, such as circumstances in which there is a release of oil only to diverters or in which only gas is released.

[2] Etkin, 2009; Holand, 2013.

[3] The Alpha Well 21 Platform "A" blowout in the Santa Barbara Channel began January 28, 1969 and discharged 80,000 barrels into nearshore California waters over an 11-day period (http://www.bsee.gov/). The blowout event also caused undersea geologic faults to open, which released oil and gas until December 1969. The National Oceanic and Atmospheric Administration (NOAA) calculated that approximately 100,000 barrels of crude oil were discharged from the well and the resulting faults. The environmental impact of this blowout contributed to the establishment of the National Environmental Policy Act of 1969 and subsequent environmental protection legislation (http://response.restoration.noaa.gov/).

[4] The Deepwater Horizon MC252 blowout on April 20, 2010 discharged 4,200,000 bbl into waters of the Gulf of Mexico over a period of 87 days (http://www.bsee.gov/).

Region of the U.S. OCS with active oil and gas exploration and production. These profiles include the overall distribution and nature of the WCDs in each OCS Region based on information in OSRPs:

- **The Gulf of Mexico (GOM) OCS Region:** This region has by far the most active and prolific oil exploration and production activity (91% of total U.S. OCS production). The Gulf of Mexico has seen an increase in drilling in deeper waters (20% of the WCD volumes are considered to occur in "deep water"[5]), and drilling is increasingly occurring in higher temperature and higher pressure (HTHP) reservoirs. The largest WCD flow rates are in the Central Gulf of Mexico Planning Area, many with potential releases of more than 250,000 bbl/day, with some drilling now occurring nearly 250 miles from shore. The Central Planning Area has clusters of relatively large WCD flow rates (>125,000 bbl/day) in deep water, relatively close to shore in the Mississippi Canyon area. WCD flow rates in the Gulf of Mexico range from 4 to 476,000 bbl/day. The average WCD flow rate for the locations in the Central Gulf of Mexico Planning Area within this sample population of data is 59,690 bbl/day, while the average WCD flow rate for the Western Gulf of Mexico Planning Area is 13,784 bbl/day.
- **The Pacific OCS Region:** Relative to the GOM, this region has few wells (431 producing wells) and no trend of significant new exploration or drilling, due in part to a moratorium on new offshore exploration within the Pacific OCS Region. As a result, oil production rates in the Pacific OCS Region peaked in 1995 and have been steadily declining since that time. All current drilling operations in this region are in the Southern California Planning Area. Well water depths range from 95 feet to a maximum of 1,198 feet, with an average depth of 406 feet. Wells are relatively close to shore, ranging approximately from 4 to 13 miles off the California coast. The wells in this region encounter pressures no greater than 3,000 psi and no hotter than 190°F, which is short of the HTHP definition of >10,000 psi and/or >300°F. The older, shallower wells within the region are associated with particularly low pressures. WCD flow rates for these operations range from 121 to 12,036 bbl/day, with an average of 3,262 bbl/day.
- **The Arctic OCS (subarea of the Alaska OCS Region):** The Chukchi Sea and Beaufort Sea are the only Planning Areas that are within the Alaska OCS and the Arctic Circle, and are collectively referred to as the Arctic OCS. The Arctic OCS has the least activity and fewest wells of the regions examined in this study. Because the Arctic OCS Region is relatively unexplored and the geologic formations are not well understood, the Bureau of Ocean Energy Management (BOEM) considers it to be a "frontier area." In the Beaufort Sea, the onshore geology extends offshore, and much of the knowledge gained from onshore exploration and production can be transferred to offshore drilling in the area. Well pressures in the Arctic OCS Region are less than 6,000 psi,[6] and subsurface well depths range from 7,000 to 8,000 feet in the Chukchi Sea and 10,200 feet in the Beaufort Sea – significantly less than subsurface depths found in the Gulf of Mexico that can exceed 30,000 feet. While specific well temperature information was not available, it is known that high pressures generally correlate with high temperatures.[7] High temperature and pressure conditions, therefore, are not expected to be a significant factor in the Arctic OCS Region. The offshore exploration activities in the Beaufort Sea and Chukchi Sea thus far have occurred in waters less than 150 feet deep; however, the potential exists in the future for drilling in deeper waters in the Arctic. Well sites examined in this region are relatively close to shore, ranging approximately from 1.5 to 69 miles off the Alaska coast, with the majority of the sites located 1.5 to 6 miles from shore. WCD flow rates in the region range from 800 to 85,000

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[5] Definitions of what constitutes "deep water" vary. BSEE defines deep-water wells as those located in water depths greater than 500 ft. A common definition of deep water used by industry and regulators across the world is greater than 1,000 meters or 3,280 feet (Holand 2013).

[6] Williams 2012; Shell Oil Company 2013.

[7] Holand 2013.

bbl/day, with an average of 20,500 bbl/day. Operations on the Arctic OCS are limited by the challenges associated with the harsh Arctic environment. Extreme cold, winds, waves, sea ice (up to eight months of the year), and reduced daylight hours create additional concerns for safe operations and may be an impediment to rescue, source control, and oil spill response operations. Weather conditions may interfere with response operations in the Arctic as much as 50% of the time, and the remoteness of the Arctic is of particular concern when it comes to mounting and sustaining a response to a WCD in the Arctic OCS.

### *WCD Test Scenarios*

Based on the information contained within the WCD profiles, a representative set of hypothetical test scenarios was created to examine the potential for WCD oil spills to come into contact with the environment. The discharge flow rates and durations for each scenario were approximated using data from nearby OSRPs, and for the purposes of this volume of the study (Volume I), were not mitigated by the use of response countermeasures or abated until the completion of a relief well. The lease blocks and blowout volumes for the nine test scenarios are listed in Table ES 1.

- **Gulf of Mexico Region:** Six scenarios were chosen in various locations and water depths across the region. Five of the six WCD scenario locations in the Gulf of Mexico were in the Central Gulf of Mexico Planning Area; the sixth site was in the Western Gulf of Mexico Planning Area. Some WCD scenarios were relatively close to shore, while others were at the far remote reaches of offshore drilling in the region. Water depths ranged from 35 feet to over 6,900 feet. WCD flow rates ranged from 26,400 to 449,000 bbl/day, and flow durations ranged from 37 days to 182 days.
- **Pacific OCS Region:** The WCD scenario modeled for the Pacific OCS Region was in the Southern California Planning Area in the vicinity of the Santa Barbara Channel and was assigned a WCD flow rate of 5,200 bbl/day. The simulated spill flowed for 170 days due to the fact that there are no drilling rigs on the West Coast available to drill a relief well.
- **Arctic OCS Region:** In the Arctic OCS Region, one scenario was in the Chukchi Sea (Posey 6912) and the other was in the Beaufort Sea (Flaxman Island 6610). These spills flowed for 28-30 days during the part of the operating season where both open water to partial ice cover may occur. The WCD discharge rates were 25,000 bbl/day and 16,000 bbl/day, respectively.

**Table ES 1: Worst Case Discharge Scenario Volumes**

| OCS Region and Spill Scenario | Total WCD Volume (bbl) |
|---|---|
| **Gulf of Mexico OCS Region** | |
| Scenario 1, MC807 | 81,718,000 |
| Scenario 2, WD2 | 3,589,000 |
| Scenario 3, WC168 | 2,006,400 |
| Scenario 4, HIA376 | 3,850,000 |
| Scenario 5 KC919 | 30,240,000 |
| Scenario 6, DC187 | 25,546,000 |
| **Pacific OCS Region** | |
| Scenario 7, SM6683 | 884,000 |
| **Arctic OCS Region** | |
| Scenario 8, P6912 | 700,000 |
| Scenario 9, FI 6610 | 480,000 |

### *Oil Fate, Transport, and Contact Modeling*

Two models were used to evaluate the potential for discharged oil to come into contact with the environment from the hypothetical WCD test scenarios. The OILMAPDeep™ model was used to determine near-field buoyant and gas plume dynamics for each blowout scenario, all of which were subsurface discharges originating at the seafloor. The initial characteristics of the discharges (i.e., locations and sizes of the subsurface plumes, rise times, and the oil droplet size distributions) were all estimated by OILMAPDeep and entered into the SIMAP$^{TM}$ stochastic model to determine the far-field transport and weathering of the oil in the water column and on the water surface.

The SIMAP stochastic model uses many different trajectories of the same spill event occurring at different times over a long time window to calculate the probability of the oil coming into contact with the water column, water surface area, and shorelines. The SIMAP results provide the probabilities of areas being exposed to oil and the minimum travel time for oil to reach those areas. Because contact with spilled oil can occur over a large range of concentrations and thicknesses, the SIMAP results were generated based on two minimum thresholds – the amounts of oil present that is necessary for effective oil spill recovery operations (8 $g/m^2$ for oiling of the water surface), and the amounts necessary to result in impacts to socioeconomic resources (1 $g/m^2$ for shoreline oiling, and 100 ppb for in-water concentration).

### *WCD Modeling Results*

These WCD scenarios were all modeled without the application of oil spill response operations and were allowed to flow unabated until a relief well was completed. Various endpoints were chosen to assess the magnitude, timing, and geographic footprint of the discharged oil.[8] The results of these WCD simulations vary widely based on each scenario's specific set of circumstances; however, it was clear that all of these WCD scenarios could result in significant consequences to the environment if not quickly and effectively abated and mitigated. While the modeling results, as a whole, present an extremely dire representation of the potential for contact between the discharged oil and the environment, they do provide a working baseline of datum that will be useful for further analysis.

[8] NOAA 2010

## 1.0 INTRODUCTION

To support BSEE's effort to update the U.S. OSRP regulations, this report models and analyzes nine hypothetical WCD scenarios. The lease blocks and blowout volumes for the nine scenarios are listed in Table 1. This report does not consider the modeling of oil spill response operations. This report is the first volume of two, and the second volume (Oil Spill Response Equipment Capabilities Analysis) will model and assess the application of oil spill response operations to mitigate these nine WCD scenarios. Specifically, this Volume of the study seeks to:

- Identify and assess changing oil spill potentials from current and emerging drilling and production trends and;
- Identify the geographical areas with a chance of oiling by worst case discharges (WCD) in the Gulf of Mexico, Pacific, and Arctic OCS Regions.

**Table 1: Worst Case Discharge Blowout Scenarios**

| OCS Region and Spill Scenario | Total WCD Volume (bbl) |
|---|---|
| **Gulf of Mexico OCS Region** | |
| Scenario 1, MC807 | 81,718,000 |
| Scenario 2, WD2 | 3,589,000 |
| Scenario 3, WC168 | 2,006,400 |
| Scenario 4, HIA376 | 3,850,000 |
| Scenario 5 KC919 | 30,240,000 |
| Scenario 6, DC187 | 25,546,000 |
| **Pacific OCS Region** | |
| Scenario 7, SM6683 | 884,000 |
| **Arctic OCS Region** | |
| Scenario 8, P6912 | 700,000 |
| Scenario 9, FI6610 | 480,000 |

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## 2.0 SPILLS FROM OFFSHORE OIL WELLS

Worldwide, there have been 607 reported offshore spills from a population of about 86,000 wells drilled since the 1950s. This equates to one release event for every 142 wells.[9] Many of these incidents occurred before the development or deployment of effective preventive technologies, such as blowout preventer (BOP), or when drilling approaches were radically different. In recent years there have been significant changes in offshore oil exploration and production with operations occurring in new frontiers of depths and in new regions with extreme environments and sensitive resources that could change future potentials.

Over the last 50 years, the United States has produced a total of about 20 trillion barrels of oil from offshore oil resources, 91% of which was produced in the Gulf of Mexico OCS Region, 8.9% in the Pacific OCS Region and 0.1% in the Arctic OCS Region (Figure 1).[10]

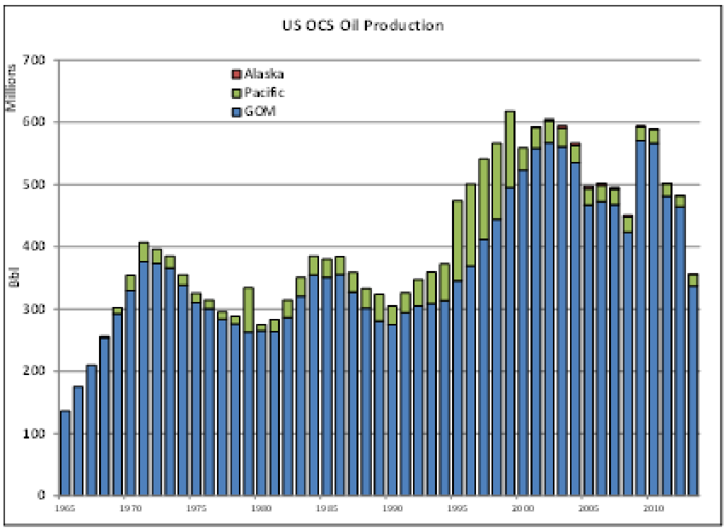


**Figure 1: Total U.S. OCS Annual Oil Production[11]**

An average of 1.8 barrels of oil was spilled for every 10,000 barrels produced, or 0.018%. From 2003 to 2012, the United States produced about 528 million barrels of oil annually. Of the 528 million barrels produced in this 10-year period, approximately 0.08% (464,000 barrels) was spilled (Figure 2).[12] If the Deepwater Horizon MC252 incident is excluded, the spillage rate was only 0.0021% of total produced oil.

[9] Holand 2013.
[10] Energy Information Administration.
[11] Energy Information Administration.
[12] Etkin 2009, updated with 2012 data.

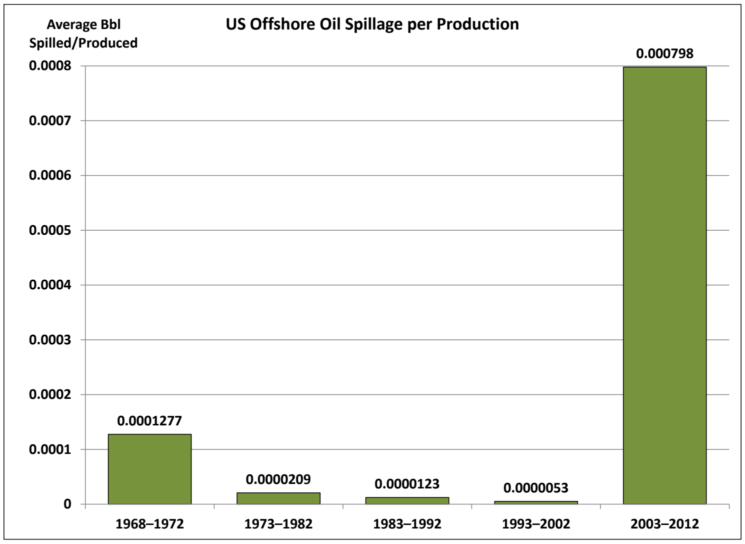


**Figure 2: Average Offshore Spillage per Production by Time Period**[13]

Annual oil spillage from offshore wells is shown in Figure 3 for 1968 to 2012. Almost 95% of the oil spilled during this time period from offshore facilities came from the Deepwater Horizon incident.[14]

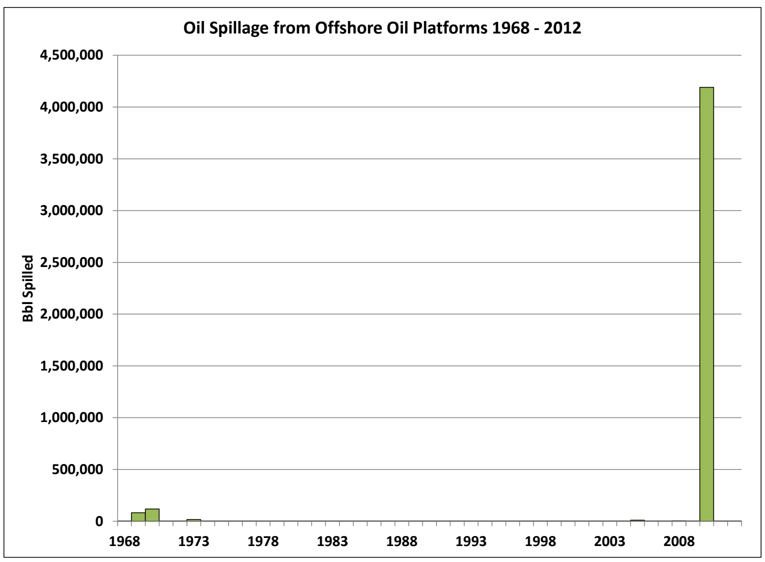


**Figure 3: Annual U.S. Offshore Oil Platform Spillage 1968-2012**[15]

Oil spills from oil platforms and the wells associated with them occur for a number of reasons other than blowouts, including equipment failure, hurricane damage, and vessel collisions. The most frequent cause of spills between 1968 and 2012 was equipment failure, which accounted for 52% of spills, followed by hurricanes, which accounted for another 24%. Blowouts accounted for 4.5% of total incidents during this period, but had a much higher potential volume than the other incident types.[16]

[13] Etkin 2009, updated with 2012 data.
[14] Etkin 2009, updated with 2012 data.
[15] Etkin 2009, updated with 2012 data.
[16] Etkin 2009, updated with 2012 data.

## 2.1 Worst Case Discharges from Offshore Oil Wells

Most blowouts involve the release of very small quantities of oil. While blowouts are not always large, they can result in WCDs from wells. The common, worldwide definition of a blowout is "loss of well control or uncontrolled flow of formation or other fluids, including flow to an exposed formation (an underground blowout) or at the surface (a surface blowout), flow through a diverter, or uncontrolled flow resulting from a failure of surface equipment or procedures."[17]

BSEE defines a blowout as "loss of well control" and "uncontrolled flow of formation or other fluids." The flow may be to an exposed formation (an underground blowout), or at the surface (a surface blowout). BSEE also defines a blowout as intentional flow through a diverter or uncontrolled flow resulting from a failure of surface equipment or procedures.[18] *In the context of this study, the term "blowout" refers to loss of well control in which there is the release of oil to the environment.*

### 2.1.1 Definition of Worst Case Discharge

In 30 CFR §254.47, BSEE stipulates that each facility operator calculate its own WCD for each Oil Spill Response Plan (OSRP). For an oil production platform facility, the size of the worst case discharge scenario is the sum of:

- The maximum capacity of all oil storage tanks and flow lines on the facility. Flow line volume may be estimated;
- The volume of oil calculated to leak from a break in any pipelines connected to the facility considering shutdown time, the effect of hydrostatic pressure, gravity, frictional wall forces and other factors; and
- The daily production volume from an uncontrolled blowout of the highest capacity well associated with the facility. In determining the daily discharge rate, [the operator] must consider reservoir characteristics, casing/production tubing sizes, and historical production and reservoir pressure data. [The] scenario must discuss how to respond to this well flowing for 30 days as required by 30 CFR §254.26(d)(1).

### 2.1.2 History of Blowouts

Based on the BSEE definition for a blowout, there were 43 incidents between 2006 and 2013, shown by type in Figure 4. Not all incidents involve the discharge of oil to the water. In a separate analysis conducted on 288 loss of well control incidents that occurred between 1956 and 2010, BSEE identified eight cases involving a discharge of oil to the environment. [19]

[17] Holand 2013.
[18] Herbst 2014.
[19] Herbst 2014.

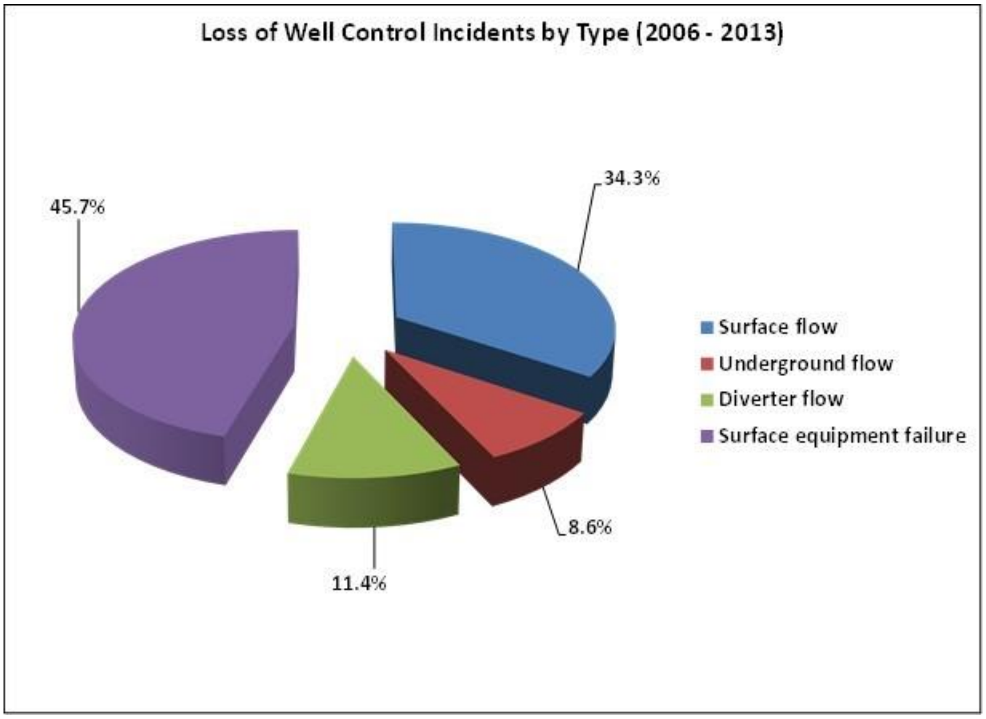


**Figure 4: Loss of Well Control Incidents (2006 - 2013) (BSEE TIMS Data)[20]**

Worldwide, there have been nine offshore oil well blowout incidents that discharged 100,000 barrels or more (Table 2). While the 1969 Santa Barbara blowout is widely reported to have discharged 100,000 barrels, BSEE's official spill volume for the incident is 80,000 barrels.

[20] Herbst 2014.

**Table 2: Ten Largest Offshore Well Blowouts Worldwide, Ordered by Volume**[21]

| Well | Date | Duration (days) | Location | Volume Spilled (bbl) |
|---|---|---|---|---|
| Ixtoc I[22] | 6/3/1979 | 290 | Bahia del Campeche, Mexico | 3,300,000 - 10,190,000 |
| Deepwater Horizon MC252[23] | 4/20/2010 | 84[24] | Gulf of Mexico, USA | 4,200,000 |
| Bull Run/Atwood Oceanics | 1/1/1983 | unknown | Dubai, UAE | 2,000,000 |
| Abkatun 91 | 10/1/1986 | unknown | Bahia del Campeche, Mexico | 247,000 |
| Montara[25] | 9/21/2009 | 74 days | Timor Sea, Australia | 28,600 - 214,300 |
| Ekofisk Bravo B-14 | 4/20/1977 | 7 days | North Sea, Norway | 202,381 |
| Funiwa 5 | 1/17/1980 | 16 days | Gulf of Guinea, Nigeria | 200,000 |
| Hasbah 6[26] | 10/2/1980 | 9 days | Persian Gulf, Saudi Arabia | 105,000 |
| Iran Marine International | 12/1/1971 | unknown | Persian Gulf, Iran | 100,000 |
| Alpha Well 21 Platform A[27] | 1/28/1969 | 11 days | Pacific, Santa Barbara, USA | 80,000 - 100,000[28] |

In the United States, there have been 31 reported offshore oil well blowouts since 1964, of which only two blowouts were 80,000 barrels or larger (Table 3). Overall, BOEM researchers calculated that "catastrophic" well blowouts of one million barrels or more in the U.S. OCS would be expected to occur once every 165 years.[29] This means that in a single year, there is a 0.6% probability of such an event. The Deepwater Horizon Macondo MC157 incident is the only U.S. spill that meets the BOEM criteria for a catastrophic incident.

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[21] Data from ERC spill databases; referenced in Etkin 2009.
[22] Boehm and Fiest 1982; Dokken 2011; ERCO/Energy Resources Co., Inc. 1982.
[23] Fitch et al. 2013; Hauck et al. 2013; McNutt et al. 2012a, 2012b; Oldenburg et al. 2011.
[24] BSEE's official data on flow duration is 84 days. Flow was Apr 22 10:22am CDT (when Deepwater Horizon rig sank) to July 15 14:24 CDT, 84 days, based on findings of fact for phase 2 of the trial. (Judge Barbier and Mag. Judge Shushan, 2015). Flow duration has been reported as being from 84 to 87 days. For example, on October 5, 2015, the Department of Justice released the U.S. District Court for the Eastern District of Louisiana Consent Decree Among Defendant BP Exploration & Production, Inc., the United States of America, and the States of Alabama, Florida, Louisiana, Mississippi, and Texas, which was accompanied by a timeline that stated that on July 15, 2010 "after 87 days of oil & gas pouring into the Gulf, Macondo well is finally shut in." The 87-day period starts with the April 20, 2010 explosion on Deepwater Horizon and the beginning of the blowout from the Macondo MC252 well. The 87-day time period is also referenced in the National Commission 2010 report, the United States v. BP et al. 2015 documentation, and NOAA's *Deepwater Horizon Oil Spill: Draft Programmatic Damage Assessment and Restoration Plan and Draft Programmatic Environmental Impact Statement* released on October 8, 2015.
[25] Commonwealth of Australia 2011.
[26] Oudenhoven 1983.
[27] Clarke and Hemphill 2001
[28] BSEE's official estimate is 80,000 bbl (Anderson et al. 2012).
[29] Based on analysis of 1964-2012 OCS spill data with 95% confidence interval of 41 to >500 years (Ji et al. 2014).

**Table 3: Top 10 U.S. Offshore Oil Well Blowouts since 1964, Ordered by Volume**[30]

| Well[31] | Date | Location | Barrels Spilled | Oil Type |
|---|---|---|---|---|
| Deepwater Horizon MC252 | 4/20/2010 | GOM | 4,200,000 | crude |
| Alpha Well 21 Platform A | 1/28/1969 | Pacific | 80,000 - 100,000 | crude |
| Main Pass Block 41 (MP-41C)[32] | 2/10/1970 | GOM | 65,000 | crude |
| ST-26B | 12/1/1970 | GOM | 53,000 | crude |
| Greenhill Timbalier Bay 251* | 9/29/1992 | GOM | 11,500 | crude |
| SS-149B[33] | 10/3/1964 | GOM | 5,100 | crude |
| Hebert Bravo 1A | 2/19/1979 | GOM | 3,500 | condensate |
| SS-72 Well 3 | 3/16/1969 | GOM | 2,500 | crude |
| SS-29-Caisson 7 | 7/1/1965 | GOM | 1,690 | condensate |
| BLDSU 6[34] | 1/13/1995 | GOM | 800 | crude |

### 2.1.3 Blowout Flow Rates and Durations

Blowouts usually have discharge flow rates that vary during the course of the events, both from changes in the well and hydrocarbon reservoir as well as blowout control actions. In most cases, there is an attempt to calculate the blowout volume from an average flow rate.

$$Volume_{blowout} = flowrate_{average} \cdot duration$$

$$Volume_{blowout}(bbl) = \frac{bbl}{day} \cdot days$$

Flow rate data of historical blowout incidents have varied considerably, likely due to different calculations. Flow rates for incidents with reasonably reliable data are shown in Table 4. Estimated flow rates of U.S. OCS wells range from less than a barrel a day to more than 449,000 barrels per day.[35]

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30 Etkin 2009; Danenberger 1980.
31 Incidents marked with asterisk (*) occurred in state waters.
32 Alpine Geophysical Associates 1971.
33 Some reports two blowouts (SS-199B and SS-149B) as a single incident (Ship Shoal SS-149/166199) with 11,847 bbl released rather than a total of 6,689 bbl, which is BSEE's recorded volume.
34 Finley et al. 1995.
35 Low-pressure production wells require gas lift or other procedures to force the oil to flow. In other wells the pressure of the reservoir is sufficient to push the oil to the production platform. Data from oil spill response plans (OSRPs) submitted to BSEE.

**Table 4: Estimates of Average Daily Flow Rates for Selected Historical Well Blowouts**

| Incident[36] | Average Oil Flow Rate (bbl/day) | Peak Flow Rate (bbl/day) |
|---|---|---|
| Deepwater Horizon MC252 | 28,800 - 35,000[37] | 35,900 - 60,000 |
| Ixtoc I-High Estimate[38] | 35,000 | unknown |
| Yum II/Zapoteca | 30,000 | unknown |
| Ixtoc I-Low Estimate | 11,400 | unknown |
| Ekofisk Bravo B-14 | 28,080 | 28,080 |
| Hasbah 6 | 11,667 | 11,667 |
| Alpha 21-A (Santa Barbara)[39] | 7,272 - 9,090 | 7,272 - 9,090 |

Likewise, flow durations have varied for various blowout incidents. In a blowout, the flow duration is dependent on the oil reservoir characteristics and the tendency for the well to fill in or bridge naturally, and the timing of the intervention. Generally, if a well is detected to have a blowout, an intervention plan is initiated nearly immediately depending on the circumstance of the incident. The length of time required to complete an intervention (i.e., source control) depends on a large number of characteristics specific to each well and logistical considerations related to the intervention operations. Source control operations are discussed in greater detail in Volume II of this study.

Many blowouts release relatively small volumes of oil into the environment over brief periods of time.[40] As shown in the data in Table 5, which is based on international data, 96% of blowouts have durations of less than five days; 25% have durations of less than 12 hours. Durations vary by well type.

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[36] Unless otherwise noted, the average flow rate was determined by dividing the total volume of spillage by the number of days of flow.
[37] The government estimates were that the flow rate began at about 62,000 BOPD, and declined to about 53,000 BOPD by July15, 2010 (Lehr et al., 2010; Oldenburg et al 2011; McNutt et al., 2011, 2012a,b; Hauck et al., 2013)
[38] Based on Dokken 2011.
[39] The average flow rate for the Alpha 21-A (Santa Barbara) blowout is based on dividing the 80,000-100,000 bbl total spillage by the 11 days of flow.
[40] Dyb et al. 2012; Holand 2013.

**Table 5: Distribution Blowout Duration**[41]

| Operation Phase | Duration of Surface Flow | | | | | | |
|---|---|---|---|---|---|---|---|
| | ≤10 min | 10 min - ≤40 min | 40 min - ≤ 2 hrs. | 2 hrs. - ≤12 hrs. | 12 hrs. - ≤2 days | 2 days - ≤5 days | > 5 days |
| Development Deep | 0% | 0% | 17% | 32% | 17% | 13% | 17% |
| Development Shallow | 0% | 0% | 18% | 12% | 23% | 17% | 23% |
| Exploration Deep | 0% | 0% | 5% | 11% | 28% | 13% | 39% |
| Exploration Shallow | 0% | 4% | 8% | 17% | 8% | 22% | 33% |
| Completion | 0% | 0% | 0% | 11% | 22% | 0% | 67% |
| Workover | 0% | 5% | 0% | 19% | 43% | 8% | 24% |
| Production | 0% | 0% | 0% | 0% | 50% | 22% | 25% |
| Wireline | 25% | 0% | 0% | 50% | 25% | 0% | 0% |
| **Total** | **1%** | **3%** | **6%** | **15%** | **26%** | **14%** | **31%** |

The flow durations for selected historical international blowouts are shown in Table 6. The longest duration of flow was for the Ixtoc I incident which released oil for 290 days in 1979 and 1980.

**Table 6: Blowout Durations for Selected Historical Blowout Incidents**[42]

| Blowout Incident | Duration (Days) |
|---|---|
| Ixtoc I | 290 |
| Deepwater Horizon MC252 | 84 |
| Labrador Relief Well | 75 |
| Montara | 74 |
| Yum II/Zapoteca | 51 |
| Main Pass 41-C | 30 |
| Labrador Cap | 25 |
| Funiwa 5 | 16 |
| Greenhill TB-251 | 14 |
| Alpha 21-A (Santa Barbara) | 11 |
| Hasbah 6 | 9 |
| Ekofisk Bravo B-14 | 7 |
| Trinimar Marine 327 | 5 |

[41] Based on data in Holand 2013.
[42] Etkin 2009.

## 2.2 FACTORS THAT MAY AFFECT THE CONSEQUENCES OF A WCD SCENARIO

Historical data provide one way to evaluate the potential for blowouts for which response preparedness needs to be considered. Past incidents, however, have occurred under different circumstances than those that may occur in the near and more distant future. It is important to consider the changing landscape of oil exploration and production that may affect the nature of future blowouts and the types of response strategies and capabilities that would be required.

### 2.2.1 Geology

The geologic conditions of the OCS vary greatly among regions, and affect the potential for oil and gas exploration. Areas that have been heavily explored, such as the Gulf of Mexico OCS Region where there have been more than 46,500 wells drilled over 50 years, have long registries of geologic data. By contrast, the U.S. Chukchi Sea is considered a "frontier area" due to the fact that it is relatively unexplored.[43] The geology in the U.S. Beaufort Sea is analogous to the onshore Alaska North Slope. Although lightly explored, the geology is well understood. In some respects, deep-water zones of the Gulf of Mexico also represent "frontier areas."

Despite improvements in seismic technology, frontier areas may present greater potential for blowouts due to the unfamiliarity with the areas and because of the different conditions of the oil reservoir, pressures, or other geologic conditions.[44] With increased understanding of these areas and the gathering of greater geologic data, the potential for a blowout may be reduced.

### 2.2.2 Natural Disasters

Oil well spill events may be caused by external factors such as earthquakes and hurricanes. While these events may not always technically cause a loss of well control or blowout, there may still be considerable oil outflow, especially given the concurrent emergency conditions that may preclude prompt and effective source control.

Offshore platform design criteria for earthquake resistance have been examined and various newer designs are claimed to be able to withstand earthquakes of 5.0 to 6.0 on the Richter scale, with some even claiming resistance to over 8.0 on the Richter scale.[45,46,47]

Hurricanes cause about 25% of offshore platform-related spills, which is a particular concern in the Gulf of Mexico. A study conducted on Gulf of Mexico platforms found that seven out of 3,400 platforms toppled and an additional three had major damage during Hurricane Ivan in 2006.[48] Another factor to consider with respect to hurricanes damaging platforms is that there is the potential for more than one well associated with the platform to spill oil. The threats posed by hurricanes are mitigated by standard, early shut-it procedures.

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[43] BOEM 2012a.
[44] Holland-Bartels and Pierce 2011; National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. 2011.
[45] Gudmestad 2003.
[46] http://www.marinetechnologynews.com/blogs/prirazlomnaya-rig-details-e28093-part-2-700440
[47] http://www.shell.com/global/aboutshell/major-projects-2/sakhalin/platforms.html ; http://www.stos.co.nz/maui.asp
[48] Energo 2006.

Incidents that occur during weather-related natural disasters cause considerable issues with regard to intervention or source control measures and spill response. Many offshore operations cannot be conducted during hazardous weather conditions. These delays will allow for more oil to be released from the well.

### 2.2.3 Water Depth

Water depth contributes to the potential of blowouts in a number of ways. Drilling in deeper waters requires newer and more advanced technologies. Due to their complexity, these technologies may have more potential to fail than simpler, shallow-water systems. Deep-water wells may also coincide with higher temperature and pressure geological formations which also increase the potential of a blowout.[49] Most deep-water wells are farther from shore than shallow water wells which exposes them to harsher weather conditions and sea states, and makes it more difficult for oil spill response and rescue operations to reach these wells. There are no data on blowouts for "ultra deep-water"[50] drilling operations as there have been no incidents at these depths. Ultra-deep wells are relatively rare and only three exploration wells and six development wells were drilled in ultra deep-waters between 2003 and 2012.[51]

The past five decades have seen a steady trend of drilling in increasingly deeper waters in the Gulf of Mexico (Figure 5); however, it should be noted that less than 0.01% of all wells drilled and less than 1.1% of all platforms operating in the Gulf of Mexico are at depths of 3,280 ft. or greater.

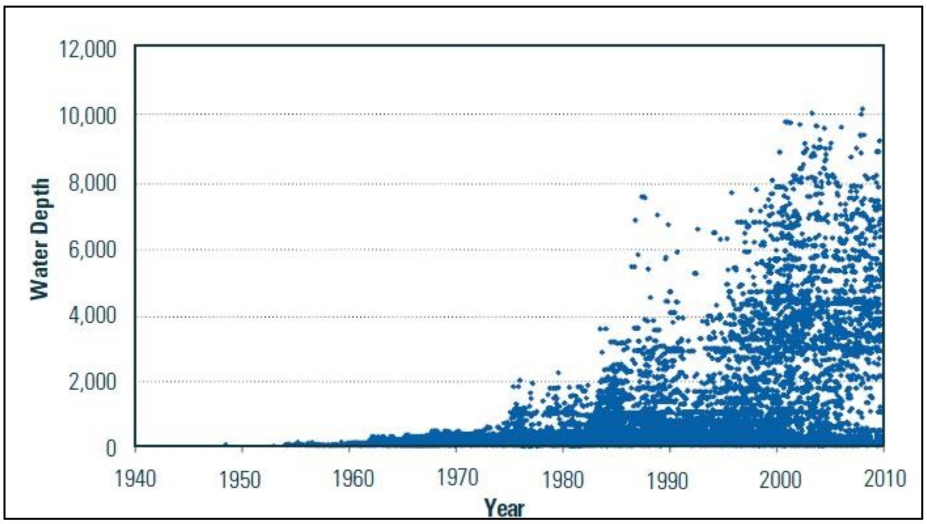


**Figure 5: Wells Drilled in Gulf of Mexico by Water Depth (in feet) 1940 - 2010[52]**

Water depth is directly correlated with the complexity of technology and operations, as well as the frequency of safety incidents.[53] There have been changes in drilling technologies that both reduce the potential for a blowout (e.g., BOPs), as well as changes that will possibly increase the severity of the blowout, such as drilling at increasing water depth.

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[49] Definitions of what constitutes "deep water" vary. BSEE defines deep-water wells as those located in water depths greater than 500 ft. A common definition of deep water used by industry and regulators across the world is greater than 1,000 meters or 3,280 feet. Holand, 2013.
[50] Ultra deep-water is defined as 10,000 of depth or greater.
[51] Dyb et al. 2012.
[52] From: BOEMRE as presented in National Commission 2011.
[53] Jablonowski 2007; Malloy 2008; Muehlenbachs et al. 2011.

Drilling in deep water presents challenges, such as:[54]

- Risers connecting drilling vessels to BOPs on the seafloor have to be greatly lengthened;
- Risers may be exposed to strong ocean currents, especially in the central Gulf of Mexico;
- Managing higher volumes of mud and drilling fluid in long rises places greater demands on operators;
- Connecting and maintaining BOPs thousands of feet below the water surface is technically difficult, and requires the use of remotely-operated vehicles (ROVs);
- BOP maintenance becomes more complicated at depth because of low water temperatures and high water pressure;
- BOPs require higher-strength materials;[55] and
- Formation of methane hydrates,[56] which can destabilize the drilling foundation and present well-control problems and block the flow through deep pipelines and conduits.[57]

In shallow waters (less than 656 feet), exploration and development rigs involve comparatively simple operations and well construction. There is direct access to well control prevention mechanisms, including BOPs.[58]

### 2.2.4 Subsurface Well Depth

Increasing subsurface well depth (i.e., the depth that a well is drilled *below* the ocean floor) is also correlated with higher formation pressures and temperatures. Since the mid-1990s, the Gulf of Mexico has seen a trend of increasing subsurface well depths (Figure 6).

[54] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2011; Holand and Awan 2012; Holand and Skalle 2001.
[55] Whitby 2007.
[56] Methane gas trapped in ice forms at low temperature and high pressure.
[57] Boatman and Peterson 2000.
[58] BOEM 2012a.

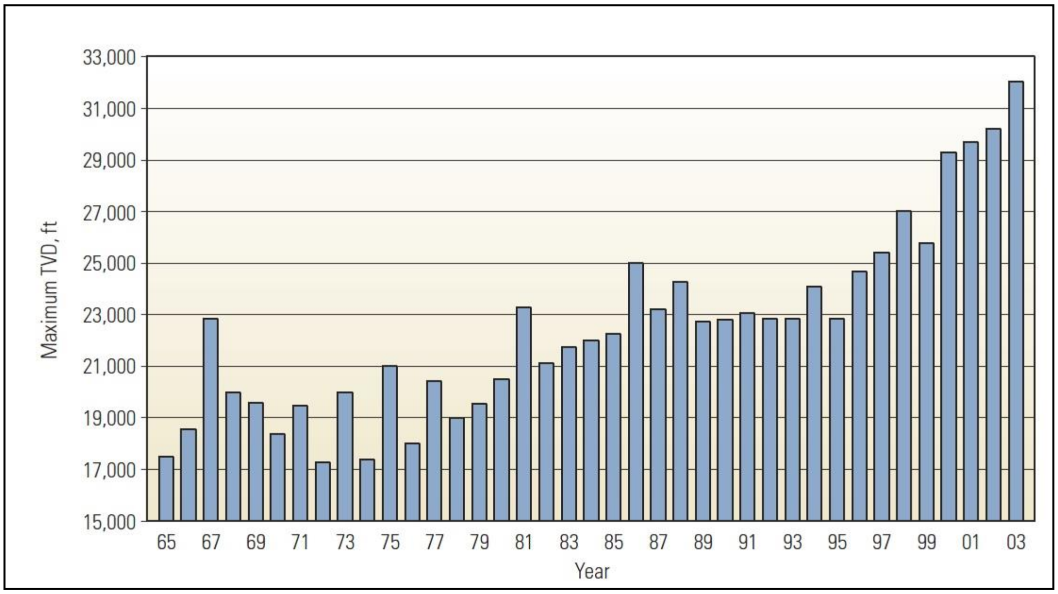


**Figure 6: True Vertical Depth (Subsurface) of Wells in Gulf of Mexico**[59]

Deeper reservoirs and higher well pressures and temperatures create unique challenges for drilling operations, which require careful balancing of pressures to prevent well collapse from excessive pore pressures, or fracturing of rock and loss of circulation from excessive drilling pressure.[60] "Managed pressure drilling" (MPD), an adaptive drilling process used to precisely control annular pressure profile throughout the wellbore, helps to ascertain downhole pressure environment limits and to manage pressure accordingly. MPD is intended to avoid continuous influx of formation fluids to the surface and safely contain any influx during operations.[61] This approach allows drilling in places where it previously had been infeasible, and allows for the drilling of high pressure wells. Deeper reservoirs also often contain larger hydrocarbon reservoirs, which increases the potential volume of discharge if a blowout does occur.

### 2.2.5 Higher Temperature and Pressure Wells

Wells drilled into geological formations that have high temperatures and high pressures (HPHT wells) present greater blowout potentials. High formation pressures are of particular concern with respect to blowouts because high pressures within a well bore are the basic cause of all blowouts, and blowouts associated with high-pressure reservoirs can result in high blowout flow rates, which in turn increase the magnitude of oil discharged.[62] As a result, blowout incident rates for HPHT wells are about six times higher than for typical wells.

### 2.2.6 Extreme Conditions and Human Error

As with many oil spills, human error coupled with mechanical or equipment failure is at the root of many offshore well blowouts.[63] The level of training and a company's "safety culture" are important factors that influence the likelihood of blowouts occurring.[64] Worker performance in extreme climates and

[59] DeBruijn et al. 2008.
[60] BOEM, 2012a.
[61] Qutob 2012; Elliott et al. 2011.
[62] BOEM 2012a.
[63] Jablonowski 2007; Muehlenbachs et al. 2011; BOEM 2012a; Winter 2010.
[64] Jablonowski 2007; Vinnem et al. 2010.

temperatures can be compromised. For example, colder temperatures in the Arctic could possibly be associated with higher rates of human error that could be a factor in intervention and response operations.[65] Colder temperatures can be expected to affect response operations and intervention operations due to changes in the ways in which equipment and metal components handle under these conditions.[66] Arctic conditions can also create challenges for response and intervention operations due to logistical constraints related to remoteness, or due to the presence of sea ice.

## 2.3 Modeling the Consequences of Worst Case Discharges

To examine the consequences of different worst case discharge scenarios, oil spill transport modeling was performed from nine locations across three OCS regions (Gulf of Mexico, Pacific, and Arctic). The purpose of the modeling was to provide insight into the probable behavior and transport of the spilled oil, and its potential for impacting the environment. For this study, it was determined that the release of oil would occur at a subsurface level; therefore the first step in the modeling process was an analysis of the oil discharge as it was released into the water column at depth. The near-field plume analyses were conducted using the OILMAPDeep blowout model[67] to determine the near-field buoyant oil and gas plume dynamics for the deep-water blowout analyses. The initial conditions resulting from these analyses were then used as inputs to the SIMAP model, which tracks far-field transport and weathering of the released oil. For the Arctic locations, the effects of ice interactions with oil were also considered in addition to the standard open water fates and transport processes accounted for in the SIMAP model. The results of 100 separate spill simulations for each scenario were then combined to create stochastic probability data for the potential of oil to contact various aspects of the surrounding environment.

### 2.3.1 Near-Field Oil Plume for Subsurface Discharges

The objective of the first step in modeling using OILMAPDeep was to characterize the oil and gas jet and buoyant plume mixture (oil, gas, and water) discharged from the wellhead blowout (Figure 7). In most blowout cases, this near-field region is within a few hundred meters of the wellhead. Beyond that distance, the plume becomes neutrally-buoyant at the so-called trapping height and oil is released from the plume as droplets that rise and continue to be transported independently by currents. The blowout model solves equations for the conservation of water mass, momentum, buoyancy, and gas mass using integral plume theory, following work outlined in McDougall (1978). An additional description of the OILMAPDeep modeling system is provided in Appendix A.

The inputs to the model include flow rate, gas-to-oil ratio (GOR) of the released hydrocarbons, and aperture or pipe diameter as listed in Table 10. The results of the near-field model provide descriptions of the behavior of the blowout plumes, their evolution within the water column, and the expected initial dilutions (concentration decreases) with distance from the wellhead (seafloor). The results provide information about the termination (trapping) height of the plumes and the oil droplet size distributions associated with the releases.

The oil droplet size distribution has a profound effect on how oil is transported after the initial plume, as the size dictates how long the oil droplet will remain suspended in the water column. Large droplets will reach the surface faster, potentially generating a floating oil slick that will drift with surface winds and currents. Small droplets will remain in the water column longer and be subjected to the subsurface advection-diffusion transport. As the oil is transported by subsurface currents away from the well site, natural dispersion of the oil droplets quickly reduces hydrocarbon component concentrations in the water

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[65] Eschenbach and Harper 2006.
[66] Personal communication, Capt. Scott Powell, Arctic Salvage Research Foundation, September 2015.
[67] McDougall 1978; Fanneløp and Sjøen 1980; Spaulding 1982; Kolluru 1993; Spaulding et al. 2000; Zheng et al. 2002, 2003.

column, with decreasing concentration at increasing distance away from the well site. However, lower rise velocities of the oil droplets correspond to longer residence times of oil suspended in the water column and thus a larger volume of affected water.

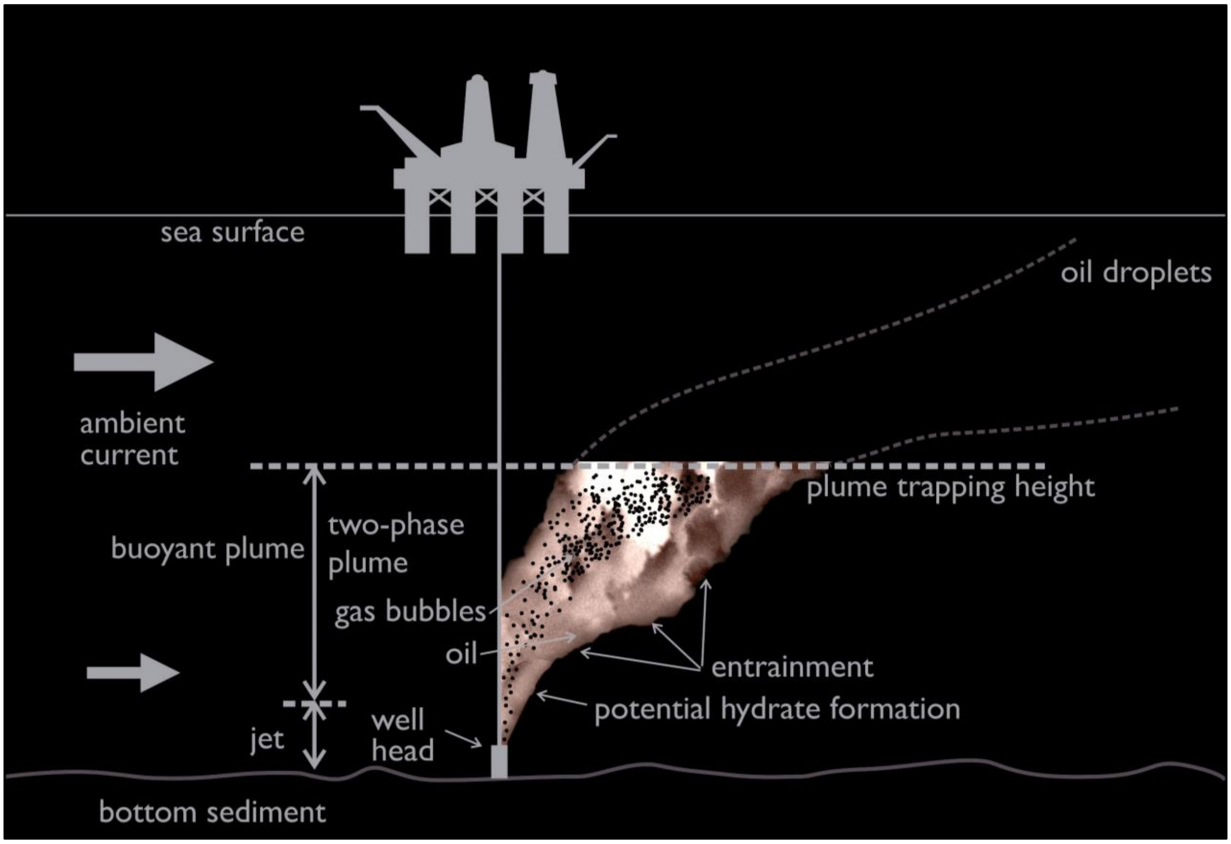


**Figure 7: General Schematic Showing Profile and Associated Dynamics of Deep Well Blowout**

Depending on the environmental conditions near the spill location, there may also be significant degradation (decay) of the oil before surfacing occurs. The oil decay rate is typically higher in warm water environments where biological productivity is high and microbial organisms may play an active role in the breakdown of oil. Thus, if the oil remains in the water column longer, there may be significantly less oil by mass that eventually reaches the surface of the water column.

From an oil spill response perspective, a turbulent blowout that results in the formation of very small oil droplets essentially acts as a natural dispersion mechanism, as these smaller size particles effectively keep the oil from surfacing. On the other hand, with large droplet sizes, there will be quick surfacing of oil, which will limit the subsurface volume exposed to oil, but result in a larger surface oil slick.

The droplet size distributions predicted by OILMAPDeep are calculated based on an estimate of a characteristic diameter ($d_{95}$) and the Rosin-Rammler distribution. In the absence of dispersant application, the predicted $d_{95}$ is most heavily influenced by the exit velocity of the discharge, which is an indicator of the energy associated with the release. The interfacial tension (IFT) of the oil also affects the droplet size distribution where lower IFT results in smaller droplets.

The results obtained in the near-field analyses were used as the starting conditions for the subsequent far-field modeling conducted in SIMAP. These results include the locations and sizes of the plumes at the termination/trapping heights, and the characterization of the oil droplet size distributions.

### 2.3.2 Far-Field Oil Transport and Weathering

RPS ASA's oil spill modeling system, SIMAP,[68] determines far-field transport and weathering of the released oil using site specific wind data and current data, and state-of-the-art transport and oil weathering algorithms (Figure 8) that quantify the surface area swept by floating oil of varying thicknesses, the fate and concentration of the subsurface oil, and the areas of shoreline affected by oil to varying degrees. SIMAP is a 3-dimensional Lagrangian model, and each component of the spilled oil is represented by an ensemble of independent mathematical particles or "spillets." Each spillet is a sub-set of the total mass spilled and is transported by both currents and surface wind drift. A detailed description of SIMAP is presented in Appendix B.

Processes simulated in the SIMAP physical fates model include oil spreading (gravitational and by shearing), evaporation, transport, vertical and horizontal dispersion, emulsification, entrainment (natural and facilitated by the application of dispersants), dissolution, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and sparingly-soluble aromatics to suspended sediments, sedimentation, and degradation (Figure 9).

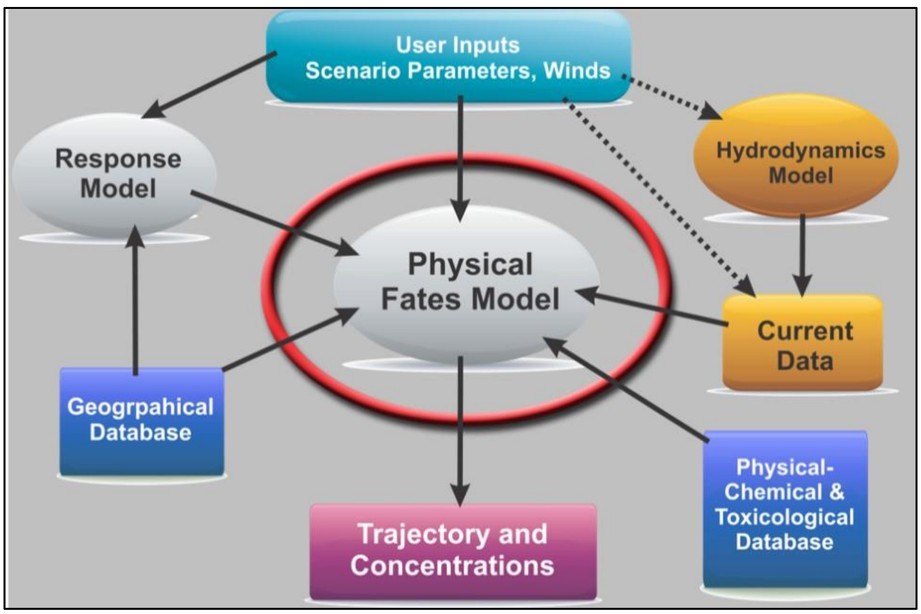


**Figure 8: SIMAP Oil Fate Model Components and Inputs Flow Diagram**

[68] French McCay 2004 & 2009

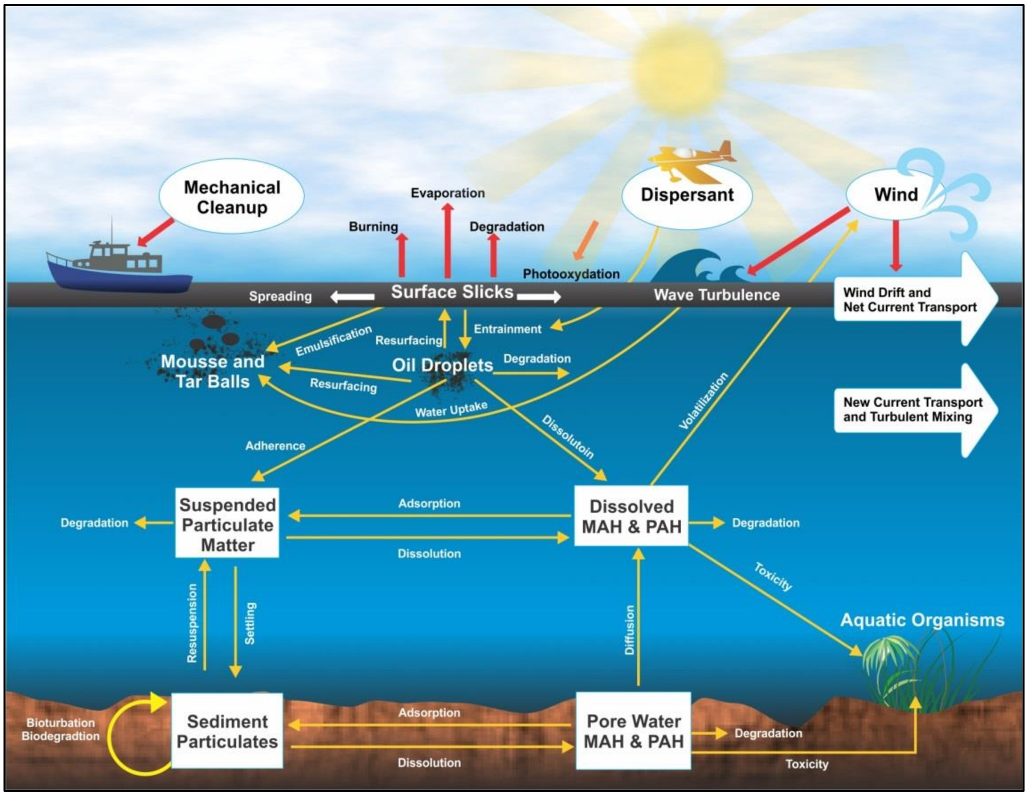


**Figure 9: Open Water Oil Fates and Behavior Processes Simulated in the SIMAP Modeling System**

### 2.3.3 Stochastic Probabilities of Contact for Oil Discharged Into the Environment

SIMAP's stochastic model is used to determine the probability of contact by oil on various resources. The stochastic analysis is a statistical analysis of results generated from many different individual trajectories of the same spill event with each trajectory having a different spill start time selected at random from a relatively long-term window. The random start time allows for the same type of spill to be analyzed under varying conditions. To reproduce the natural variability of winds, the model uses wind data which varies both spatially (multiple points) and temporally (changing with time). The hydrodynamic and wind data hindcast data sources used for each study region are described in this section and Appendix D: Environmental Model Input Data.

The stochastic analysis provides two types of information: 1) probability of various areas experiencing oil exposure, and 2) the shortest time required for oil to reach any point within the areas predicted to be oiled.[69] Figure 10 illustrates the stochastic modeling process, with the left panel showing four individual trajectories predicted by SIMAP for an arbitrary example scenario. Because these trajectories started on different dates/times, they were exposed to varying environmental conditions, and thus traveled in different directions. To compute the stochastic results, all 100 individual trajectories (like the four shown) are overlaid, and the number of times that a given location is reached by different trajectories is used to calculate the probability of oiling for that location. This is shown as the stacked results in the right panel of Figure 10. The predicted cumulative footprint area and probabilities of surface oiling, as shown by the last map in the stacked figures to the right, are generated by a statistical analysis including all 100 individual trajectories. It is important to note that a single trajectory (from one spill release time) encounters only a relatively small portion of the overall probability footprint derived from all 100

[69] These two endpoints are used to support evaluation of OSRPs

individual trajectories. This information is presented in this portion of the overall study for surface oil, shoreline oil and oil within the water column.

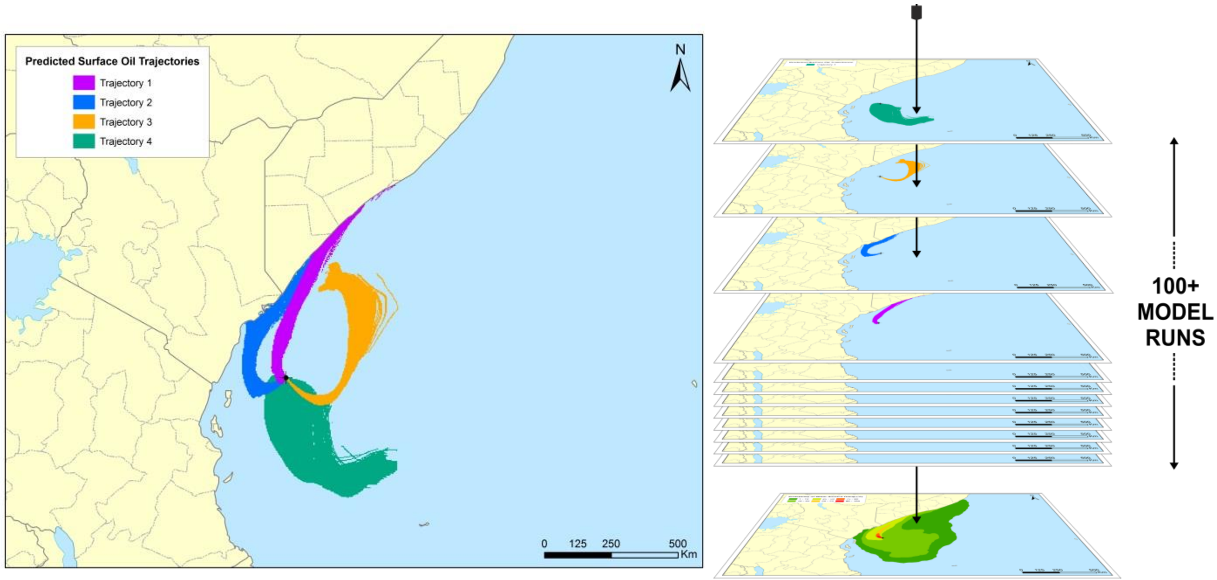


**Figure 10: Examples of Four Individual Spill Trajectories and Resulting Cumulative Footprint Area Predicted by SIMAP for a Generic Spill Scenario**

The stochastic model is capable of evaluating areas affected for different concentrations of oil over a prescribed minimum threshold value. These thresholds are often based on oil spill response requirements or environmental impact assumptions. For this study, the thresholds listed in Table 7 and Table 8 were assessed in the stochastic analysis.

**Table 7: Stochastic Thresholds for Water Surface and Shoreline Oiling**

| Stochastic Threshold Type | Cutoff Threshold (Mass/Unit Area) | Cutoff Threshold (Thickness) | Rationale | Visual Appearance | References |
|---|---|---|---|---|---|
| **Oil on Water Surface** | 8.0 $g/m^2$ | 8.0 µm, 0.08 mm, 0.0003 in | Minimum thickness for which response equipment can skim/remove oil from the surface, surface dispersants are effectively applied, or oil can be boomed/collected for in situ burning. | Fresh oil at this thickness corresponds to a slick being a dark brown or metallic sheen. | NOAA 2010 |
| **Shoreline Oil** | 1.0 $g/m^2$ | 1.0 µm, 0.001 mm, $3.94 \times 10^{-5}$ in | This is the threshold for potential effects on socioeconomic resource uses, as this amount of oil may conservatively trigger the need for shoreline cleanup on amenity beaches, and impact shoreline recreation and tourism. | May appear as a coat, patches or scattered tar | French-McCay et al. 2011; French McCay et al. 2012 |

In the model simulations, if oil contained less than 1% of volatile hydrocarbons, it was considered sufficiently weathered to be a tarball awash by waves and so not included with floating oil that is visible on the water surface. Thus, the probability of surface oiling and floating oil trajectory results do not indicate the presence of these weathered tarballs; they depict floating fresh and partially-weathered oil and mousse. However, the weathered tarballs, as with surface floating oil, can come ashore if transported by surface currents towards a shoreline. The shoreline figures include these weathered tarballs that have come ashore. The modeled oil thickness on shore is an average volume per unit area for the shore segment, whereas actual shoreline oiling may include patchy oil and emulsions (mousse), as well as tarballs, in a given area.

**Table 8: Stochastic Threshold for In-Water Concentration**

| Stochastic Threshold Type | Cutoff Threshold (Concentration) | Rationale | References |
|---|---|---|---|
| **In-Water Concentration** | 1.0 ppb of dissolved PAHs or 1 µg/L of dissolved PAHs; corresponds to 100 µg/L of fresh or whole oil (THC) in the water column, as the soluble PAHs are approximately 1% of the total mass | Water column impacts for both ecological and socioeconomic (e.g., seafood) resources can be quantified at concentrations exceeding 1 ppb dissolved PAH or 100 ppb total oil; this threshold is typically used as a screening threshold for potential impacts on sensitive organisms. | Trudel et al. 1989; French-McCay 2004; French McCay 2002; French McCay et al. 2012 |

With regard to in-water concentrations of total hydrocarbons, the 100 ppb threshold is based on fresh crude oil having a volatile polycyclic aromatic hydrocarbons (PAH) content of ~1% and the 1 ppb threshold for potential effects from PAH concentrations. Thus, this threshold is conservative as highly weathered oil would be much less toxic (on a whole-oil concentration basis) than fresh oil upon which the threshold is based due to its loss of volatile components (including PAHs). In addition, the in-water concentration results provided in Sections 3.3, 4.3, and 5.3 indicate when, for any single 30-minute time step in the model, the threshold of 100 ppb is exceeded in a particular cell. Toxicity would be more likely to occur if there is extended, as opposed to brief, exposure. Therefore, given both these factors (weathering and duration of exposure), the 100 ppb threshold is a conservative threshold for potential effects resulting from water column concentrations.

It is also important to note that this is not a toxicological analysis and this report does not evaluate impacts to the environment. This is primarily a physical study that investigates where, given a particular set of environmental forcing conditions, released oil may be expected to travel through the water column and along shorelines over time. More detailed exposure modeling would be necessary to portray water column effects, which was outside of the scope of this project.

For further context as to the visual appearance of oil at the thresholds provided in Table 7, the guidance provided in Table 9 should be used when analyzing the modeling results presented herein. For comparison purposes, the thickness of a human hair is 10 to 100 µm.

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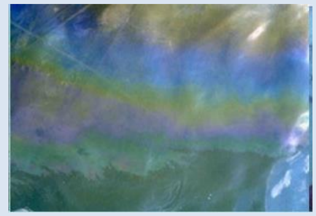
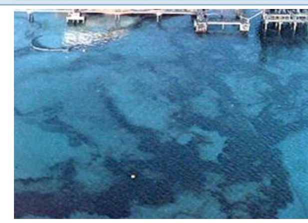
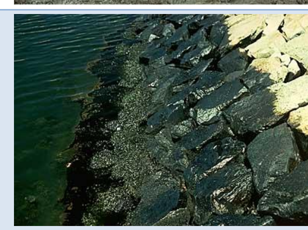
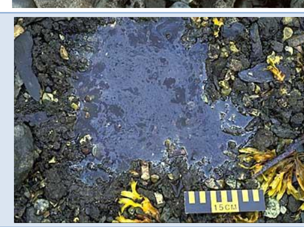
**Table 9: Visual Appearance of Oil on Water Surface at Varying Thicknesses**

| Oil Thickness | Description[70] | Appearance |
|---|---|---|
| **0.3-5 g/m²**<br>(0.3-5.0 µm;<br>0.0003-0.005 mm) | Rainbow sheen |  |
| **>100 g/m²**<br>(>100 µm; >0.1 mm) | Fresh oil; brown to black |  |
| **Fresh oil or mousse > 10,000 g/m²**<br>(1cm; 10 mm; 10,000 µm) thick | Pooled Oil |  |
| **Oil or mousse > 10,000 g/m²**<br>(1cm) to <10,000 g/m² (1cm) thick | Cover |  |
| **< 1,000 g/m²**<br>(0.1 cm; 1 mm; 1,000 µm) | Coat; can be scraped off with fingernail |  |
| **100 g/m²**<br>(0.01 cm; 0.1 mm; 100 µm) | Stain; Visible oil which cannot be scraped off with fingernail |  |
| **< 100 g/m²**<br>(0.01 cm; 0.1 mm; 100 µm) | Film; Transparent or iridescent sheen, or oily film |  |

[70] NOAA, NOS 2007

### 2.3.4 General Interpretation of Worst Case Discharge Scenario Modeling Results

This section provides some notes for the general interpretation of the near-field and far-field analysis results presented in Section 3.3.3 for the Gulf of Mexico OCS Region, Section 4.3.3 for the Pacific OCS Region, and Section 5.3.3 for the Arctic OCS Region.

***Subsurface Oil Plume – Near-Field Analysis***

**Summary Tables**: The near-field oil plume results, as predicted by OILMAPDeep, are presented in summary tables in each scenario section for all regions (e.g., Table 17) and contain the following information:

- The oil release depth was the total depth of the water column at each site assuming that the release of oil was occurring at the seabed.
- The GORs for the well locations were provided by BSEE and were based on actual or estimated reservoir data collected by the various operators. In general, the higher the GOR the more turbulent the subsurface release.
- The oil droplet size distribution in the water column given the physics of the release and the properties of the oil. The diameter of the median droplet size from the predicted distribution is provided in the summary tables.
- The buoyant trapping depth in the water column depth, as predicted by OILMAPDeep. The buoyant trapping depth is the point in the water column where oil droplets are no longer forced by the physics of the release plume and begin to behave based on their own buoyancy. Depending on depth, pressure, and size, droplets may begin to rise or stay trapped at depth. The far-field transport modeling is initiated at the buoyant trapping depth.
- The percentage of oil mass to reach the surface and time it takes for that full percentage of the total mass of the oil released to rise to the surface.

Note that the rise velocity of oil droplets calculated in OILMAPDeep is a simplification of the processes that are occurring and included in the SIMAP model. Some of the processes that affect the rise velocity include the degree of weathering thus a change in oil density, the density of water at depth and vertical stratification. Therefore, rise velocities presented herein using OILMAPDeep for the near-field model are approximations and may differ from those derived during the far-field modeling using SIMAP. It is also important to note that the flow of the blowout well could, and often does, change as the blowout naturally bridges, the reservoir is depleted, or the reservoir pressure reduces. However, the modeling for this task does not consider changes in flow or changes in oil characteristics.

***Surface Oil – Far-Field Analysis***

**Summary Tables:** Various metrics and statistics of interest (e.g., probability of exceedance above shoreline oil threshold, shoreline length (miles) affected above threshold) from the far-field stochastic modeling are summarized in tables in each scenario section (e.g., Table 18). Statistics are shown by each oiling threshold of concern representing potential impacts to socioeconomic and environmental resources (1 $g/m^2$) and implications to cleanup activities (8 $g/m^2$).

**Probability of Oil Contact Figures:** The probability of oiling maps for each scenario define the area and the associated probability in which sea surface (e.g., Figure 23), water column (e.g., Figure 24), and shoreline oiling (e.g., Figure 25) above the defined thresholds would be expected should a worst case blowout occur. The colored area in the stochastic maps indicates areas that *may* receive oil pollution in the event of that particular spill scenario. The 'hotter' the color (e.g., reds), the more likely an area would be affected; the cooler the colors (e.g., greens), the less likely an area would be affected. The probability of oil contamination was based on a statistical analysis of the resulting ensemble of individual trajectories for each spill scenario. These figures do not imply that the entire contoured area would be covered with oil in the event of a spill, nor do they provide any information on the quantity of oil that would be found in a given area.

**Minimum Travel Time Figures:** The footprint of the one minimum travel time map per scenario (e.g., Figure 23, bottom) corresponds to the oil contamination probability maps for oil above the threshold (8 $g/m^2$) in which response equipment can be used. These figures illustrate the shortest time required for oil to reach any point within the footprint at a thickness or concentration exceeding the defined threshold for surface oiling. These results are based on the ensemble of all individual trajectories. It is important to note that these minimum travel time figures represent time since the start of the release, and so include the rise time for the oil to reach the surface, as derived from the near-field analysis discussed above.

### 2.3.5 Worst Case Discharge Scenario Selection

Nine WCD oil spill scenarios, as shown in Table 10 and Table 11, were selected for modeling. Locations for the scenarios are shown in Figure 11, Figure 12, and Figure 13. For each scenario, a representative oil type was chosen based on information on typical °API values found in each region, and a full list of properties for these oils is provided in Appendix E: Oil Characterization and Chemistry. The duration of flow for the baseline modeling involved the longest potential duration of flow which was assumed to be a flow that would be stopped by successful intervention with a relief well.

The scenarios were developed for purposes of oil-spill response analysis. These scenarios are extreme examples and do not represent likely events.

**Table 10: Inputs for WCD Modeling Scenarios**

| Scenario Number[71] | Planning Area | Lease Block | Latitude/ Longitude | Water Depth (ft) | Distance from Shore | Sea/Water Interface Diameter[72] (in) | Open Hole Diameter (in) | GOR (scf/STB)[73] | Oil Name/°API[74] |
|---|---|---|---|---|---|---|---|---|---|
| **1** | Central GOM | Mississippi Canyon (MC807) | 28.157842 -89.2156 | 3,030 | 53 miles (46 nm) | 14.000 | 10.200 | 894 | South LA Crude, 34.5 |
| **2** | Central GOM | West Delta (WD28) | 29.13848 -89.563623 | 35 | 6.4 miles (5.6 nm) | 10.750 | 9.875 | 588 | South LA Crude, 34.5 |
| **3** | Central GOM | West Cameron (WC168) | 29.388171 -93.406424 | 42 | 29 miles (25 nm) | 7.750 | 6.500 | 3,448 | South LA Condensate, 57.5 |
| **4** | Western GOM | High Island East/South Ext. (HIA376) | 27.943209 -93.667917 | 334 | 129 miles (112 nm) | 14.750 | 9.875 | 1,220 | South LA Crude, 34.5 |
| **5** | Central GOM | Keathley Canyon (KC919) | 26.080171 -92.037507 | 6,940 | 250 miles (217 nm) | 13.625 | 12.250 | 893 | South Louisiana Crude, 34.5 |
| **6** | Central GOM | DeSoto Canyon (DC187) | 28.785337 -87.39878 | 4,490 | 116 miles (101 nm) | 13.625 | 12.250 | 654 | South LA Crude, 34.5 |
| **7** | Southern California | Santa Maria 6683 | 34.33732 -120.4209 | 1,073 | 9.2 miles (8 nm) | 9.625 | 6 | 3,000 | Point Arguello Light Crude, 30.3 |
| **8** | Chukchi Sea | Posey 6912 | 71.102403 -163.2819 | 150 | 69 miles (60 nm) | 12.348 | 13.375 | 800 | Alaskan North Slope Crude, 30.9 |
| **9** | Beaufort Sea | Flaxman Island 6610 | 70.227 -146.0186 | 120 | 4.5 miles (3.9 nm)[75] | 8.544 | 9.625 | 900 | Prudhoe Bay Crude Low Volatile, 24.8 |

[71] For each of the two Arctic locations (Chukchi/ Beaufort), there are two seasonal scenarios – one early and one late season, the latter of which may involve ice.
[72] These are not pipe diameters. These are the open hole diameters used to calculate the highest daily WCDs.
[73] Standard cubic feet per stock tank barrel.
[74] An alternative measure of density of oil; the higher the °API, the lighter the oil.
[75] Distance is to mainland, distance to coastal barrier islands is 1.5 miles (1.3 nm).

**Table 11: Discharge Parameters for Study Baseline WCD Scenarios**

| Scenario Number | Planning Area | Lease Block | WCD Flow Rate (bbl/day) | Flow Duration Relief Well Only (days) | Total WCD Volume (bbl) | Optimal Source Control (days) | Sub-Optimal Source Control (days) |
|---|---|---|---|---|---|---|---|
| **1** | Central GOM | MC807 | 449,000 | 182 | 81,718,000 | 21 | 60 |
| **2** | Central GOM | WD28 | 97,000 | 37 | 3,589,000 | 7 | 28 |
| **3** | Central GOM | WC168 | 26,400 | 76 | 2,006,400 | 7 | 28 |
| **4** | Western GOM | HIA376 | 77,000 | 50 | 3,850,000 | 7 | 28 |
| **5** | Central GOM | KC919 | 252,000 | 120 | 30,240,000 | 21 | 60 |
| **6** | Central GOM | DC187 | 241,000 | 106 | 25,546,000 | 21 | 60 |
| **7** | Southern California | Santa Maria 6683 | 5,200 | 170 | 884,000 | 1 | 17 |
| **8** | Chukchi Sea | Posey 6912 | 25,000 | 28 | 700,000 | 7 | 21 |
| **9** | Beaufort Sea | Flaxman Island 6610 | 16,000 | 30 | 480,000 | 7 | 21 |

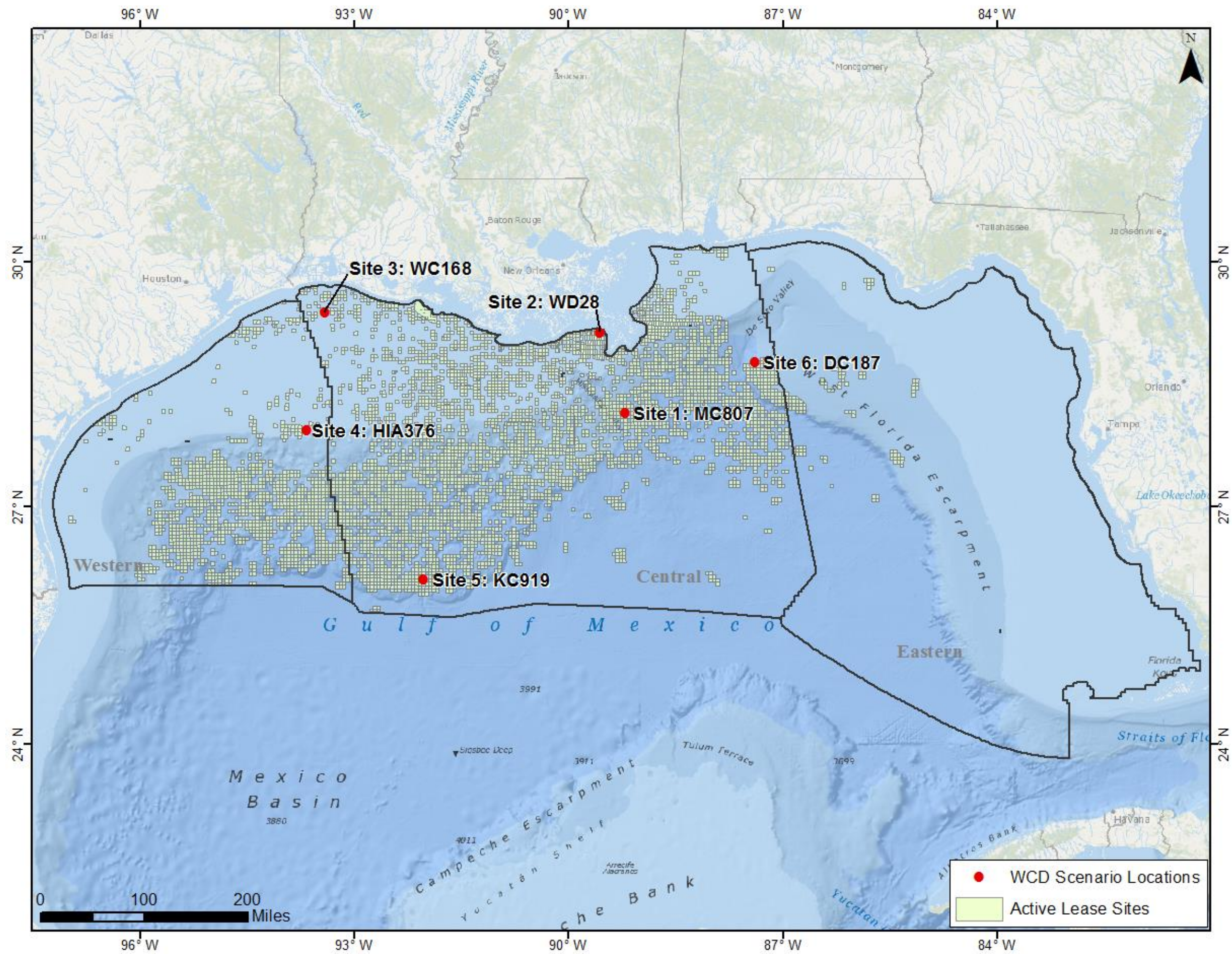



**Figure 11: Locations of Gulf of Mexico OCS Region Scenarios for Worst Case Discharge Analysis**

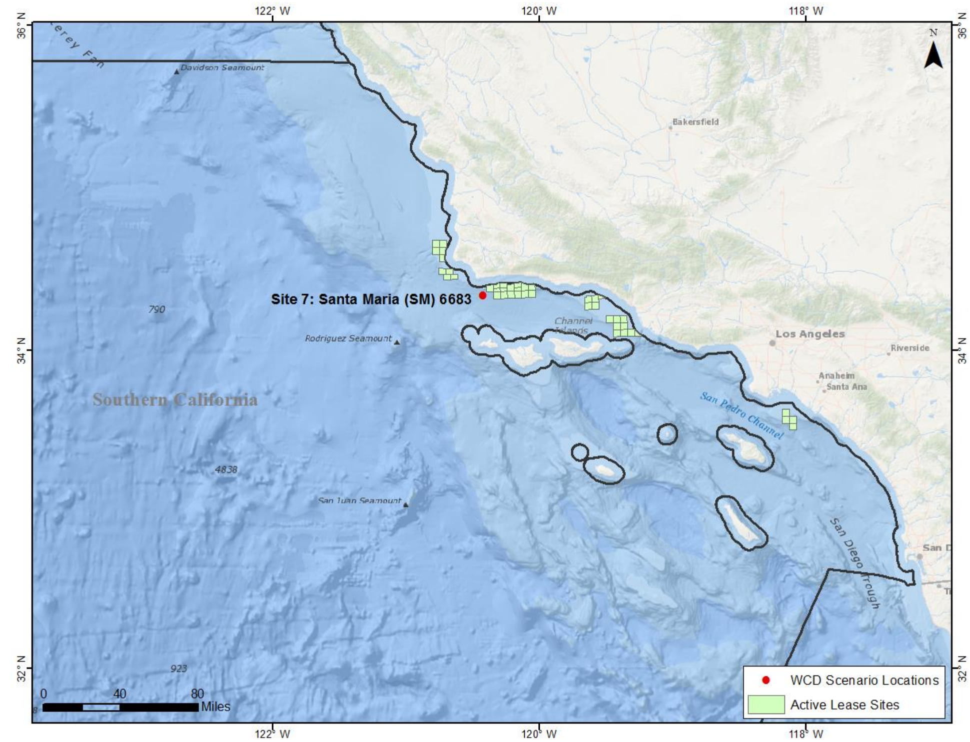



Figure 12: Location of Southern California Scenario for Worst Case Discharge Analysis

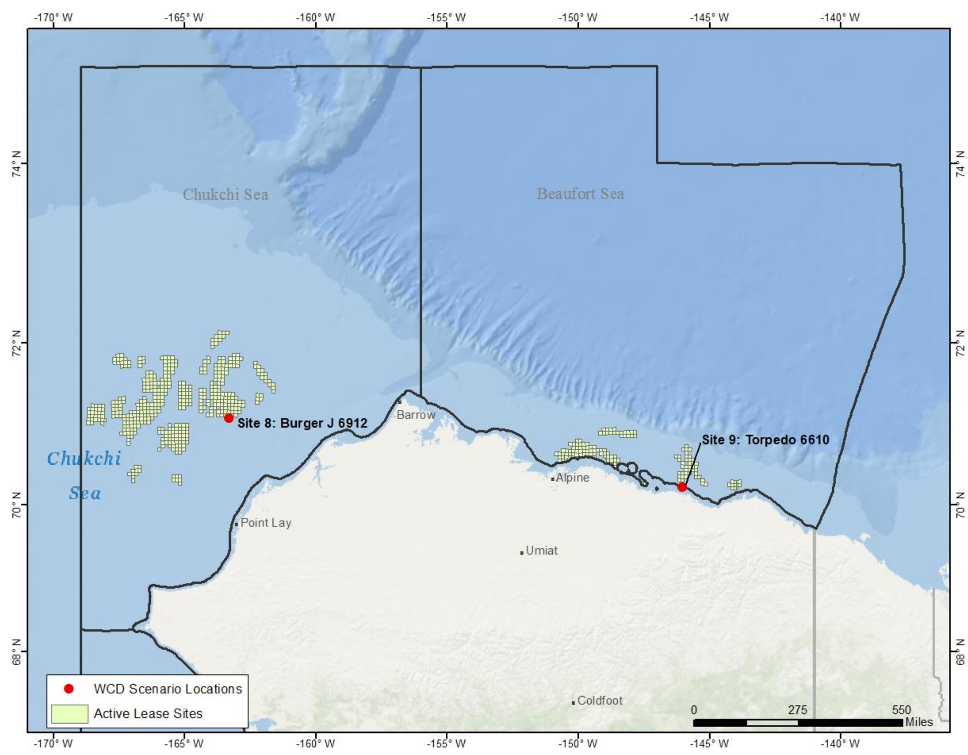



Figure 13: Locations of Arctic OCS Region Scenarios for Worst Case Discharge Analysis

### 2.3.6 Benchmarking of WCD Scenario Flow Volumes

The total volume of discharge based on the average daily flow rate and the duration of flow is of greatest concern in determining impacts of blowouts and the necessary spill responses. The total volumes of spillage for the modeling scenarios (based on durations assumed for successful intervention with relief wells) were benchmarked to the actual volumes of oil spilled for the largest worldwide blowouts, as shown in Table 12 and Figure 14.

**Table 12: Study Scenario Total Blowout Volume Benchmarking Relative to Highest Volume**

| Study Scenario | Volume (bbl) | Relative to Past Incidents | |
|---|---|---|---|
| | | Deepwater Horizon MC252/Study Scenario | Ixtoc I (High)/Study Scenario |
| Scenario 1 (Central GOM MC807) | 81,718,000 | 19.457 | 8.019 |
| Scenario 5 (Central GOM KC919) | 30,240,000 | 7.200 | 2.968 |
| Scenario 6 (Central GOM DC187) | 25,546,000 | 6.082 | 2.507 |
| Scenario 4 (Western GOM HIA376) | 3,850,000 | 0.917 | 0.378 |
| Scenario 2 (Central GOM WD28) | 3,589,000 | 0.855 | 0.352 |
| Scenario 3 (Central GOM WC168) | 2,006,400 | 0.478 | 0.197 |
| Scenario 7 (SM6683) | 884,000 | 0.210 | 0.087 |
| Scenarios 8/9 (P6912) | 700,000 | 0.167 | 0.069 |
| Scenarios 10/11 (FI6610) | 480,000 | 0.114 | 0.047 |

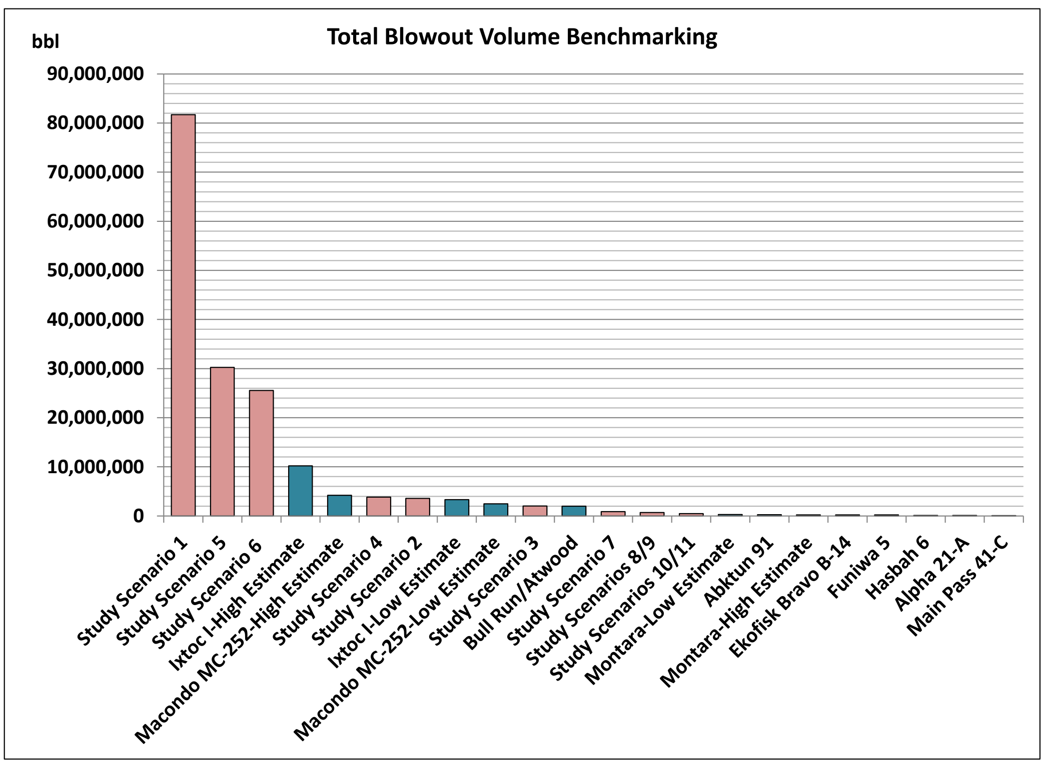



**Figure 14: Total Blowout Volume Benchmarking Comparison**

## 3.0 WCD PROFILES FOR THE GULF OF MEXICO OCS REGION

The Gulf of Mexico OCS Region has, by far, the greatest number of wells and the highest production rate (91% of total U.S. OCS production) among the OCS Regions. The three Gulf of Mexico OCS Region Planning Areas, along with individual drilling platforms, are shown in Figure 15. The numbers of producing wells by time period are in Table 13.

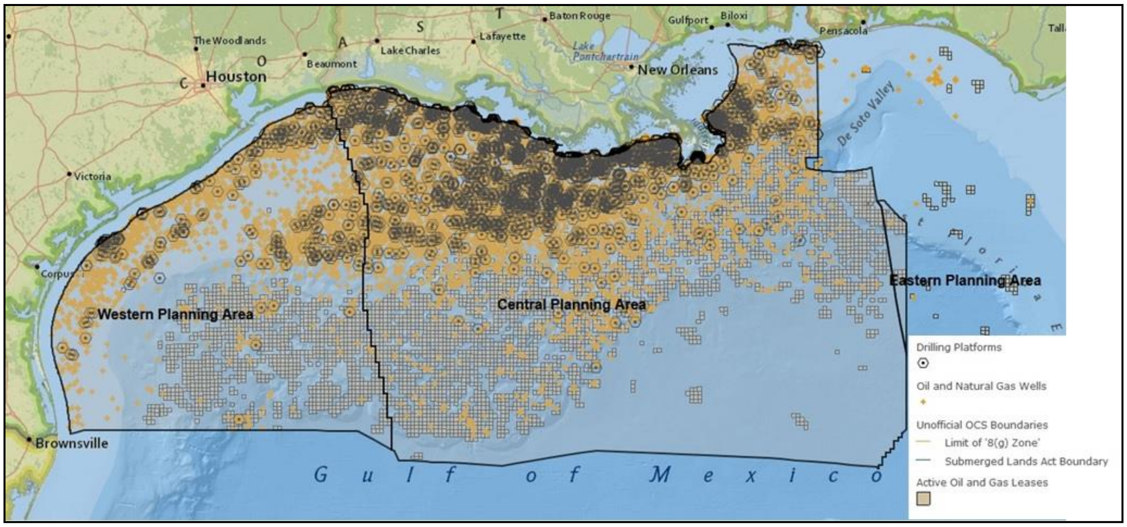



**Figure 15: Gulf of Mexico OCS Region Well Map**[76]

**Table 13: Number of Producing Wells in the Gulf of Mexico OCS Region**[77]

| Time Period | Number of Producing Wells During Time Period |
|---|---|
| 1940 - 1963 | 0 |
| 1964 - 1994 | 12,645 |
| 1995 - 2004 | 13,560 |
| 2005 - 2013 | 8,946 |

### 3.1 GEOGRAPHICAL ANALYSIS OF GULF OF MEXICO OCS REGION WCD VOLUMES

An ArcGIS-10 compatible ArcMap™ document was created that geographically displays the WCD volumes specified in Oil Spill Response Plans (OSRPs) for each OCS region (Arctic, Pacific, and the Gulf of Mexico) as of December 12, 2014 and July 8, 2015 (the dates on which the data were received). WCD locations are represented as symbols of varying size proportional to the corresponding WCD volumes. The map also provides the state and federal protractions for each OCS Region. Graphs with the WCDs grouped by volume and distance from shore are provided for each OCS Region. The tables and graphs are linked into the ArcMap™ document as figures so that when polygons representing the three OCS Regions are chosen, the summary information is made available. Appendix F: WCD Portfolio Metadata provides the metadata for this ArcMap™ document. This section of the report provides the analysis of the WCD volumes for the Gulf of Mexico OCS region.

An important caveat for this analysis is that the WCD information is derived from the OSRPs and does not include all of the wells in the Gulf of Mexico. Therefore, information presented is based on a representative number of wells presented in the OSRPs as of December 12, 2014 and the data analyzed herein should be considered a sample dataset of the Gulf of Mexico OCS population. The data points

[76] http://www.arcgis.com/home/webmap/viewer.html?webmap=0275bf48adde40d88df75e5ef0a17197
[77] Based on queries at: http://www.data.bsee.gov/homepg/data_center/leasing/WaterDepth/wdlist.asp

used in these maps contain a number of inaccuracies for various reasons.  For instance, a number of the data points in these maps represent a pipeline WCD.  Therefore, a single point is being used for the WCD volumes of pipelines that may span a hundred miles in some instances.

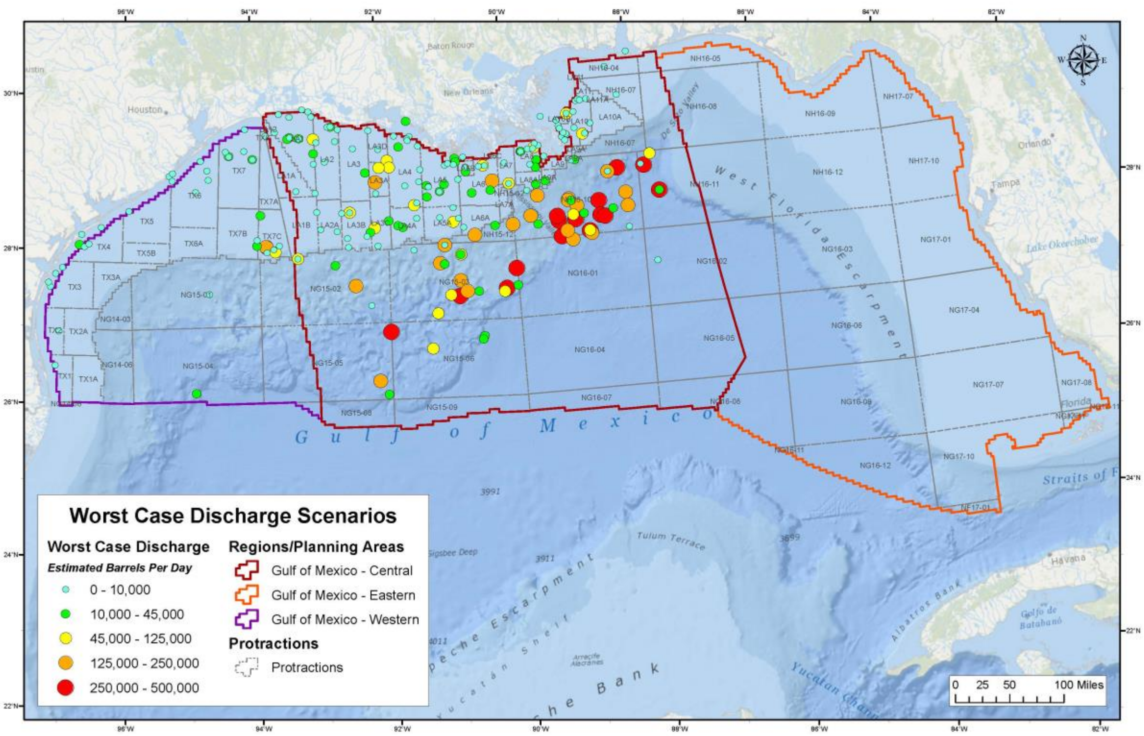



**Figure 16: Worst Case Discharge Flow Rates (bbl/day) Specified in the OSRP Locations in the Entire Gulf of Mexico OCS Region as of December 12, 2014**

### 3.1.1 Spatial and Volume Distribution

All of the WCD volumes specified in the Gulf of Mexico OSRPs, as provided by BSEE in December 2014, are in the Central and Western Gulf of Mexico Planning Areas (Figure 17 and Figure 18), with the majority of the WCD volumes occurring in the Central Gulf of Mexico Planning Area Figure 17).  There are no data points in the Eastern Gulf of Mexico and relatively few in the Western Gulf of Mexico Planning Area (Figure 18).  Eighty percent of the WCD volumes specified in the Gulf of Mexico OSRPs are in water depths less than 3,280 ft. (1,000 m); therefore, the other 20% of the WCD volumes are considered to occur in deep water.  The Central Planning Area has clusters of relatively large WCD flow rates (>125,000 bbl/day) in deep water relatively close to shore in the Mississippi Canyon area, specifically in BSEE Protraction Regions NH 16-10, NH 15-12 and NG 15-03 (Figure 17).

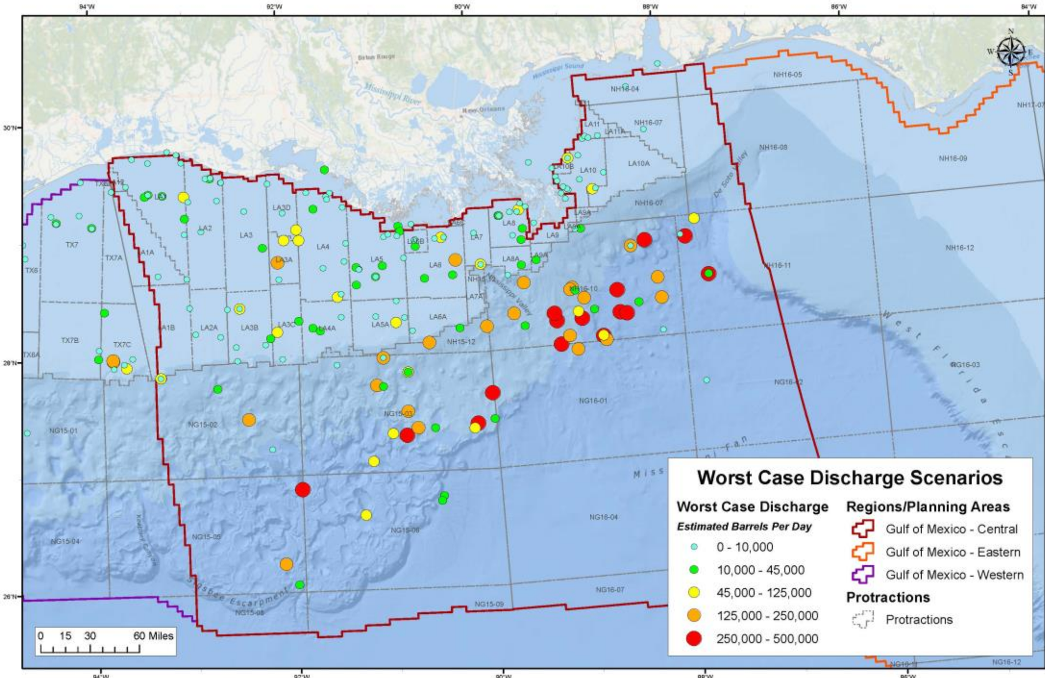



**Figure 17: Worst Case Discharge Flow Rates (bbl/day) Specified in the OSRP Locations in the Central and Western Gulf of Mexico Planning Areas as of December 12, 2014**

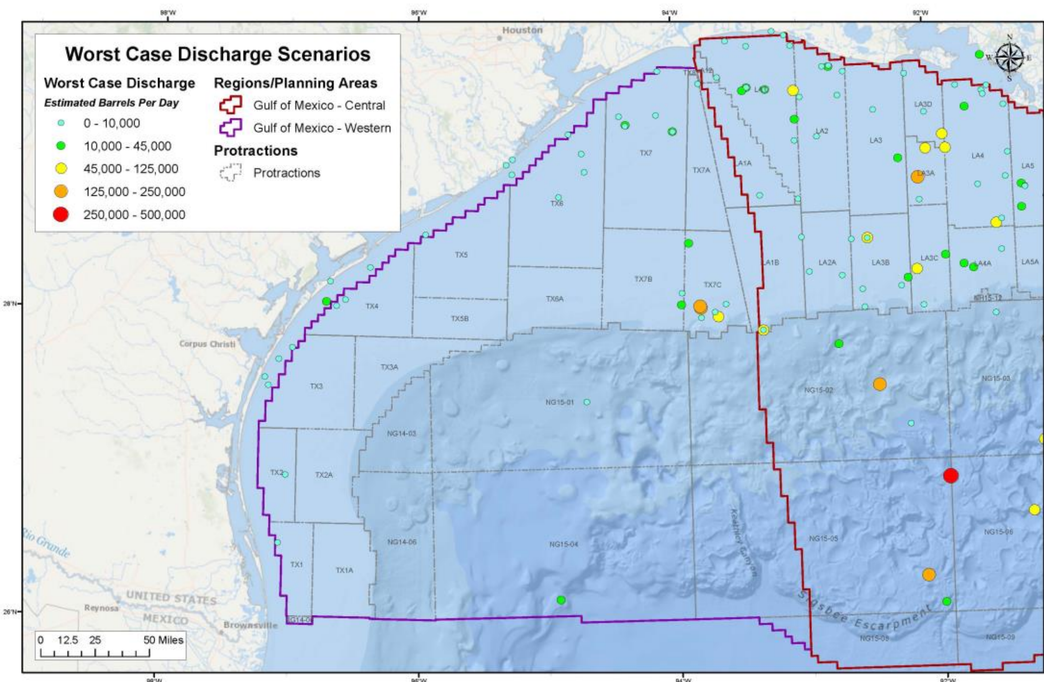
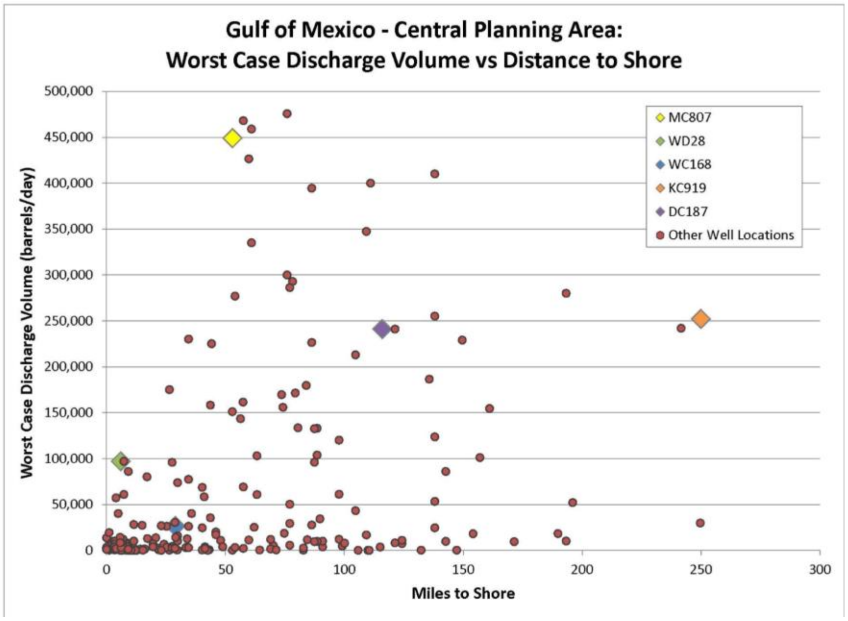



**Figure 18: Worst Case Discharge Flow Rates (bbl/day) Specified in the OSRP Locations in the Central and Western Gulf of Mexico Planning Areas as of December 12, 2014**

Based on the data contained within the OSRP's, the largest WCD flow rates involving releases of greater than 250,000 bbl/day occur 50 miles or more from shore. The range of WCD flow rates for the Gulf of Mexico within this sample population of data is 4 to 476,000 bbl/day. The average WCD flow rate for the locations in the Central Gulf of Mexico Planning Area within this sample population of data is 59,690 bbl/day, while the average WCD flow rate for the Western Gulf of Mexico Planning Area is 13,784 bbl/day.



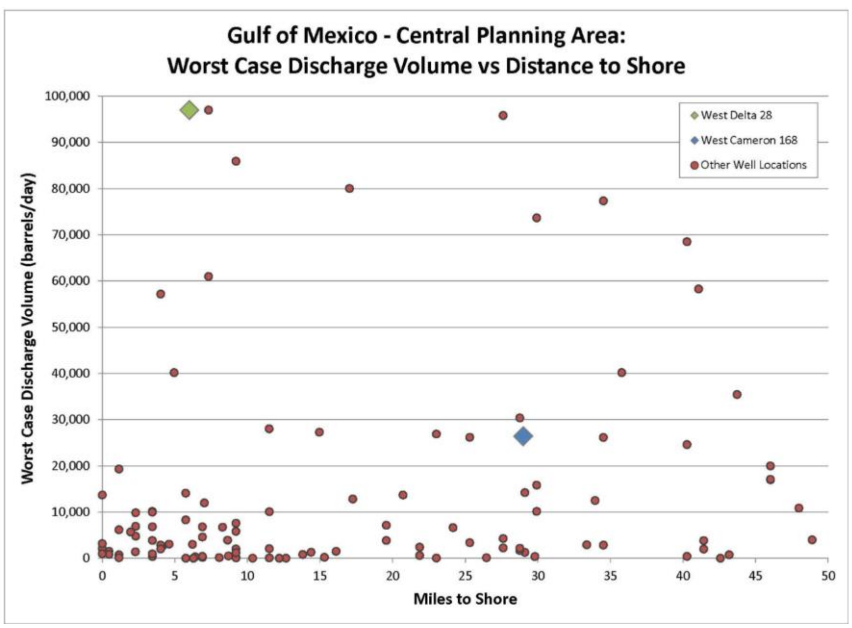
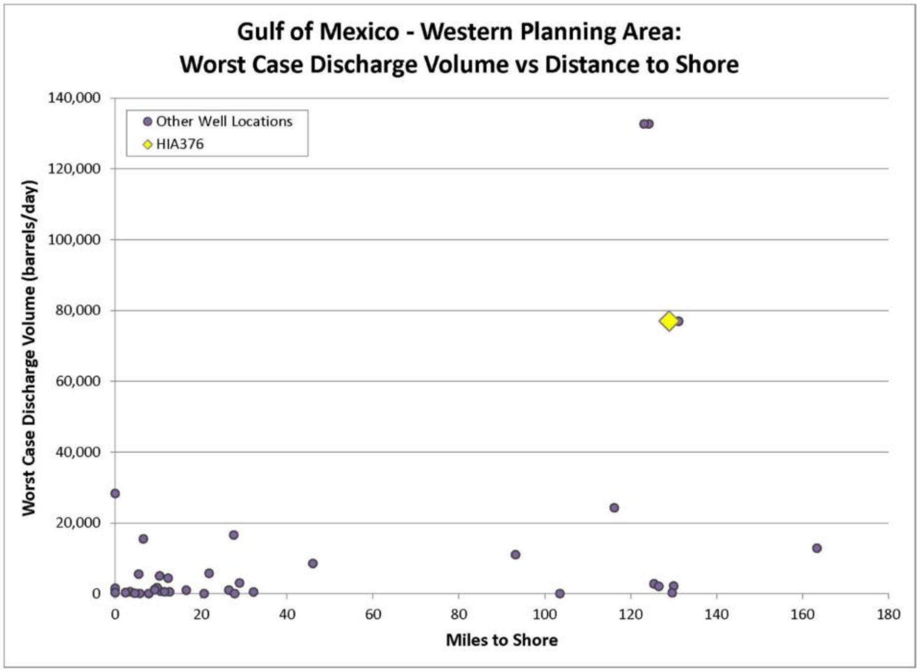




**Figure 19: Distances to Shore for WCD Volumes in the Central Gulf of Mexico Planning Area with All WCD Volumes (Top) and Those within 50 Miles (43 nm) of Shore (Bottom) and the Locations of the Scenarios Used in Modeling Highlighted**



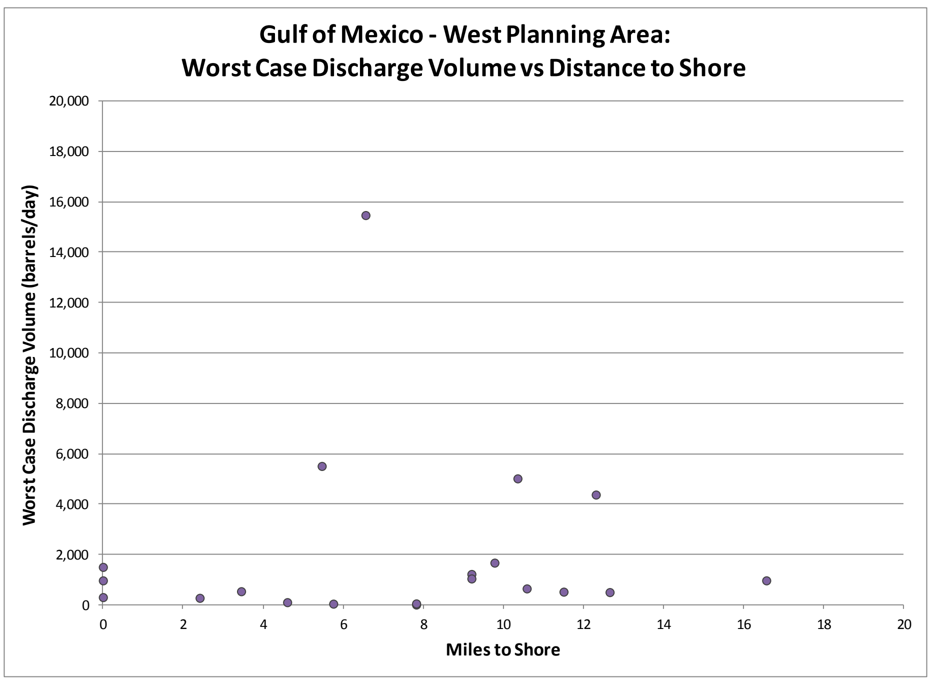




**Figure 20: Distances to Shore for WCD Volumes in the Western Gulf of Mexico Planning Area with All WCD Volumes (Top) and those within 50 miles (43 nm) of Shore (Bottom) and the Locations of the Scenarios Used in Modeling Highlighted**

The flow rates for some wells in the Gulf of Mexico, such as those selected for the six Gulf of Mexico study scenarios, ranging from 26,400 to 449,000 bbl/day (Table 11), are significantly higher than those for the Pacific and Arctic OCS Regions.

## 3.2 OTHER GENERAL TRENDS

Due to rapid development of new drilling technologies, the region faces a unique mixture of factors that could affect the nature of a WCD scenario.

### 3.2.1 Water Depth

The trend toward drilling activities in deeper waters (Table 14) is an important factor that will determine the nature of future spill scenarios in the Gulf of Mexico. Wells in deeper waters are generally also further from shore, which creates challenges for spill response and intervention or source control operations.

### 3.2.2 Temperature and Pressure

Gulf of Mexico drilling is increasingly moving into higher temperature and higher pressure reservoirs. Blowouts associated with high-pressure reservoirs can result in higher discharge flow rates[78]. HPHT wells are defined as those with shut-in pressures exceeding 10,000 psi (690 bars) and/or bottom-hole temperatures equal to or above 300°F,[79] and are particularly common in the Gulf of Mexico. Of the production and development wells tested in the Gulf of Mexico in a study conducted between 1980 and 1996, 0.15% encounter pressures of 10,000 psi or greater.[80] In recent years, the number of HPHT wells has increased worldwide, including in deep-water parts of the Gulf of Mexico, such as Eugene Island, Mobile Bay, South Texas, and West Cameron, which can be seen in Figure 21.[81]

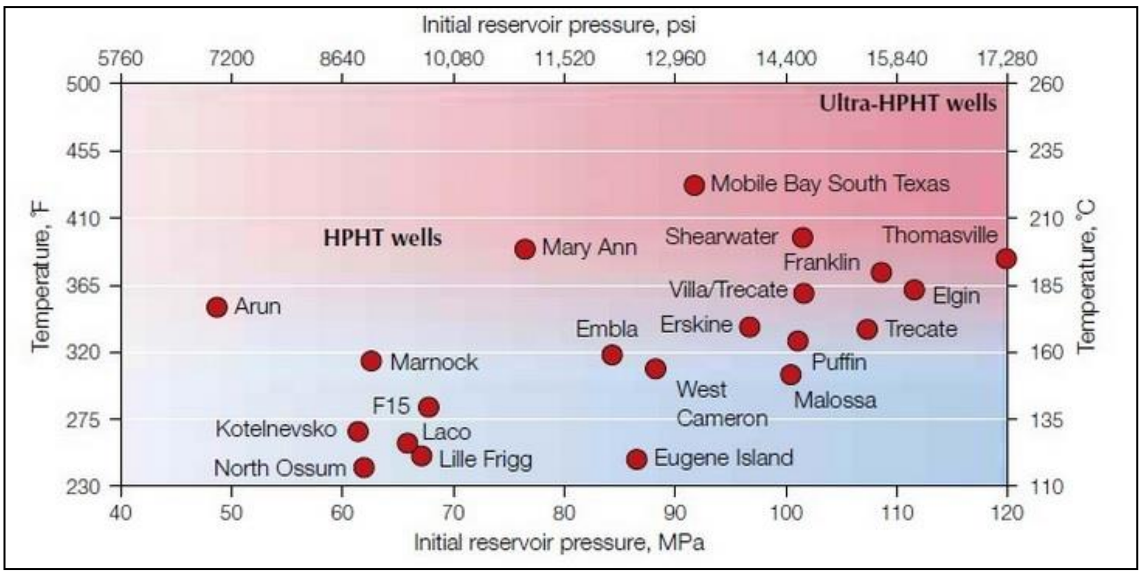



**Figure 21: HPHT Wells Worldwide[82]**

### 3.2.3 Subsurface Well Depth Issues

Increasing subsurface well depth, the depth *below* the ocean floor, is also correlated with higher formation pressures and temperatures. Since the mid-1990s, the Gulf of Mexico has seen a trend of increasing subsurface well depths (refer to Figure 6).

[78] BOEM 2012a.
[79] Holand 2013; USDOI 2010; Midé 2010.
[80] Holand 2013.
[81] Adamson et al. 1998.
[82] http://drilleng-group1-onshoredrilling.wikispaces.com/Drill+under+extreme+conditions

**Table 14: Water Depth for Gulf of Mexico OCS Region Wells**[83]

| Water Depth (ft.) | 1964 - 1994 | | | | 1995 - 2004 | | | | 2005 - 2014 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wells Drilled | | Production Wells | | Wells Drilled | | Production Wells | | Wells Drilled | | Production Wells | |
| | # | % | # | % | # | % | # | % | # | % | # | % |
| **0 - 33** | 2,142 | 6.8% | 979 | 7.7% | 617 | 5.5% | 880 | 6.5% | 243 | 5.40% | 529 | 5.90% |
| **34 - 164** | 15,296 | 48.5% | 6,236 | 49.3% | 4,721 | 42.2% | 6,382 | 47.1% | 1,779 | 39.20% | 3,966 | 44.30% |
| **165 - 328** | 10,535 | 33.4% | 4,298 | 34.0% | 2,924 | 26.1% | 4,422 | 32.6% | 912 | 20.10% | 2,767 | 30.90% |
| **329 - 656** | 2,072 | 6.6% | 740 | 5.9% | 758 | 6.8% | 920 | 6.8% | 218 | 4.80% | 568 | 6.30% |
| **657 - 1,312** | 873 | 2.8% | 325 | 2.6% | 458 | 4.1% | 492 | 3.6% | 73 | 1.60% | 316 | 3.50% |
| **1,311 - 1,968** | 297 | 0.9% | 55 | 0.4% | 260 | 2.3% | 147 | 1.1% | 88 | 1.90% | 138 | 1.50% |
| **1,969 - 2,624** | 113 | 0.4% | 4 | 0.0% | 181 | 1.6% | 50 | 0.4% | 96 | 2.10% | 72 | 0.80% |
| **2,625 - 3,280** | 130 | 0.4% | 8 | 0.1% | 290 | 2.6% | 114 | 0.8% | 210 | 4.60% | 174 | 1.90% |
| **3,281 - 3,936** | 31 | 0.1% | 0 | 0.0% | 301 | 2.7% | 71 | 0.5% | 170 | 3.70% | 121 | 1.40% |
| **3,937 - 4,592** | 12 | 0.0% | 0 | 0.0% | 226 | 2.0% | 19 | 0.1% | 204 | 4.50% | 90 | 1.00% |
| **4,592 - 5,248** | 4 | 0.0% | 0 | 0.0% | 119 | 1.1% | 19 | 0.1% | 102 | 2.20% | 46 | 0.50% |
| **5,249 - 5,904** | 7 | 0.0% | 0 | 0.0% | 111 | 1.0% | 22 | 0.2% | 128 | 2.80% | 60 | 0.70% |
| **5,905 - 6,560** | 3 | 0.0% | 0 | 0.0% | 62 | 0.6% | 9 | 0.1% | 76 | 1.70% | 26 | 0.30% |
| **6,561 - 7,216** | 3 | 0.0% | 0 | 0.0% | 87 | 0.8% | 11 | 0.1% | 92 | 2.00% | 34 | 0.40% |
| **7,217 - 7,872** | 3 | 0.0% | 0 | 0.0% | 26 | 0.2% | 2 | 0.0% | 75 | 1.70% | 11 | 0.10% |
| **7,873 - 8,528** | 0 | 0.0% | 0 | 0.0% | 22 | 0.2% | 0 | 0.0% | 33 | 0.70% | 16 | 0.20% |
| **8,529 - 9,184** | 0 | 0.0% | 0 | 0.0% | 15 | 0.1% | 0 | 0.0% | 21 | 0.50% | 9 | 0.10% |
| **9,185 - 9,840** | 0 | 0.0% | 0 | 0.0% | 8 | 0.1% | 0 | 0.0% | 13 | 0.30% | 3 | 0.00% |
| **9,841 - 10,496** | 0 | 0.0% | 0 | 0.0% | 1 | 0.0% | 0 | 0.0% | 2 | 0.00% | 0 | 0.00% |
| **Total** | **31,521** | **100.0%** | **12,645** | **100.0%** | **11,187** | **100.0%** | **13,560** | **100.0%** | **4,535** | **100.00%** | **8,946** | **100.00%** |
| **Average Depth** | **322 ft.** | | **278 ft.** | | **889 ft.** | | **392 ft.** | | **1,593 ft.** | | **629 ft.** | |
| **1,311 - 2,624 ft.** | **1.3%** | | **0.5%** | | **3.9%** | | **1.5%** | | **4.0%** | | **2.3%** | |
| **2,625 - 5,248 ft.** | **0.6%** | | **0.1%** | | **8.4%** | | **1.6%** | | **15.0%** | | **4.8%** | |
| **>5,249 ft.** | **0.0%** | | **0.0%** | | **3.0%** | | **0.3%** | | **9.7%** | | **1.8%** | |

[83] Derived from data queries at: http://www.data.bsee.gov/homepg/data_center/leasing/WaterDepth/wdmaster.asp

## 3.3 CONSEQUENCE ANALYSIS FOR GULF OF MEXICO OCS REGION

### 3.3.1 WCD Scenario Selections

The consequences of various WCDs in the Gulf of Mexico OCS Region were investigated by modeling six representative scenarios to determine the potential for spilled oil to come into contact with resources in the Gulf of Mexico. All of the scenarios except one (Scenario 4 - HIA376) were in the Central Gulf of Mexico Planning Area (Table 15). The flow rates for some wells in the Gulf of Mexico, such as those selected for the six Gulf of Mexico study scenarios (Table 15), are significantly higher than those for the Pacific and Arctic OCS Regions. With these high flow rates, the likelihood of a larger-volume well blowout is considerably greater than in other regions. Larger-volume scenarios create challenges for spill response operations.

**Table 15: WCD Scenarios for the Gulf of Mexico OCS Region**

| Scenario Number | Planning Area | Lease Block | Oil Name/°API[84] | WCD Flow Rate (bbl/day) | Flow Duration Relief Well Only (days) | Total WCD Release Volume (bbl) |
|---|---|---|---|---|---|---|
| **1** | Central GOM | Mississippi Canyon (MC807) | South Louisiana Crude 34.5 | 449,000 | 182 | 81,718,000 |
| **2** | Central GOM | West Delta (WD28) | South Louisiana Crude 34.5 | 97,000 | 37 | 3,589,000 |
| **3** | Central GOM | West Cameron (WC168) | South Louisiana Condensate 57.5 | 26,400 | 76 | 2,006,400 |
| **4** | Western GOM | High Island East South Extension (HIA376) | South Louisiana Crude 34.5 | 77,000 | 50 | 3,850,000 |
| **5** | Central GOM | Keathley Canyon (KC919) | South Louisiana Crude 34.5 | 252,000 | 120 | 30,240,000 |
| **6** | Central GOM | DeSoto Canyon (DC187) | South Louisiana Crude 34.5 | 241,000 | 106 | 25,546,000 |

[84] An alternative measure of density of oil; the higher the °API, the lighter the oil.

### 3.3.2 Scenario 1 – Mississippi Canyon (MC807)

The Mississippi Canyon (MC807) scenario in the Central Gulf of Mexico Planning Area is the largest WCD scenario assessed for this consequence analysis.

**Table 16: Well Information for Scenario 1 – Gulf of Mexico Mississippi Canyon 807 (MC 807)**

| WCD Scenario: Lease Block Mississippi Canyon 807 (MC807)<br>Central GOM Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 449,000 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 182 days |
| **Total WCD Release Volume** | 81,718,000 bbl |
| **Simulation Duration (45 days following end of release)** | 227 days |
| **API Gravity (South Louisiana Crude)** | 34.5 |
| **Latitude, Longitude** | 28.157842°N, 89.2156°W |
| **Depth to Sea Floor** | 3,030 feet |
| **Distance to Shoreline** | 53 miles (46 nm) |

#### *MC807 Oil Plume, Fate, and Transport Modeling Results*

The near-field oil plume simulation found that 63% of the total oil mass would reach the surface within 5 days of the release and the buoyant trapping depth was 1,759 feet (Table 17). Therefore, the far-field oil transport for this case was initiated from 1,759 ft. with a median droplet size of 211 microns. For guidance on general interpretation of the plume and stochastic modeling results refer to Section 2.3.4.

**Table 17: Near-Field Oil Plume Behavior for Scenario 1 – Gulf of Mexico Mississippi Canyon 807 (MC 807)**

| WCD Scenario: Lease Block Mississippi Canyon 807 (MC807)<br>Central GOM Planning Area | |
|---|---|
| **Near-Field Oil Plume** | |
| **Oil Release Depth** | 3,030 feet |
| **GOR** | 893.5 scf/stb |
| **Median Droplet Size** | 211 microns |
| **Buoyant Trapping Depth** | 1,759 feet |
| **Percentage of Oil Mass to Reach Surface** | 63% |
| **Time for Percentage of Oil Mass to Reach Surface** | 5 days |

In the Gulf of Mexico, all but one of the six spill scenarios was modeled with South Louisiana Crude. South Louisiana Crude is a light crude oil and therefore it does not persist on the sea surface as long as would a heavier crude or heavy fuel oil (HFO). This oil can readily dissipate or entrain naturally into the water column in rough sea conditions. South Louisiana Crude has a rapid rate of evaporation due to the high content of volatile components. However, as compared to much lighter oils such as condensates and diesels, large spills of South Louisiana Crude in warmer climates and moderate seas can result in surface oil slicks, oil emulsions, and weathered tar mats capable of traveling far distances and may result in widespread shoreline oiling.

To demonstrate the typical behavior of South Louisiana Crude, an instantaneous release of the oil was modeled and tracked over time.  Figure 22 provides the results of this analysis and shows the rapid rate of evaporation that exists and the persistence of the oil on the surface when modeling this oil.

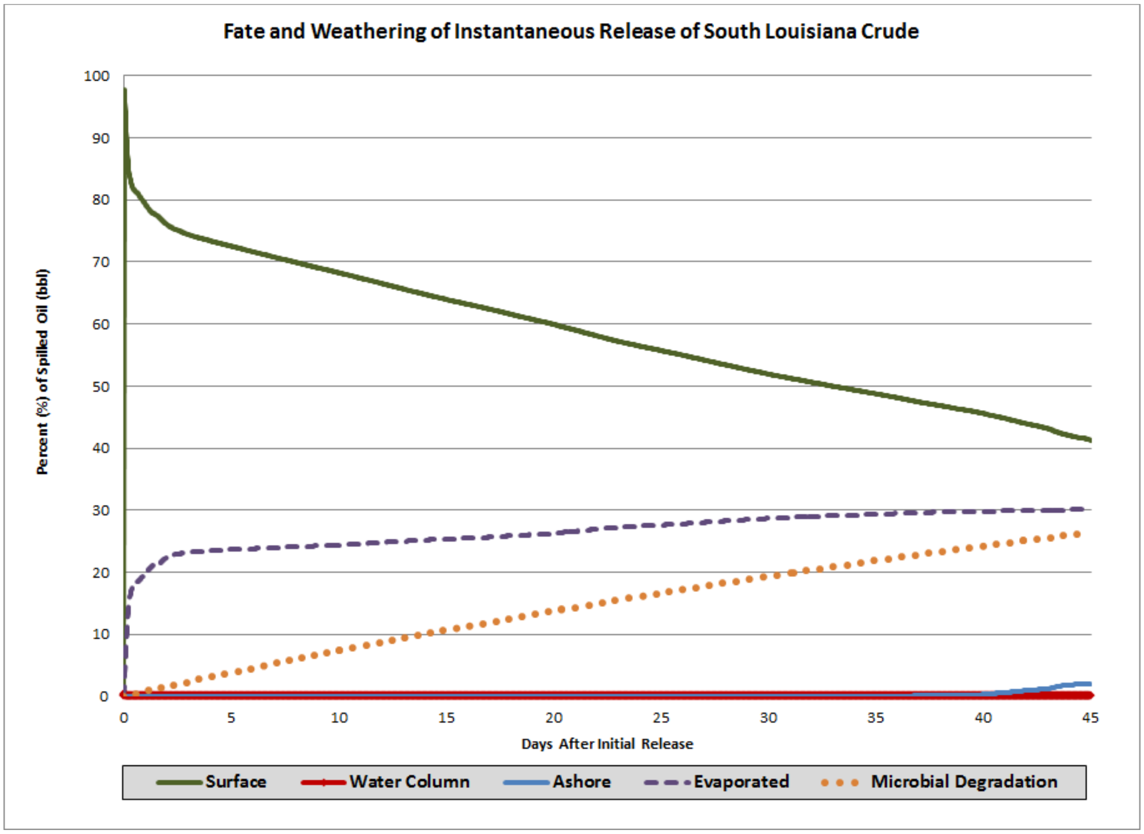



**Figure 22: Fate and Weathering Graph Showing the Typical Behavior of South Louisiana Crude in the Environment as a Result of an Instantaneous Release**

Table 18 summarizes the stochastic modeling results of the far-field oil transport.  Statistics are shown by each oiling threshold of concern representing potential impacts to socioeconomic and environmental resources (1 $g/m^2$) and implications to cleanup activities (8 $g/m^2$).

**Table 18: Far-Field Oil Transport Summary for Scenario 1 – Gulf of Mexico Mississippi Canyon 807 (MC 807)**

| **WCD Scenario: Lease Block Mississippi Canyon 807 (MC807)<br>Central GOM Planning Area** | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 $g/m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 500 miles of spill site; Figure 25 - Figure 29 |
| Minimum time for oil above the threshold (1 $g/m^2$) used to determine effects on socioeconomic resources to reach shore | 4.0 days |
| Shoreline length (miles) affected by oil above the threshold of 1 $g/m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 100% of simulations at >2,500 mi; ~50% at >3,500 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | Greatest up to approximately 200 miles from the release with 1-10 % probability approximately 900 miles from release point; Figure 23 (top) |
| Minimum time (days) to exceed the surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 125 miles of spill site; Figure 23 (bottom) |
| Minimum time (days) surface oil greater than 8 $g/m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 4.5 days |
| Water surface area ($miles^2$) affected by oil above the surface oil threshold of 8 $g/m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 100% of simulations at >1 $mi^2$; 67% of simulations at >1,000 $mi^2$ |
| Average percentage of total oil that is transported out of modeled area | 1.81 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column. The modeling results illustrate in gridded format the spatial extent of surface (Figure 23), water column, (Figure 24) and shoreline (Figure 25 through Figure 29) oiling probabilities for the spills using the thresholds outlined in Table 7 and Table 8.

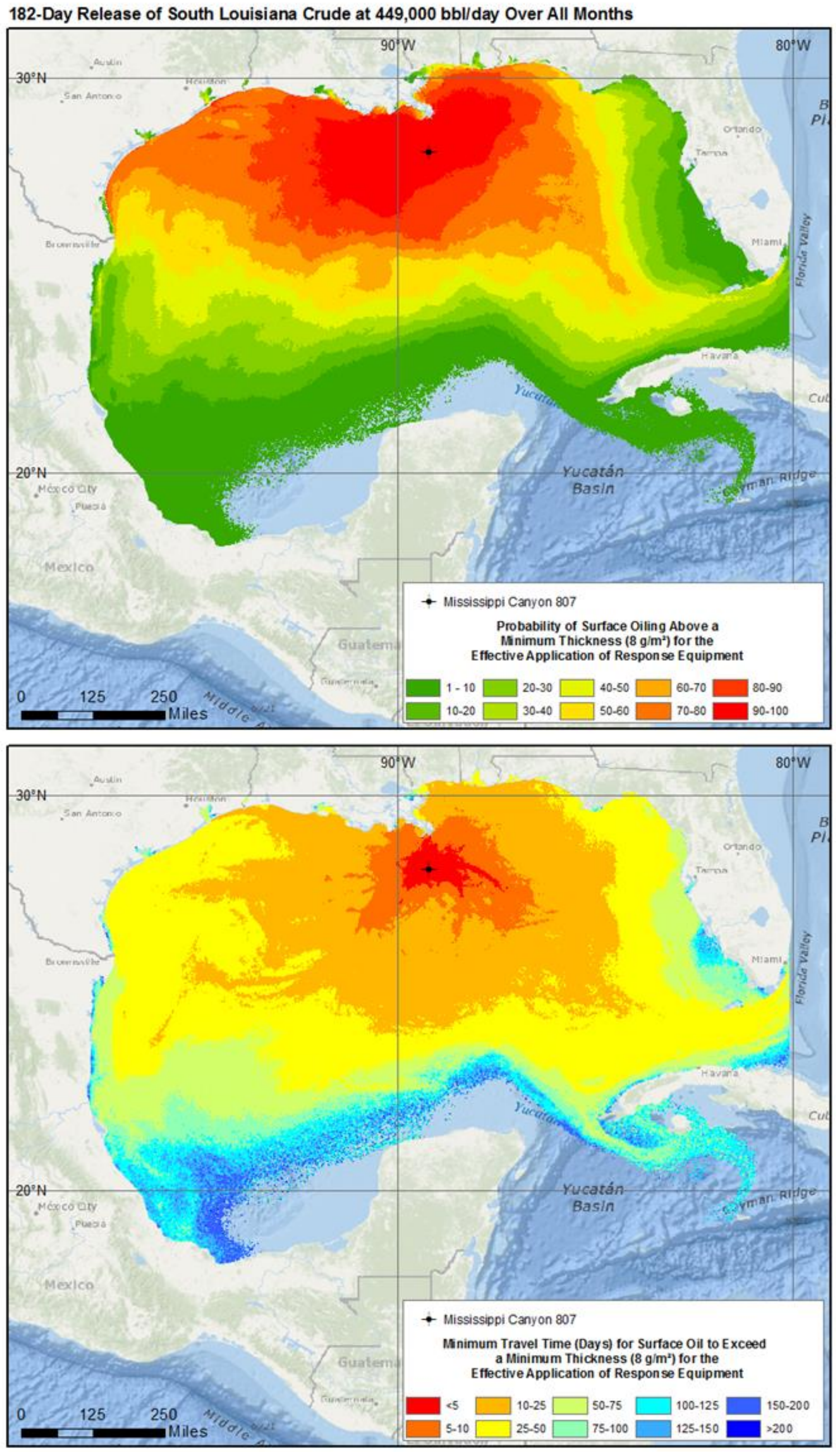



**Figure 23: Scenario 1, GOM-MC807 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 23 provides the model results showing potential implications for cleanup activity along the water surface. Location of high probabilities of oiling thickness above the threshold for which response equipment can be applied (8 g/m$^2$) would be the regions targeted or prioritized for surface cleanup and removal in a response situation. From this analysis, the greatest exceedance of surface oil >8 g/m$^2$ was approximately 200 miles from the spill site (Table 18). The minimum time for oil of this threshold to reach shore was approximately 4.5 days and in the area at the tip of Louisiana off the Mississippi delta or "Birds Foot" region (Table 18, Figure 23). The higher floating surface oil probabilities (80-100%) for MC807 cover a large portion of the Gulf of Mexico. Similar to the floating surface oil, the higher probabilities where total hydrocarbon concentrations in the water column would exceed 100 ppb was widespread (Figure 24).

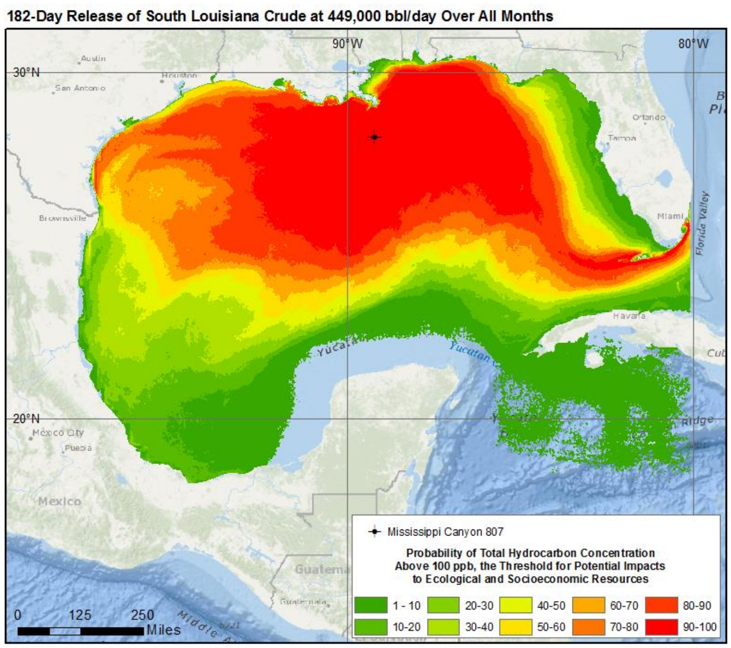



**Figure 24: Scenario 1, GOM-MC807 – Probability of Total Hydrocarbon Concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur)**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 4 days (Table 18). Within approximately 500 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. All simulations (100%) in the stochastic set had over 2,500 miles of shoreline oiled above the socioeconomic threshold, while 50% showed greater than 3,500 miles. Shoreline oiling above the socioeconomic threshold occurred from the Texas coastline all the way around the Gulf of Mexico to the Florida Keys (Figure 25 to Figure 29). The highest probability of oiling is modeled to occur from Texas to the panhandle of Florida, and along the southern coast of the Florida Keys. High shoreline oiling probabilities in the MC807 scenario cover a large portion of the Gulf coast and most of the coastal shoreline socioeconomic and environmental resources in the Gulf of Mexico would have probable contact with oil if a spill of this magnitude were to occur.

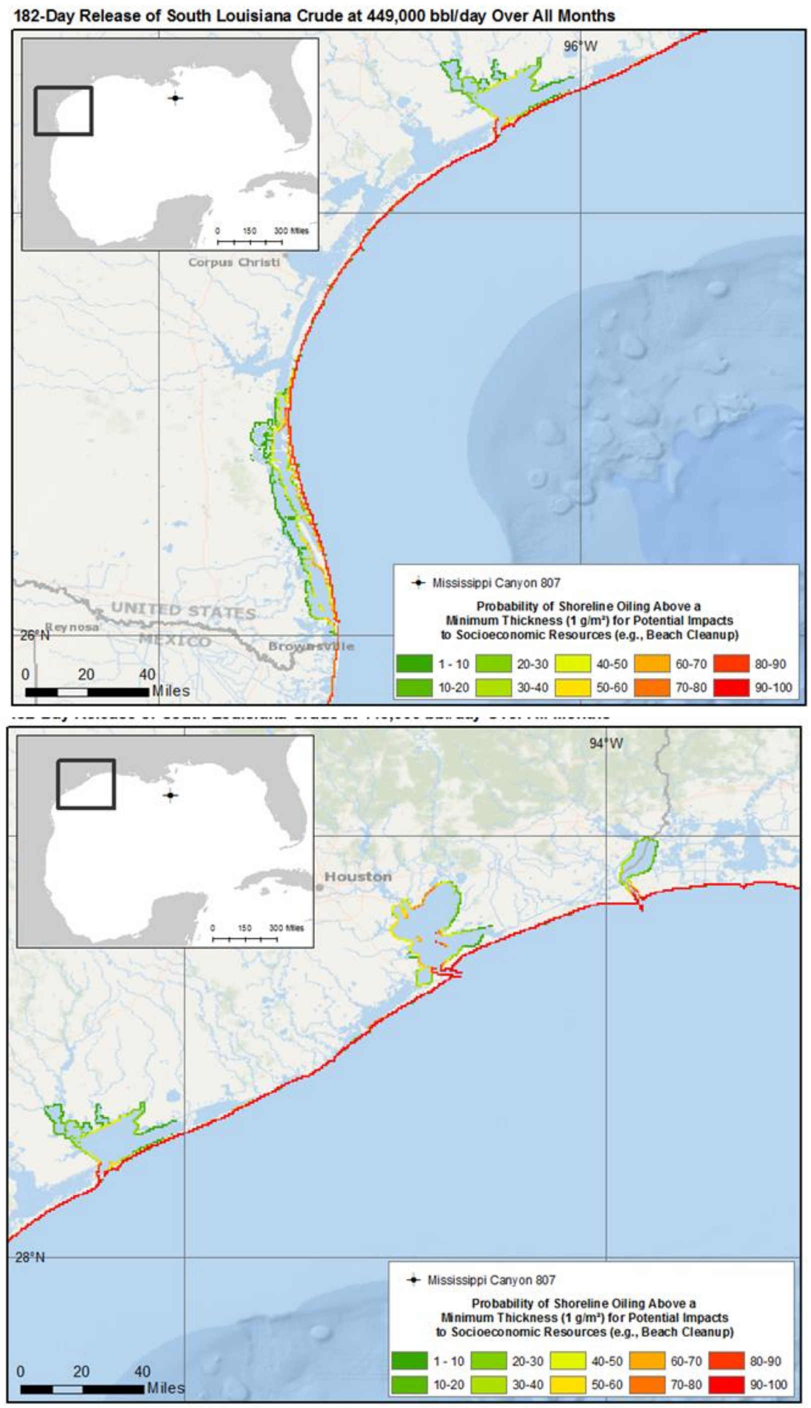



**Figure 25: Scenario 1, GOM-MC807 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 $g/m^2$ ($3.94 \times 10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Texas and Louisiana Coasts**

182-Day Release of South Louisiana Crude at 449,000 bbl/day Over All Months

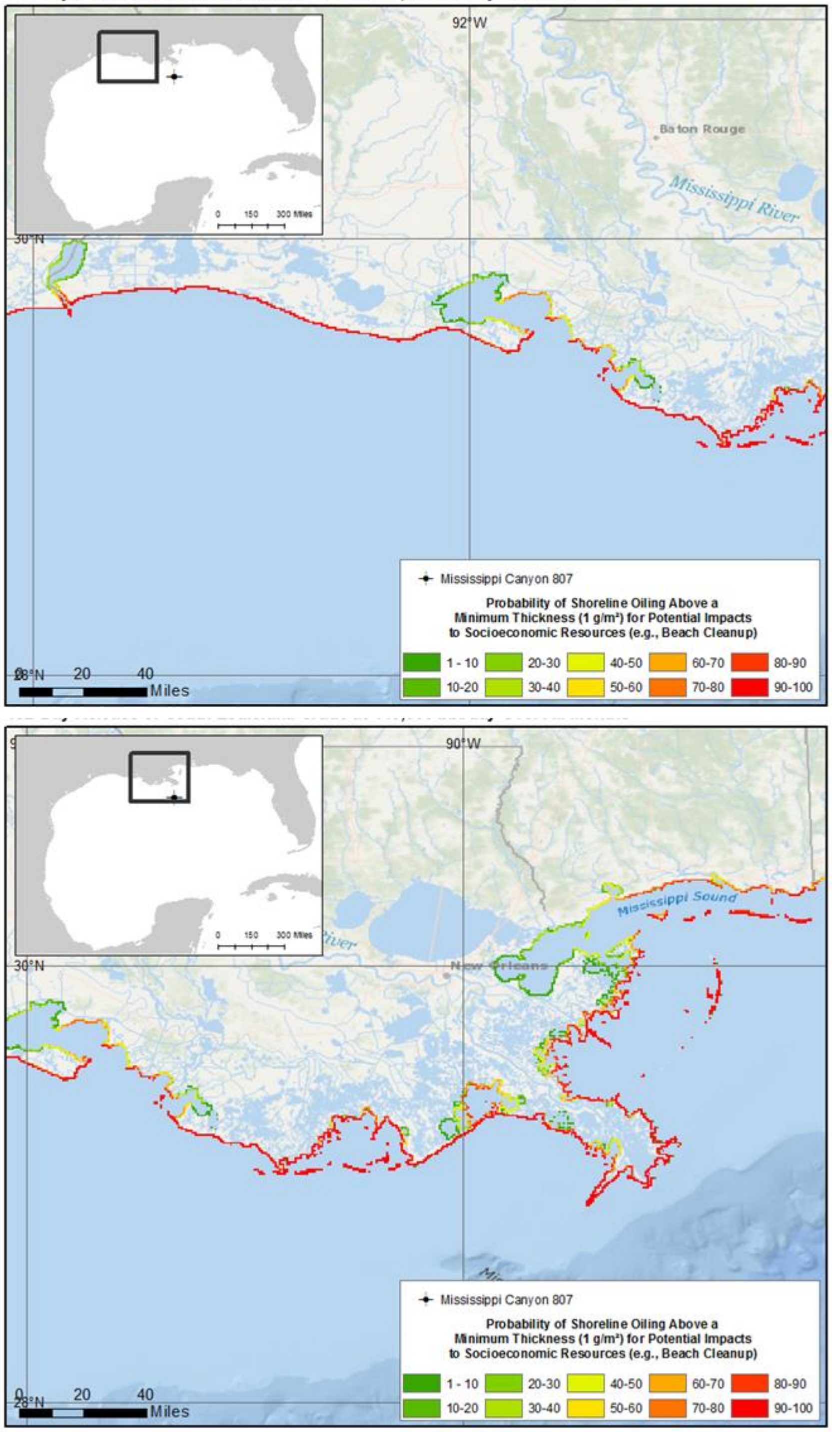



**Figure 26: Scenario 1, GOM-MC807 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana and Mississippi Coasts**

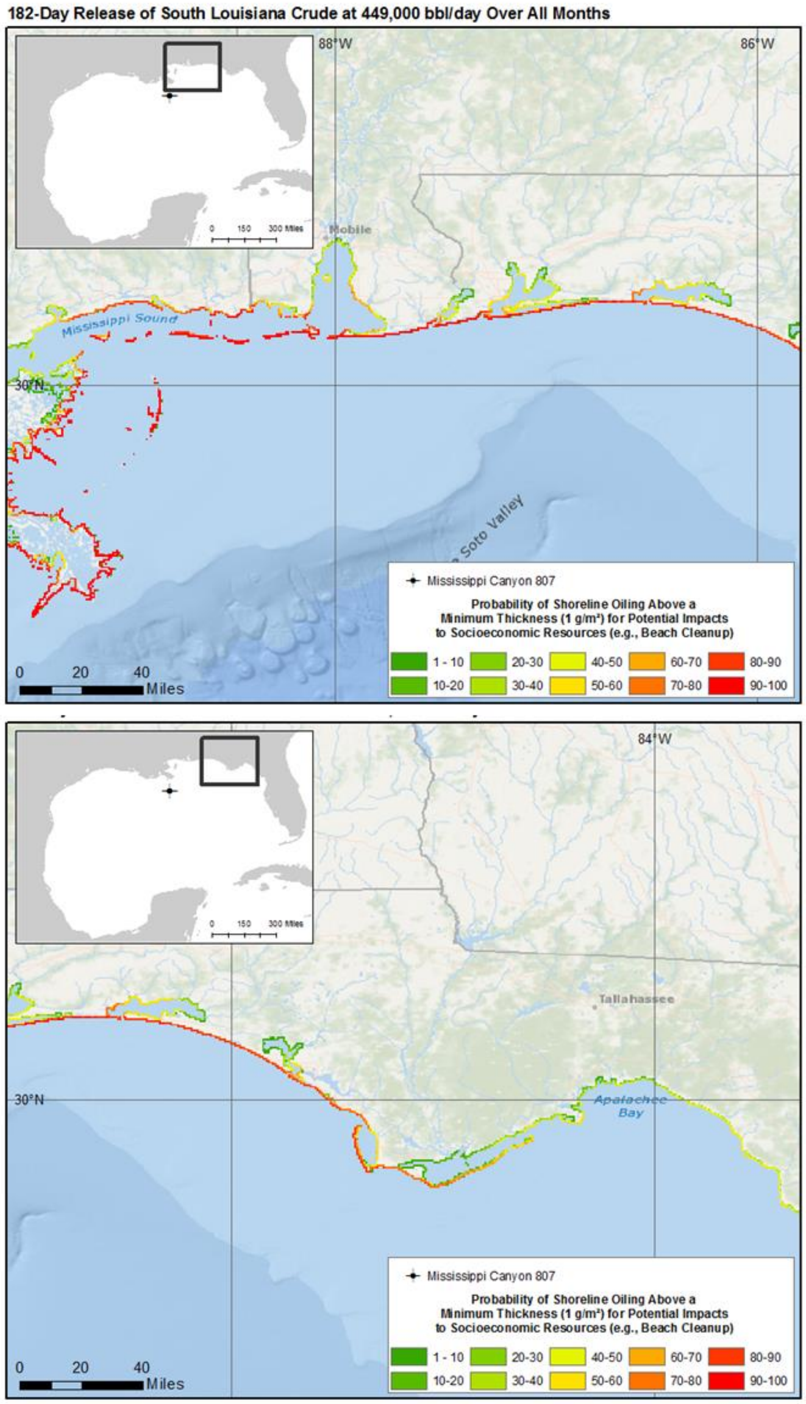



**Figure 27: Scenario 1, GOM-MC807 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m² (3.94 x $10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana, Mississippi, Alabama, and Florida Coasts**

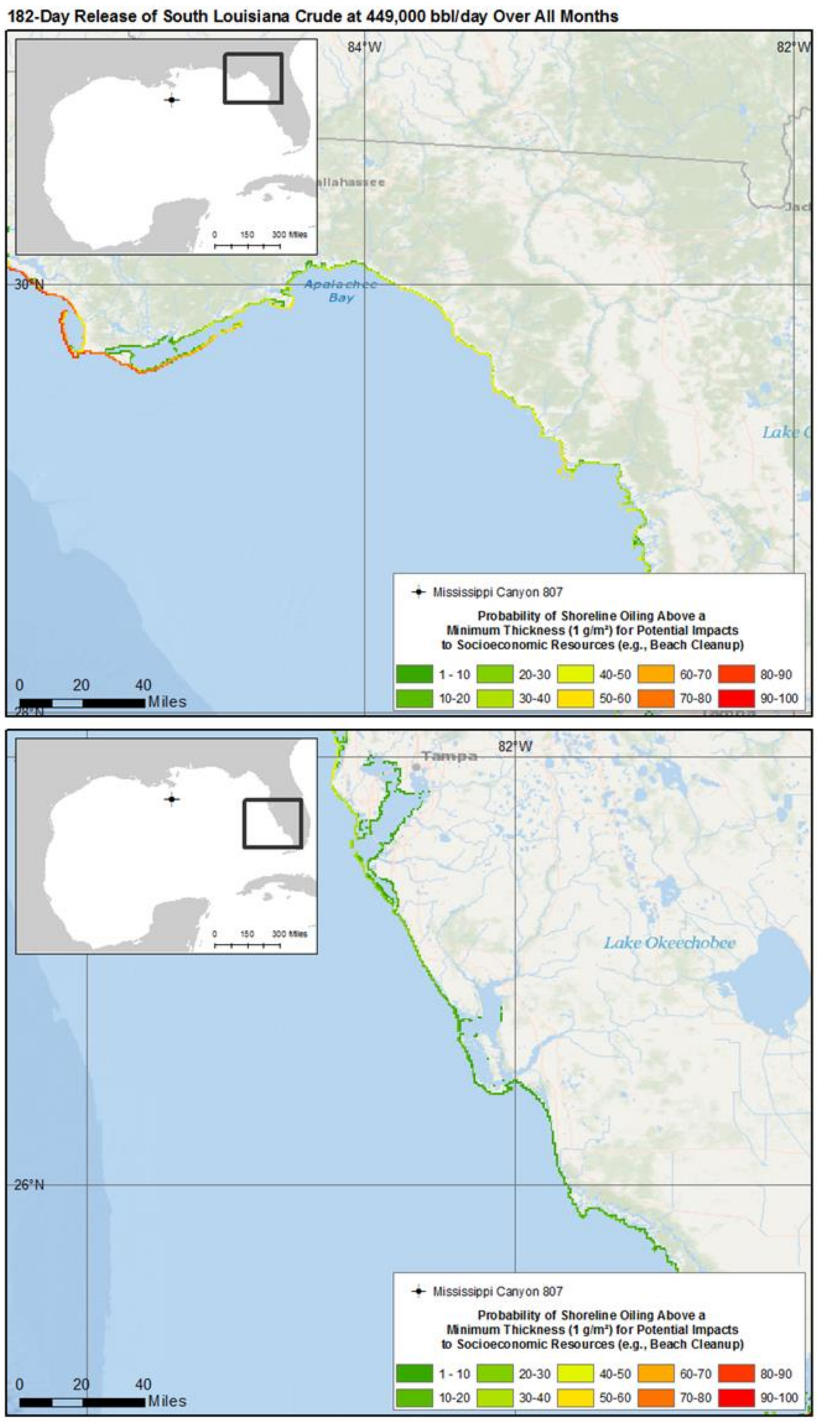



**Figure 28: Scenario 1, GOM-MC807 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along the North Florida Coast**

182-Day Release of South Louisiana Crude at 449,000 bbl/day Over All Months

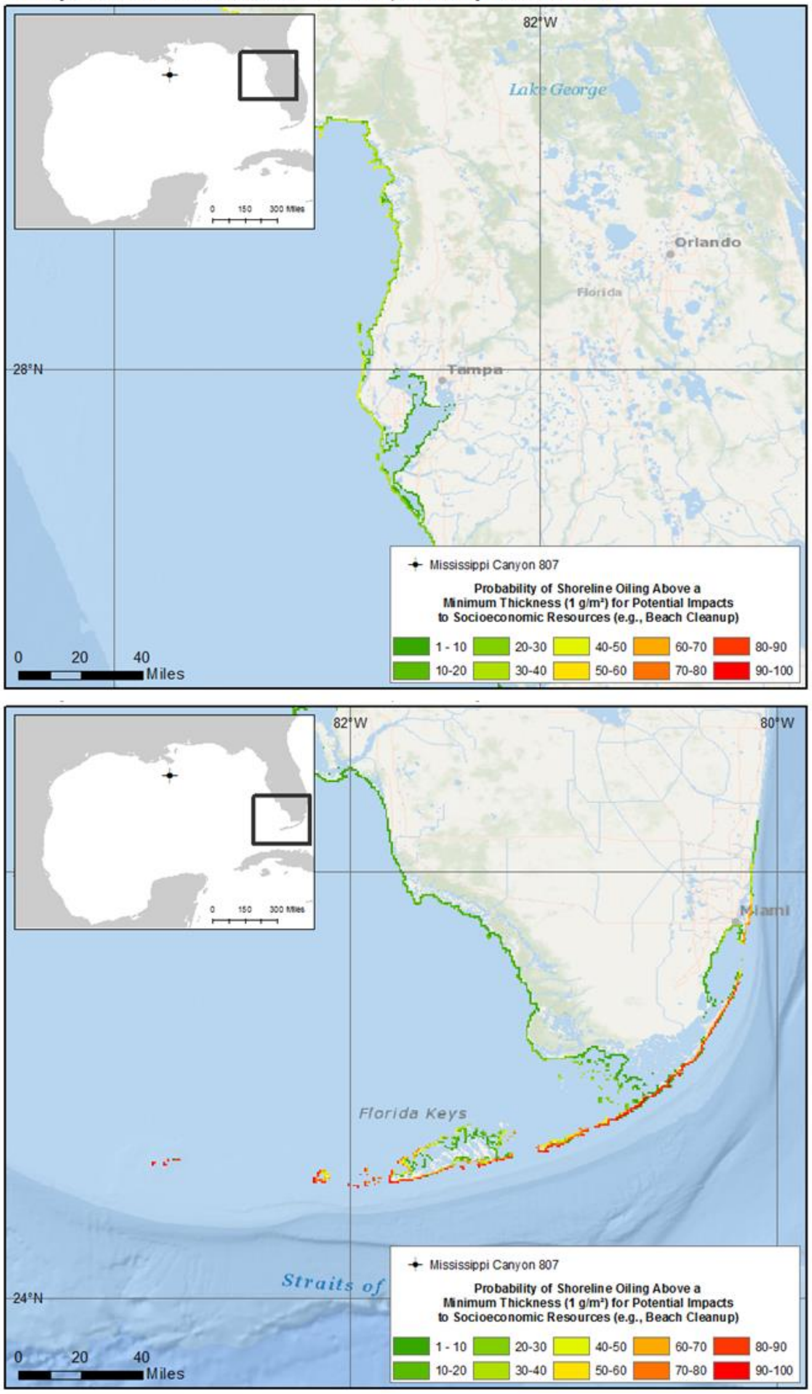



**Figure 29: Scenario 1, GOM-MC807 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along the Central and South Florida Coast**

### 3.3.3 Scenario 2 – West Delta 28 (WD28)

The West Delta 28 (WD28) scenario in the Central Gulf of Mexico Planning Area is one of the smaller, nearshore WCDs assessed for the consequence analysis.

**Table 19: Well Information for Scenario 2 – Gulf of Mexico West Delta 28 (WD28)**

| WCD Scenario: Lease Block West Delta 28 (WD28)<br>Central GOM Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 97,000 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 37 days |
| **Total WCD Release Volume** | 3,589,000 bbl |
| **Simulation Duration (45 days following end of release)** | 82 days |
| **API Gravity (South Louisiana Crude)** | 34.5 |
| **Latitude, Longitude** | 29.13848°N, 89.563623°W |
| **Depth to Sea Floor** | 35 feet |
| **Distance to Shoreline** | 6.4 miles (5.6 nm) |

#### *WD28 Oil Plume and Transport Modeling Results*

The near-field oil plume simulation for this scenario found that 93% of the total oil mass would reach the surface in less than one hour of the release. Due to the shallow location of WD28, no buoyant trapping depth was observed (Table 20). Therefore, the far-field oil transport for this case was initiated 1.6 ft. from the surface with a median droplet size of 227 microns.

**Table 20: Near-Field Oil Plume Behavior for Scenario 2 – Gulf of Mexico West Delta 28 (WD28)**

| WCD Scenario: Lease Block Gulf of Mexico West Delta 28 (WD28)<br>Central GOM Planning Area | |
|---|---|
| **Near-Field Oil Plume** | |
| **Oil Release Depth** | 35 feet |
| **GOR** | 588 scf/stb |
| **Median Droplet Size** | 227 microns |
| **Buoyant Trapping Depth** | 0 feet |
| **Percentage of Oil Mass to Reach Surface** | 93% |
| **Time for Percentage of Oil Mass to Reach Surface** | <1 hours |

Table 21 summarizes the stochastic modeling results of the far-field oil transport. Statistics are shown by each oiling threshold of concern representing potential impacts to socioeconomic and environmental resources (1 $g/m^2$) and implications to cleanup activities (8 $g/m^2$).

**Table 21: Far-Field Oil Transport Summary for Scenario 2 – Gulf of Mexico West Delta 28 (WD28)**

| **WCD Scenario: Lease Block West Delta 28 (WD28)**<br>**Central GOM Planning Area** | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 $g/m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 75 miles of spill site; Figure 32 - Figure 35 |
| Minimum time for oil above the threshold (1 $g/m^2$) used to determine effects on socioeconomic resources to reach shore | 1.0 day |
| Shoreline length (miles) affected by oil above the threshold of 1 $g/m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 95% of simulations at >500 mi; ~20% at >1,200 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | Greatest in immediate proximity of release with 1-10 % probability approximately 600 miles from release point; Figure 30 (top) |
| Minimum time (days) to exceed the surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 130 miles of spill site; Figure 30 (bottom) |
| Minimum time (days) surface oil greater than 8 $g/m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 1 day |
| Water surface area ($miles^2$) affected by oil above the surface oil threshold of 8 $g/m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 98% of simulations at >100 $mi^2$; 8% of simulations at >2,000 $mi^2$ |
| Average percentage of total oil that is transported out of modeled area | 0.03 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column. The modeling results illustrate in gridded format the spatial extent of surface (Figure 30) water column (Figure 31) and shoreline (Figure 32 through Figure 35) oiling probabilities for the spills using the thresholds outlined in Table 7 and Table 8.

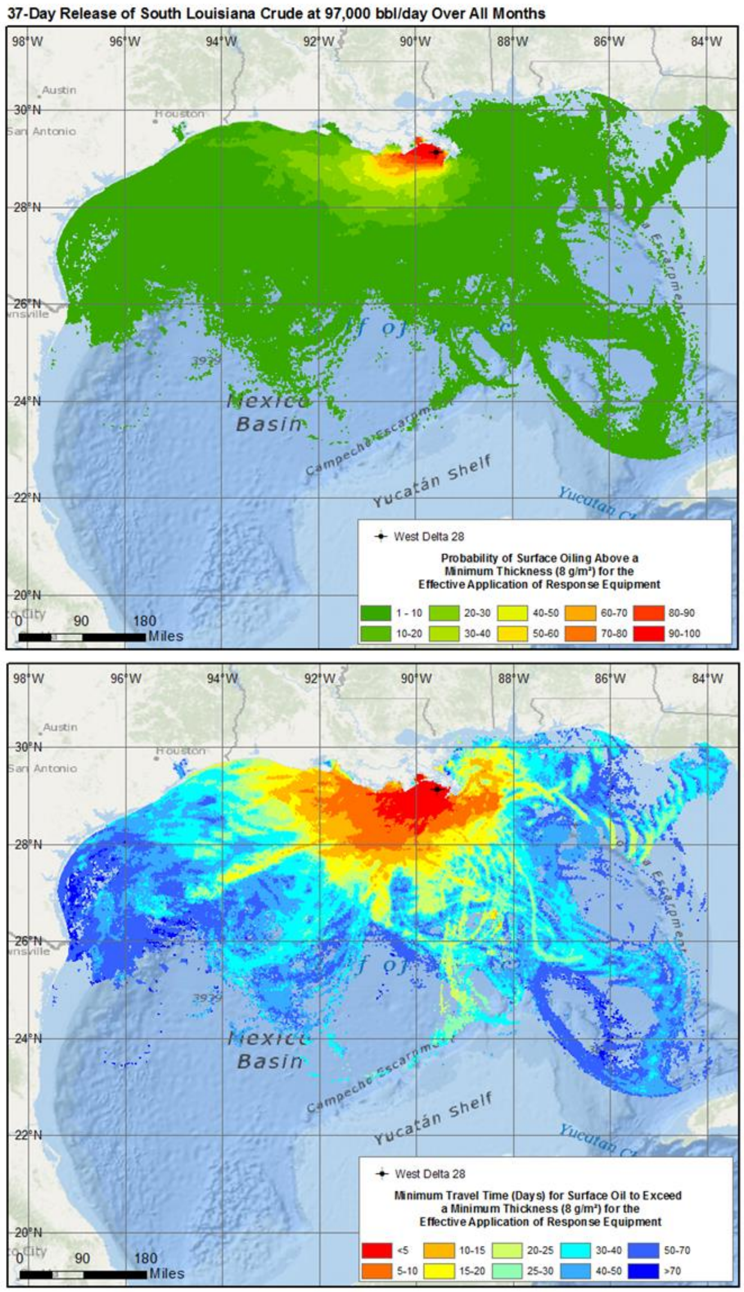



**Figure 30: Scenario 2, GOM-WD28 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 30 provides the model results showing potential implications for cleanup activity along the water surface. Location of high probabilities of oiling thickness above the threshold for which response equipment can be applied (8 $g/m^2$) would be the regions targeted or prioritized for surface cleanup and removal in a response situation. From this analysis, the greatest exceedance of surface oil >8 $g/m^2$ was in the immediate vicinity of the spill site (Table 21). The minimum time for oil of this threshold to reach shore was approximately 1 day and in the area right at the tip of Louisiana off the Mississippi delta or "Birds Foot" region (Table 21, Figure 30). Similar to the floating surface oil, the higher probabilities where total hydrocarbon concentrations in the water column would exceed 100 ppb were observed in the same area off the Louisiana coast (Figure 31).

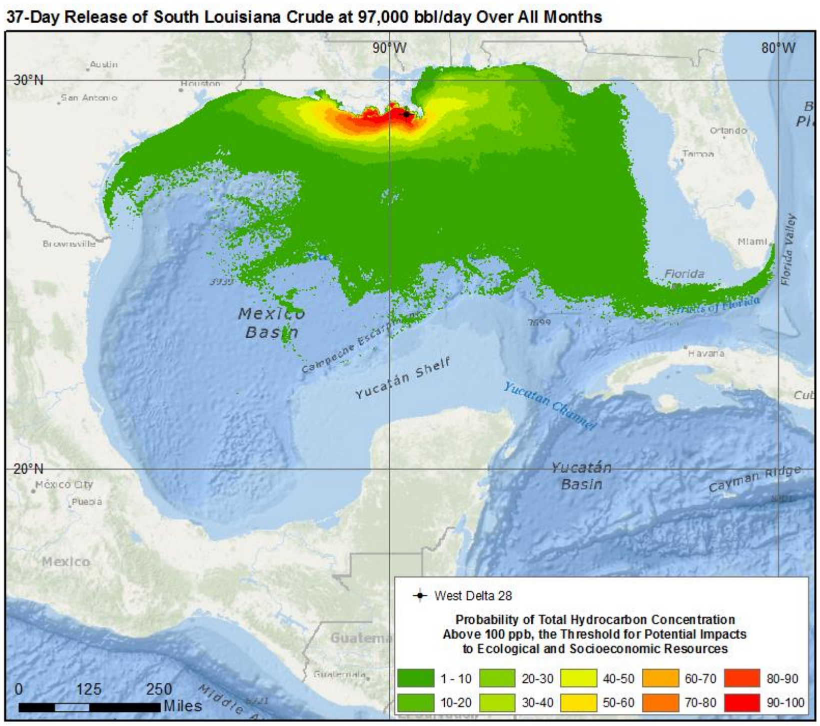



**Figure 31: Scenario 2, GOM-WD28 – Probability of Total Hydrocarbon Concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur)**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 1 day (Table 21). Within approximately 75 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. A large number of the simulations (95%) in the stochastic set had over 500 miles of shoreline oiled above the socioeconomic threshold, while 20% showed greater than 1,200 miles. Shoreline oiling above the socioeconomic threshold occurred from the Texas coastline all the way around the Gulf of Mexico to the Florida Keys (Figure 32 - Figure 35). The highest probability of oiling would occur along the Louisiana coast off the Mississippi delta or "Birds Foot." Shoreline oiling probability above the socioeconomic threshold in the WD28 scenario was widespread in the Gulf of Mexico region, but the coastal socioeconomic and environmental resources near the Mississippi Delta would have probable contact with oil if a spill of this magnitude were to occur from this spill site.

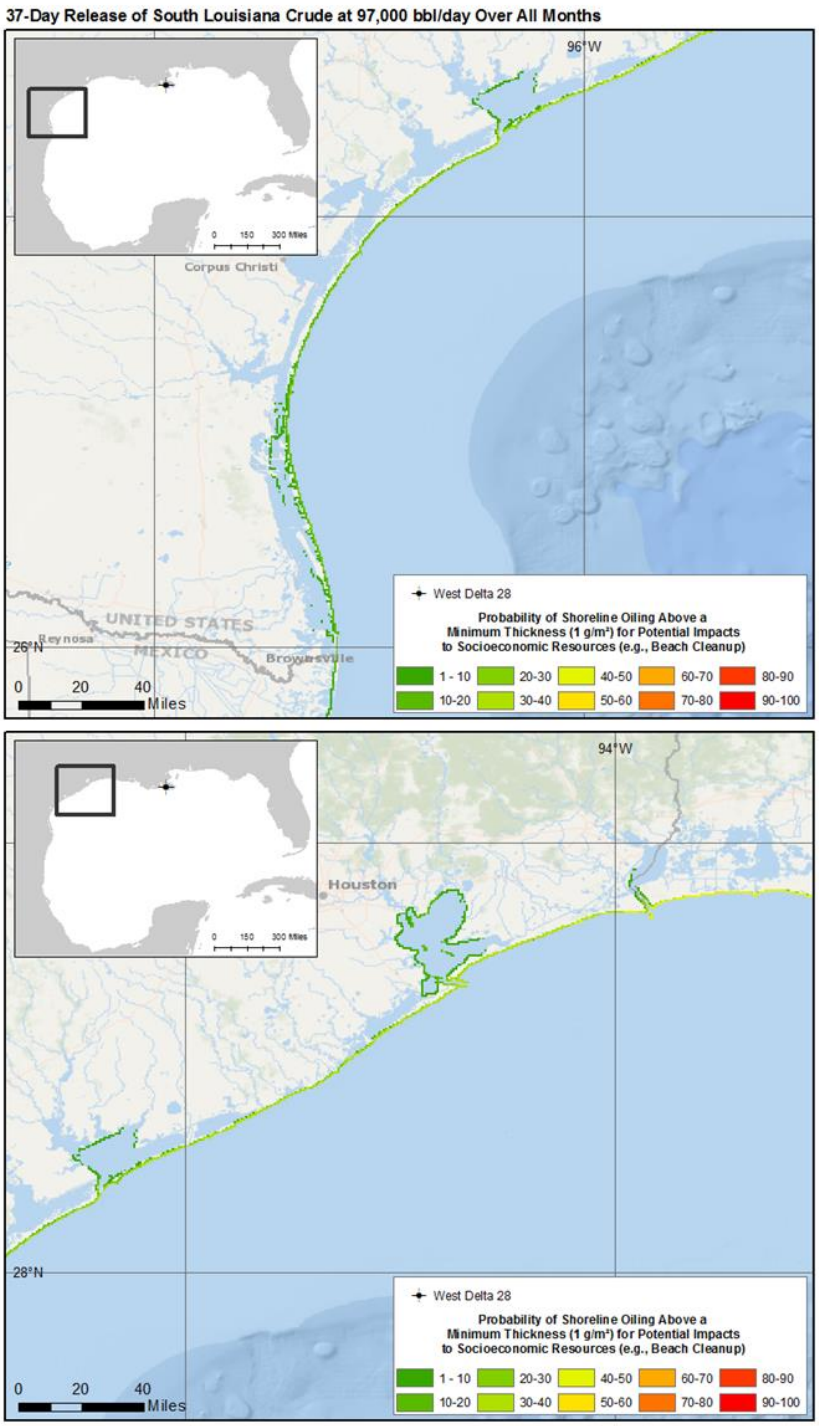



**Figure 32: Scenario 2, GOM-WD28 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Texas and Louisiana Coasts**

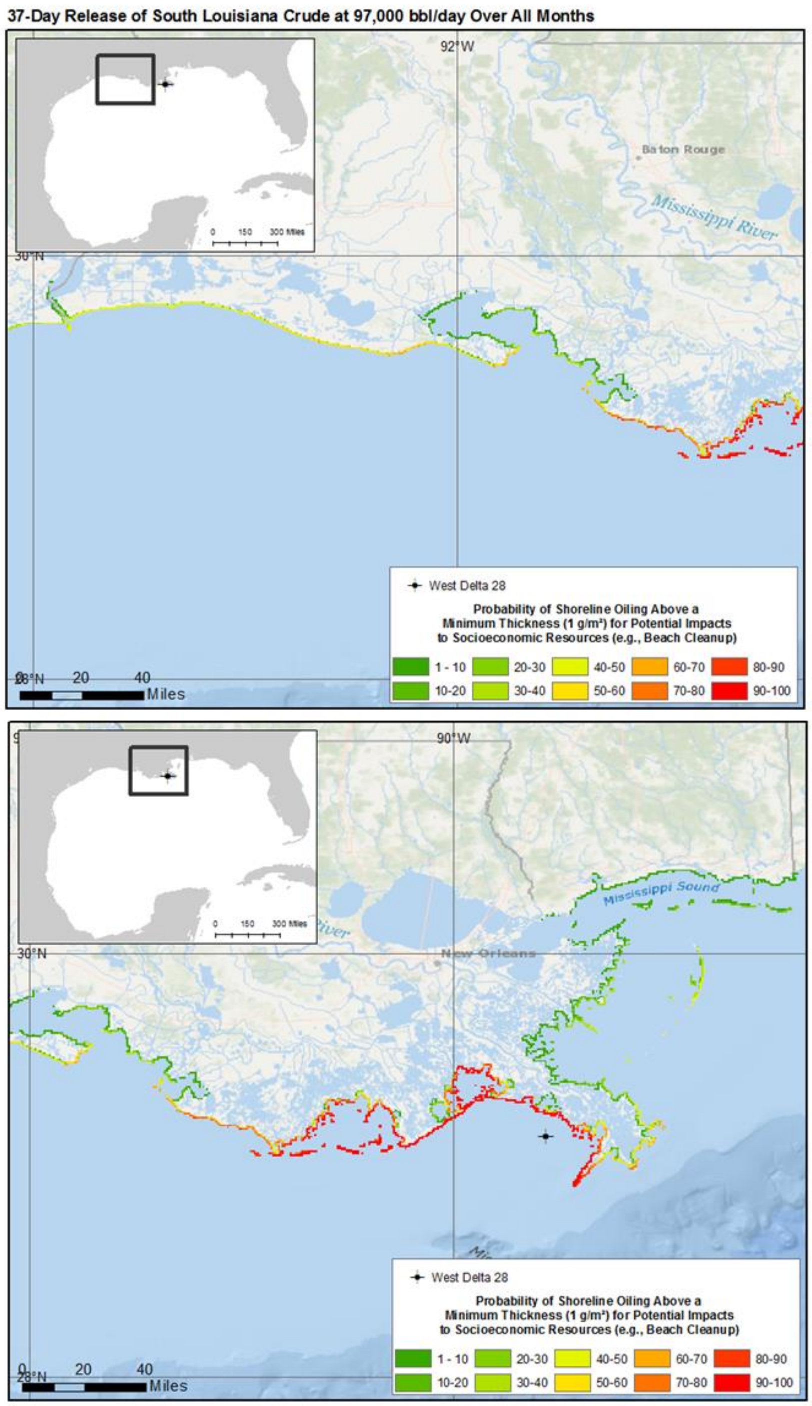



**Figure 33: Scenario 2, GOM-WD28 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana and Mississippi Coasts**

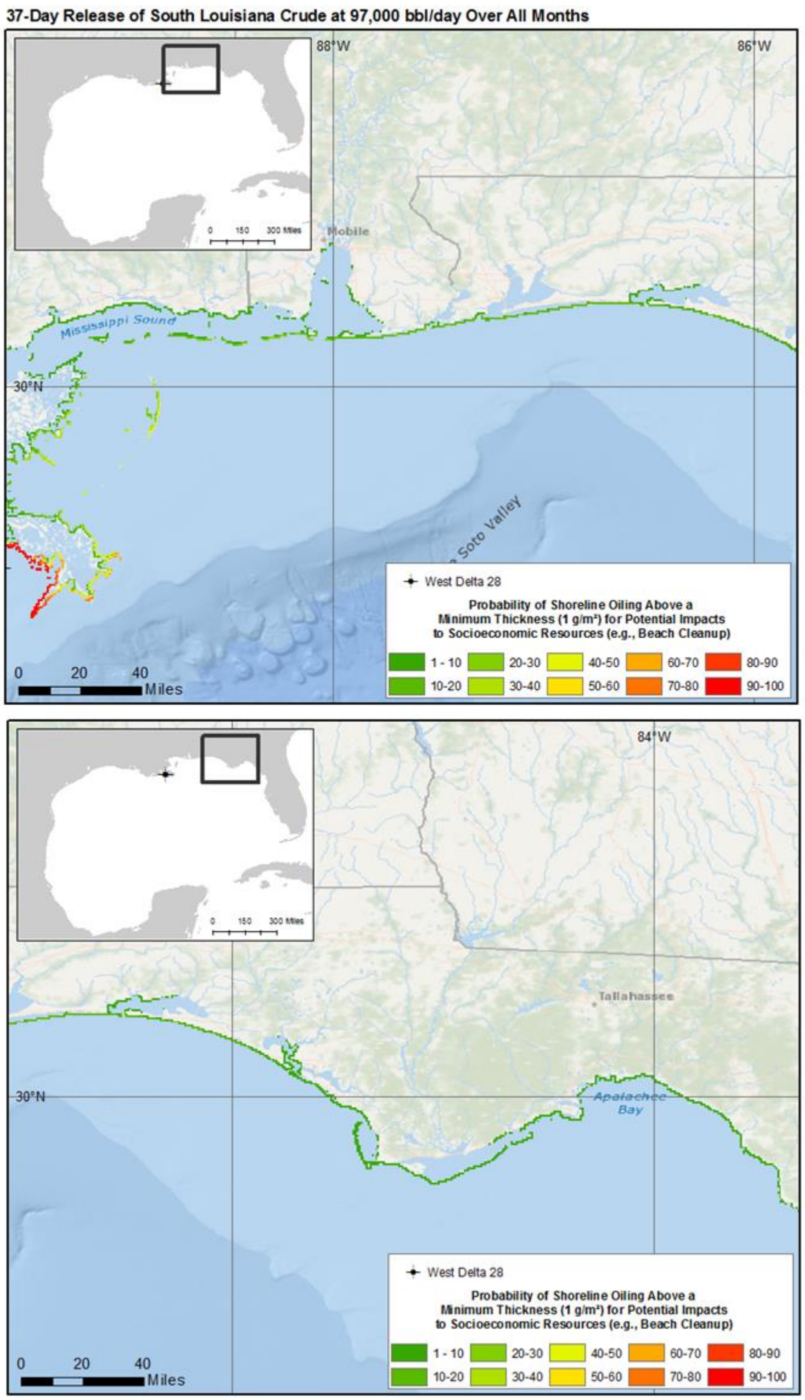



**Figure 34: Scenario 2, GOM-WD28 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana, Mississippi, Alabama, and Florida Coasts**

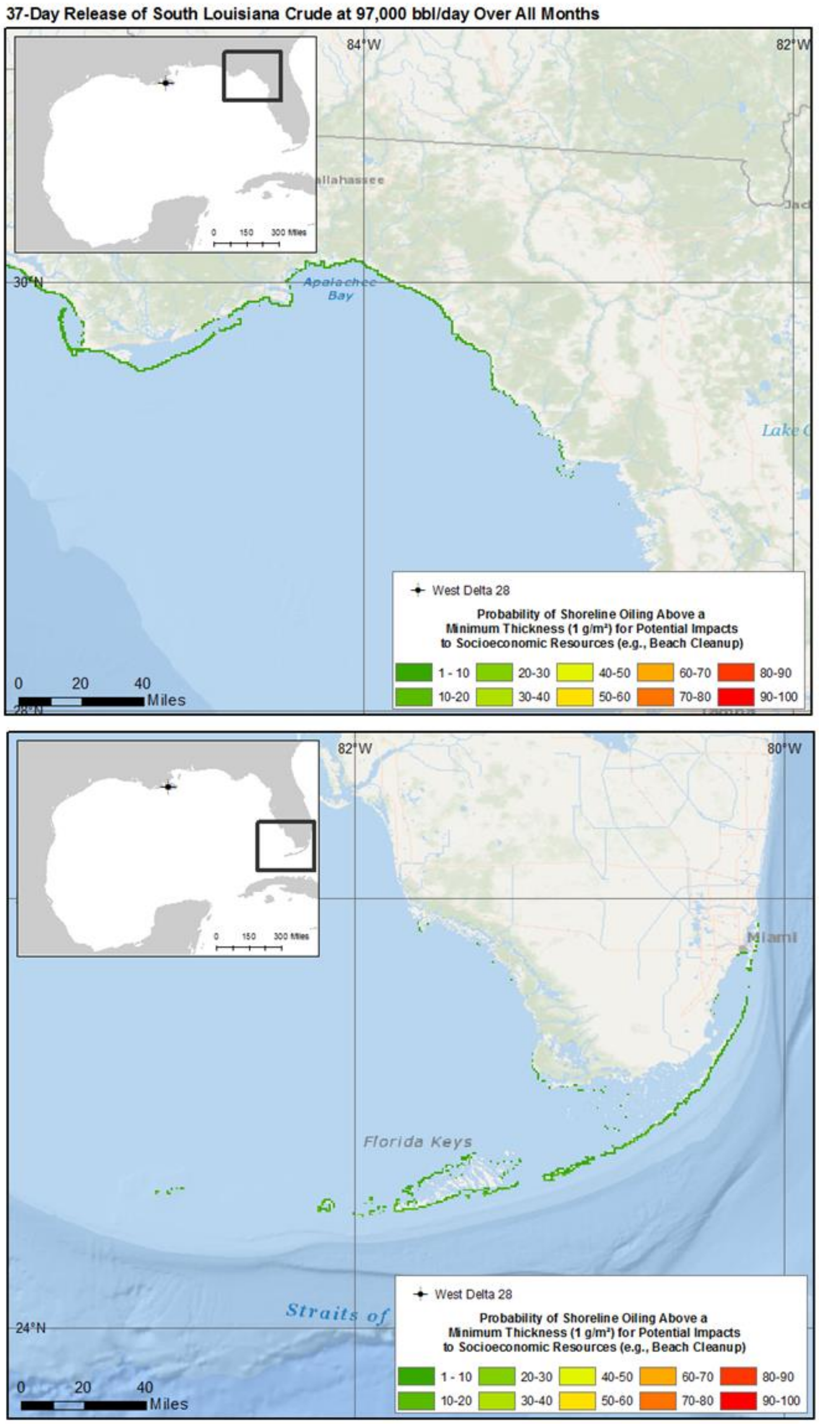



**Figure 35: Scenario 2, GOM-WD28 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x $10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along the Florida Coast**

### 3.3.4 Scenario 3 – West Cameron 168 (WC168)

The West Cameron 168 (WC168) scenario in the Central Gulf of Mexico Planning Area is one of the smaller spills assessed for the consequence analysis, and is the only spill involving a discharge of South Louisiana Condensate.

**Table 22: Well Information for Scenario 3 – Gulf of Mexico West Cameron 168 (WC168)**

| WCD Scenario: Lease Block West Cameron 168 (WC168)<br>Central GOM Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 26,400 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 76 days |
| **Total WCD Release Volume** | 2,006,400 bbl |
| **Simulation Duration (45 days following end of release)** | 121 days |
| **API Gravity (South Louisiana Condensate)** | 57.5 |
| **Latitude, Longitude** | 29.388171°N, 93.406424°W |
| **Depth to Sea Floor** | 42 feet |
| **Distance to Shoreline** | 29 miles (25 nm) |

#### *WC168 Oil Plume, Fate, and Transport Modeling Results*

The near-field oil plume simulation for this scenario found that 93% of the total oil mass would reach the surface in less than one hour of the release. Due to the shallow location of WC168, no buoyant trapping depth was observed (Table 23). Therefore, the far-field oil transport for this case was initiated 1.6 ft. from the surface with a median droplet size of 152 microns.

**Table 23: Near-Field Oil Plume Behavior for Scenario 3 – Gulf of Mexico West Cameron 168 (WC168)**

| WCD Scenario: Lease Block Gulf of Mexico West Cameron 168 (WC168)<br>Central GOM Planning Area | |
|---|---|
| **Near-Field Oil Plume** | |
| **Oil Release Depth** | 42 feet |
| **GOR** | 3,448 scf/stb |
| **Median Droplet Size** | 152 microns |
| **Buoyant Trapping Depth** | 0 feet |
| **Percentage of Oil Mass to Reach Surface** | 93% |
| **Time for Percentage of Oil Mass to Reach Surface** | <1 hours |

Scenario 3 (WC168) is modeled with South Louisiana Condensate. South Louisiana Condensate is a non-persistent oil that is very light and thus, tends to evaporate and dissipate quickly. Persistence is short for this oil type due to the rapid rate of evaporation of the volatile components and because it can readily dissipate and disperse naturally in moderate to rough sea conditions.

To demonstrate the typical behavior of South Louisiana Condensate, an instantaneous release of the oil was modeled and tracked over time (Figure 36). The figure below provides the results of this analysis and shows the rapid rate of evaporation and the lack of persistence on the water surface that exists when modeling this oil.

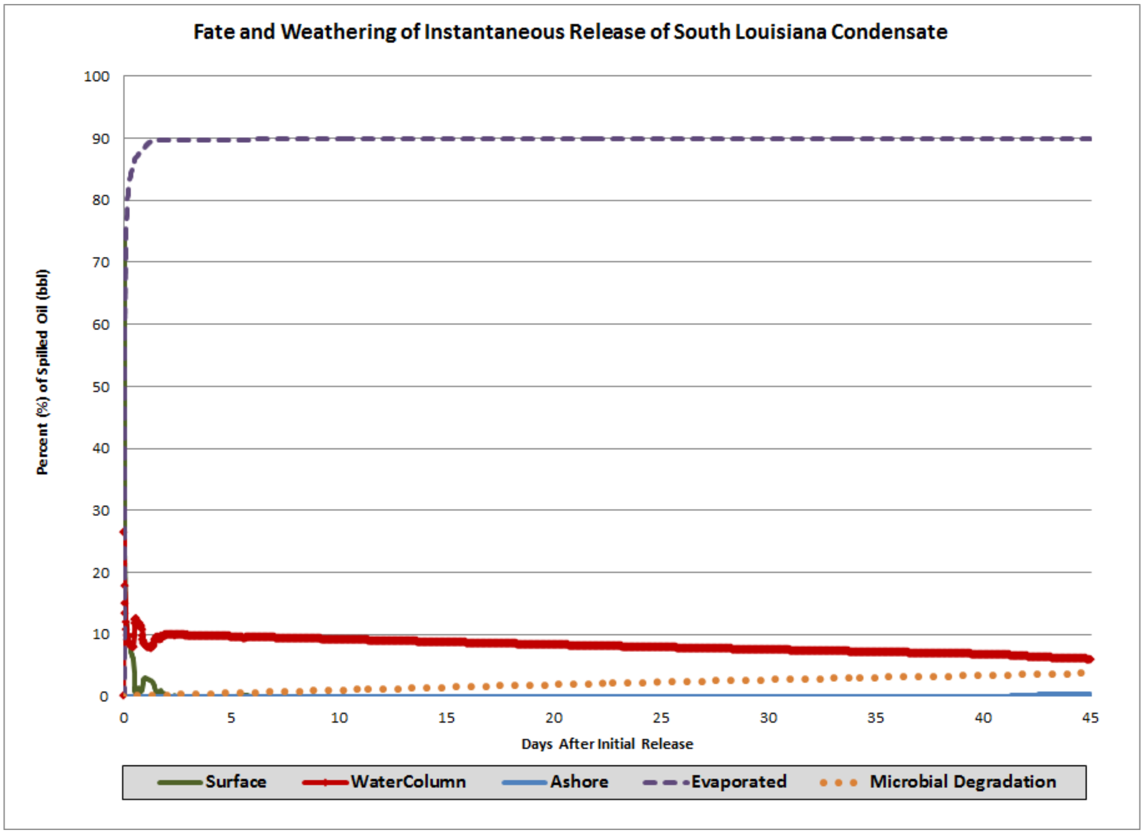



**Figure 36: Fate and Weathering Graph Showing the Typical Behavior of South Louisiana Condensate in the Environment As a Result of an Instantaneous Release**

Table 24 summarizes the stochastic modeling results of the far-field oil transport. Statistics are shown by each oiling threshold of concern representing potential impacts to socioeconomic and environmental resources (1 $g/m^2$) and implications to cleanup activities (8 $g/m^2$).

**Table 24: Far-Field Oil Transport Summary for Scenario 3 – Gulf of Mexico West Cameron 168 (WC168)**

| **WCD Scenario: Lease Block West Cameron 168 (WC168)**<br>**Central GOM Planning Area** | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 $g/m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 150 miles of spill site; Figure 39 - Figure 41 |
| Minimum time for oil above the threshold (1 $g/m^2$) used to determine effects on socioeconomic resources to reach shore | 2.0 days |
| Shoreline length (miles) affected by oil above the threshold of 1 $g/m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 96% of simulations at >200 mi; ~45% at >400 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | Greatest in immediate proximity of release with 1-10 % probability approximately 30 miles from release point; Figure 37 (top) |
| Minimum time (days) to exceed the surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 15 miles of spill site; Figure 37 (bottom) |
| Minimum time (days) surface oil greater than 8 $g/m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 5.5 days |
| Water surface area ($miles^2$) affected by oil above the surface oil threshold of 8 $g/m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 100% of simulations at >1 $mi^2$; 26% of simulations at >5 $mi^2$ |
| Average percentage of total oil that is transported out of modeled area | 0.0001 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column. The modeling results illustrate in gridded format the spatial extent of surface (Figure 37) water column (Figure 38) and shoreline (Figure 39 through Figure 41) oiling probabilities for the spills using the thresholds outlined in Table 7 and Table 8.

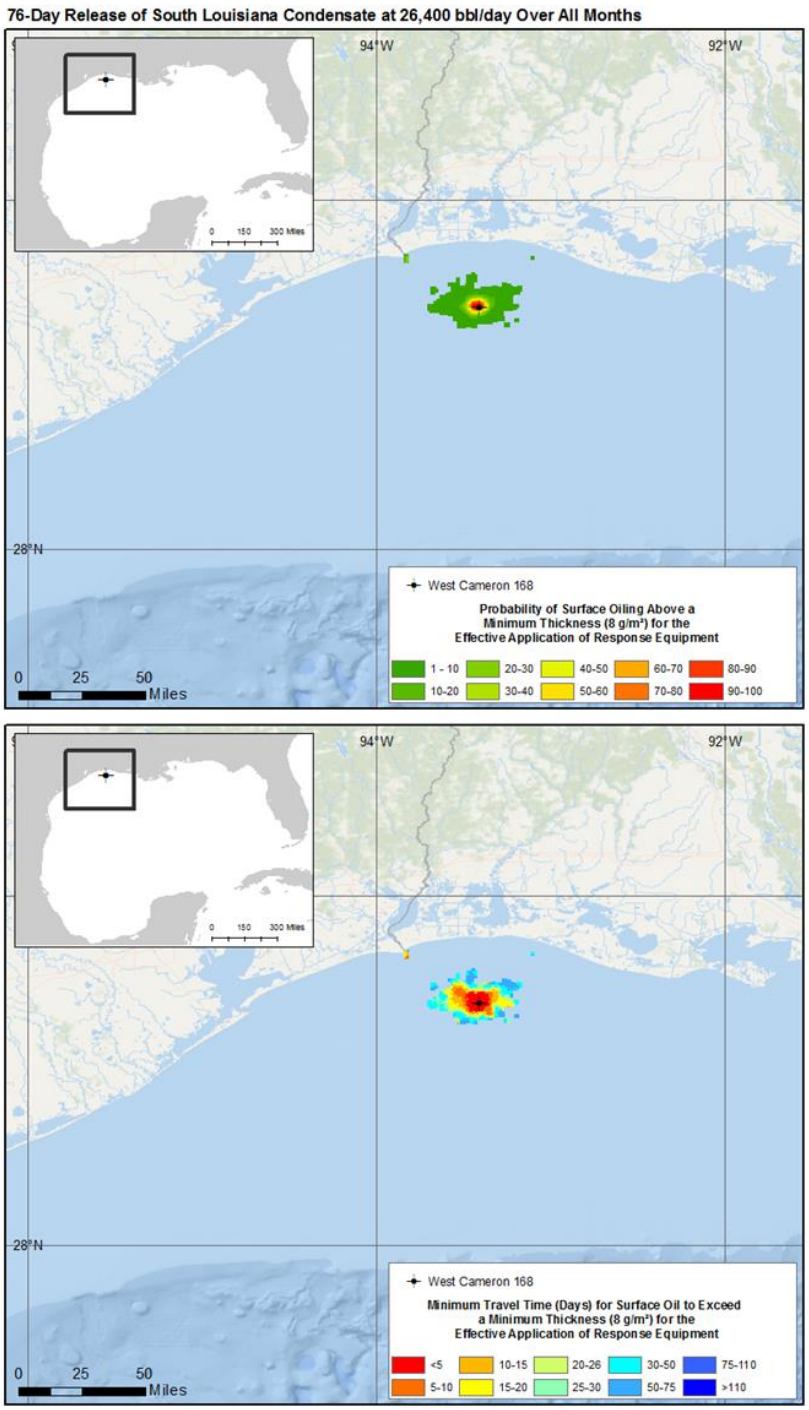



**Figure 37: Scenario 3, GOM-WC168 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 37 provides the model results showing potential implications for cleanup activity along the water surface. Location of high probabilities of oiling thickness above the threshold for which response equipment can be applied (8 g/m$^2$) would be the regions targeted or prioritized for surface cleanup and removal in a response situation. From this analysis, the greatest exceedance of surface oil >8 g/m$^2$ was in the immediate vicinity of the spill site (Figure 37). The minimum time for oil of this threshold to reach shore was 5.5 days near the entrance of Sabine Pass, just at the border of Louisiana and Texas (Table 24, Figure 37). The higher probabilities where total hydrocarbon concentrations in the water column would exceed 100 ppb were observed stretching along the Texas shelf and coast (Figure 38).

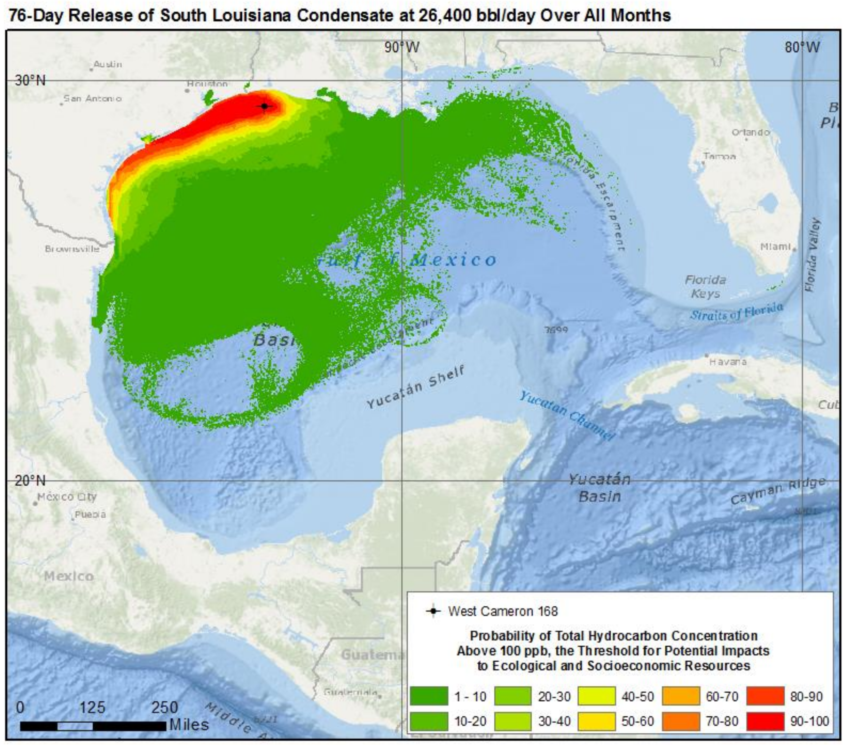



**Figure 38: Scenario 3, GOM-WC168 – Probability of Total Hydrocarbon Concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur).**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 2 days (Table 24). Within approximately 150 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. The majority of the simulations (96%) in the stochastic set had over 200 miles of shoreline oiled above the socioeconomic threshold, while 45% showed greater than 400 miles. Shoreline oiling above the socioeconomic threshold occurred from the Texas coastline to the Florida panhandle, and on the Florida Keys (Figure 39 through Figure 41). The highest probability of oiling occurred along the Louisiana and Texas coast from Lake Calcasieu to Galveston Bay, straddling the state border. Shoreline oiling probability above the socioeconomic threshold in the WC168 condensate scenario was not as widespread as compared to the crude blowout scenarios simulated in the Gulf of Mexico. However, despite the light oil type, the socioeconomic and environmental shoreline resources between Lake Calcasieu and Galveston Bay would have probable contact with oil if a spill of this magnitude were to occur from this spill site.

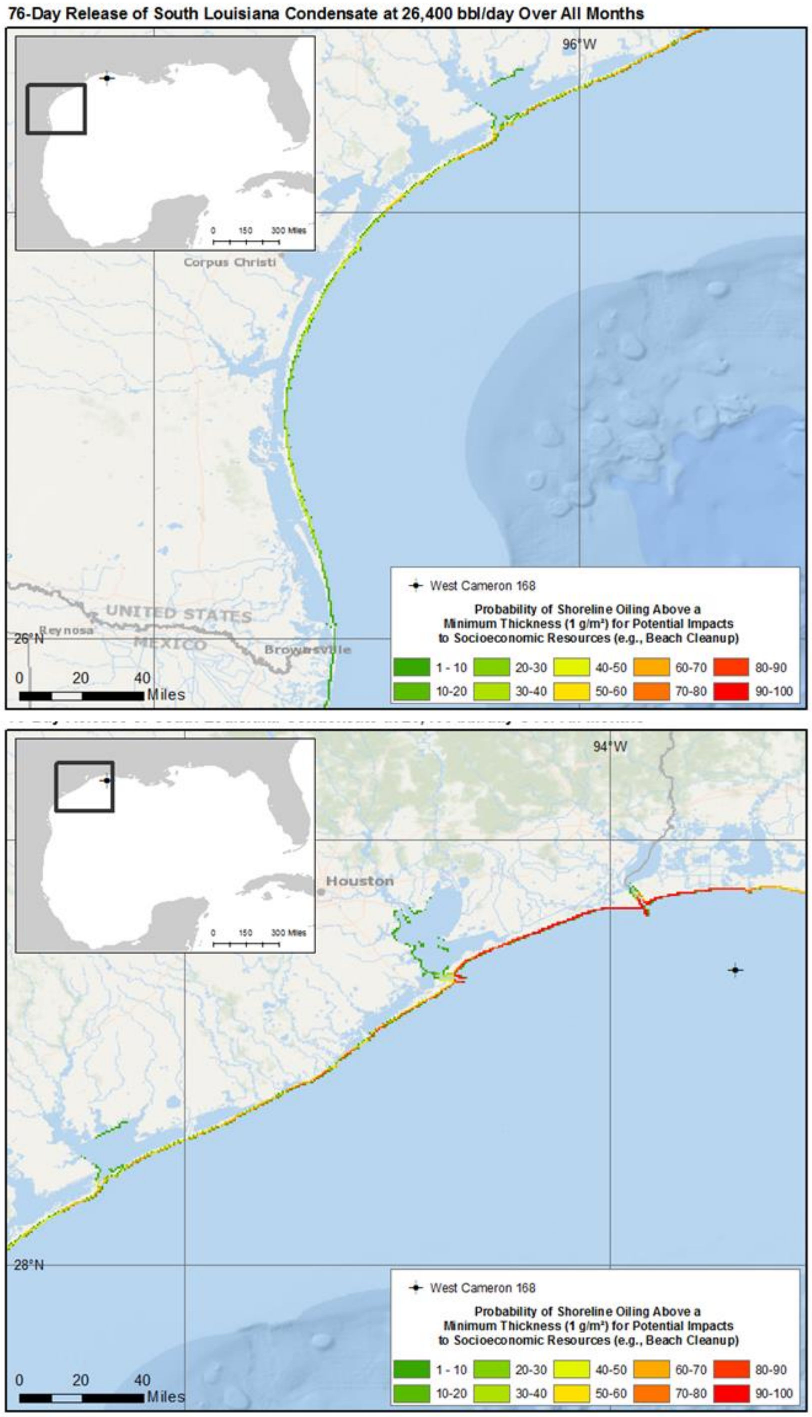



**Figure 39: Scenario 3, GOM-WC168 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 $g/m^2$ (3.94 x $10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Texas and Louisiana Coasts**

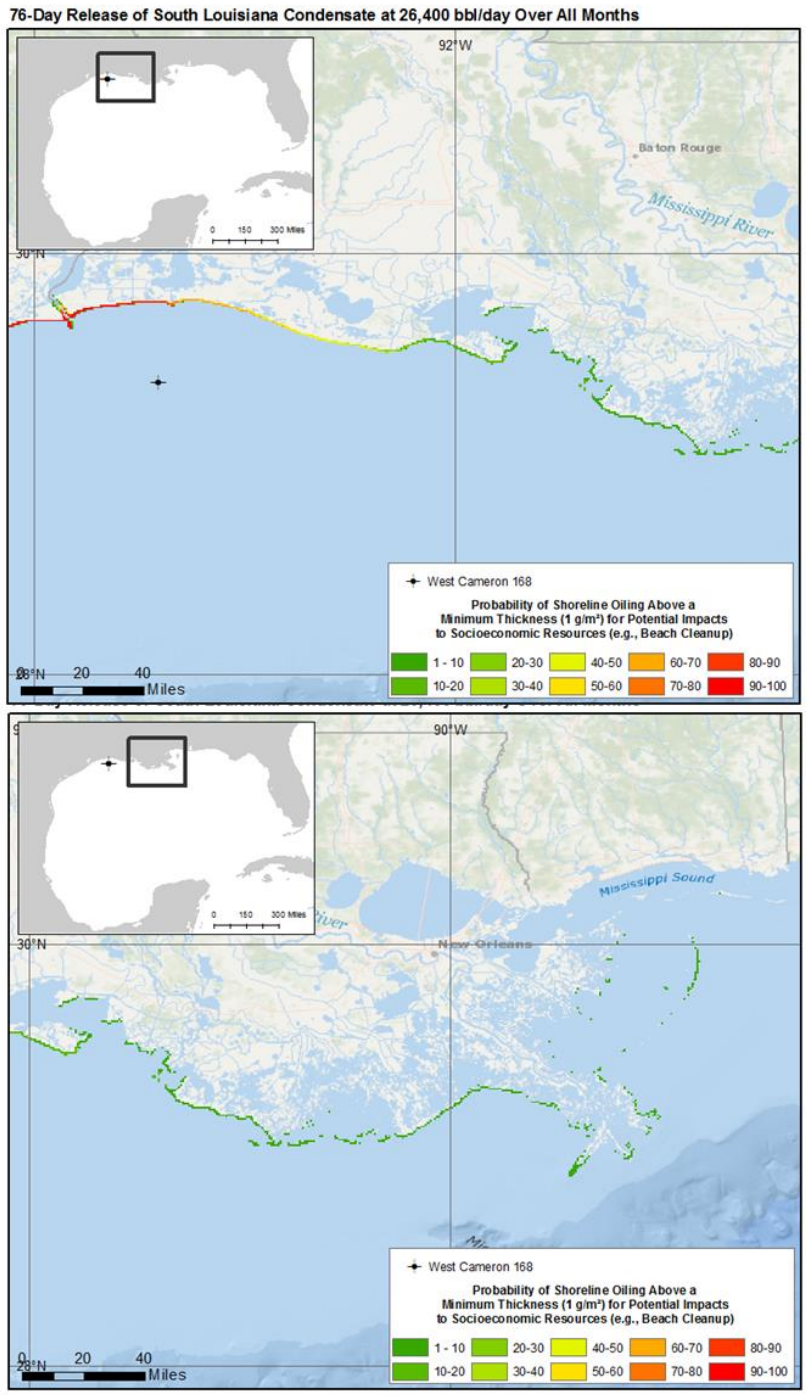



**Figure 40: Scenario 3, GOM-WC168 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 $g/m^2$ (3.94 x $10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana and Mississippi Coasts**

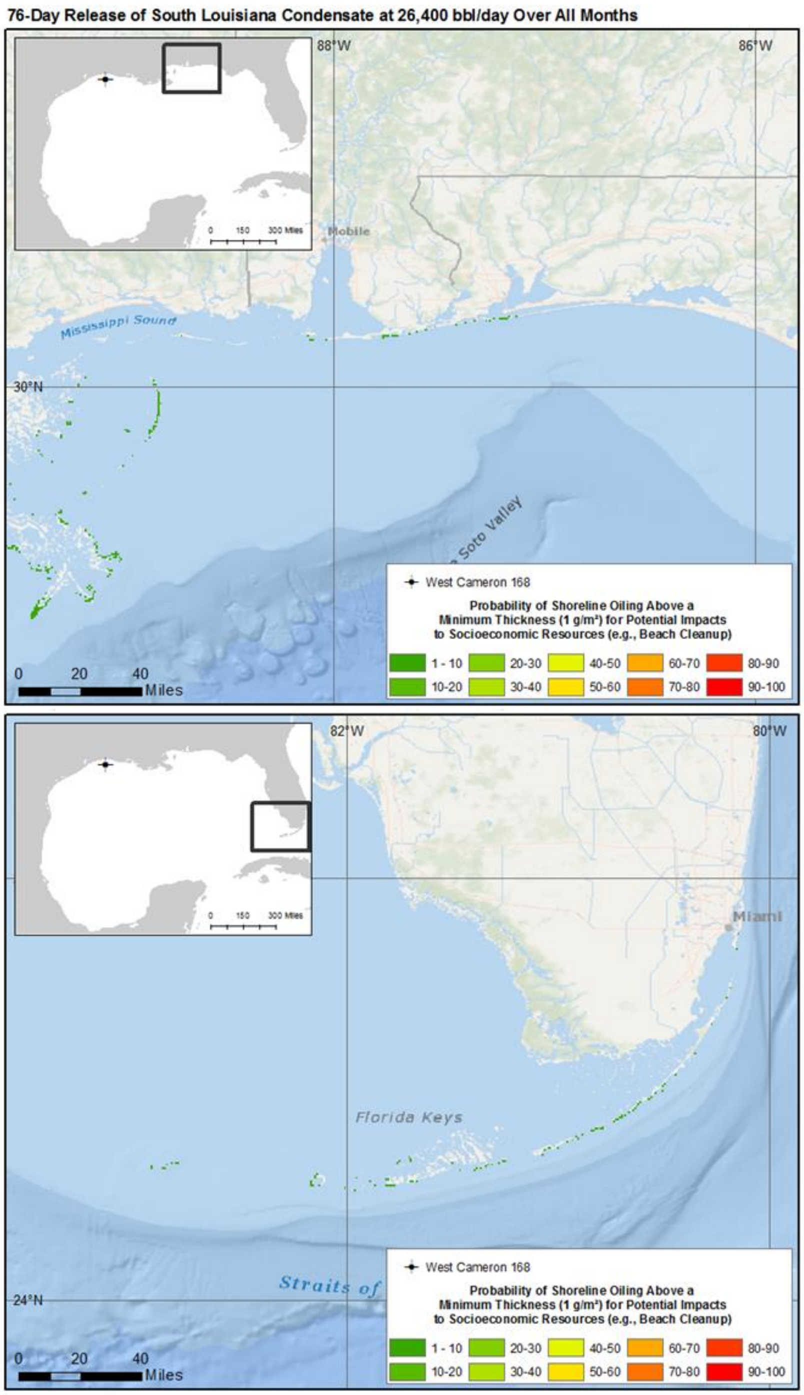



**Figure 41: Scenario 3, GOM-WC168 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana, Mississippi, Alabama, and Florida Coasts**

### 3.3.5 Scenario 4 – High Island East South Extension 376 (HIA376)

The High Island East South Extension 376 (HIA376) is the only scenario in the Western Gulf of Mexico Planning Area, and is one of the smaller WCDs assessed for the consequence analysis.

**Table 25: Well Information for Scenario 4 – Gulf of Mexico High Island East South Extension 376 (HIA376)**

| WCD Scenario: Lease Block High Island East South Extension 376 (HIA376)<br>Western GOM Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 77,000 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 50 days |
| **Total WCD Release Volume** | 3,850,000 bbl |
| **Simulation Duration (45 days following end of release)** | 95 days |
| **API Gravity (South Louisiana Crude)** | 34.5 |
| **Latitude, Longitude** | 27.943209°N, 93.667917°W |
| **Depth to Sea Floor** | 334 feet |
| **Distance to Shoreline** | 129 miles (112 nm) |

#### *HIA376 Oil Plume and Transport Modeling Results*

The near-field oil plume simulation for this scenario found that 100% of the total oil mass would reach the surface in less than one hour of the release. Due to the shallow location of HIA376, no buoyant trapping depth was observed (Table 26). Therefore, the far-field oil transport for this case was initiated 1.6 ft. from the surface with a median droplet size of 985 microns.

**Table 26: Near-Field Oil Plume Behavior for Scenario 4 – Gulf of Mexico High Island East South Extension 376 (HIA376)**

| WCD Scenario: Lease Block High Island East South Extension 376 (HIA376)<br>Western GOM Planning Area | |
|---|---|
| **Near-Field Oil Plume** | |
| **Oil Release Depth** | 334 feet |
| **GOR** | 1,220 scf/stb |
| **Median Droplet Size** | 985 microns |
| **Buoyant Trapping Depth** | 1.6 feet |
| **Percentage of Oil Mass to Reach Surface** | 100% |
| **Time for Percentage of Oil Mass to Reach Surface** | <1 hours |

**Table 27: Far-Field Oil Transport Summary for Scenario 4 – Gulf of Mexico High Island East South Extension 376 (HIA376)**

| **WCD Scenario: Lease Block High Island East South Extension 376 (HIA376)**<br>**Western GOM Planning Area** | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 g/$m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 100 miles of spill site; Figure 44 through Figure 46 |
| Minimum time for oil above the threshold (1 g/$m^2$) used to determine effects on socioeconomic resources to reach shore | 6.0 days |
| Shoreline length (miles) affected by oil above the threshold of 1 g/$m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 97% of simulations at >200 mi; ~17% at >1,000 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 g/$m^2$ (minimum thickness for which response equipment can be applied) | Greatest within 100 miles of release with 1-10 % probability approximately 1,000 miles from release point; Figure 42 (top) |
| Minimum time (days) to exceed the surface oil threshold of 8 g/$m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 90 miles of spill site; Figure 42 (bottom) |
| Minimum time (days) surface oil greater than 8 g/$m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 6.5 days |
| Water surface area (miles$^2$) affected by oil above the surface oil threshold of 8 g/$m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 97% of simulations at >100 mi$^2$; 36% of simulations at >1,000 mi$^2$ |
| Average percentage of total oil that is transported out of modeled area | 0.02 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column. The modeling results illustrate in gridded format the spatial extent of surface (Figure 42), water column, (Figure 43) and shoreline (Figure 44 through Figure 46) oiling probabilities for the spills using the thresholds outlined in Table 7 and Table 8.

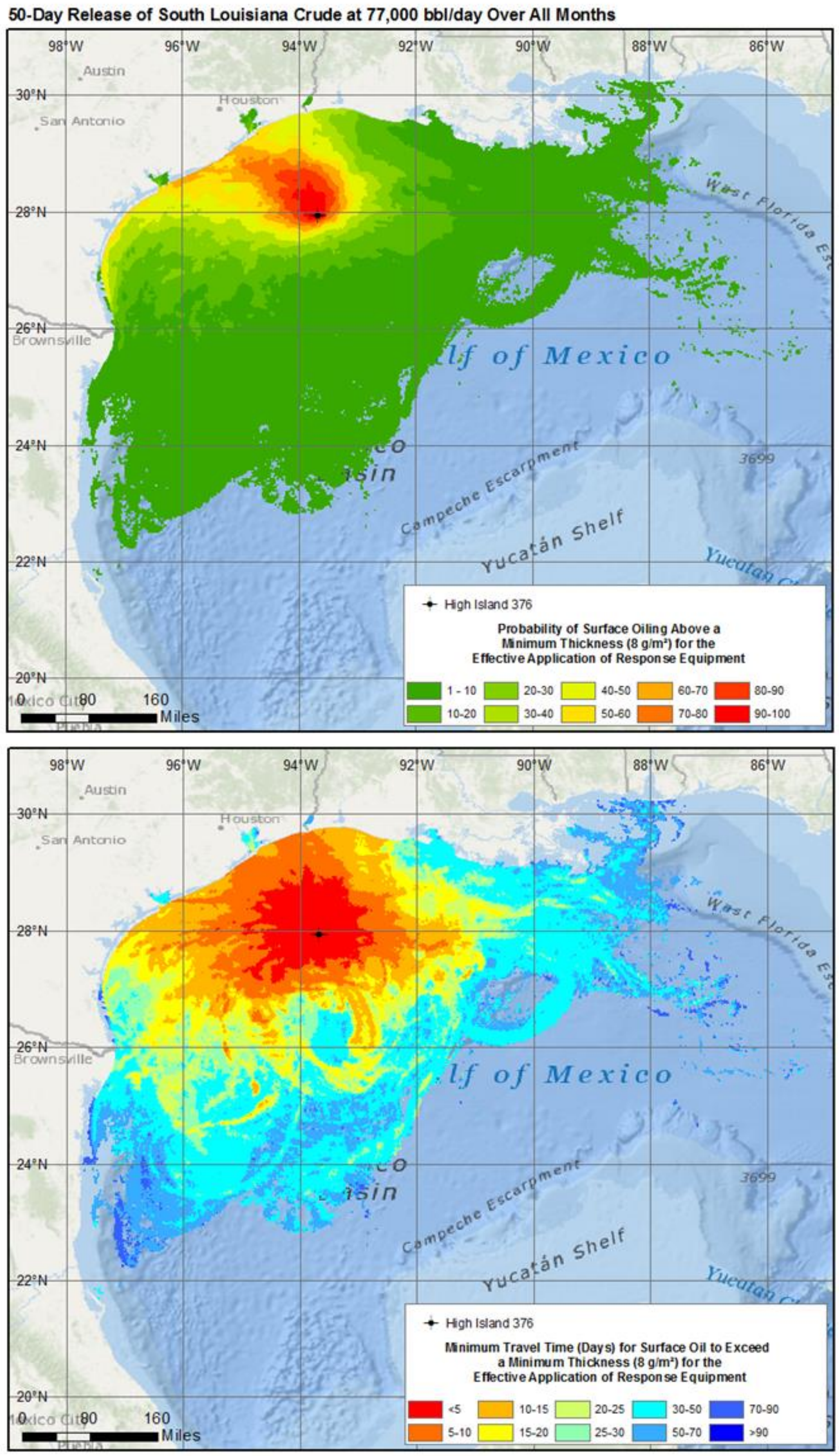



**Figure 42: Scenario 4, GOM-HIA376 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 42 provides the model results showing potential implications for cleanup activity along the water surface. Location of high probabilities of oiling thickness above the threshold for which response equipment can be applied (8 $g/m^2$) would be the regions targeted or prioritized for surface cleanup and removal in a response situation. From this analysis, the greatest exceedance of surface oil >8 $g/m^2$ was within 100 miles of the spill site (Figure 42). The higher floating surface oil probabilities (80-100%) for HIA376 were primarily on the Texas shelf and coastline. The minimum time for oil of this threshold to reach shore was 6.5 days along the coast of Texas between Galveston Bay and Matagorda Bay (Table 27, Figure 42). If a spill of this magnitude were to occur from this site, the first place near shore response equipment would be recommended to be applied would be in this region. The higher probabilities where that total hydrocarbon concentrations in the water column would exceed100 ppb were observed exclusively offshore and on the Texas shelf (Figure 43).

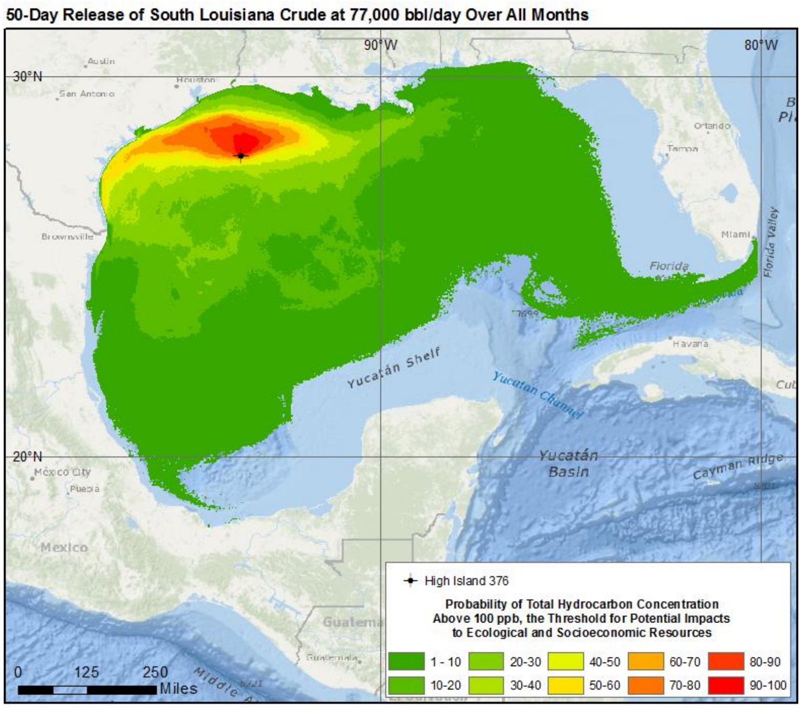



**Figure 43: Scenario 4, GOM-HIA376 – Probability of total hydrocarbon concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur)**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 6 days (Table 27). Within approximately 100 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. The majority of the simulations (97%) in the stochastic set had over 200 miles of shoreline oiled above the socioeconomic threshold, while 17% showed greater than 1,000 miles. Shoreline oiling above the socioeconomic threshold occurred from the Texas coastline to the Florida panhandle, and on the Florida Keys (Figure 44 - Figure 46). The highest probability of oiling occurred along the Texas coast. Shoreline oiling probability above the socioeconomic threshold in the HIA376 scenario was not as widespread as compared to the larger crude blowout scenarios simulated in the Gulf of Mexico. However, the socioeconomic and environmental shoreline resources along the Texas coast would have probable contact with oil if a spill of this magnitude were to occur from this spill site.

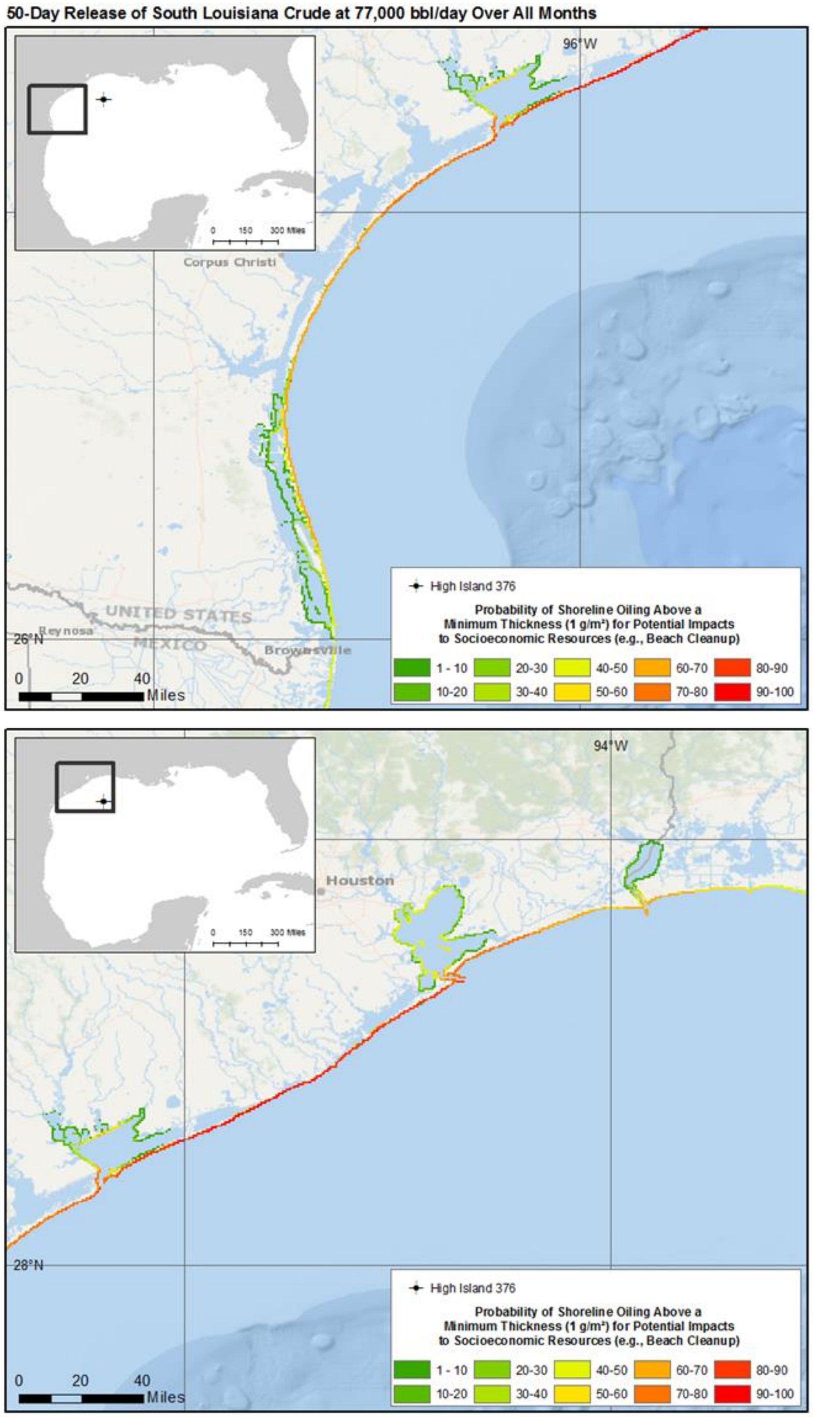



**Figure 44: Scenario 4, GOM-HIA376 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Texas and Louisiana Coasts**

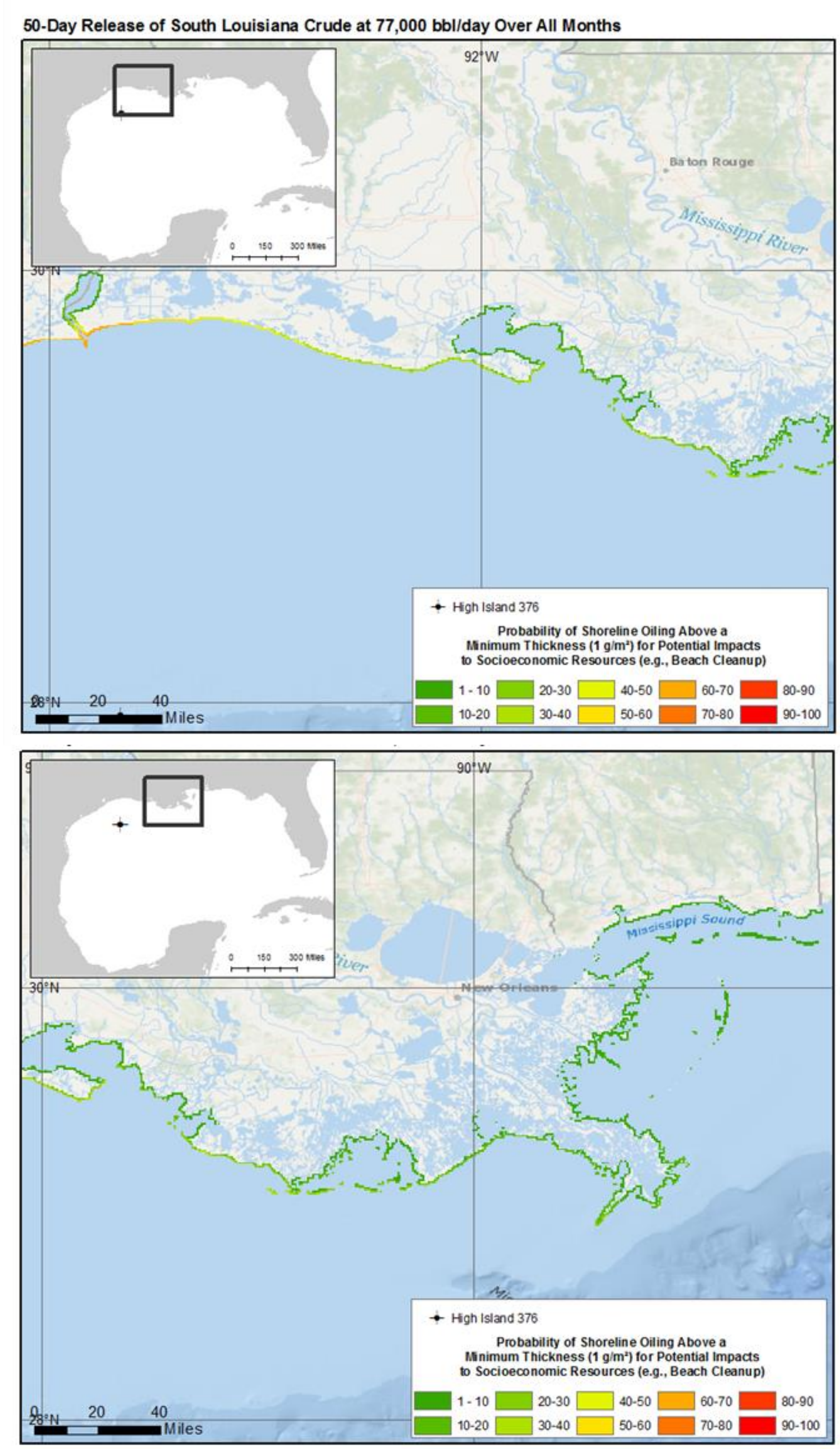



**Figure 45: Scenario 4, GOM-HIA376 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana and Mississippi Coasts**

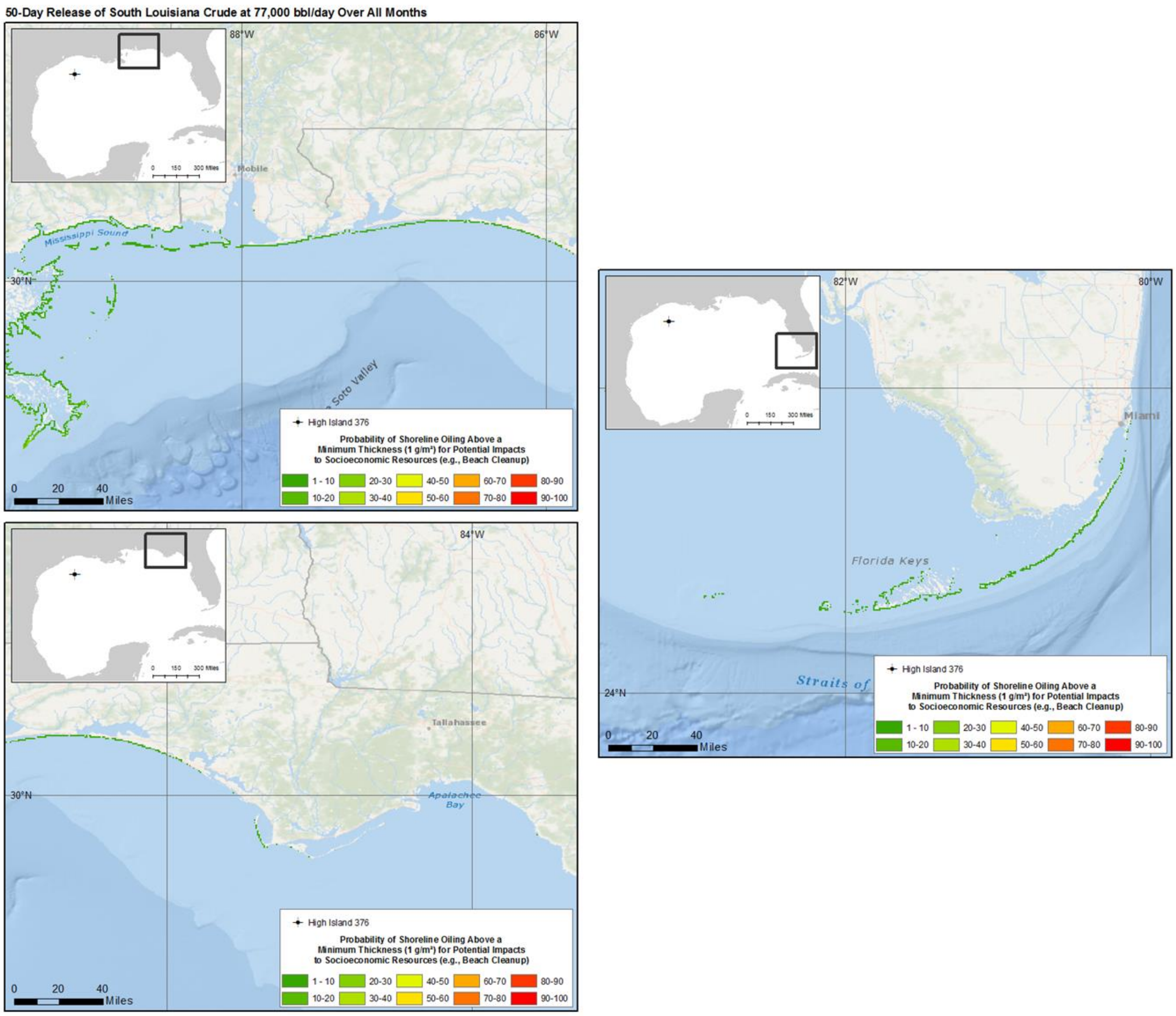



**Figure 46: Scenario 4, GOM-HIA376 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana, Mississippi, Alabama, and Florida Coasts**

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### 3.3.6 Scenario 5 – Keathley Canyon 919 (KC919)

The Keathley Canyon 919 (KC919) scenario in the Central Gulf of Mexico Planning Area is one of the larger WCD spills assessed for the consequence analysis, and is the furthest from shore.

**Table 28: Well Information for Scenario 5 – Gulf of Mexico Keathley Canyon 919 (KC919)**

| WCD Scenario: Lease Block Keathley Canyon 919 (KC919)<br>Central GOM Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 252,000 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 120 days |
| **Total WCD Release Volume** | 30,240,000 bbl |
| **Simulation Duration (45 days following end of release)** | 165 days |
| **API Gravity (South Louisiana Crude)** | 34.5 |
| **Latitude, Longitude** | 26.080171°N, 92.037507°W |
| **Depth to Sea Floor** | 6,940 feet |
| **Distance to Shoreline** | 250 miles (217 nm) |

***KC919 Oil Plume and Transport Modeling Results***

The near-field oil plume simulation for this scenario found that 55% of the total oil mass would reach the surface in 28 hours of the release and the buoyant trapping depth was 4,268 feet (Table 29). Therefore, the far-field oil transport for this case was initiated from 4,268 ft. with a median droplet size of 695 microns.

**Table 29: Near-Field Oil Plume Behavior for Scenario 5 – Gulf of Mexico Keathley Canyon 919 (KC919)**

| WCD Scenario: Lease Block Keathley Canyon 919 (KC919)<br>Central GOM Planning Area | |
|---|---|
| **Near-Field Oil Plume** | |
| **Oil Release Depth** | 6,940 feet |
| **GOR** | 893 scf/stb |
| **Median Droplet Size** | 695 microns |
| **Buoyant Trapping Depth** | 4,268 feet |
| **Percentage of Oil Mass to Reach Surface** | 55% |
| **Time for Percentage of Oil Mass to Reach Surface** | 28 hours |

Table 30 summarizes the stochastic modeling results of the far-field oil transport. Statistics are shown by each oiling threshold of concern representing potential impacts to socioeconomic and environmental resources (1 $g/m^2$) and implications to cleanup activities (8 $g/m^2$).

**Table 30: Far-Field Oil Transport Summary for Scenario 5 – Gulf of Mexico Keathley Canyon 919 (KC919)**

| WCD Scenario: Lease Block Keathley Canyon 919 (KC919)<br>Central GOM Planning Area | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 $g/m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 400 miles of spill site; Figure 49 through Figure 52 |
| Minimum time for oil above the threshold (1 $g/m^2$) used to determine effects on socioeconomic resources to reach shore | 12.0 days |
| Shoreline length (miles) affected by oil above the threshold of 1 $g/m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 94% of simulations at >1,000 mi; ~20% at >2,000 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | Greatest within approximately 200 miles of release with 1-10 % probability approximately 1,000 miles from release point; Figure 47 (top) |
| Minimum time (days) to exceed the surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 125 miles of spill site; Figure 47 (bottom) |
| Minimum time (days) surface oil greater than 8 $g/m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 15 days |
| Water surface area ($miles^2$) affected by oil above the surface oil threshold of 8 $g/m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 85% of simulations at >100 $mi^2$; 46% of simulations at >1,000 $mi^2$ |
| Average percentage of total oil that is transported out of modeled area | 0.61 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column.  The modeling results illustrate in gridded format the spatial extent of surface (Figure 47), water column (Figure 48), and shoreline (Figure 49 through Figure 52) oiling probabilities for the spills using the thresholds outlined in Table 7 and Table 8.

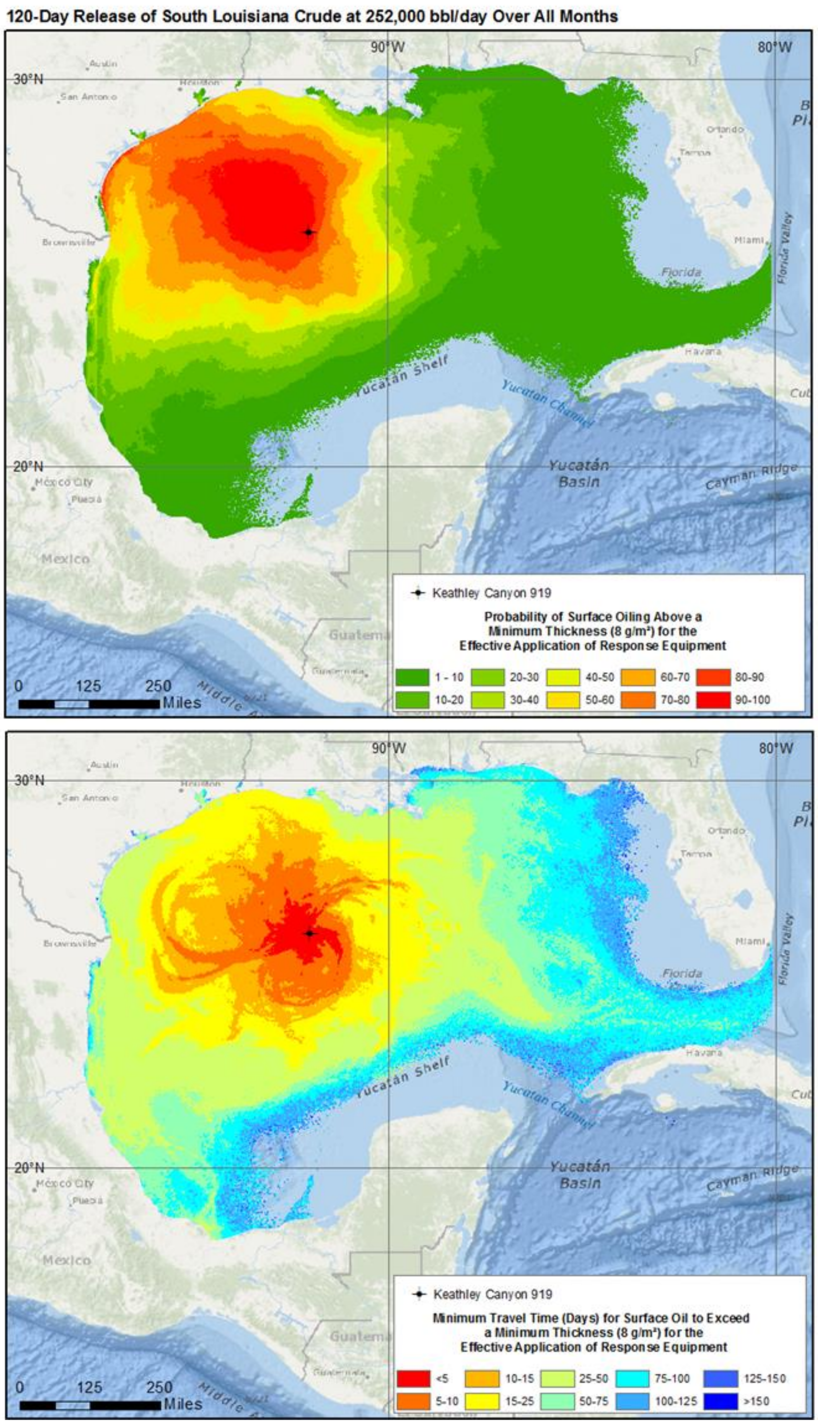


**Figure 47: Scenario 5, GOM-KC919 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 47 provides the model results showing potential implications for cleanup activity along the water surface. Location of high probabilities of oiling thickness above the threshold for which response equipment can be applied (8 $g/m^2$) would be the regions targeted or prioritized for surface cleanup and removal in a response situation. From this analysis, the greatest exceedance of surface oil >8 $g/m^2$ was within 200 miles of the spill site (Figure 47). The higher floating surface oil probabilities (80-100%) for KC919 were primarily offshore in the western Gulf and on the Texas shelf. The minimum time for oil of this threshold to reach shore was 15 days along the southeast Texas coast (Table 30, Figure 47). If a spill of this magnitude were to occur from this site, the first place near shore response equipment would be recommended to be applied would be in this region. Similar to the surface oil probabilities, the higher probabilities where total hydrocarbon concentrations in the water column would exceed 100 ppb were primarily offshore in the western and central Gulf (Figure 48).

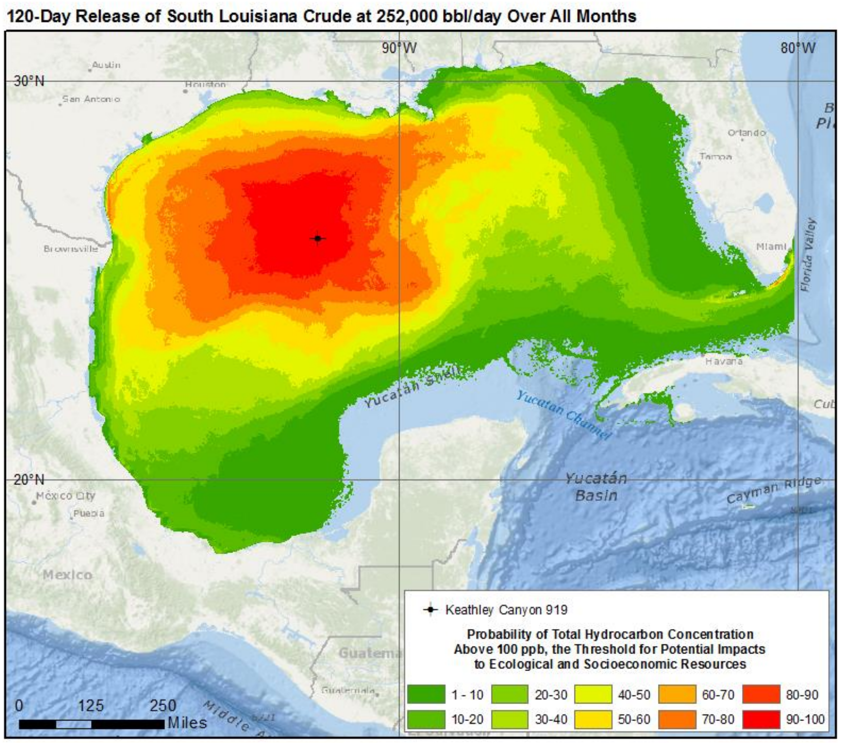


**Figure 48: Scenario 5, GOM-KC919 – Probability of Total Hydrocarbon Concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur)**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 12 days (Table 30). Within approximately 400 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. A large number of the simulations (94%) in the stochastic set had over 1,000 miles of shoreline oiled above the socioeconomic threshold, while 20% showed greater than 2,000 miles. Shoreline oiling above the socioeconomic threshold occurred from the Texas coastline all the way across the Gulf of Mexico to the Florida panhandle, and on the Florida Keys (Figure 49 - Figure 52). The highest probability of oiling occurred along the Texas and Louisiana coastlines. Shoreline oiling probability above the threshold in the KC919 scenario was widespread and the socioeconomic and environmental resources along the Texas and Louisiana coast would have probable contact with oil if a spill of this magnitude were to occur from this spill site.

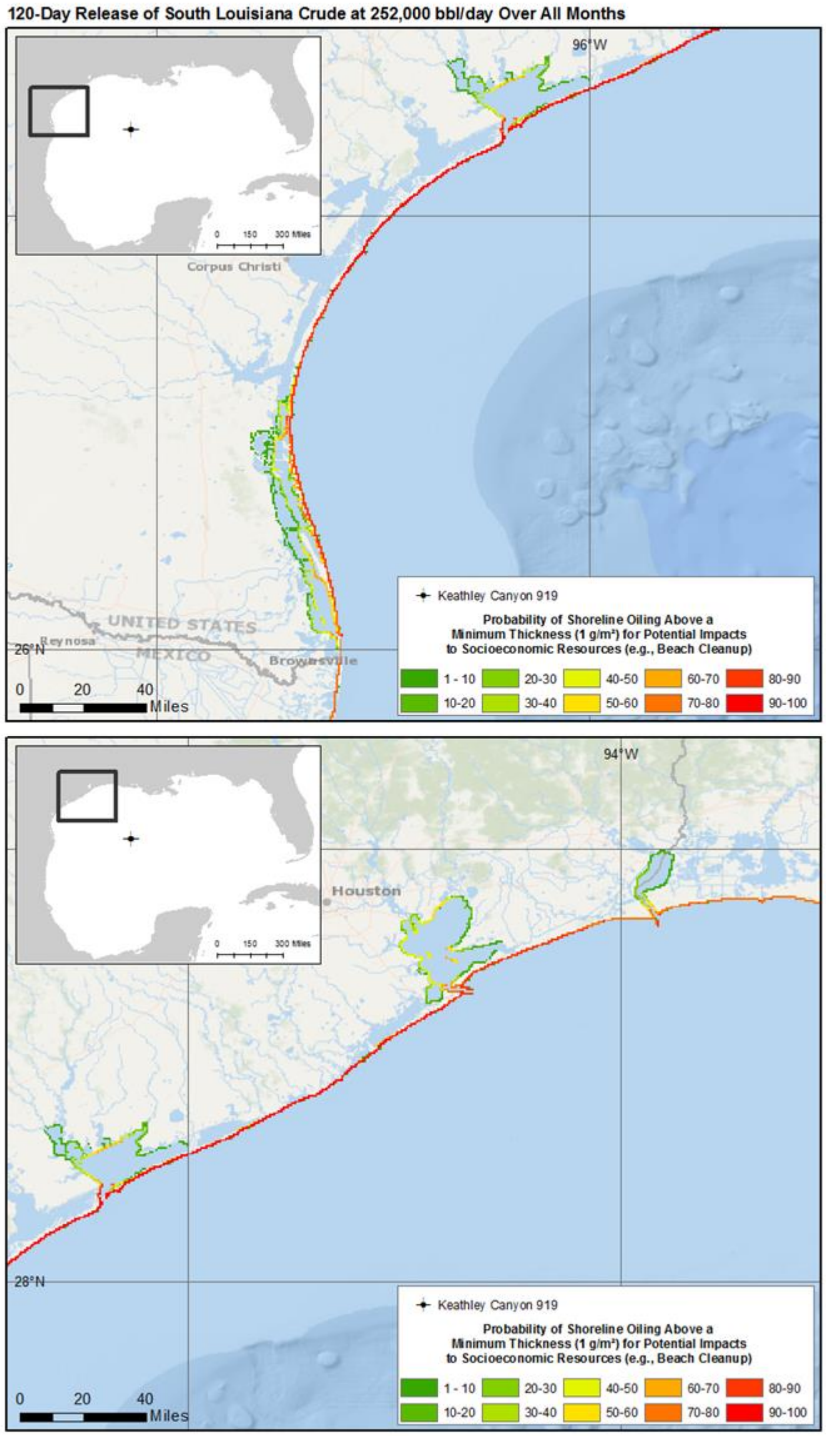


**Figure 49: Scenario 5, GOM-KC919 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Texas and Louisiana Coasts**

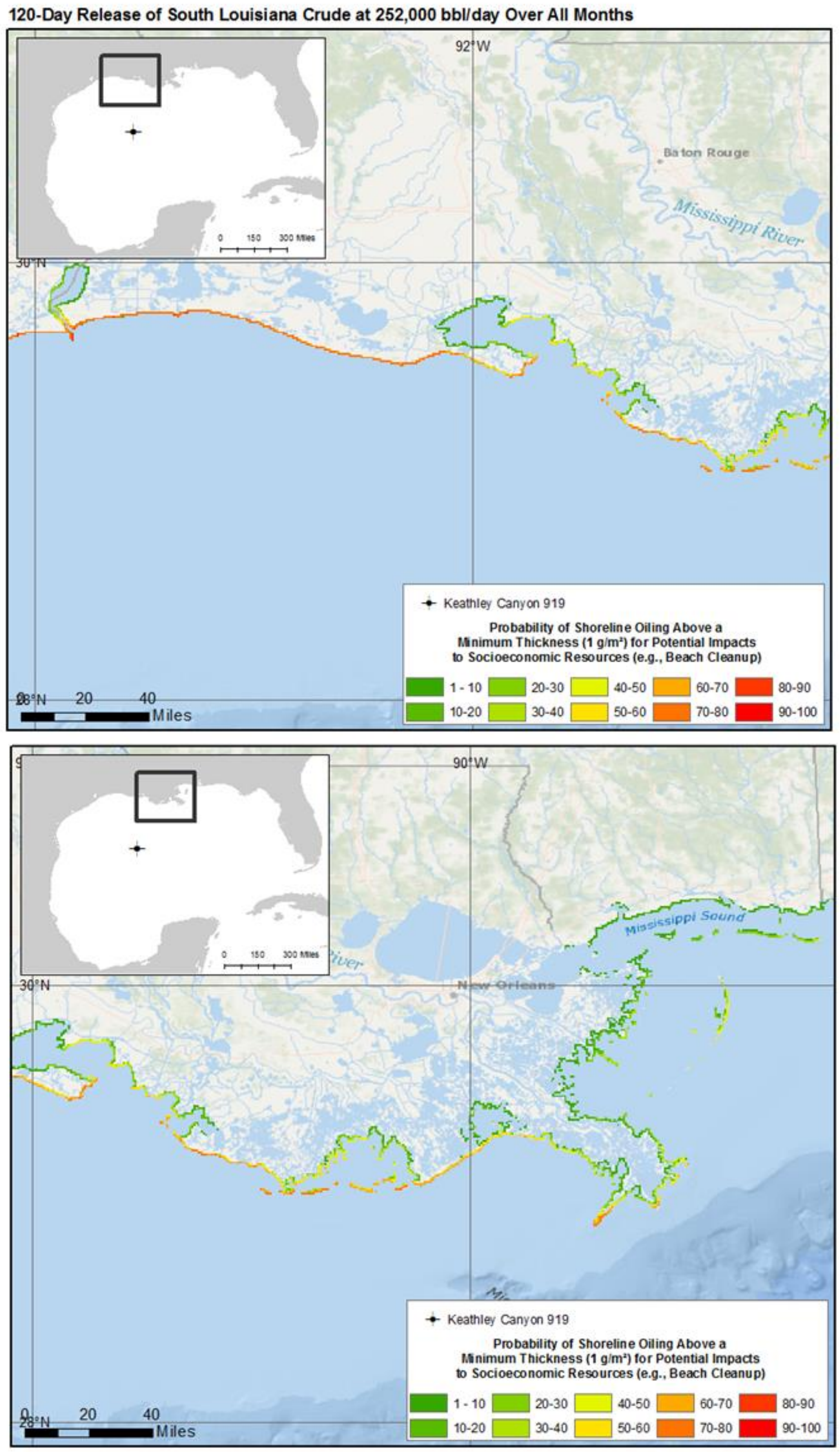


**Figure 50: Scenario 5, GOM-KC919 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x $10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana and Mississippi Coasts**

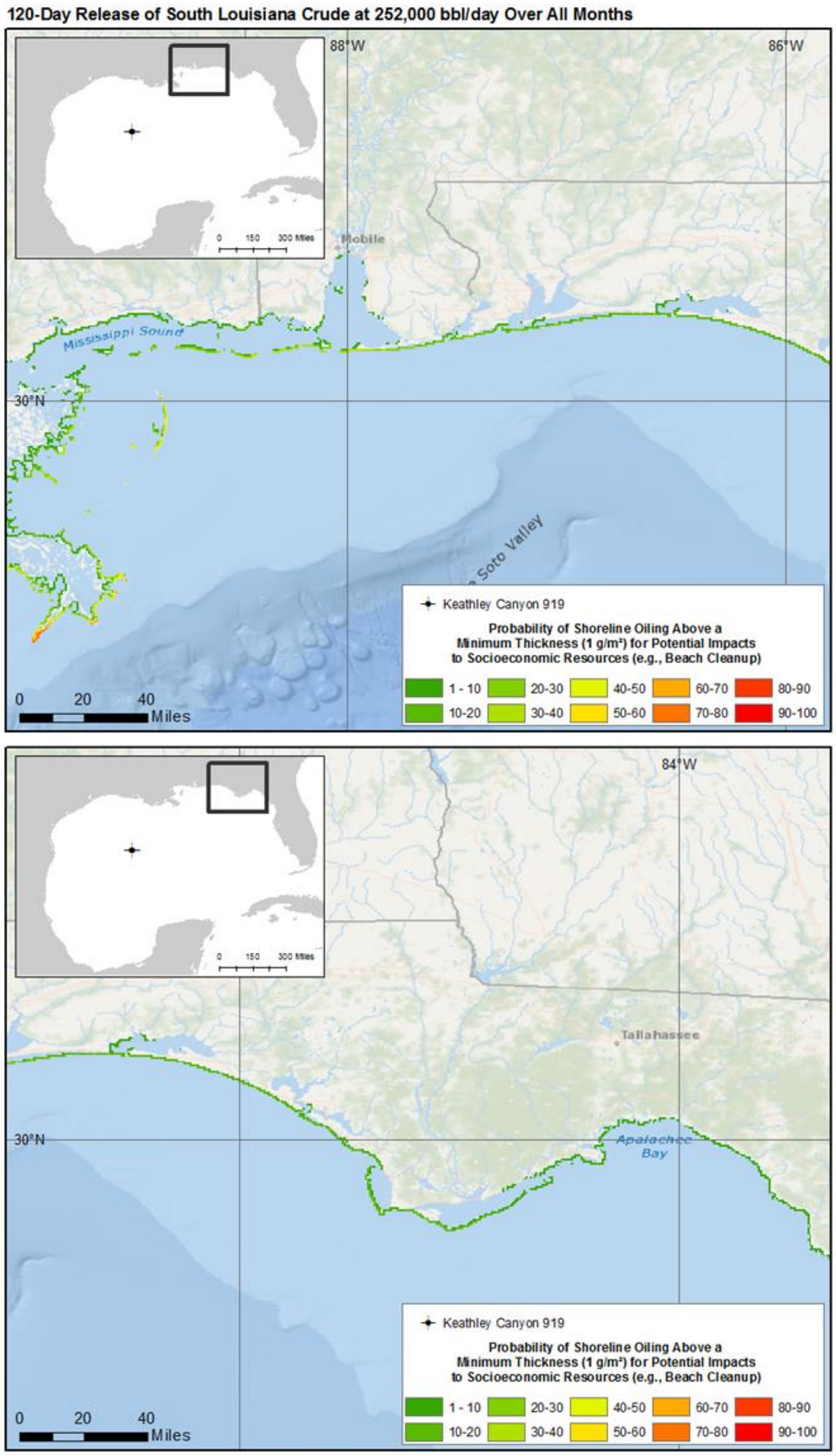


**Figure 51: Scenario 5, GOM-KC919 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m² (3.94 x $10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana, Mississippi, Alabama, and Florida Coasts**

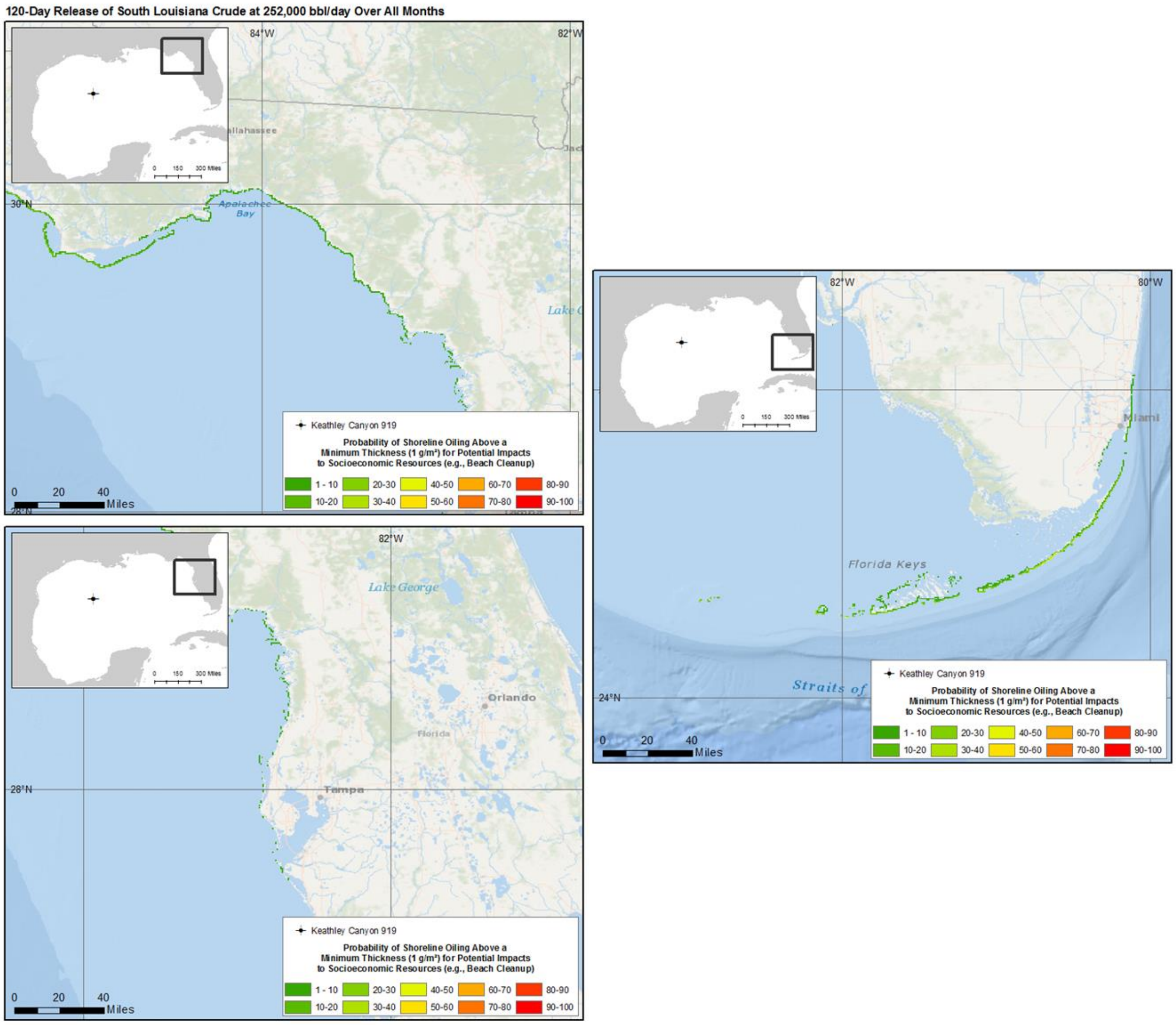


**Figure 52: Scenario 5, GOM-KC919 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along the Florida Coast**

### 3.3.7 Scenario 6 – DeSoto Canyon 187 (DC187)

The DeSoto Canyon (DC187) scenario in the Central Gulf of Mexico Planning Area, is one of the larger spills assessed for the consequence analysis.

**Table 31: Well Information for Scenario 6 – DeSoto Canyon 187 (DC187)**

| WCD Scenario: Lease Block DeSoto Canyon 187 (DC187)<br>Central GOM Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 241,000 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 106 days |
| **Total WCD Release Volume** | 25,546,000 bbl |
| **Simulation Duration (45 days following end of release)** | 151 days |
| **API Gravity (South Louisiana Crude)** | 34.5 |
| **Latitude, Longitude** | 28.785337ºN, 87.39878ºW |
| **Depth to Sea Floor** | 4,490 feet |
| **Distance to Shoreline** | 116 miles (101 nm) |

#### *DC187 Oil Plume and Transport Modeling Results*

The near-field oil plume simulation for this scenario found that 63% of the total oil mass would reach the surface in 26 hours of the release and the buoyant trapping depth was 3,143 feet (Table 32). Therefore, the far-field oil transport for this case was initiated from 3,143 ft. with a median droplet size of 689 microns.

**Table 32: Near-Field Oil Plume Behavior for Scenario 6 – DeSoto Canyon 187 (DC187)**

| WCD Scenario: Lease Block DeSoto Canyon 187 (DC187)<br>Central GOM Planning Area | |
|---|---|
| **Near-Field Oil Plume** | |
| **Oil Release Depth** | 4,490 feet |
| **GOR** | 654 scf/stb |
| **Median Droplet Size** | 689 microns |
| **Buoyant Trapping Depth** | 3,143 feet |
| **Percentage of Oil Mass to Reach Surface** | 63% |
| **Time for Percentage of Oil Mass to Reach Surface** | 26 hours |

**Table 33: Far-Field Oil Transport Summary for Scenario 6 – DeSoto Canyon 187 (DC187)**

| WCD Scenario: Lease Block DeSoto Canyon 187 (DC187)<br>Central GOM Planning Area | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 $g/m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 200 miles of spill site; Figure 55 through Figure 59 |
| Minimum time for oil above the threshold (1 $g/m^2$) used to determine effects on socioeconomic resources to reach shore | 5.0 days |
| Shoreline length (miles) affected by oil above the threshold of 1 $g/m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 99% of simulations at >1,000 mi; ~25% at >2,500 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | Greatest within approximately 70 miles of release with 1-10 % probability approximately 1,000 miles from release point; Figure 53 (top) |
| Minimum time (days) to exceed the surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 125 miles of spill site; Figure 53 (bottom) |
| Minimum time (days) surface oil greater than 8 $g/m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 7.5 days |
| Water surface area ($miles^2$) affected by oil above the surface oil threshold of 8 $g/m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 97% of simulations at >100 $mi^2$; 25% of simulations at >3,000 $mi^2$ |
| Average percentage of total oil that is transported out of modeled area | 1.55 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column. The modeling results illustrate in gridded format the spatial extent of surface (Figure 53), water column (Figure 54), and shoreline (Figure 55 through Figure 59) oiling probabilities for the spills using the thresholds outlined in Table 7 and Table 8.

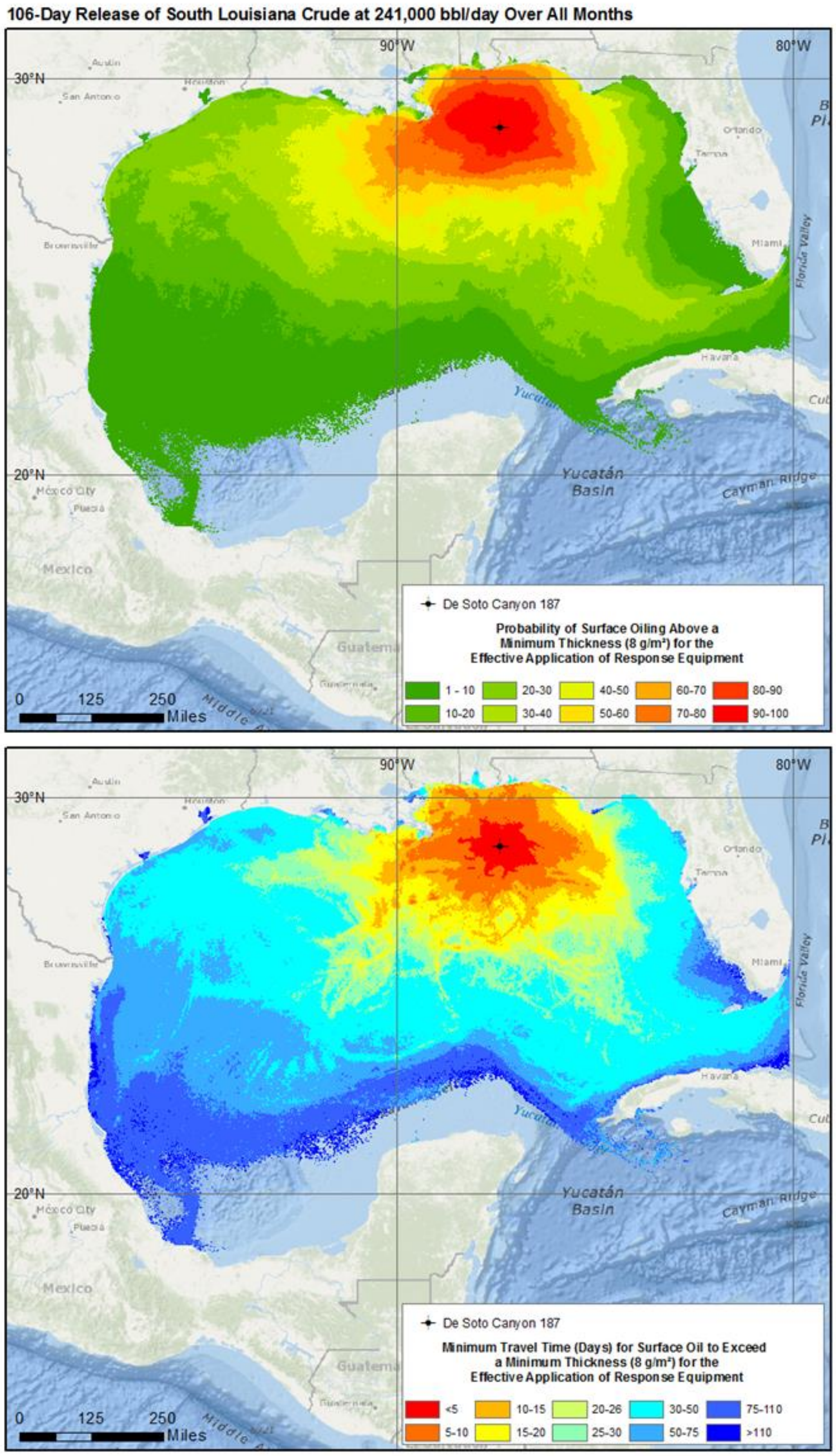


**Figure 53: Scenario 6, GOM-DC187 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 53 provides the model results showing potential implications for cleanup activity along the water surface. From this analysis, the greatest exceedance of surface oil >8 g/m$^2$ was within 70 miles of the spill site (Figure 53). The higher floating surface oil probabilities (80-100%) for DC187 were primarily offshore in the central Gulf and along the eastern Louisiana, Mississippi, Alabama, and Florida shelf. The high surface oil probabilities around the Florida Keys are actually tarballs, which show up in the shoreline probability figures. The minimum time for oil of this threshold to reach shore was 7.5 days along Louisiana coast at the Mississippi Delta or "Bird's Foot" (Table 33, Figure 53). If a spill of this magnitude were to occur from this site, the first place near shore response equipment would be recommended to be applied would be in this region. Similar to the surface oil probabilities, the higher probabilities where total hydrocarbon concentrations in the water column would exceed100 ppb were primarily offshore in the central Gulf (Figure 54). Probabilities of subsurface contamination also stretched south, down to the Straits of Florida due to the loop current.

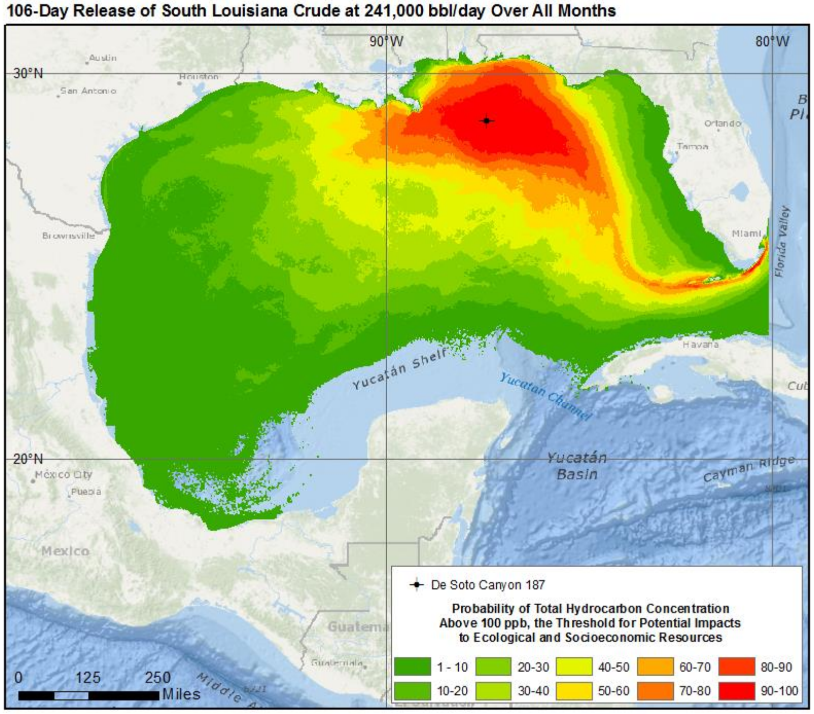


**Figure 54: Scenario 6, GOM-DC187 – Probability of Total Hydrocarbon Concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur)**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 5 days (Table 33). Within approximately 200 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. The majority of the simulations (99%) in the stochastic set had over 1,000 miles of shoreline oiled above the socioeconomic threshold, while 25% showed greater than 2,500 miles. Shoreline oiling above the socioeconomic threshold was widespread and occurred from the Texas coastline all the way across the Gulf of Mexico to the western Florida coast including the Florida Keys (Figure 55 - Figure 59). The highest probability of shoreline oiling occurred from Louisiana to the Florida panhandle coastline. The socioeconomic and environmental resources along the Louisiana, Mississippi, and Alabama coast would have probable contact with oil if a spill of this magnitude were to occur from this spill site.

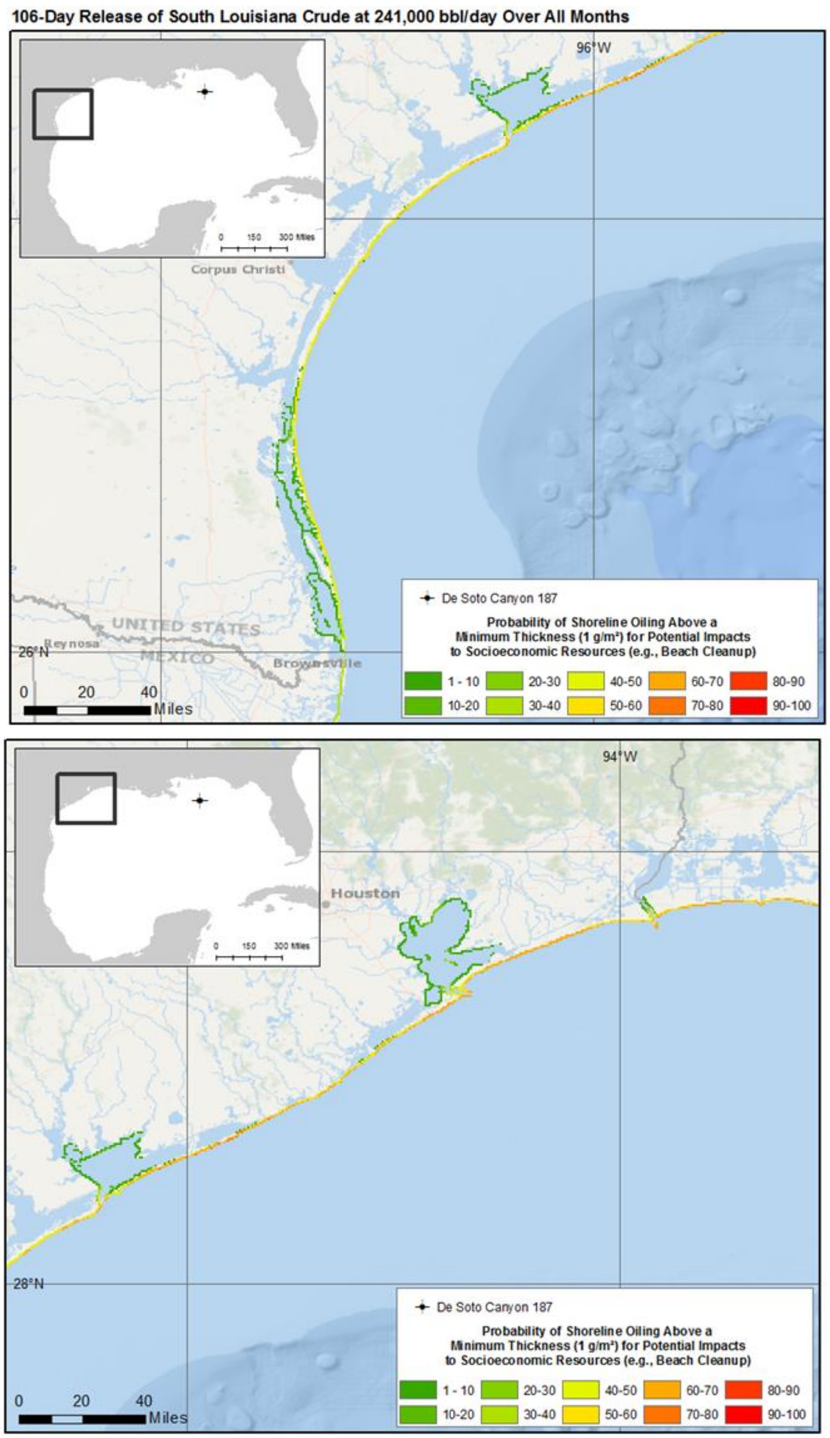


**Figure 55: Scenario 6, GOM-DC187 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Texas and Louisiana Coasts**

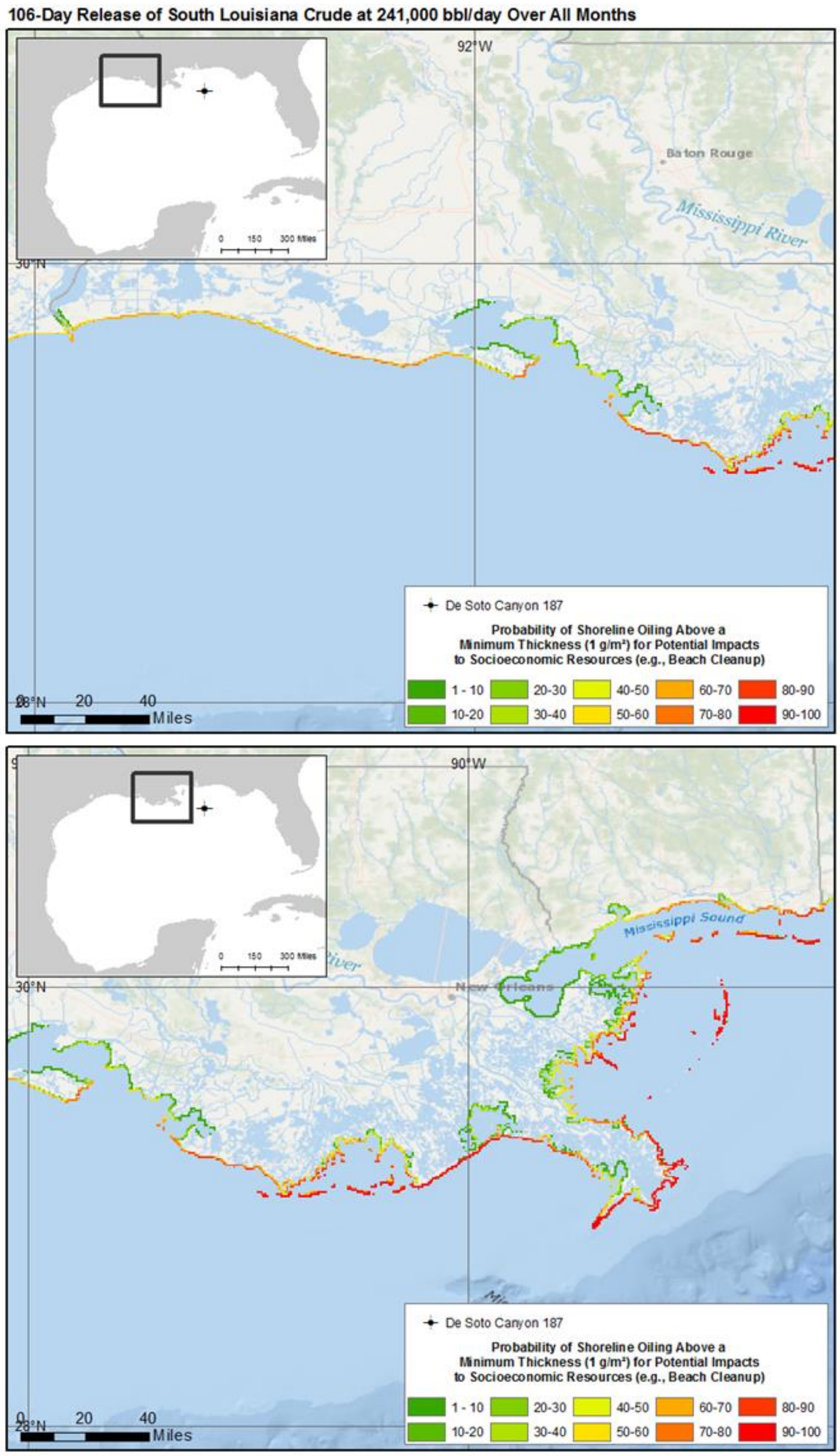


**Figure 56: Scenario 6, GOM-DC187 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana and Mississippi Coasts**

106-Day Release of South Louisiana Crude at 241,000 bbl/day Over All Months

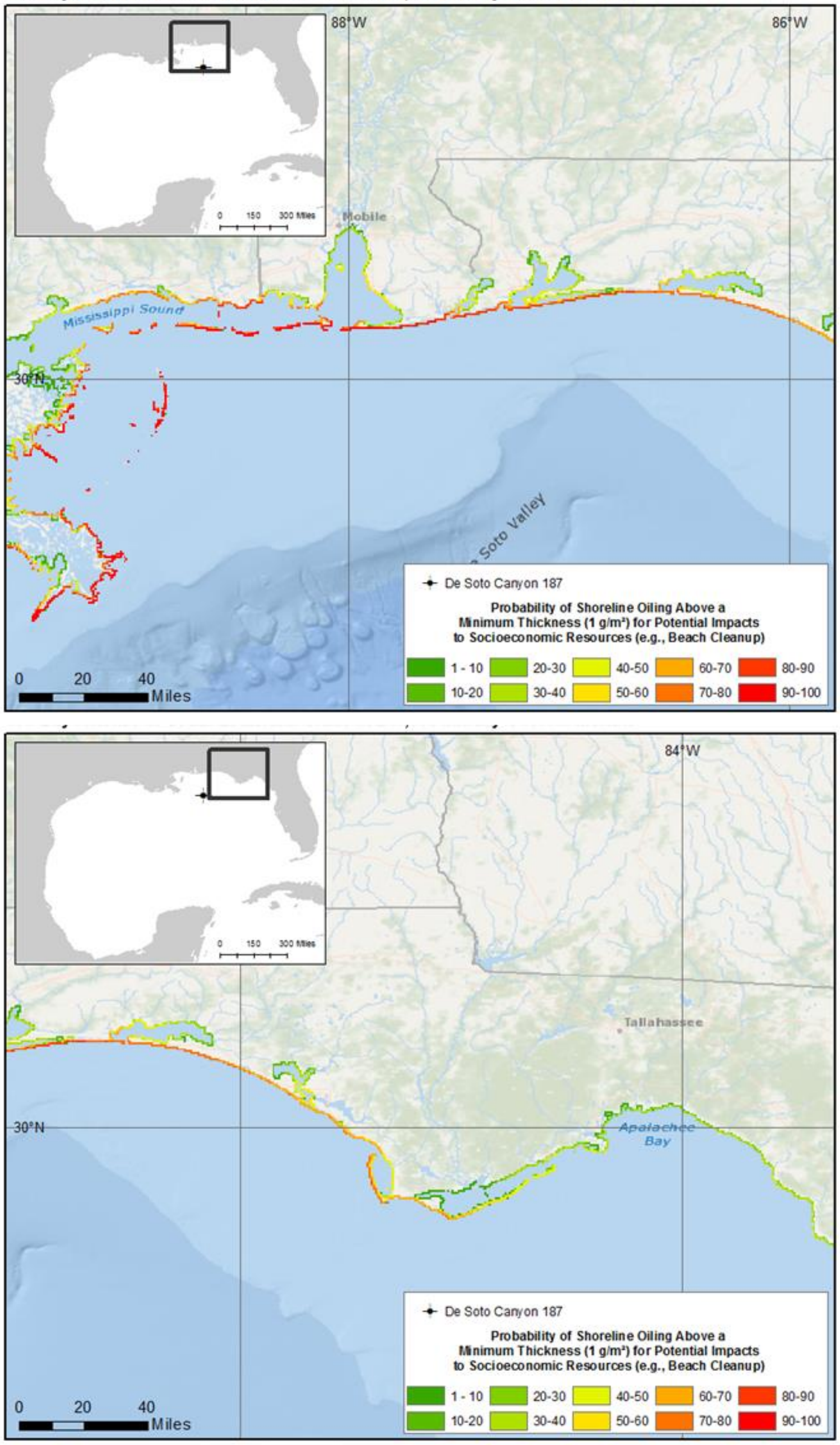


**Figure 57: Scenario 6, GOM-DC187 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 $g/m^2$ ($3.94 \times 10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along Louisiana, Mississippi, Alabama, and Florida Coasts**

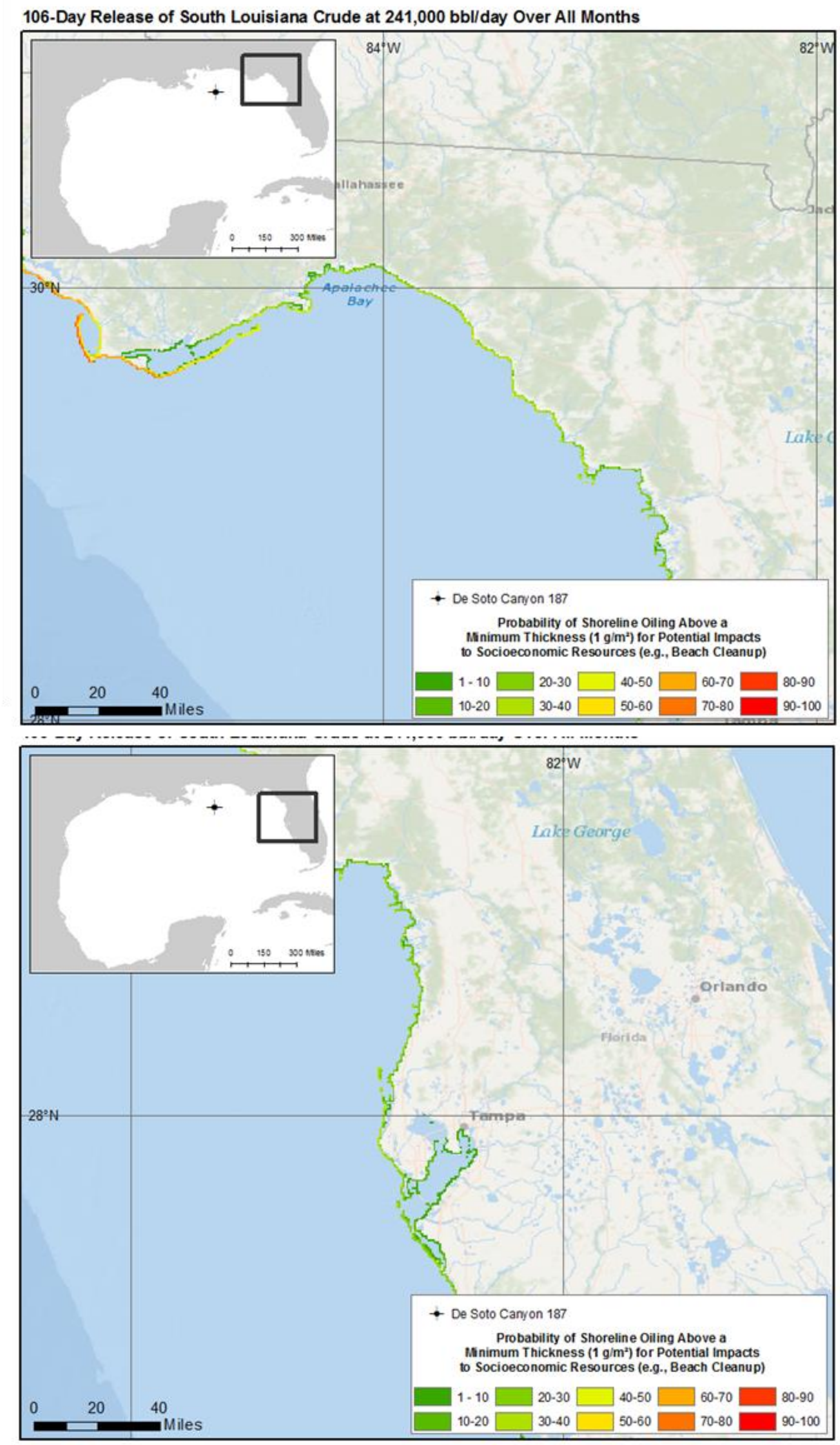


**Figure 58: Scenario 6, GOM-DC187 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m² (3.94 x $10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along the north Florida Coast**

106-Day Release of South Louisiana Crude at 241,000 bbl/day Over All Months

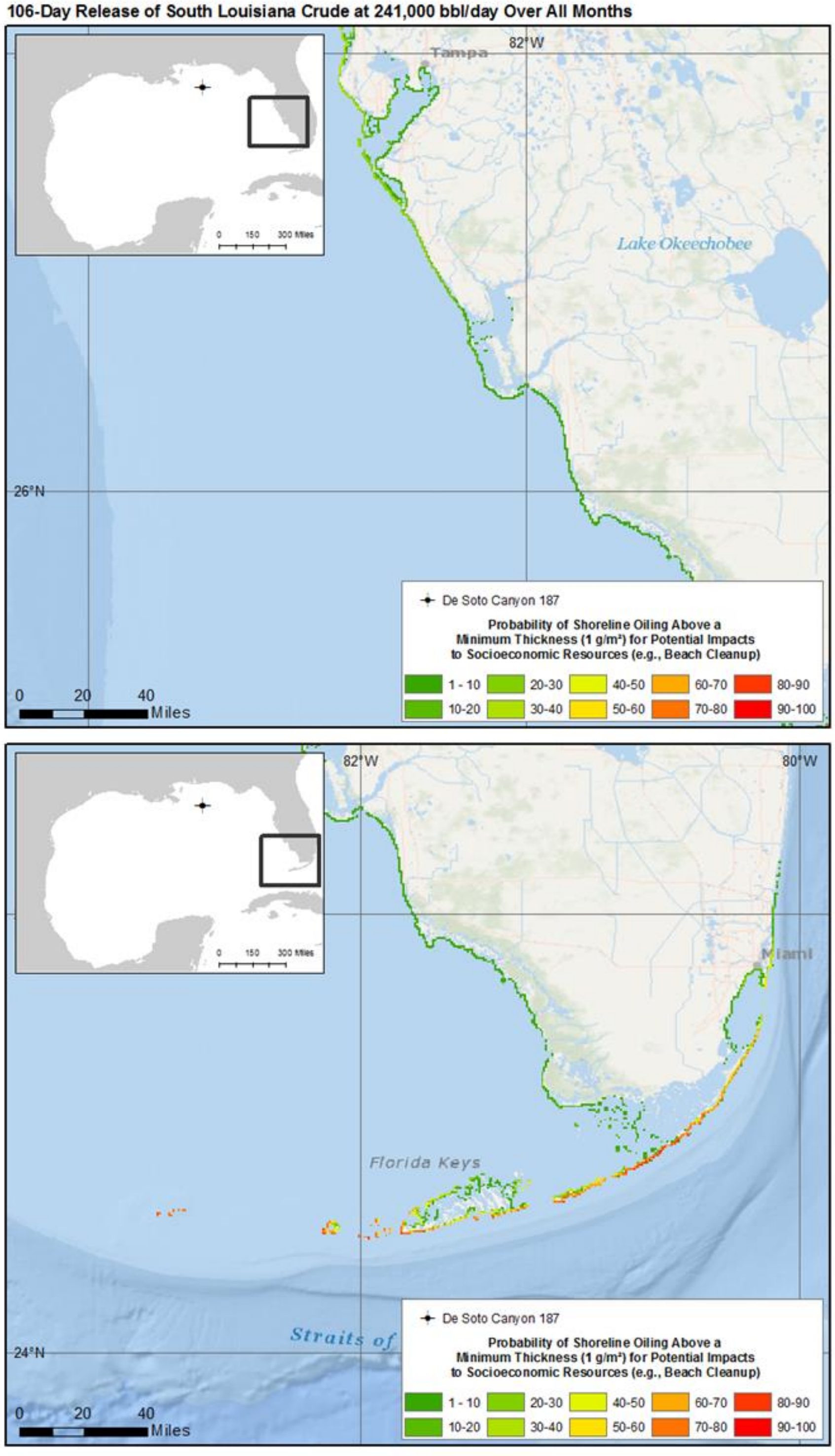


**Figure 59: Scenario 6, GOM-DC187 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 $g/m^2$ ($3.94 \times 10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along the south Florida Coast**

## 4.0 WCD PROFILES FOR THE PACIFIC OCS REGION

The Pacific OCS Region has 431 producing wells and there are no plans for significantly increasing production in this region. The history of wells drilled in the Pacific OCS Region is shown in Figure 60.

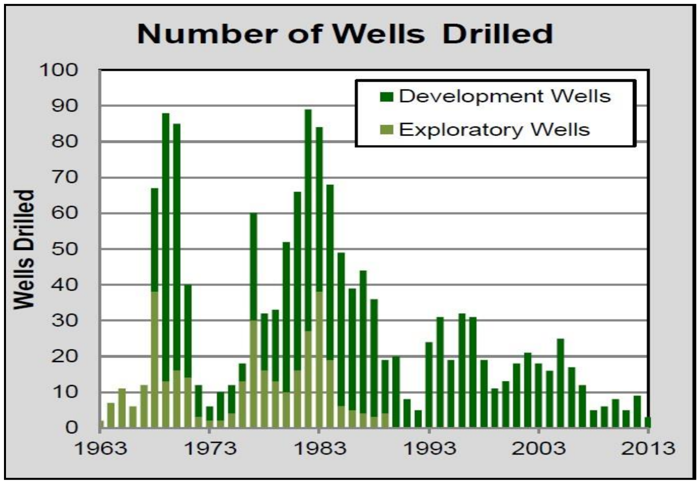


**Figure 60: History of Wells Drilled in Pacific OCS Region**[85]

Currently, all wells in the Pacific OCS Region are off the shore of southern California (Figure 61), though the region has planning areas all along the Pacific coast. Data on the platforms in the Pacific OCS Region are shown in Table 34. These data indicate that there are 1,386 well slots on 23 platforms. There were five new development wells drilled in 2013.

In contrast to the Gulf of Mexico OCS Region, the Pacific OCS Region has relatively few wells and no trend of significant new exploration or drilling, due in part to moratorium on new offshore exploration within the Pacific OCS Region. As a result, oil production rates in the Pacific OCS Region peaked in 1995 and have been declining since (Figure 62).

[85] BSEE Pacific OCS Region (POCS) Production and Development Statistics. July 2014 (Data for December 2013)

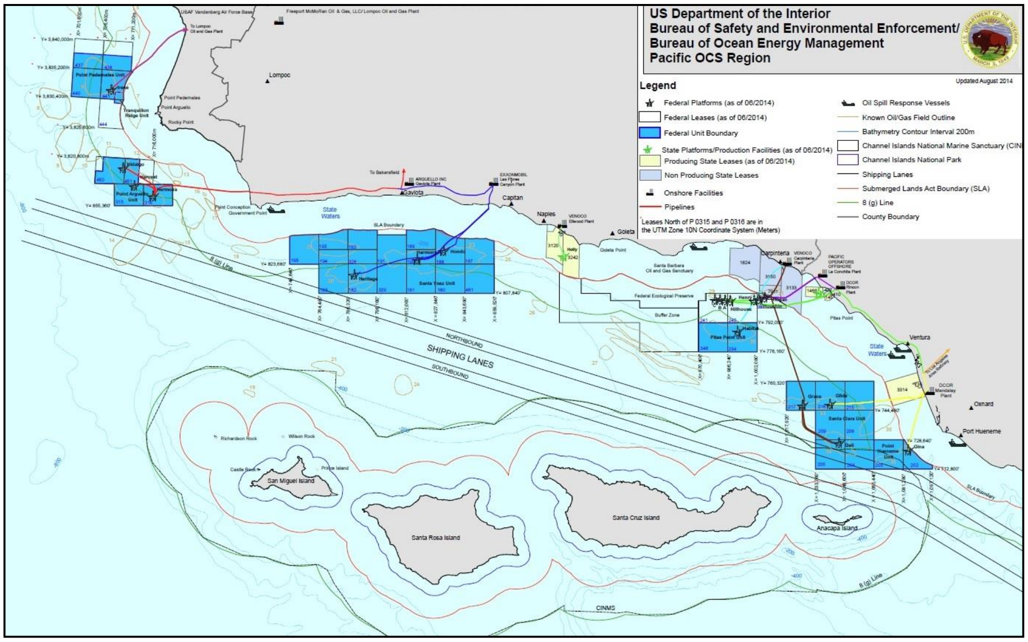


**Figure 61: Pacific OCS Region Well Map**

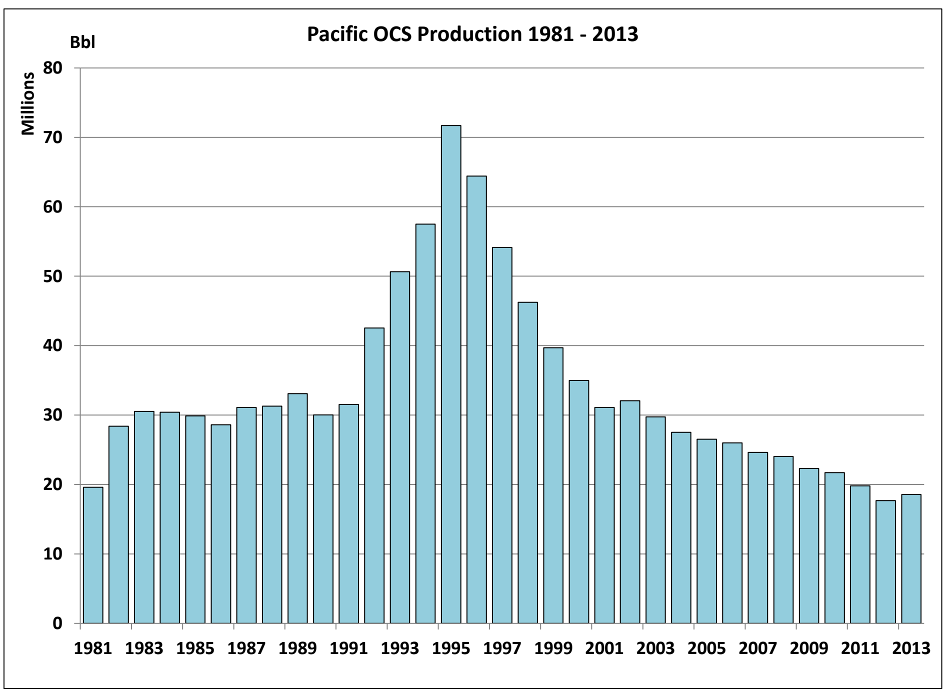


**Figure 62: Pacific OCS Region Production 1981- 2013[86]**

86 Data from U.S. Energy Information Administration (http://www.eia.gov/petroleum )

**Table 34: Pacific OCS Region Platform Data**[87]

| Platform | Producing Wells | Water Depth (ft.) | Annual Production (million bbl) |
|---|---|---|---|
| **Edith** | 15 | 161 | 124 |
| **Ellen** | 23 | 265 | 494 |
| **Eureka** | 30 | 700 | 893 |
| **Henry** | 20 | 173 | 135 |
| **Hogan** | 11 | 154 | 102 |
| **Houchin** | 16 | 163 | 136 |
| **A** | 36 | 188 | 263 |
| **B** | 31 | 190 | 321 |
| **C** | 25 | 192 | 188 |
| **Hillhouse** | 31 | 190 | 216 |
| **Harmony** | 26 | 1,198 | 3,413 |
| **Hondo** | 22 | 842 | 1,707 |
| **Gina** | 6 | 95 | 108 |
| **Heritage** | 25 | 1,075 | 2,322 |
| **Habitat** | 5 | 290 | 0 |
| **Harvest** | 12 | 675 | 600 |
| **Hermosa** | 9 | 603 | 524 |
| **Hidalgo** | 6 | 430 | 346 |
| **Irene** | 15 | 242 | 1,654 |
| **Hildago** | 4 | 430 | 88 |
| **Heritage** | 17 | 1,075 | 3,559 |
| **Gilda** | 23 | 205 | 343 |
| **Grace** | 1 | 318 | 37 |
| **Gail** | 21 | 739 | 984 |
| **Irene** | 1 | 242 | 0 |
| **Totals: 23** | **431** | | **18,558** |

## 4.1 Geographical Analysis of Pacific OCS Region WCD Volumes

### 4.1.1 Spatial and Volume Distributions

All of the WCD volumes specified in the Pacific OSRPs, as provided by BSEE on December 12, 2014, are in the Southern California Planning Area (Figure 63). As was the case for the geographical analysis of WCD volumes as specified in the OSRPs for the Gulf of Mexico, information presented is based on a representative number of wells presented in the OSRPs as of December 2014 and the data analyzed herein

[87] BSEE Pacific OCS Region (POCS) Production and Development Statistics. July 2014 (Data for December 2013)

should be considered a sample dataset of the Pacific-wide population, well short of the common definition of deep water, as 3,280 feet (1,000 m) or greater.[88] The cluster of wells identified as potential WCD scenarios are in production areas near Point Conception, and to the south in the Santa Barbara Channel and the Channel Islands area. Well sites examined in this region are relatively close to shore, ranging approximately from 4 to 13 miles off the California coast.

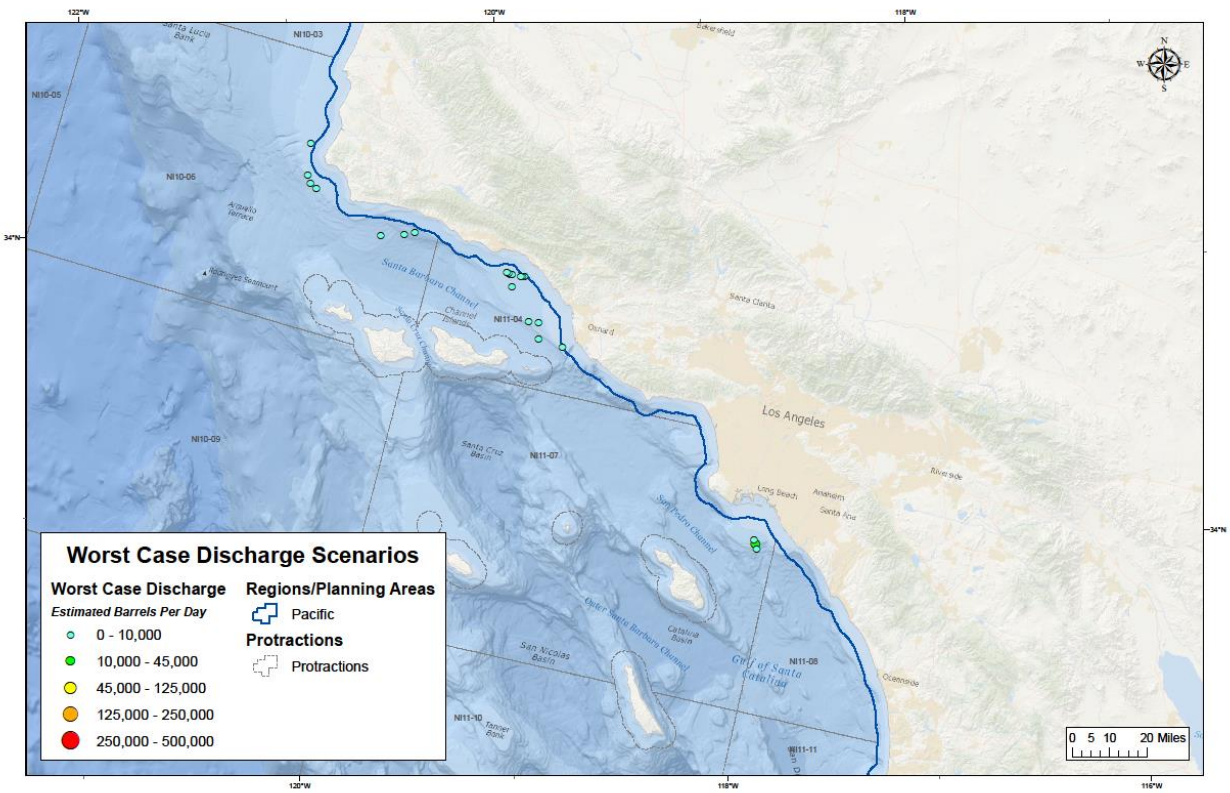


**Figure 63: Worst Case Discharge Flow Rates (bbl/day) Specified in the OSRP Locations in Pacific OCS Region**

Based on the data contained within the OSRPs as of December 2014, a majority of the WCD flow rates in the Pacific OCS Region are low (<12,000 bbl/day) as compared to those in the Gulf of Mexico and Arctic OCS Regions (Figure 64). Of the sites investigated, as provided by BSEE, the WCD flow rates range from 121 to 12,036 bbl/day, with an average of 3,262 bbl/day. The WCD flow rate investigated in this modeling study was 5,200 bbl/day.

The average flow rates for the Pacific OCS Region wells range from 100 bbl/day to 9,750 bbl/day *per platform*.[89] Information on individual well flow rates was not available for this study. Platforms often collect oil from multiple wells, and the flow rates for individual wells associated with a particular platform vary.

[88] Holand 2013.

[89] BSEE Pacific OCS Region (POCS) Production and Development Statistics. July 2014 (Data as of December 2013).


**Figure 64: Distances to Shore for WCD Volumes in the Pacific OCS Region and the Location of the Scenario Used in Modeling Highlighted**

## 4.2 OTHER GENERAL TRENDS

There have been no significant changes in the types of offshore drilling operations in the Pacific OCS Region that would increase the potential for blowouts.

Because of the relatively shallow water depths of wells in the Pacific OCS Region, water depth is not an important contributing factor to blowout potential in the region. Water depth and well temperature and pressure tend to be correlated, and this relationship is borne out in the Pacific OCS Region. The shallow-water wells in this region encounter pressures no greater than 3,000 psi and no hotter than 190°F- well short of the HTHP definition of >10,000 psi and/or >300°F.[90] The older shallower wells within the region are associated with particularly low pressures.

## 4.3 CONSEQUENCE ANALYSIS FOR PACIFIC OCS REGION

### 4.3.1 WCD Scenario Selection

Due to the small number of wells and platforms in the Pacific OCS Region and their general proximity to each other geographically, one oil WCD spill scenario, in the Southern California Santa Barbara Channel Planning Area (Table 35), was chosen for consequence analysis. This particular well site represents a large WCD volume release (relative to the Pacific OCS Region), and is situated geographically where a discharge has a high probability of contacting the Channel Islands National Marine Sanctuary and National Park Unit.

**Table 35: WCD Scenarios for the Pacific OCS Region**

| Scenario Number | Planning Area | Lease Block | Oil Name/°API[91] | WCD Flow Rate (bbl/day) | Flow Duration Relief Well Only (days) | Total WCD Release Volume (bbl) |
|---|---|---|---|---|---|---|
| **7** | Southern California Santa Barbara Channel | Santa Maria 6683 | California Light Crude 30.3 | 5,200 | 170 | 884,000 |

[90] Based on personal communication with BSEE Pacific Region.
[91] An alternative measure of density of oil; the higher the °API, the lighter the oil.

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### 4.3.2 Scenario 7 – Santa Maria 6683 (SM6683)

The Santa Maria 6683 WCD scenario in the Southern California Santa Barbara Channel Planning Area resulted in a total of 884,000 bbl of California Light Crude oil released over a course of 170 days at approximately 9 miles (8 nm) from shore and a depth of 1,075 ft. The extended flow duration of 170 days was largely due to the fact that there are no drilling rigs operating on the U.S. West Coast that are available to drill a relief well, should one be necessary to stop the flow of a blowout. The summary of the well information for this WCD scenario is provided in Table 36.

**Table 36: Well Information for Scenario 7 – Santa Maria 6683 (SM6683)**

| WCD Scenario: Lease Block Santa Maria 6683 (SM6683)<br>Southern California Santa Barbara Channel Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 5,200 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 170 days |
| **Total WCD Release Volume** | 884,000 bbl |
| **Simulation Duration (45 days following end of release)** | 215 days |
| **API Gravity ( Point Arguello Light)** | 30.3 |
| **Latitude, Longitude** | 34.33732$^{o}$N, 120.4209$^{o}$W |
| **Depth to Sea Floor** | 1,075 feet |
| **Distance to Shoreline** | 9.2 miles (8 nm) |

#### *SM6683 Oil Plume, Fate, and Transport Modeling Results*

This section provides the near-field plume behavior, oil fate, and far-field transport results for the oil spill model scenario in the Pacific OCS Region (Table 35). For guidance on general interpretation of the near-field plume and far-field stochastic modeling results refer to Section2.3.4.

The near-field oil plume simulation for this scenario found that 97% of the total oil mass would reach the surface within 7 hours of the release and the buoyant trapping depth was 508 feet (Table 37). Therefore, the far-field oil transport for this case was initiated from 1,073 ft. with a median droplet size of 1,811 microns.

**Table 37: Near-Field Oil Plume Behavior for Scenario 7 – Santa Maria 6683 (SM6683)**

| WCD Scenario: Lease Block Santa Maria 6683 (SM6683)<br>Southern California Santa Barbara Channel Planning Area | |
|---|---|
| Near-Field Oil Plume | |
| **Oil Release Depth** | 1,075 feet |
| **GOR** | 3,000 scf/stb |
| **Median Droplet Size** | 1,811 microns |
| **Buoyant Trapping Depth** | 508 feet |
| **Percentage of Oil Mass to Reach Surface** | 97% |
| **Time for Percentage of Oil Mass to Reach Surface** | 7 hrs. |

California Light Crude is a highly emulsifiable oil that is persistent on the sea surface. Because the oil emulsifies quickly, it does not dissolve or entrain easily. To demonstrate the typical behavior of California Light Crude, an instantaneous release of the oil was modeled and tracked over time. Figure 65 provides the results of this analysis and shows the persistence of the oil on the surface and the steady rate of evaporation present when modeling this oil.

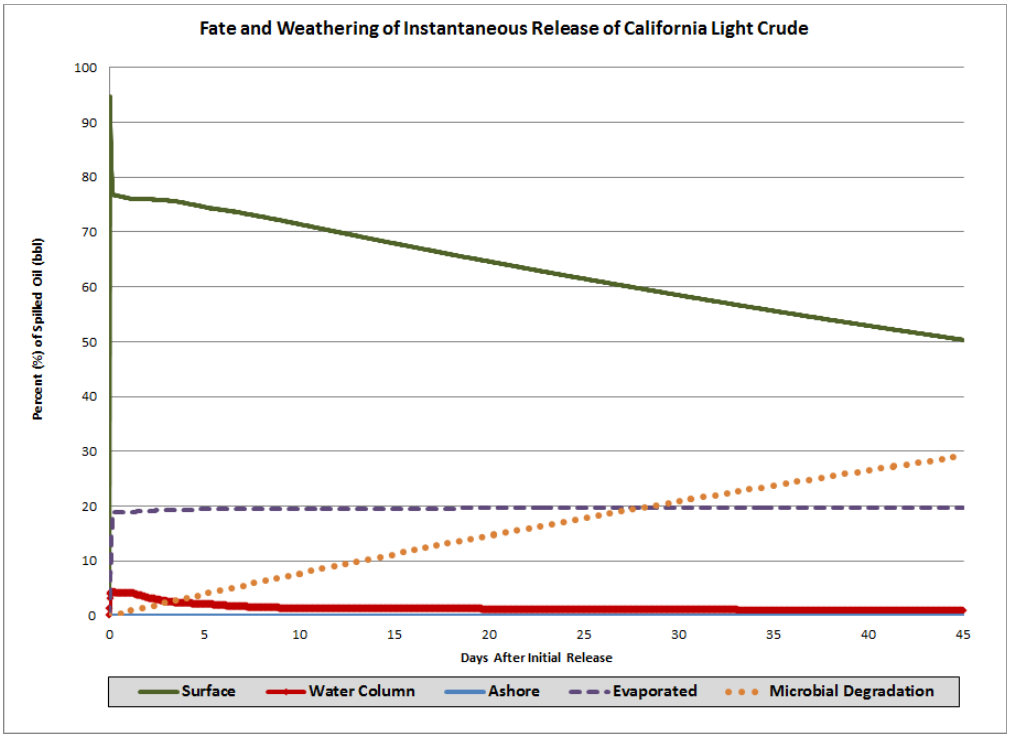


**Figure 65: Mass Balance Graph Showing the Typical Behavior of California Light Crude in the Environment**

Table 38 summarizes the stochastic modeling results of the far-field oil transport. Statistics are shown by each oiling threshold of concern representing potential impacts to socioeconomic and environmental resources (1 $g/m^2$) and implications to cleanup activities (8 $g/m^2$).

**Table 38: Far-Field Oil Transport Summary for Scenario 7 – Santa Maria 6683 (SM6683)**

| **WCD Scenario: Lease Block Santa Maria 6683 (SM6683)<br>Southern California Santa Barbara Channel Planning Area** | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 $g/m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 600 miles of spill site; Figure 68 |
| Minimum time for oil above the threshold (1 $g/m^2$) used to determine effects on socioeconomic resources to reach shore | 1.0 days |
| Shoreline length (miles) affected by oil above the threshold of 1 $g/m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 99% of simulations at >800 mi; ~60% at >1200 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | Greatest in immediate proximity of release with 1-10 % probability approximately 80 miles from release point; Figure 66 |
| Minimum time (days) to exceed the surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 10 miles of spill site; Figure 66 |
| Minimum time (days) surface oil greater than 8 $g/m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 3.5 days |
| Water surface area ($miles^2$) affected by oil above the surface oil threshold of 8 $g/m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 51% of simulations at >0.5 $mi^2$; 12% of simulations at >5 $mi^2$ |
| Average percentage of total oil that is transported out of modeled area | 4.9 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column. The modeling illustrates in gridded format the spatial extent of surface (Figure 66), water column (Figure 67), and shoreline (Figure 68) oiling probabilities for the spills using the thresholds outlined in Table 7 and Table 8.

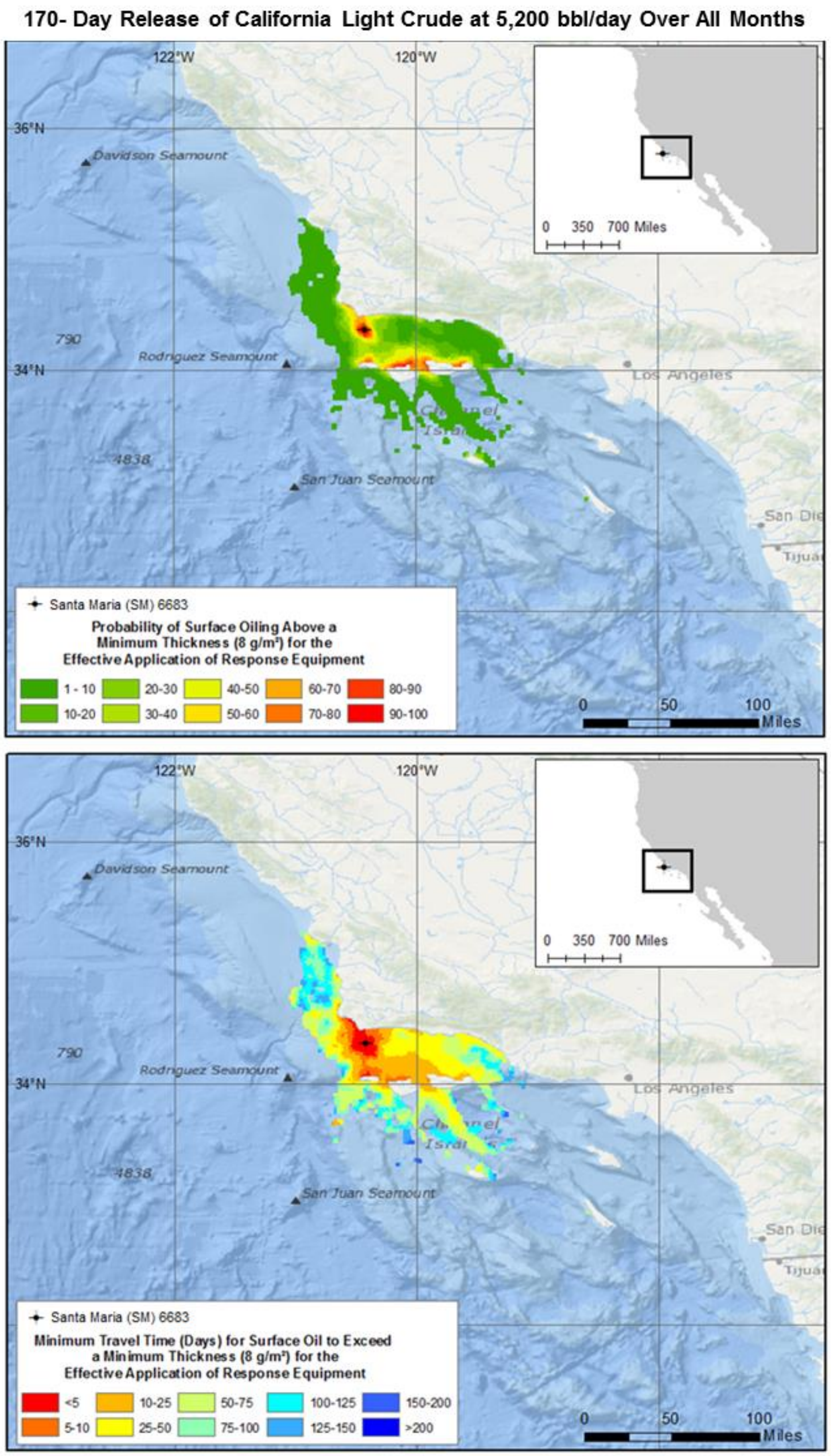


**Figure 66: Scenario 7, CA-SM6683 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 66 provides the model results showing potential implications for cleanup activity along the water surface. From this analysis, the greatest exceedance of surface oil >8 g/m$^2$ was in the immediate vicinity of the spill site (Table 38). The higher floating surface oil probabilities (80%-100%) for Santa Maria 6683 were offshore and along the California coast from Point Conception south to the Baja peninsula. The minimum time for oil of this threshold to reach shore was approximately 3.5 days and in the area of Point Conception (Table 38, Figure 66).

Because the oil simulated in this scenario emulsifies quickly, slowing its dispersion into the water column, the higher probabilities where total hydrocarbon concentrations in the water column would exceed 100 ppb were primarily adjacent to and east of the spill site, stretching from Point Conception to the eastern end of the Santa Barbara Channel area, including the waters surrounding the Channel Islands (Figure 67).

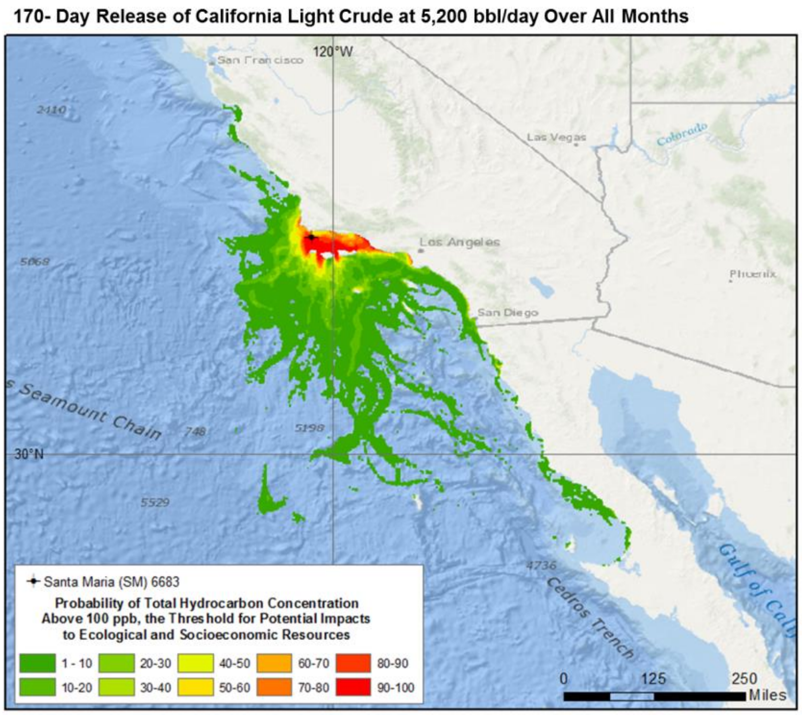


**Figure 67: Scenario 7, CA-SM6683 – Probability of Total Hydrocarbon Concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur)**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 1 day (Table 33). Within approximately 600 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. A majority of the simulations (99%) in the stochastic set had over 800 miles of shoreline oiled above the socioeconomic threshold, while 92% showed greater than 800 miles. Shoreline oiling above the socioeconomic threshold occurred from the southern California coast to the Baja region (Figure 68). The highest probability of shoreline oiling occurred from Point Conception to the Channel Islands and down the U.S. border. The socioeconomic and environmental shoreline resources in this region would have probable contact with oil if a spill of this magnitude were to occur.

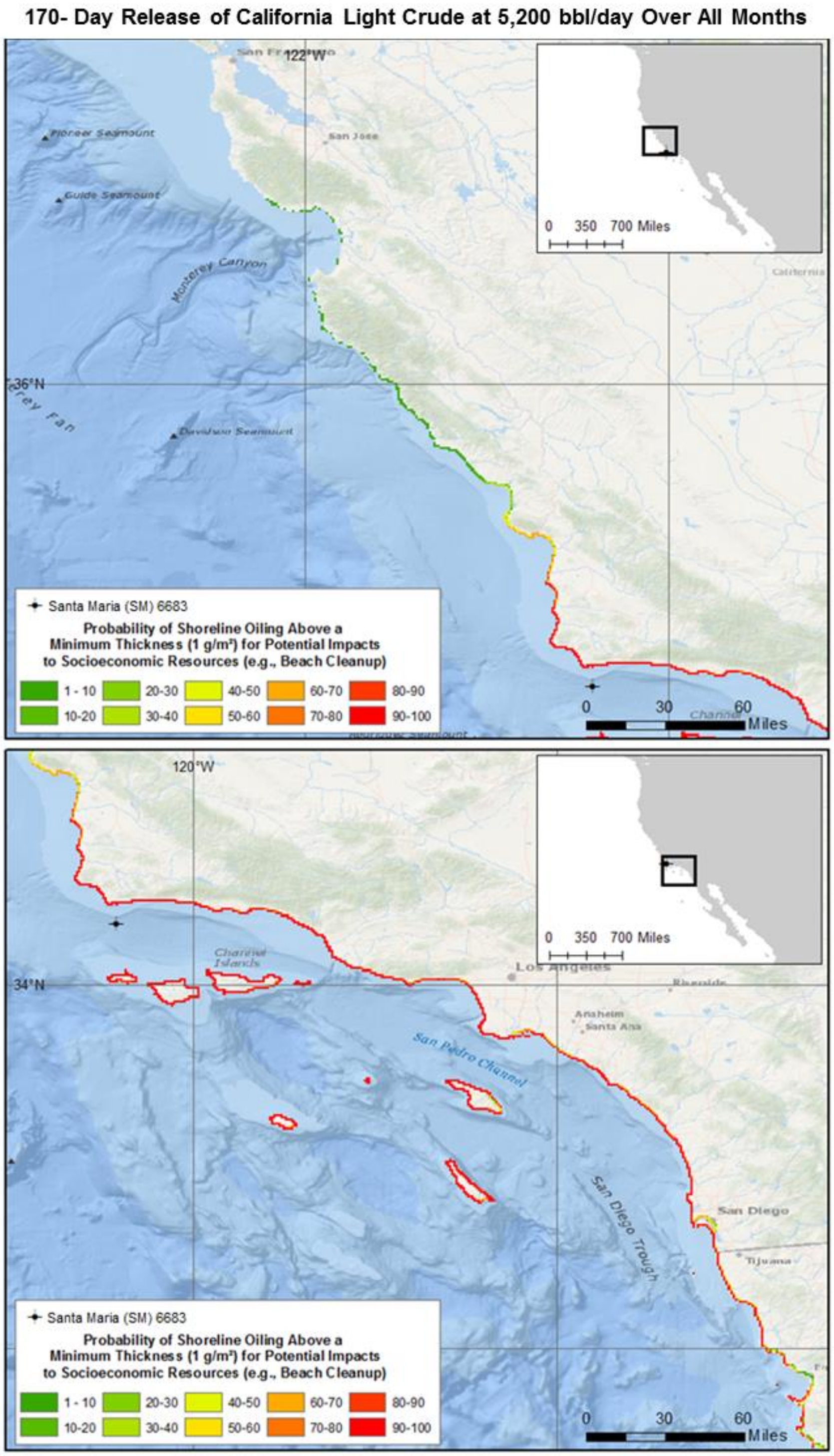


**Figure 68: Scenario 7, CA-SM6683 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along the Southern California Coast**

## 5.0 WCD PROFILE FOR THE ARCTIC OCS

The Chukchi Sea and Beaufort Sea Planning Areas are the only Planning Areas within the Arctic Circle and are collectively referred to as the Arctic OCS. The numbers of wells drilled in the Arctic OCS, grouped by planning area, are shown in Table 39.

**Table 39: Number of Wells in the Arctic OCS**[92]

| Alaska Region Planning Area | Number of Wells | | |
|---|---|---|---|
| | Exploration | Development | Total |
| **Beaufort Sea (Arctic OCS Region)** | 30 | 7 | **37** |
| **Chukchi Sea (Arctic OCS Region)** | 5 | 0 | **5** |
| **Total** | **35** | **7** | **42** |

Exploration and development activities in the Chukchi and Beaufort Seas as part of the BOEM 2012 – 2017 Program are shown in Figure 69. The black dots on the map are oil and natural gas wells that were drilled and became inactive during the 1980s and 1990s.

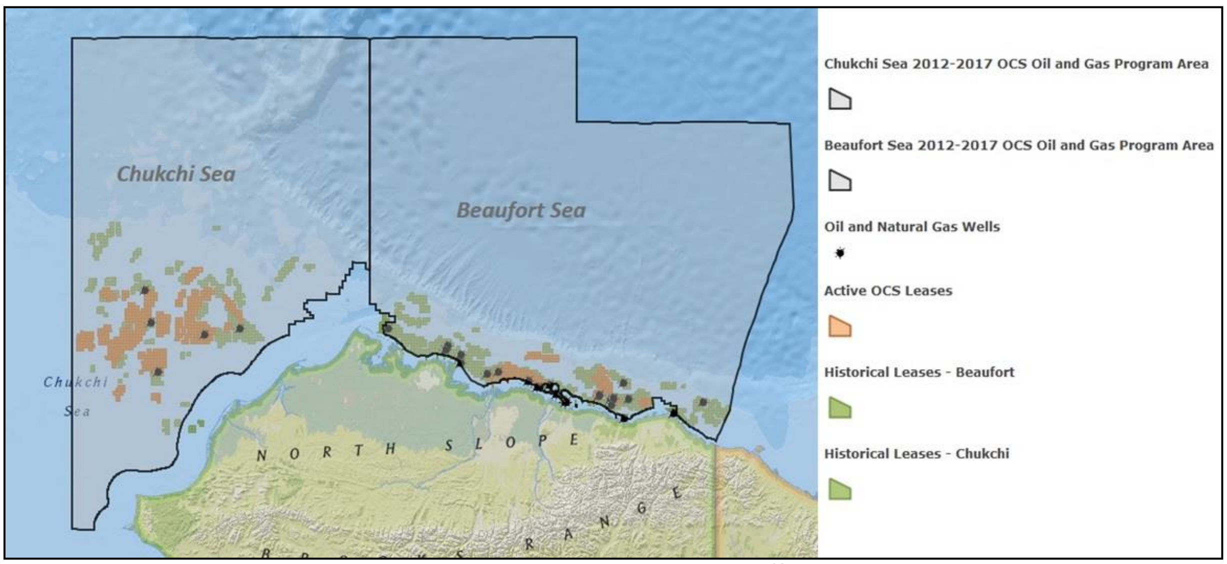


**Figure 69: Arctic OCS Historical and Active Exploration Well Map**[93]

## 5.1 GEOGRAPHICAL ANALYSIS OF ARCTIC OCS WCD VOLUMES

### 5.1.1 Spatial and Volume Distribution

The offshore exploration well drilling activities in the Beaufort Sea and Chukchi Sea thus far have occurred in waters less than 150 feet deep, however the potential exists in the future for drilling in deeper waters in the Arctic.

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[92] http://www.boem.gov/uploadedFiles/BOEM/About_BOEM/BOEM_Regions/Alaska_Region/Historical_Data/OCS%1020Wells%20Drilled%20by%20Planning%20Area%20-%20AK.pdf

[93] http://www.arcgis.com/home/webmap/viewer.html?webmap=ec25cf340e8b42bda6cb03c9aa512c8a.

All of the WCD volumes specified in the Arctic OSRPs, as provided by BSEE on July 8, 2015, are shown in Figure 70. As was the case for the geographical analysis of WCD volumes as specified in the OSRPs for the Gulf of Mexico and Pacific OCS Regions, information presented is based on a representative number of wells presented in the OSRPs as of July 2015 and the data analyzed herein should be considered a sample dataset of the Arctic-wide population. Well sites examined in this region are relatively close to shore ranging approximately from 1.5 to 69 miles off the Alaska coast, with the majority of the sites in 1.5 to 6 miles from shore.

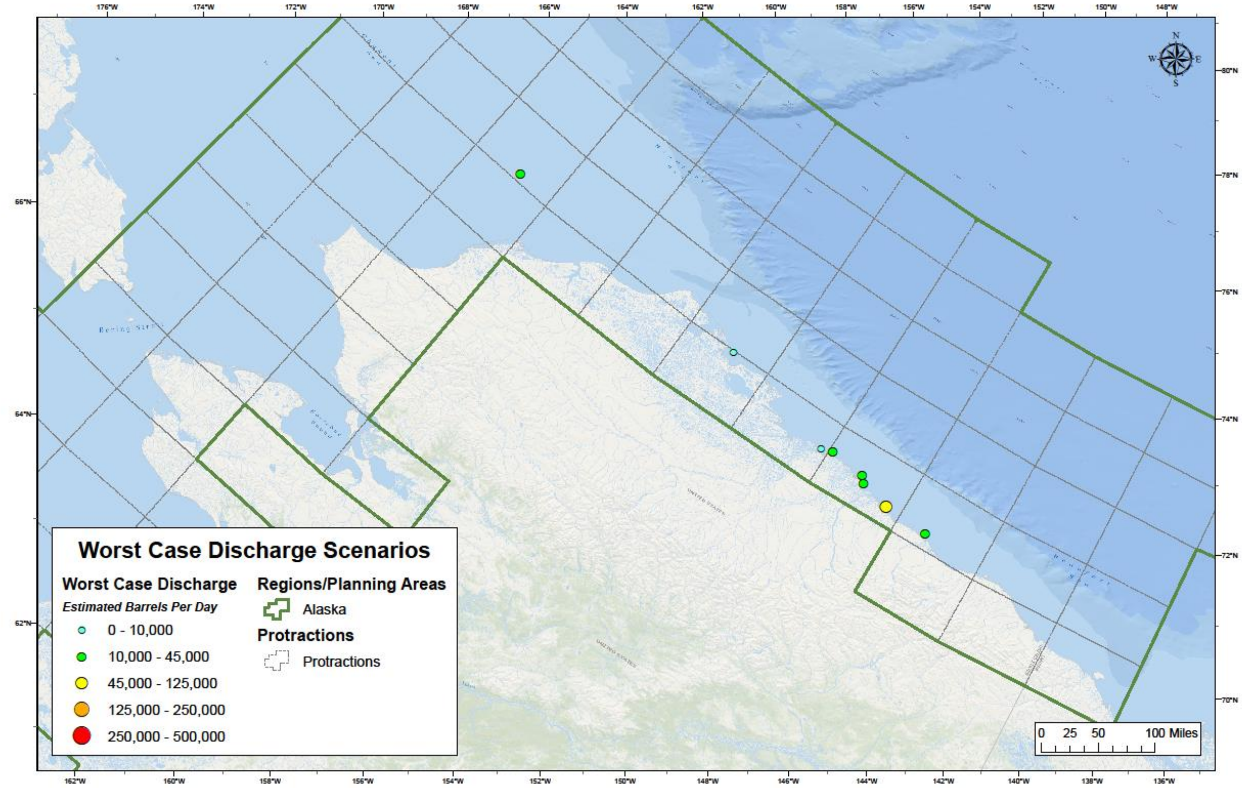


**Figure 70: Worst Case Discharge Flow Rate (bbl/day) Specified in the OSRP Locations in Arctic OCS**

Based on the data contained within the Arctic OSRPs as of July 2015, a majority of the WCD flow rates in the Arctic OCS are higher (>12,000 bbl/day) than those in the Pacific OCS Region but lower compared to those in the Gulf of Mexico OCS Region (Figure 71). Of the sites investigated, as provided by BSEE, the WCD flow rates range from 800 to 85,000 bbl/day, with an average of 20,502 bbl/day.

The average flow rates for the Arctic OCS wells range from 800 bbl/day to 85,000 bbl/day *per platform*. Platforms often collect oil from multiple wells, and the flow rates for individual wells associated with a particular platform vary.


**Figure 71: Distances to Shore for WCD Volume Scenarios in the Arctic OCS**

## 5.2 Other General Trends

Because the Arctic OCS is relatively unexplored and the geologic formations are not well understood, BOEM considers it to be a "frontier area."[94] In the Beaufort Sea, the onshore geology extends offshore and much of the knowledge gained from onshore exploration and production can be transferred to offshore drilling in the area. Well pressures in the Arctic OCS are less than 6,000 psi,[95] and subsurface well depths that are 7,000 to 8,000 feet in the Chukchi Sea and 10,200 feet in the Beaufort Sea - significantly less than subsurface depths found in the Gulf of Mexico that can exceed 30,000 feet. While

[94] BOEM 2012a.
[95] Williams 2012; Shell Oil Company 2013.

specific well temperature information was not available, it is known that high pressures generally correlate with high temperatures.[96] High temperature and pressure conditions, therefore, are not expected to be a significant factor in the WCDs profiles in the Arctic OCS Region.

The Arctic OCS has the least activity and fewest wells of the regions examined in this study, but faces unique issues due to the harsh Arctic environment. Extreme cold, winds, waves, sea ice (up to eight months of the year), and reduced daylight hours present challenges to safe drilling operations, and may be an impediment to rescue, source control, and oil spill response operations. The remoteness of Arctic drilling areas is of particular concern for managing the consequences of a significant spill, as response resources may have to travel great distances by air and sea to reach the site of an incident (Figure 72 and Figure 73). Weather conditions may interfere with response operations in the Arctic as much as 50% of the time.[97]

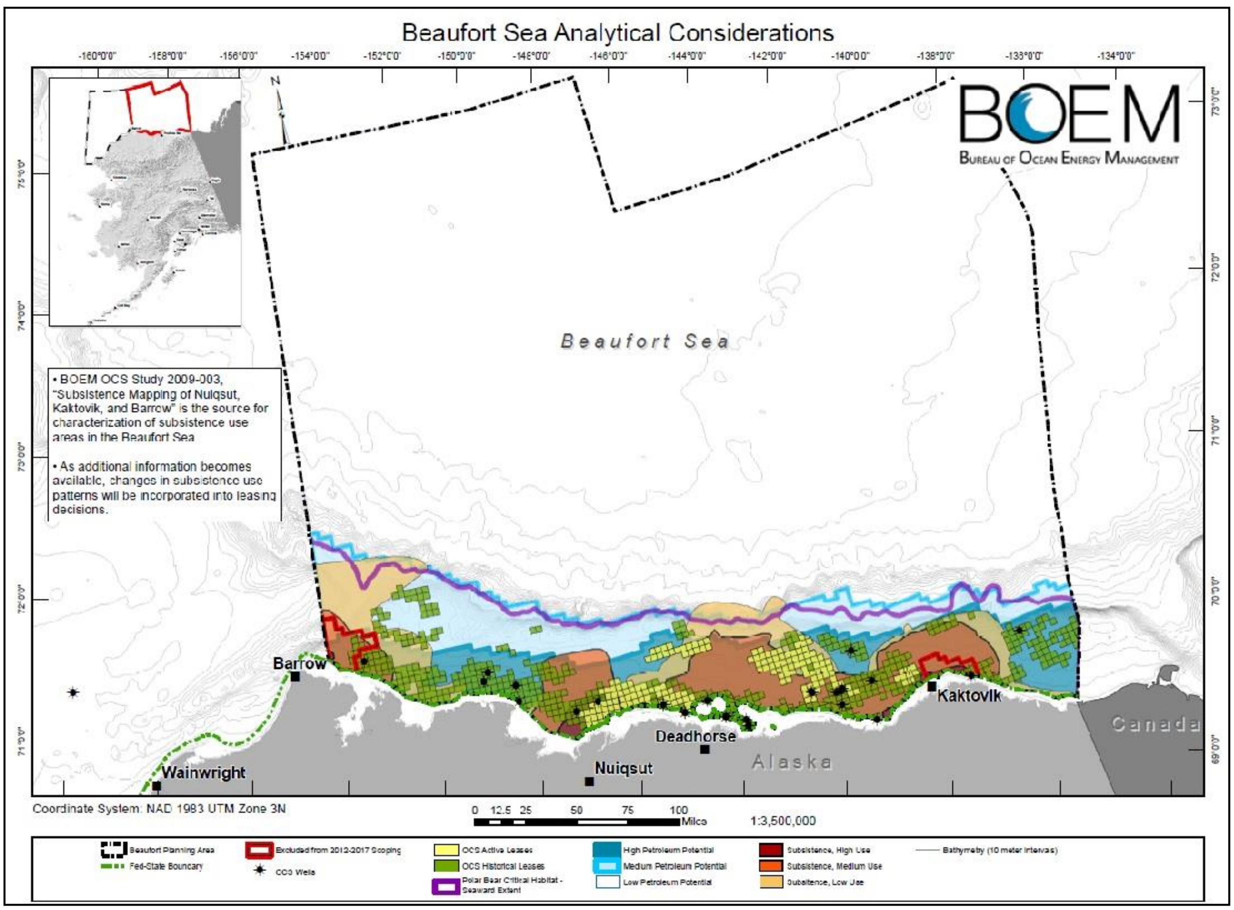


**Figure 72: Beaufort Sea OCS Planning Area Analytical Considerations[98]**

[96] Holand 2013.
[97] Nuka Research and Planning 2014.
[98] BOEM 5-Year Program Area 2012. (http://www.boem.gov/five-year-program-2017-2022/)

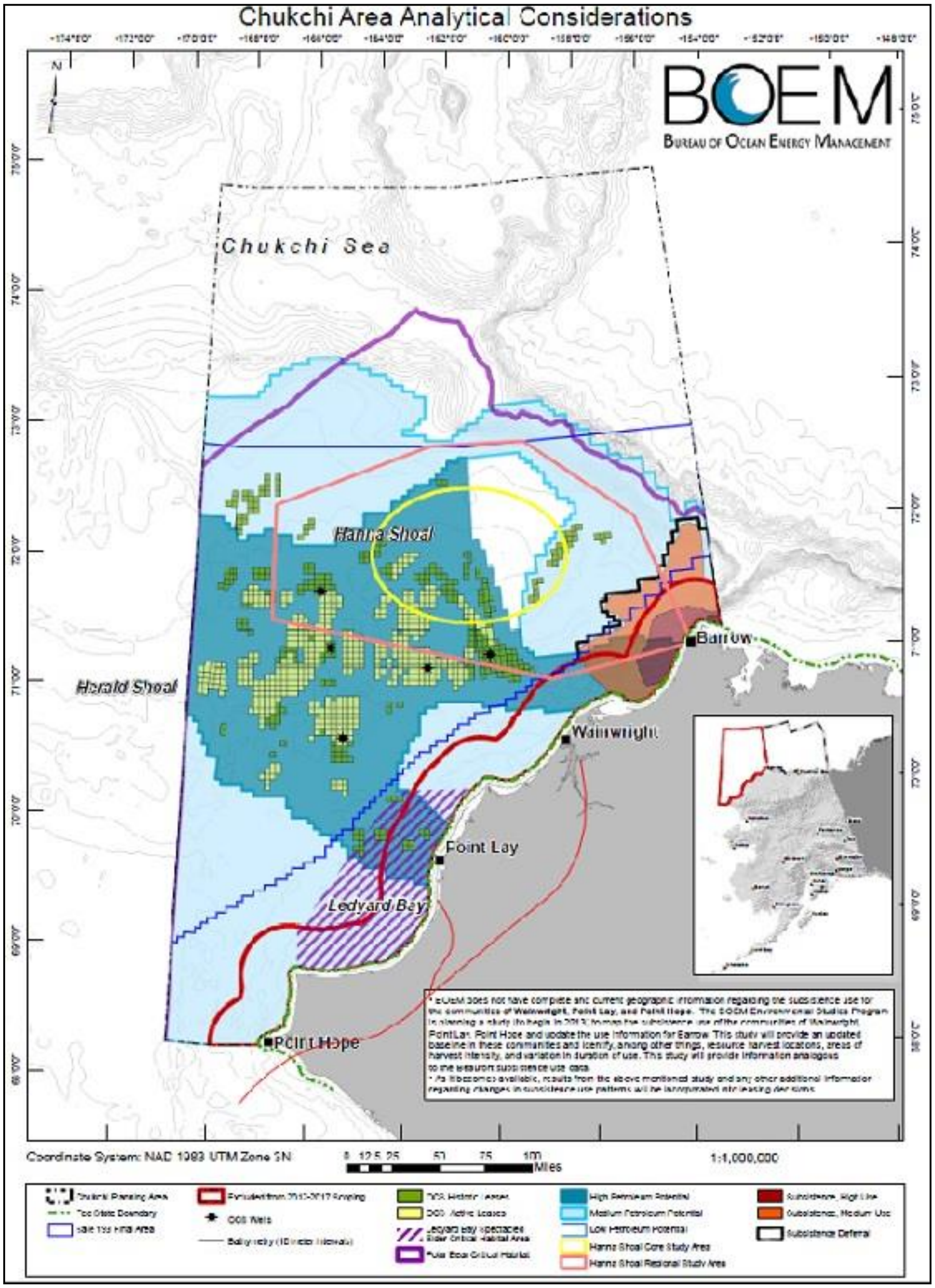


**Figure 73: Chukchi Sea OCS Planning Area Analytical Considerations**[99]

[99] BOEM 5-Year Program Area 2012. (http://www.boem.gov/five-year-program-2017-2022/)

## 5.3 CONSEQUENCE ANALYSIS FOR ARCTIC OCS

### 5.3.1 WCD Scenario Selections

The consequences of a WCD were investigated by modeling a representative scenario for each Planning Area in the Arctic OCS to determine the potential for spilled oil to come into contact with resources in the region (Table 40). For the Chukchi Sea, an offshore site was chosen 69 miles (60 nm) from shore and in 190 feet of water depth within the Posey 6912 Lease Block. For the Beaufort Sea, a nearshore site was chosen approximately 4 miles from the mainland and in 160 feet of water in the Flaxman Island 6610 Lease Block. The WCD flow rates modeled in this study were 25,000 bbl/day for the Posey 6912 site and 16,000 bbl/day for Flaxman Island 6610 location (Table 11).

Two oil types were used: 1) 2002 Alaskan North Slope Crude in the Chukchi Sea, and 2) 1999 Alaskan Prudhoe Bay Crude in the Beaufort Sea. Both oil types are persistent on the sea surface because of the relatively low concentration of lighter components that evaporate quickly and the ease to which these oils emulsify. In addition, these oils do not entrain or disperse easily.

The spill events were modeled during the operating season, an industry definition for the partial-to open-ice season whereby drilling operations can commence (typically defined as June-October in the Beaufort and Chukchi Seas), and oil was assumed to spill 28 to 30 days following the initial release. These oil releases were within the ice-free season; however, the fate of the oil was then tracked for 45 days after the end of the release. Thus, the spill trajectories beginning in mid to late September would overlap with the beginning of the ice season. Appendix C provides a description of how the interaction of oil and ice was modeled for this project.

**Table 40: WCD Scenarios for the Arctic OCS**

| Scenario Number | Planning Area | Lease Block | Oil Name/°API[100] | WCD Flow Rate (bbl/day) | Flow Duration Relief Well Only (days) | Total WCD Release Volume (bbl) |
|---|---|---|---|---|---|---|
| **8** | Chukchi Sea | Posey 6912 (P6912) | Alaskan North Slope Crude 30.9 | 25,000 | 28 | 700,000 |
| **9** | Beaufort Sea | Flaxman Island 6610 (FI6610) | Alaskan Prudhoe Bay Crude (Low Volatile) 24.8 | 16,000 | 30 | 480,000 |

[100] An alternative measure of density of oil; the higher the °API, the lighter the oil.

### 5.3.2 Scenario 8 – Posey 6912 (P6912)

Arctic Posey 6912 (P6912) is an offshore (69 miles [60 nm] from shore) and shallow water (190 ft) well in the Chukchi Sea Planning Area.

**Table 41: Well Information for Scenario 8 – Arctic Posey 6912 (P6912)**

| WCD Scenario: Lease Block Posey 6912 (P6912)<br>Chukchi Sea Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 25,000 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 28 days |
| **Total WCD Release Volume** | 700,000 bbl |
| **Simulation Duration (45 days following end of release)** | 73 days |
| **API Gravity (Alaskan North Slope Crude)** | 30.9 |
| **Latitude, Longitude** | 71.1024$^{0}$N, 163.281852$^{0}$W |
| **Depth to Sea Floor** | 190 feet |
| **Distance to Shoreline** | 69 miles (60 nm) |

#### *P6912 Oil Plume, Fate, and Transport Modeling Results*

This section provides the near-field plume behavior, oil fate, and far-field transport results for Scenario 8. For guidance on general interpretation of the near-field plume and far-field stochastic modeling results refer to Section2.3.4.

The near-field oil plume simulation for this scenario found that 100% of the total oil mass would reach the surface within <1 hour of the release and the buoyant trapping depth was 0 feet (Table 42). Therefore, the far-field oil transport for this case was initiated from the water surface with a median droplet size of 1,817 microns.

**Table 42: Near-Field Oil Plume Behavior for Scenario 8 – Arctic Posey 6912 (P6912)**

| WCD Scenario: Lease Block Posey 6912(P6912)<br>Chukchi Sea Planning Area | |
|---|---|
| **Near-Field Oil Plume** | |
| **Oil Release Depth** | 190 feet |
| **GOR** | 800 scf/stb |
| **Median Droplet Size** | 1,817 microns |
| **Buoyant Trapping Depth** | 0 feet |
| **Percentage of Oil Mass to Reach Surface** | 100% |
| **Time for Percentage of Oil Mass to Reach Surface** | <1 hrs. |

To demonstrate the typical behavior of Alaskan North Slope Crude, an instantaneous release of the oil was modeled and tracked over time. Figure 74 provides the results of this analysis and shows that approximately 42% of the oil released will evaporate, up to 25% will remain in the water column and decay from biodegradation and other processes, and the remaining 35% will remain either on the surface or will be stranded on a shoreline. In the deterministic model run that was used for the oil weathering, the oil remaining on the water's surface stayed primarily offshore with very little to no standing on any shorelines.

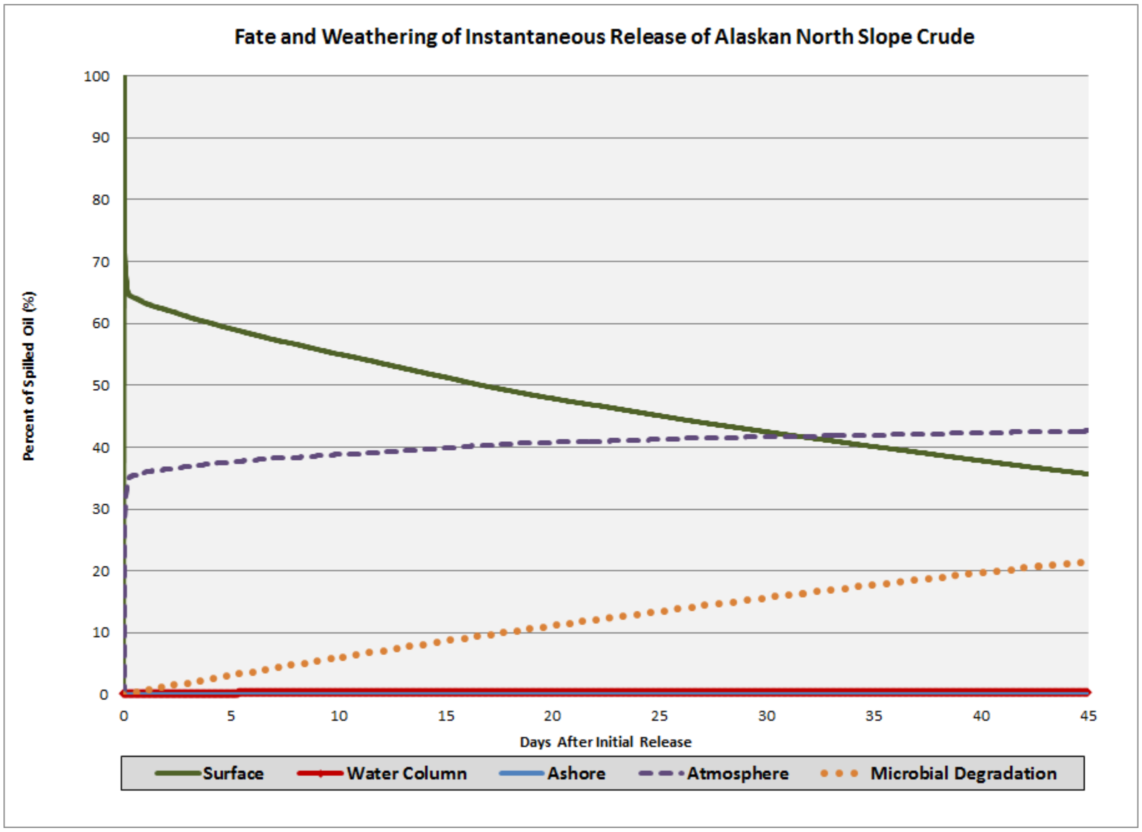


**Figure 74: Mass Balance Graph Showing the Typical Behavior of Alaskan North Slope Crude in the Environment**

Table 43 summarizes the stochastic modeling results of the far-field oil transport. Statistics are shown by each oiling threshold of concern representing potential impacts to socioeconomic and environmental resources (1 g/m2) and implications to cleanup activities (8 $g/m^2$).

**Table 43: Far-Field Oil Transport Summary for Scenario 8 – Arctic Posey 6912 (P6912)**

| **WCD Scenario: Lease Block Posey 6912 (P6912)**<br>**Chukchi Sea Planning Area** | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 $g/m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 600 miles of spill site; Figure 77 |
| Minimum time for oil above the threshold (1 $g/m^2$) used to determine effects on socioeconomic resources to reach shore | 4.0 days |
| Shoreline length (miles) affected by oil above the threshold of 1 $g/m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 90% of simulations at >50 mi; ~27% at >500 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | Greatest in immediate proximity of release with 1-10 % probability approximately 450 miles from release point; Figure 75 |
| Minimum time (days) to exceed the surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 55 miles of spill site; Figure 75 |
| Minimum time (days) surface oil greater than 8 $g/m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 7 days |
| Water surface area ($miles^2$) affected by oil above the surface oil threshold of 8 $g/m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 83% of simulations at >50 $mi^2$; 38% of simulations at >200 $mi^2$ |
| Average percentage of total oil that is transported out of modeled area | 1.97 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column. The modeling results illustrate in gridded format the spatial extent of surface (Figure 75), water column (Figure 76) and shoreline (Figure 77) oiling probabilities and minimum travel times for the spills using the thresholds outlined in Table 7 and Table 8.

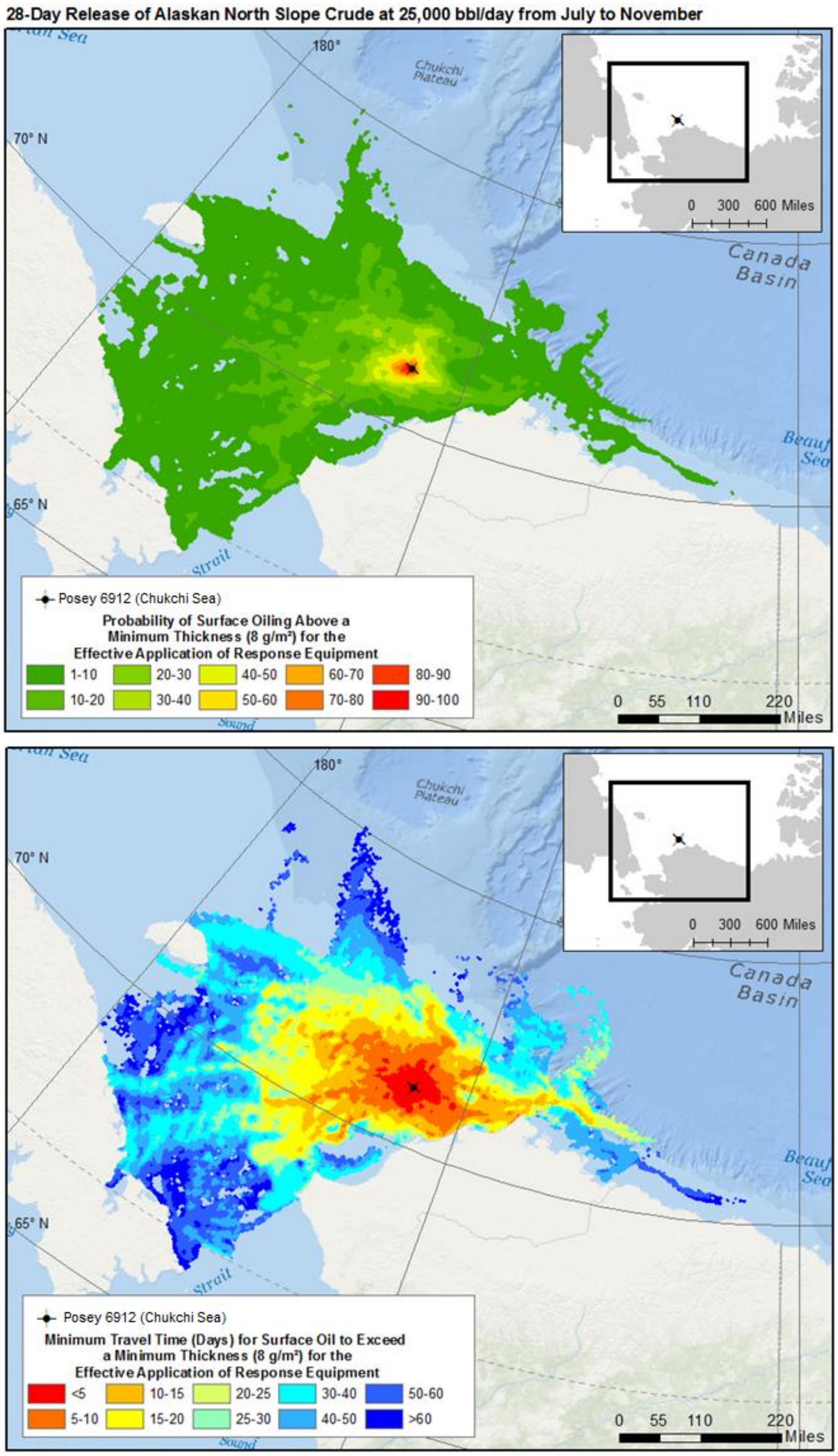


**Figure 75: Scenario 8, ArcticP6912 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 75 provides the model results showing potential implications for cleanup activity along the water surface. From this analysis, the greatest exceedance of surface oil >8 g/m$^2$ was in the immediate vicinity of the spill site (Table 43). The higher floating surface oil probabilities (80-100%) for Posey 6912 are centrally located around the spill site on the Chukchi shelf. The minimum time for oil of this threshold to reach shore was approximately 7 days along the coast between Wainwright and Point Lay (Table 43, Figure 75). Similar to the floating surface oil, the higher probabilities where total hydrocarbon concentrations in the water column would exceed 100 ppb was also relatively close to the spill site (Figure 76).

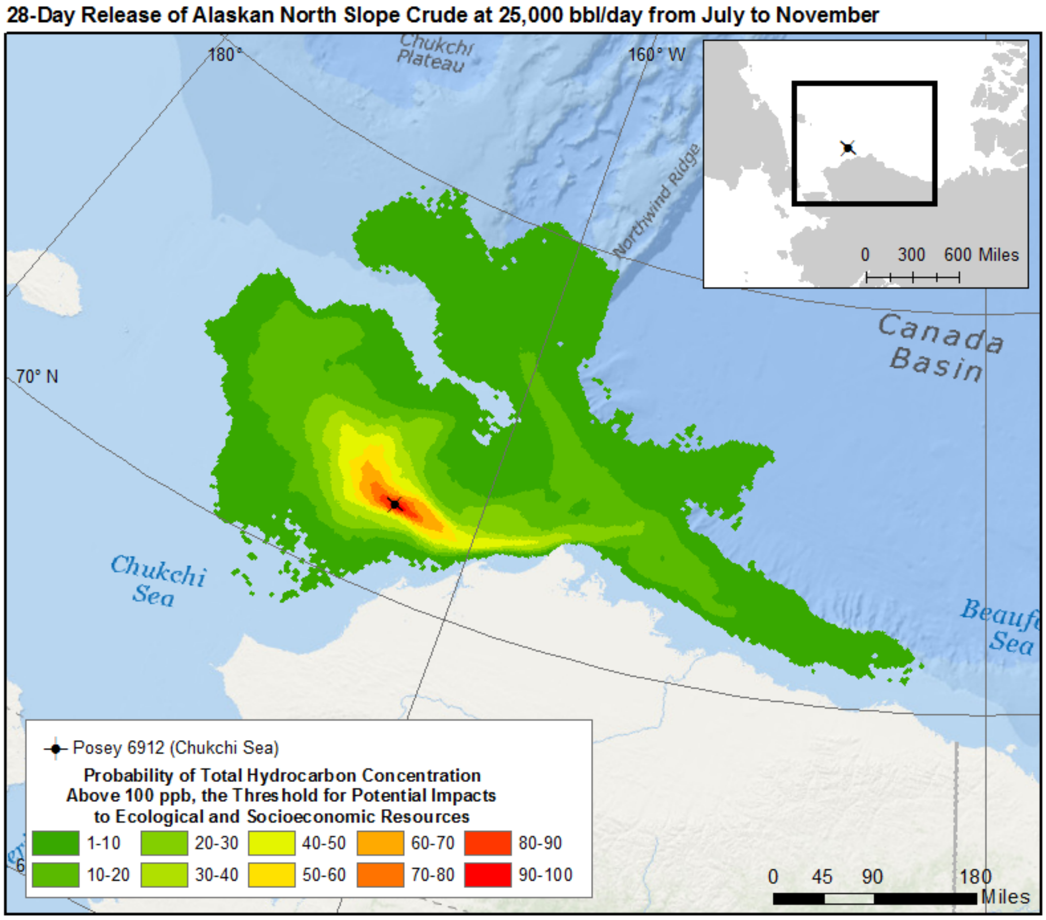


**Figure 76: Scenario 8, Arctic-P6912 – Probability of Total Hydrocarbon Concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur)**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 4 days (Table 43). Within approximately 600 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. A large number of the simulations (90%) in the stochastic set had over 50 miles of shoreline oiled above the socioeconomic threshold, while 27% showed greater than 500 miles. Shoreline oiling above the socioeconomic threshold occurred along the northern Alaska coastline (Figure 77). The highest probability of oiling occurred near Point Barrow.

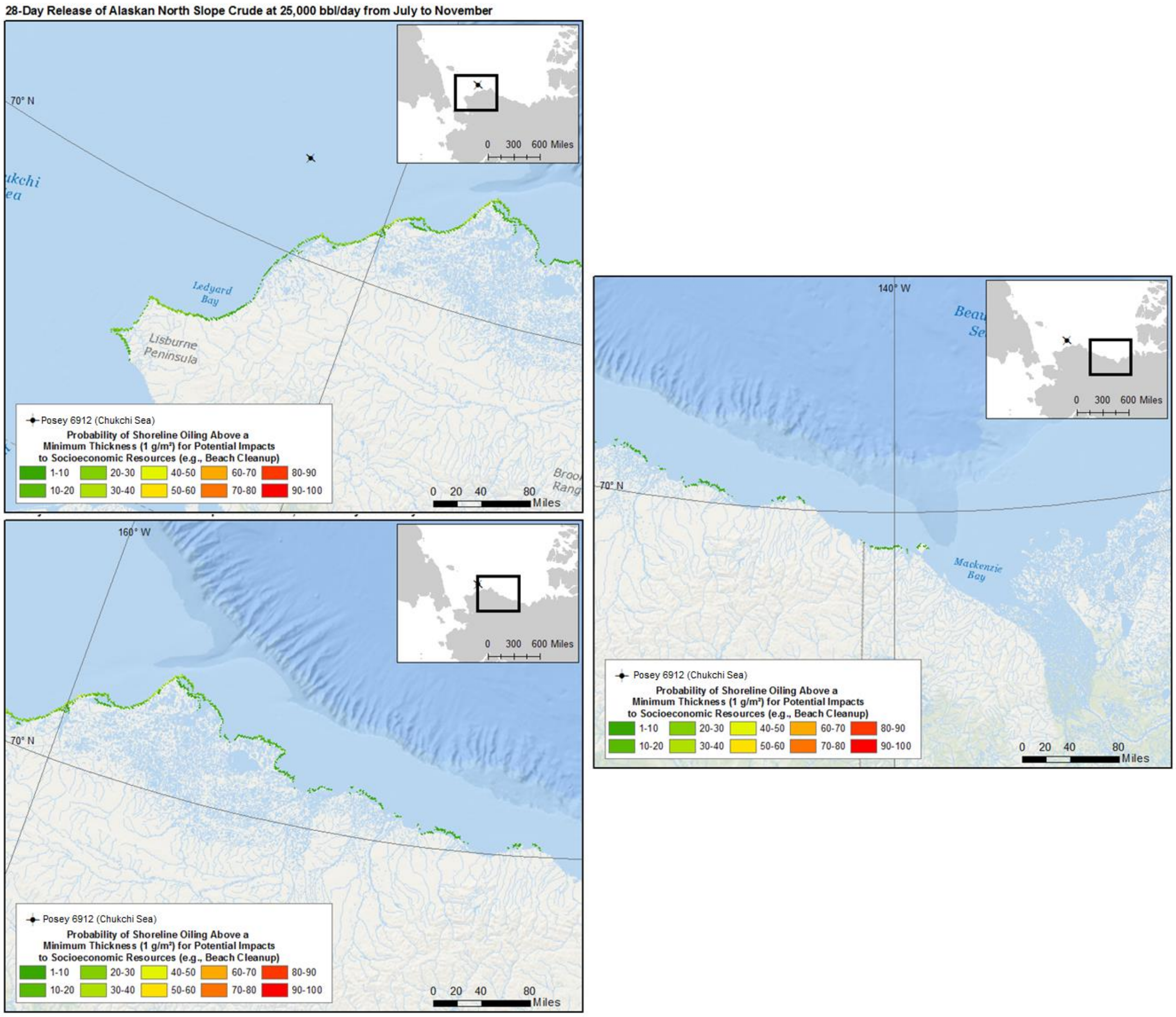


**Figure 77: Scenario 8, Arctic-P6912 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m² (3.94 x $10^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along U.S. and Canada Coastlines**

### 5.3.3 Scenario 9 – Flaxman Island 6610 (FI6610)

Flaxman Island 6610 (FI6610) is a nearshore (1.5-4.5 miles [1.3-3.9 nm] from shore) and shallow-water (160 ft) well in the Beaufort Sea Planning Area

**Table 44: Well Information for Scenario 9 – Arctic Flaxman Island 6610(FI6610)**

| WCD Scenario: Lease Block Flaxman Island 6610(FI6610)<br>Beaufort Sea Planning Area | |
|---|---|
| **Well Information** | |
| **WCD Daily Flow Rate** | 16,000 bbl/day |
| **Flow Duration Based on Relief Well Completion Time** | 30 days |
| **Total WCD Release Volume** | 480,000 bbl |
| **Simulation Duration (45 days following end of release)** | 75 days |
| **API Gravity (Prudhoe Bay Crude)** | 24.8 |
| **Latitude, Longitude** | 70.227$^{0}$N, 146.0186$^{0}$W |
| **Depth to Sea Floor** | 160 feet |
| **Distance to Shoreline** | 4.5 miles (3.9 nm) to mainland, 1.5 miles (1.3 nm) to coastal barrier islands |

#### *FI6610 Oil Plume, Fate, and Transport Modeling Results*

The near-field oil plume simulation for this scenario found that 100% of the total oil mass would reach the surface within <1 hour of the release and the buoyant trapping depth was 0 feet (Table 45). Therefore, the far-field oil transport for this case was initiated from the water surface with a median droplet size of 1,817 microns.

**Table 45: Near-Field Oil Plume Behavior for Scenario 9 – Arctic Flaxman Island 6610 (FI6610)**

| WCD Scenario: Lease Block Flaxman Island 6610 (FI6610)<br>Beaufort Sea Planning Area | |
|---|---|
| **Near-Field Oil Plume** | |
| **Oil Release Depth** | 160 feet |
| **GOR** | 900 scf/stb |
| **Median Droplet Size** | 1,192 microns |
| **Buoyant Trapping Depth** | 0 feet |
| **Percentage of Oil Mass to Reach Surface** | 100% |
| **Time for Percentage of Oil Mass to Reach Surface** | <1 hrs. |

To demonstrate the typical behavior of Alaskan Prudhoe Bay Crude, an instantaneous release of the oil was modeled and tracked over time. Figure 78 provides the results of this analysis and shows the persistence of the oil on the surface and the steady rate of evaporation present when modeling this oil.

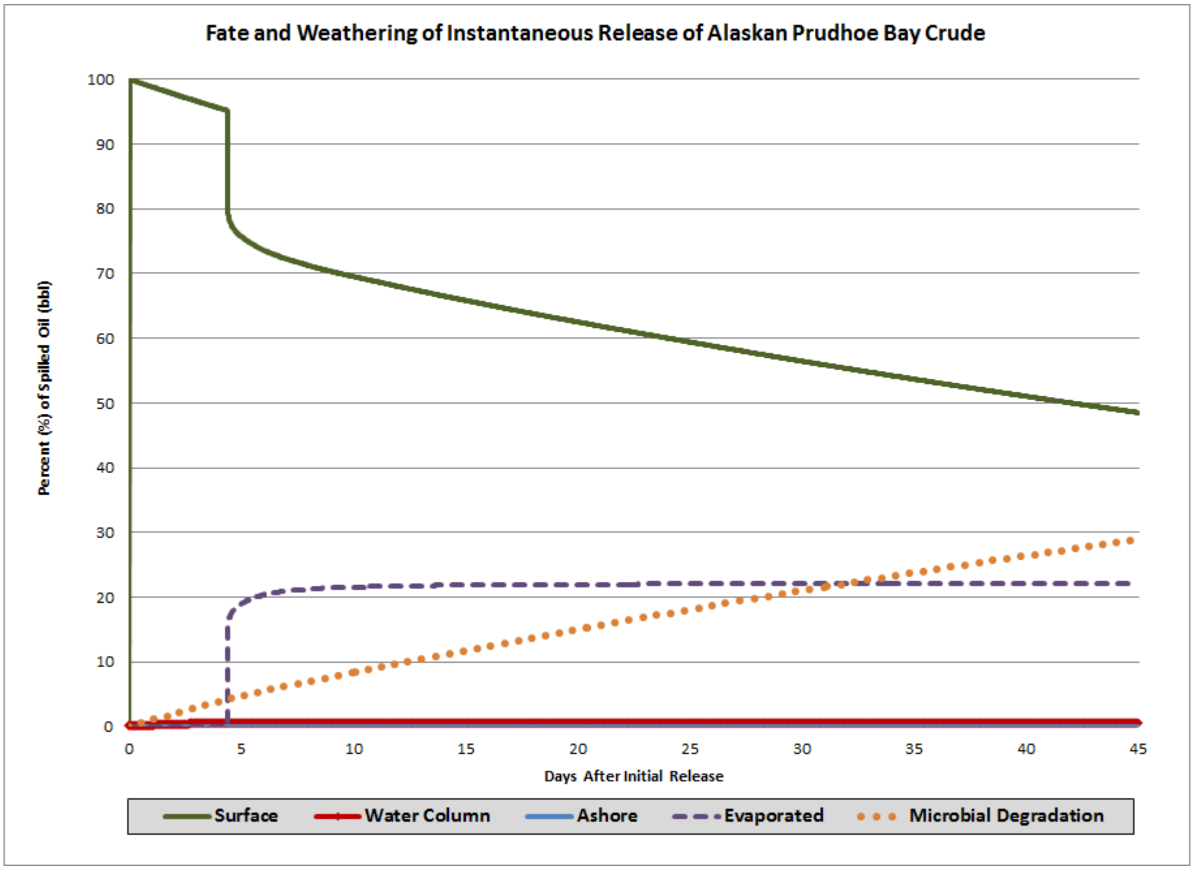


**Figure 78: Mass Balance Graph Showing the Typical Behavior of Alaskan – Prudhoe Bay Crude in the Environment**

Table 46 summarizes the stochastic modeling results of the far-field oil transport. Statistics are shown by each oiling threshold of concern representing potential impacts to socioeconomic and environmental resources (1 g/m2) and implications to cleanup activities (8 g/$m^2$).

**Table 46: Far-Field Oil Transport Summary for Scenario 9 – Arctic Flaxman Island 6610 (FI6610)**

| **WCD Scenario: Lease Block Flaxman Island 6610 (FI6610)**<br>**Beaufort Sea Planning Area** | |
|---|---|
| **Far-Field Oil Transport** | |
| ***Modeling Results Showing Potential to Create Socioeconomic and Environmental Risk*** | |
| Probability of exceedance above shoreline oil threshold of 1 $g/m^2$ used to determine effects on socioeconomic resources | 90-100 % within approximately 50 miles of spill site; Figure 81 |
| Minimum time for oil above the threshold (1 $g/m^2$) used to determine effects on socioeconomic resources to reach shore | 1.0 day |
| Shoreline length (miles) affected by oil above the threshold of 1 $g/m^2$ (used to determine effects on socioeconomic resources) at any instant in time | 99% of simulations at >200 mi; ~20% at >600 mi |
| ***Modeling Results Showing Potential Implications for Cleanup Activity*** | |
| Probability of exceedance above surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | Greatest in immediate proximity of release with 1-10 % probability approximately 250 miles from release point; Figure 79 |
| Minimum time (days) to exceed the surface oil threshold of 8 $g/m^2$ (minimum thickness for which response equipment can be applied) | <10 days within approximately 60 miles of spill site; Figure 79 |
| Minimum time (days) surface oil greater than 8 $g/m^2$ (minimum thickness for which response equipment can be applied) reaches shore | 1.0 day |
| Water surface area (miles$^2$) affected by oil above the surface oil threshold of 8 $g/m^2$ (the minimum thickness for which response equipment can be applied) at any instant in time | 93% of simulations at >100 mi$^2$; 36% of simulations at >500 mi$^2$ |
| Average percentage of total oil that is transported out of modeled area | 1.97 % |

The following set of figures provides the stochastic model results showing potential implications for cleanup activity along the water surface and the potential to create socioeconomic and environmental consequences to the shoreline and water column.  The modeling results illustrate in gridded format the spatial extent of surface (Figure 79), water column (Figure 80) and shoreline (Figure 81) oiling probabilities and minimum travel times for the spills using the thresholds outlined in Table 7 and Table 8.

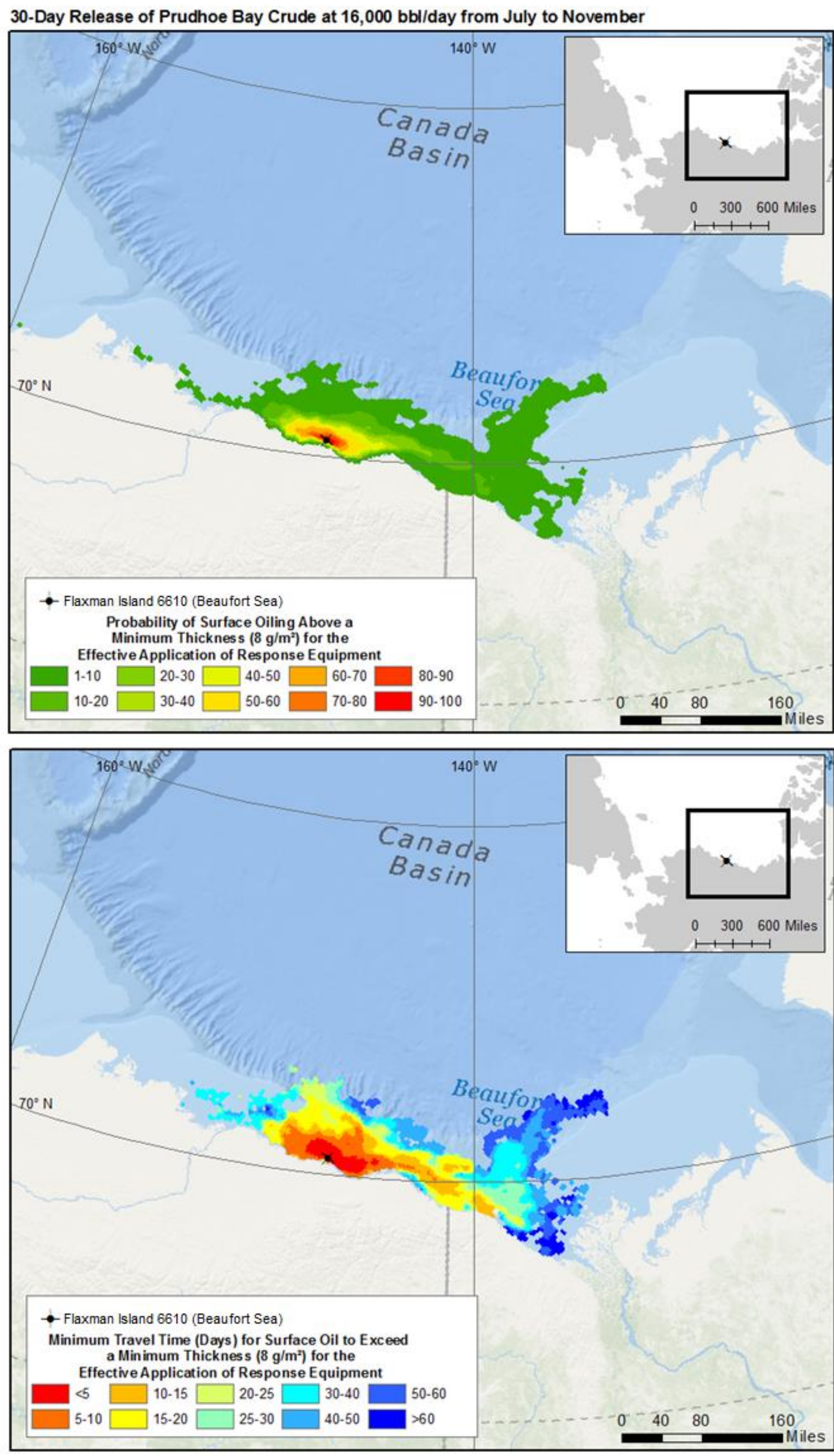


**Figure 79: Scenario 9, Arctic FI6610 – Water Surface Oiling Probabilities (Top) and Minimum Travel Times (Bottom) for Floating Oil ≥8.0 g/m$^2$ (0.0003 in, the Minimum Thickness for the Effective Application of Response Equipment)**

Figure 79 provides the model results showing potential implications for cleanup activity along the water surface. From this analysis, the greatest exceedance of surface oil >8 g/m$^2$ was in the immediate vicinity of the spill site (Table 46). The higher floating surface oil probabilities (80-100%) for this scenario were nearshore on the Beaufort shelf and stretch from the US-Canadian border and up the North Slope of the Alaska coast. The minimum time for oil of this threshold to reach shore was approximately 1 day off the coast of Deadhorse (Table 46, Figure 79).

The higher probabilities where total hydrocarbon concentrations in the water column would exceed 100 ppb stretched from the spill site to the northwest along the Beaufort shelf (Figure 80). Note that the pattern of the subsurface oiling is different from that of the surface oiling (Figure 79) in that it the majority of the subsurface oil travels to the northwest while the surface oil travels more towards the east and northeast of the spill site. This is caused by the prevailing direction of the currents and winds with the subsurface oil being influenced more by the currents, and the surface oil being influenced more by the winds.

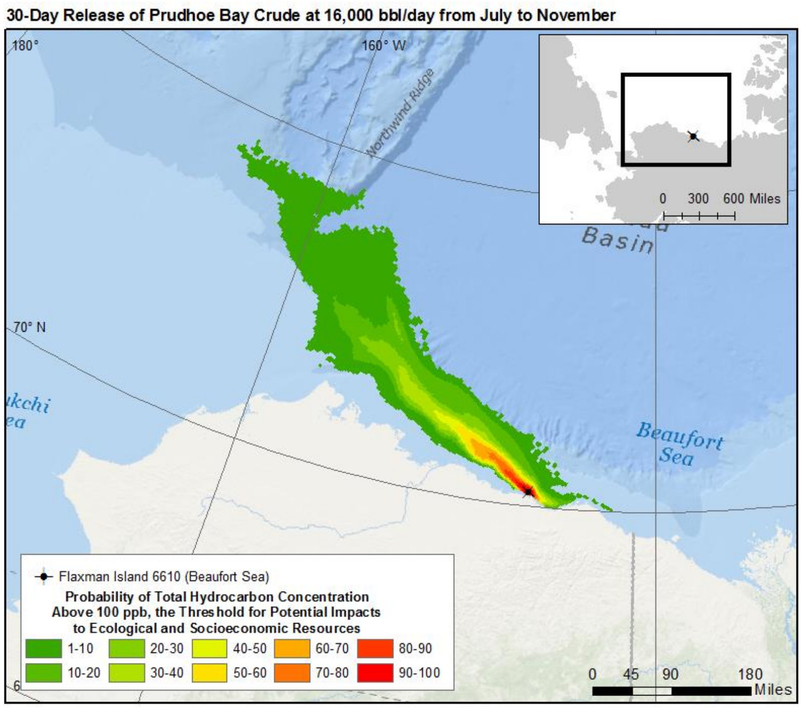


**Figure 80: Scenario 9, Arctic FI6610 – Probability of Total Hydrocarbon Concentration ≥ 100 ppb (the Threshold above which Potential Impacts to Ecological and Socioeconomic Resources Could Occur)**

The minimum time for oil to accumulate above the socioeconomic threshold on any shoreline was 1 day (Table 46). Within approximately 50 miles of the spill site, the probability that shoreline oiling would exceed the socioeconomic threshold was 90-100%. The majority (99%) of the simulations in the stochastic set had over 200 miles of shoreline oiled above the socioeconomic threshold, while 20% showed greater than 600 miles. Shoreline oiling above the socioeconomic threshold occurred along the northern Alaska coastline and areas of the Canadian Beaufort to the Mackenzie River delta (Figure 81). The highest probability of oiling occurred midway from the U.S.-Canadian border to Point Barrow on the North Slope.

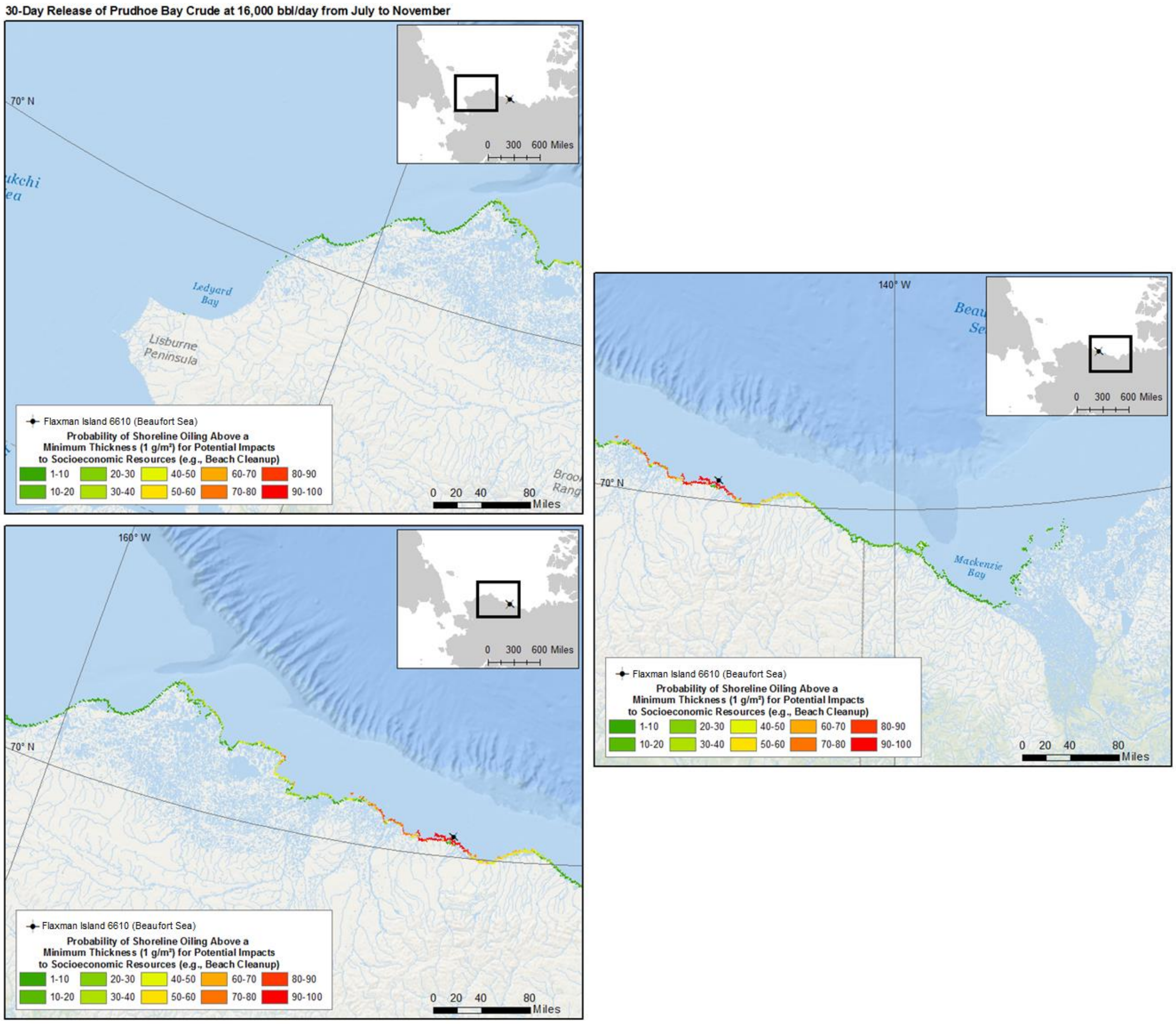


**Figure 81: Scenario 9, Arctic FI6610 – Shoreline Oiling Probabilities for Shoreline Oil (Including Weathered Tarballs) ≥1 g/m$^2$ (3.94 x 10$^{-5}$ in, the Minimum Thickness for Potential Impacts to Socioeconomic Resources) along U.S. Coastlines**

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## APPENDIX A: OILMAPDEEP MODEL DESCRIPTION

As offshore oil development proceeds into deeper water, the possibility of blowouts becomes of increasing concern. The principal issues are the difficulty in mounting effective containment and cleanup for such spills and of the effects of subsurface oil that may travel many kilometers in the water column. As an example, oil released from the IXTOC blowout (Gulf of Mexico, September 1979) was dispersed throughout the water column and resulted in high concentrations of petroleum hydrocarbons in the vicinity of the well.

To address this issue, RPS ASA's OILMAPDeep was developed to serve as a tool to evaluate potential accidental releases of oil and gas from a deep-water well blowout, and furthermore to be able to evaluate spill response activities such as subsurface[101] dispersant application.

OILMAPDeep contains two sub-models, a plume model, and a droplet size model. The plume model predicts the evolution of buoyant plume position, geometry, and centerline rise velocity and oil and gas concentrations until either surfacing or reaching a terminal height at which point the plume is no longer buoyant and so is trapped. The droplet model predicts the size and volume (mass) distribution of oil droplets. The plume dynamics transport released oil to the plume termination height, after which point the transport of the oil is dominated by the ambient environmental conditions. The near-field blowout model results calculated in OILMAPDeep define the initial conditions for the far-field simulations, where the oil mass is initially released at the plume trap height in droplets defined by the calculated size distribution.

The OILMAPDeep blowout model is based on the work of McDougall (gas plume model, 1978), Fanneløp and Sjøen (1980a, plume/free surface interaction), Spaulding (1982, oil concentration model), Kolluru, (1993, World Oil Spill Model implementation), Spaulding et al. (2000, hydrate formation) and Zheng et al. (2002, 2003, gas dissolution). A simplified integral jet theory is employed for the vertical as well as for the horizontal motions of the gas-oil plume. Oil and gas buoyancy are incorporated based on their respective densities. For gas, it includes the effects of compression based on methane characteristics. The necessary model parameters defining the rates of entrainment and spreading of the jet are obtained from laboratory studies (Fanneløp and Sjøen, 1980a). The gas plume analysis is described in McDougall (1978), Spaulding (1982), and Fanneløp and Sjøen (1980a). Gas dissolution is included based on formulations originally from Johnson et al. (1969) and Clift et al. (1978). The dissolution algorithm is a function of initial gas bubble size, the appropriate gas saturation depending on the temperature and the estimated water column concentration of dissolved gas in the plume water. The formulation includes a calculation of the mass transfer coefficient as a function of bubble size. The bubbles are approximated as spheres for small size, ellipsoids for intermediate size, and spherical-caps for large size. Consistent with Zheng et al. (2003), the critical diameter between small and intermediate size ranges is 5 mm and between intermediate and large size ranges is 13 mm. A hydrate formation and dissociation model is formulated based on an equilibrium kinetics model developed by Bishnoi and Mainik (1989) and colleagues at the University of Calgary.

Oil droplet size distribution calculations are based on the methodology presented by Yapa and Zheng (2001), which uses a maximum diameter ($d_{95}$) calculation and the associated volumetric droplet size distribution. The maximum diameter formulation is based on Hinze (1955), and the droplet size distribution is described utilizing a Rosin-Rammler (1933) distribution.

[101] With respect to undersea application of oil dispersants, this report uses the term "subsurface." Other studies and reports may use the term "subsea." Both terms are used interchangeably by industry and regulators, and should be considered synonyms.

**Description of a Blowout**

In a well blowout, discharged materials consisting of a mixture of gaseous and liquid hydrocarbon, go through three phases:

**1) Momentum jet**

The immediate pressure difference between inside the well and the ambient water drives the discharge. Due to the relative high-density of the deep ocean water, this jet momentum dissipates relatively quickly and is confined to the vicinity of the release point (on the order of meters).

**2) Buoyant density plume**

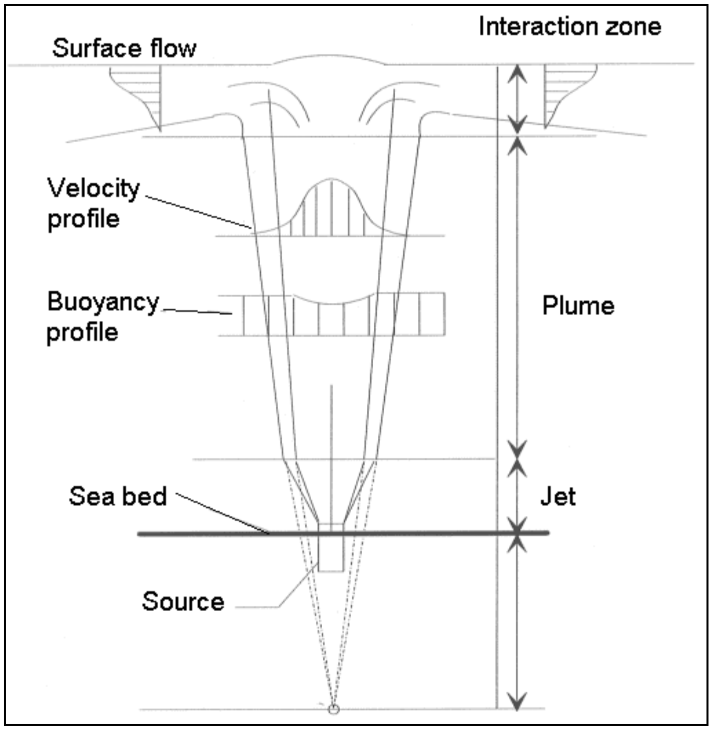
As the discharge moves upward, the density difference between the expanding gas bubbles in the plume and the receiving water results in a buoyant force which drives the plume. As the plume rises, it continues to entrain sea water, reducing the plume's velocity and buoyancy and increasing its radius.

The oil in the release is rapidly mixed due to turbulence in the plume, resulting in a break up into small droplets. These droplets (typically a few micrometers to millimeters in diameter) are transported upward by the rising plume; their individual rise velocities contributing little to their upward motion in this region.

**3) Free rise and advection-diffusion**

As the plume reaches the sea surface or its *termination height* (when all momentum is lost), it can be deflected in a radial pattern within a horizontal / surface flow zone without appreciable loss of momentum. This radial jet carries the oil particles rapidly away from the center of the plume, while the velocity and oil concentrations in this surface flow zone decrease.

Plumes that do not reach the surface terminate within the water column and the plume acts to transport the oil droplets to this termination height. Subsequently (in the so-called far field), oil particles ascend to the surface solely by their own buoyancy. Rise velocities of oil droplets are much slower than the velocity of a buoyant gas-liquid plume, resulting in particle transport that may take considerably longer to reach the surface and result in transport farther (horizontally) from the release site due to ambient currents.




In order to reproduce this dynamic and complex process, blowout simulations are performed in two steps:

A. Near-field analysis, describing the oil/gas plume generated by the blowout that typically evolves vertically due to vertical processes (momentum and relative buoyancy), and
B. Far-field analysis, describing the long term transport and weathering of the released oil mixture, that typically evolves as a horizontal process due to currents and winds

The near-field model results provide the initial conditions for both the stochastic and deterministic modes of the far-field modeling. The near-field results depend more on the blowout conditions (flow rate, GOR, and pipe diameter), and less on the environmental conditions (e.g., seasonality). Conversely, the far-field modeling is highly dependent on the environmental conditions such as winds and currents as the main the drifting/driving forces.

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## APPENDIX B: SIMAP MODEL DESCRIPTION

SIMAP™ is a computer modeling software application that estimates physical fates and biological effects of releases of oil. In SIMAP, both the physical fates and biological effects models are three-dimensional. There is also a two-dimensional oil spill model for quick trajectories and screening of scenarios and a three-dimensional stochastic model for risk assessment and contingency planning applications. The models are coupled to a geographic information system (GIS), which contains environmental and biological data, and also to databases of physical-chemical properties and biological abundance, containing necessary inputs for the models.

SIMAP was derived from the physical fates and biological effects submodels in the Natural Resource Damage Assessment Models for Coastal and Marine and Great Lakes Environments (NRDAM/CME and NRDAM/GLE), which were developed for the U.S. Department of the Interior (USDOI) as the basis of Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) Natural Resource Damage Assessment (NRDA) regulations for Type A assessments (French et al., 1996; Reed et al., 1996). The physical fates model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills (French McCay, 2003, 2004; French McCay and Rowe, 2004), as well as test spills designed to verify the model's transport algorithms (French et al., 1997).

Applications for SIMAP include impact assessment; hindcast/forecast of spill response; NRDA; contingency planning; ecological risk assessment; cost-benefit analysis, and drills and education. The model may be run for a hindcast/forecast of a specific release, or be used in stochastic mode to evaluate the probable distribution of contamination. SIMAP contains several major components:

- The physical fates model estimates surface distribution and subsurface concentrations of the spilled oil and its components over time.
- The probability of effects from an oil discharge is quantified using the three-dimensional stochastic model.
- Currents that transport contaminant(s) and organisms are entered using the graphical user interface or generated using a (separate) hydrodynamic model. Alternatively, existing current data sets may be imported.
- Environmental, chemical, and biological databases supply required information to the model for computation of fates and effects.
- The user supplies information about the spill (time, place, oil type, and amount spilled) and some limited environmental conditions at the time (such as temperature and wind data).

SIMAP is applicable to a wide variety of environmental conditions. It is set up and runs within RPS ASA's standard GIS or ESRI's ArcView GIS, and can be applied to any aquatic environment (fresh or salt) in the world. It uses any of a variety of hydrodynamic data file formats (1-, 2- and 3-dimensional; time varying or constant) and allows 2-d vertically-averaged current files to be created within the program system when modeled currents are not available. Outputs include easily interpreted visual displays of dissolved and particulate concentrations and trajectories over time, as appropriate to the properties of the chemical being simulated.

- SIMAP specifically simulates the following processes: slick spreading, transport, and entrainment of floating oil;
- Evaporation and volatilization (to atmosphere);
- Transport and dispersion of entrained oil and dissolved aromatics in the water column;
- Dissolution and adsorption of entrained oil and dissolved aromatics to suspended sediments;
- Sedimentation and re-suspension;
- Natural degradation;

- Shoreline entrainment; and
- Boom and dispersant effectiveness.

The physical and biological models require environmental, oil and biological data as inputs. The data come from many sources including government and private data services, field studies and research. Modeling techniques are used to fill in "holes" in the observational data, thus allowing complete specification of needed data. The environmental database is geographical, including data of the following types: coastline, bathymetry, shoreline type, ecological habitat type, and temporally varying ice coverage and temperature. This information is stored in the simplified GIS. The chemical database includes physical-chemical parameters for a wide variety of oils and petroleum products. Data have been compiled by RPS ASA from existing, but diffuse, sources.

An oil spill is simulated using site-specific wind, current, and other environmental data gathered from existing information, on-line services, and/or field studies. Shoreline and habitat types, as well as bathymetry, are mapped and gridded for use as model input. The physical, chemical, and toxicological properties of the spilled oil are provided by the oil database or updated to the specific conditions of the release. The model estimates the fate of the oil over time. The model outputs are time-varying concentrations and mass per unit area on surfaces (i.e., water surface, shoreline, sediments), which quantifies exposure to aquatic biota and habitats. Atmospheric loading in space and time is also computed, and provides input to air dispersion models.

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## APPENDIX C: MODELING OIL INTERACTIONS IN ICE

Oil interactions with mobile sea ice or immobile landfast ice, or the ice that is attached to or grounded on shore or land, involve several processes that affect transport and fate of the oil. If oil is released at or above the water surface, it may spill into water and/or onto the surface of the ice. Oil deposited on ice may absorb into surface snow, run off and become trapped between cracks or in open water fields between floes, and/or become encapsulated in the ice. Oil released into and under water may become trapped under the ice in ridges and keels, or build up along and become trapped in sea or landfast ice edges (Figure 82; Drozdowski et al., 2011). Many of these interactions and processes are at a finer scale than can be captured in oil spill models using inputs from large scale meteorological, hydrodynamic and coupled ocean-ice models. However, the influence of ice on net transport and fate processes is simulated by considering potential reduction in surface area of the oil and the water in contact with the atmosphere, which changes the wave environment, spreading, movements, volatilization, and mixing.

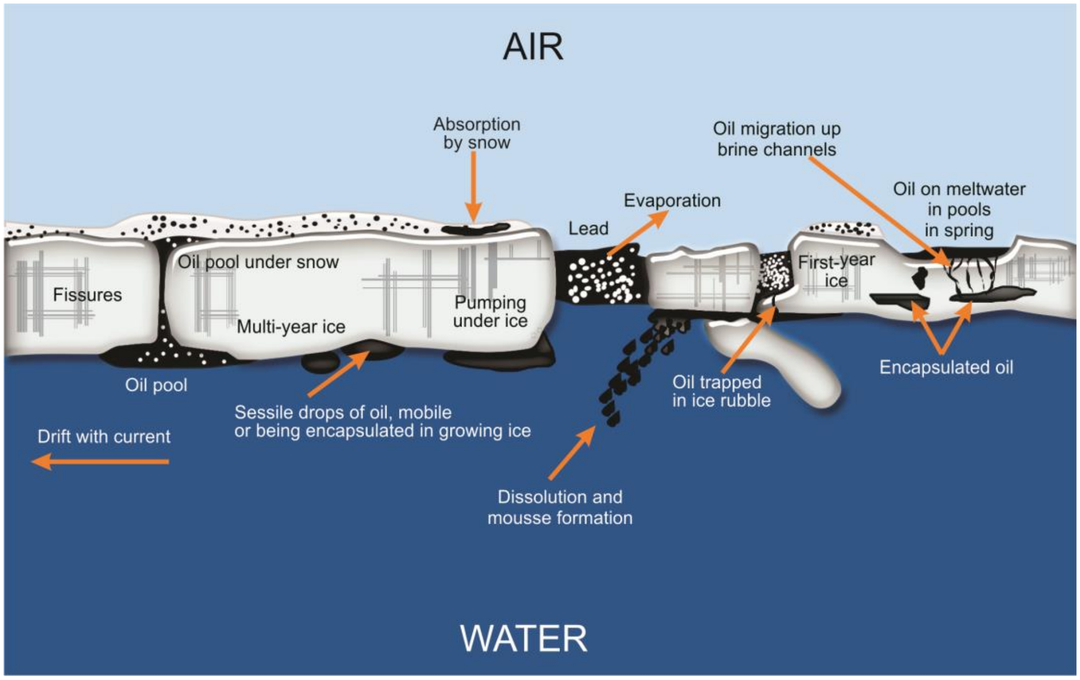


**Figure 82: General Schematic Showing Dynamics and Characteristics of Sea Ice and Oil Interaction at the Sea Surface (Source: Original Figure by Alan A. Allen)**

### C1 Oil Transport in Sea Ice

When oil interacts with mobile sea ice, some fraction of that oil will become contained (either on top, in, or underneath the ice) and will then travel with the ice floe (Drozdowski et al., 2011). Sea ice fields can drift rapidly and over great distances in the Arctic (Peterson et al., 2008). The fraction of oil moving with the ice verses in open water depends on conditions and specifics of the release. In some cases, all of the oil becomes completely frozen in the ice and remains there until it melts. This scenario is readily modeled (i.e., 100% of oil drifts with ice). However, in most cases since sea ice can be patchy, only partial amounts may become either encapsulated or trapped (e.g., between ice fragments or under ice sheet in small cavities) (Drozdowski et al., 2011), depending on ice coverage, subsurface roughness, winds and currents, and ice formation/melting dynamics.

To simplify the problem, the ice coverage or concentration information provided by ice data or an ice model can be used as an indicator of whether oil follows the surface currents or the ice currents. Ice coverage information available in coupled hydrodynamics and ice models typically is based on or calibrated to remotely sensed satellite data. A rule of thumb followed by past modeling studies is oil will generally drift with ice when ice coverage is greater than 30% (Drozdowski et al., 2011; Venkatesh et al., 1990). For more description of the ice coverage information and ice currents utilized in this modeling study refer to Appendix D.

When a coupled ocean-ice model is available and can provide water currents and ice velocities, the SIMAP™ model uses the ice coverage data to determine whether floating (or ice-trapped) oil moves with the surface water currents or the ice. If the ice coverage is <30%, the oil is assumed not to be trapped and moves with surface water currents. If ice coverage exceeds this threshold, the ice is assumed to have ample spatial coverage to trap the oil in it or between floes, and oil is transported along with the ice using the ice velocities from the ocean-ice model.

In areas and at times where ice cover <30%, floating oil is transported with surface water currents and a wind drift algorithm to account for wind-induced drift current not resolved by the hydrodynamic model plus Stokes drift caused by wave motions. Wind drift is predicted in SIMAP based on the modeling analysis of Stokes drift and Ekman flow by Youssef (1993) and Youssef and Spaulding (1993, 1994). According to this algorithm, at moderate wind speeds, floating oil drifts 20° to the right of downwind at about 3.5% of wind speed. Alternatively, a constant drift speed percentage and angle may be used in simulations; however, the modeled drift is used in the examples herein. In areas where ice exceeds 30%, and an ice drift model provides transport velocities, the ice drift model has accounted for wind drift, and so no additional wind drift is added in SIMAP.

To simulate oil transport in this study, the SIMAP model used the ice coverage variable, and both the regular water currents and the ice currents or ice velocities available in the hydrodynamics and ice model TOPAZ4 (Appendix D).

### C.2 Oil Transport and Interaction with Landfast Ice

Immobile or fixed landfast ice which seasonally extends out from the coast may act as a natural barrier where oil collects. The ice edge is complex with ridges, keels, cracks, and crevices where oil can become trapped. During landfast ice melt, oil that has been stored along the edge may either release back into open water, or may retreat back with the ice towards the coast (Drozdowski et al., 2011).

In the model, when oil encounters landfast ice at the surface of the ocean it is assumed to trap along the ice edge and remain immobile until ice retreats. When landfast ice is no longer present at trapped oil's location, the oil is released back into the water as floating oil. In areas deep enough for landfast ice to have subsurface open channels (i.e., where the ice sheet may not extend completely to the seabed in all areas), entrained oil is allowed to circulate underneath the surface ice using subsurface current data for transport. The thickness of landfast ice is typically about 2 m in the Beaufort Sea; thus, in deeper waters subsurface oil spillets continue to move with currents, whereas in shallower areas, subsurface oil spillets remain stationary for the time where landfast ice is present. Monthly representations of the landfast edge along the entire coast (capturing average growth and retreat patterns) were prepared as data inputs, as described in Section C.4.

### C.3 Effects of Ice on Oil Fates and Behavior Process

The presence of ice can shelter oil from the wind and waves (Drozdowski et al., 2011). Thus, weathering processes such as evaporation and emulsification, and behavior s such as spreading and entrainment are slowed (Spaulding, 1988). Field data show evaporation, dispersion, and emulsification significantly slowed in ice leads. Wave-damping, the limitations on spreading dictated by the presence of sea ice, and temperature appear to be the primary factors governing observed spreading and weathering rates (Sørstrøm et al., 2010).

As with transport, the ice coverage or concentration variable provided in the ice model is used as an index to control oil weathering and behavior processes (Table 47). Oil behaves as it would in open water in

<30% ice coverage.  Ice coverage exceeding 80% is assumed fast ice and effectively continuous ice cover.  Evaporation and volatilization of oil under/in ice, as well as spreading, emulsification, and entrainment into the surface water are zeroed in fast ice.  Oil spilled on top of fast ice is allowed to evaporate, but does not spread from the initial condition of the release.  Degradation of subsurface and ice-bound oil occurs during all ice conditions, at rates occurring at the location (i.e., floating versus subsurface) without ice present.  Dissolution of soluble aromatics proceeds for subsurface oil and oil under ice using the normal open-water algorithm (French McCay, 2004).

In ice coverage between 30% and 80%, a linear reduction in wind speed from the open-water value (used in <30% ice) to zero in fast ice (>80% ice coverage) is applied to simulate shielding from wind effects.  This reduces the evaporation, volatilization, emulsification, and entrainment rates due to reduced wind and wave energy.  Terminal thickness of oil is increased in proportion to ice coverage in this range (i.e., oil is thickest at >80% ice coverage).

**Table 47: Percent Ice Coverage Thresholds for Oil Fates and Behavior Processes Applied in the SIMAP Model**

| Ice Cover (Percent) | Advection | Evaporation & Emulsification | Entrainment | Spreading |
|---|---|---|---|---|
| **0 - 30 (Drift Ice)** | Surface oil moves as in open water | As in open water | As in open water | As in open water |
| **30 - 80 (Ice Patches and Leads)** | Surface oil moves with the ice | Linear reduction with ice cover (i.e., none at 80% ice cover) | Linear reduction with ice cover (i.e., none at 80% ice cover) | Terminal thickness increased in proportion to ice coverage |
| **80 - 100 (Pack Ice)** | Surface oil moves with the ice | None | None | None |

Assumptions applied to fates and behavior processes are not well quantified by field experiments or other studies.  In addition, the coupled ocean-ice models available to date do not resolve the details of leads, fractures, and ice roughness.  The applied thresholds, or the discrete bands of 0 to 30, 30 to 80, and 80 to 100%, may not reflect the fate of oil in real ice cover at fine scales.

## C.4 Landfast Ice for Arctic

Numerous general definitions of landfast ice can be found in the literature (see review in Eicken et al., 2006).  Barry et al. (1979) provides a clear list of criteria to distinguish landfast ice from other forms of sea ice: "(i) the ice remains relatively immobile near the shore for a specified time interval; (ii) the ice extends from the coast as a continuous sheet; (iii) the ice is grounded or forms a continuous sheet which is bounded at the seaward edge by an intermittent or nearly continuous zone of grounded ridges."  Though this definition thoroughly describes the attributes of landfast ice, for the purposes of this modelling study a more concrete definition of landfast was required.  In the interest of accurately and consistently identifying landfast ice, Eicken et al. (2006) define landfast ice as sea ice contiguous with the shoreline and lacking motion detectable in satellite imagery for approximately 20 days.  Using this definition, Mahoney et al. (2012) quantified the coverage of landfast ice along the Alaskan Arctic coast.

A BOEM study (Mahoney et al., 2012) quantified the extent of landfast ice along the Arctic coast of Alaska including the Chukchi and Beaufort Seas.  Publically available shapefiles were extracted from the project website (http://boemre-new.gina.alaska.edu/beaufort-sea/landfast-summary).  Monthly averaged means (1996-2008) were utilized as baseline data for the Arctic landfast ice coverage.

Landfast ice coverage was available for more eastern portions (east of the Mackenzie River delta) of the modelling zone through the National Snow and Ice Data Center (NSIDC) (Konig Beatty, 2012).  Monthly data from the years 1991 through 1998 were composited into mean monthly landfast ice coverage. This dataset included ice concentration percentages for each raster cell. Cells with a concentration of greater than 15% were considered to have landfast ice. This concentration level most strongly corresponded with the higher resolution shapefile data available through BOEM (Mahoney et al., 2012). These mean raster datasets were converted into shapefile extents.

These two datasets (BOEM and NSIDC) were then merged to create continuous landfast ice coverage (monthly average) for the entire area of interest. The BOEM dataset (1996-2008) provided higher resolution and more recent years than the NSIDC dataset (1991-1998). Therefore, the BOEM dataset served as the reference dataset for merging. Figure 83, Figure 84 and Figure 85 show the composited monthly average landfast ice coverage used in this modeling study.

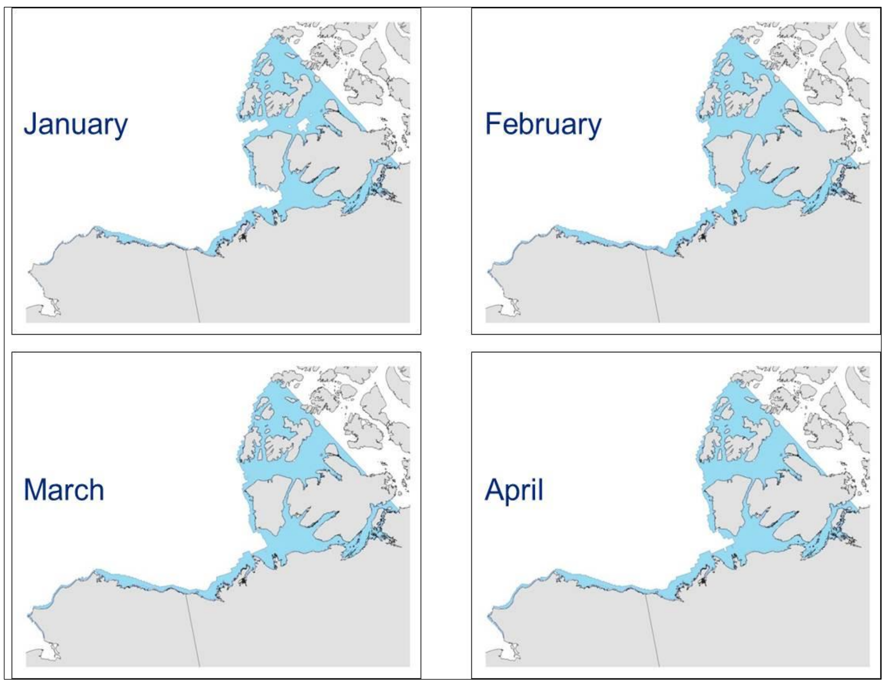


**Figure 83: U.S. Chukchi and U.S/Canada Beaufort January-April Monthly Average Landfast Ice Coverage**

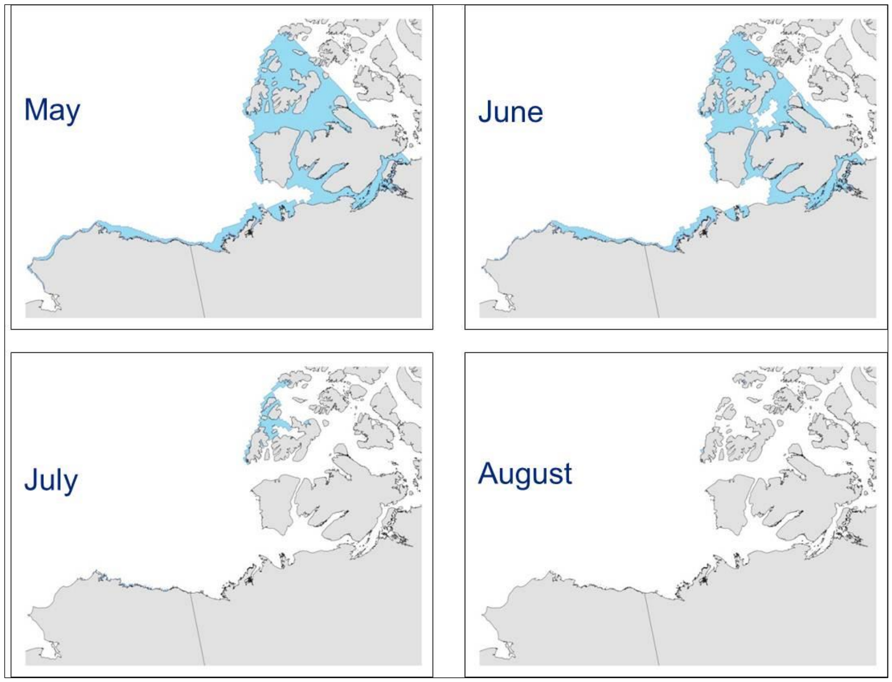


**Figure 84: U.S. Chukchi and U.S/Canada Beaufort May-August Monthly Average Landfast Ice Coverage**

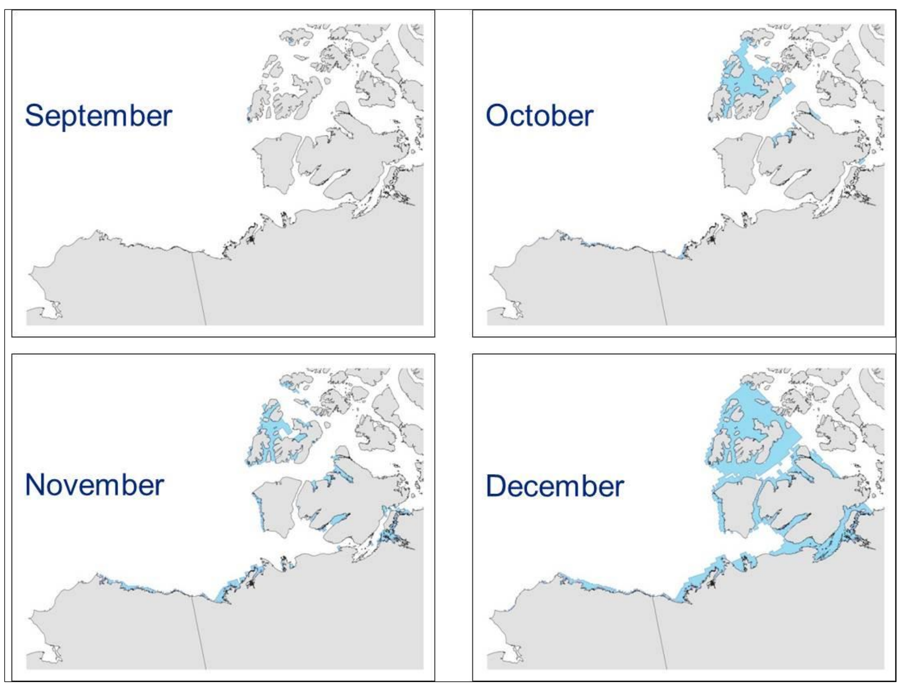


**Figure 85: U.S. Chukchi and U.S/Canada Beaufort September-December Monthly Average Landfast Ice Coverage**

## C.5 References


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## APPENDIX D: ENVIRONMENTAL MODEL INPUT DATA

This appendix provides a description of environmental model input data used in the SIMAP™ modeling. These inputs include bathymetry, shoreline type, winds, currents, temperature, and salinity.

### D.1 Bathymetry

Bathymetry is an important input for oil spill modeling. Data for the study area were obtained from the General Bathymetric Chart of the Oceans (GEBCO) Digital Atlas.[102] The GEBCO Digital Atlas consists of a global one arc-minute grid. The grid is largely generated by combining quality-controlled ship depth soundings with interpolation between points guided by satellite-derived gravity data. A subset of the gridded GEBCO data was extracted to generate the depth grid used for an input to the SIMAP model. Figure 86 through Figure 88 provide the depth grids (with depths in feet) used for oil spill modeling in each of the three geographic locations.

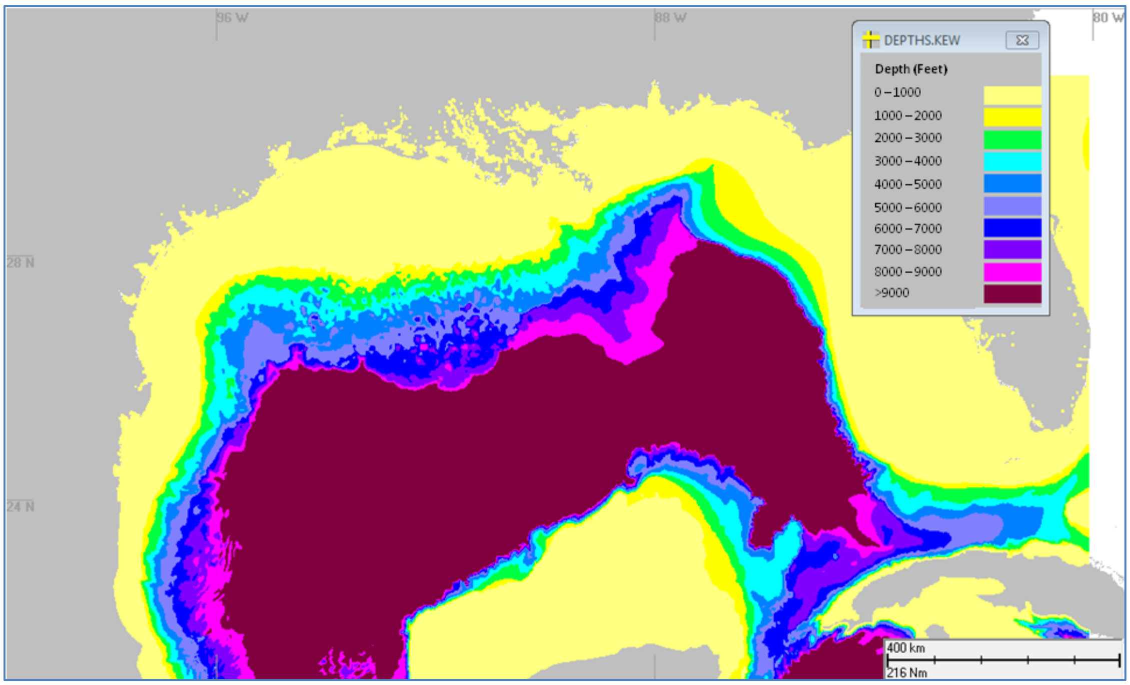


**Figure 86: Depth Grid (in Feet) Used for Oil Spill Modeling in the Gulf of Mexico Location.**

[102] GEBCO, 2009.

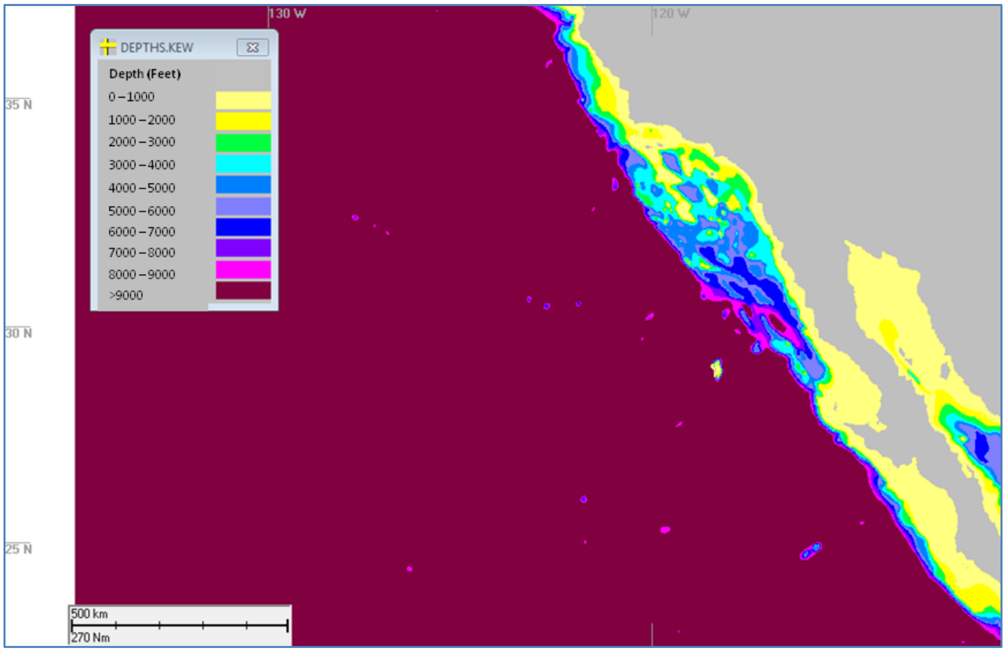


**Figure 87: Depth Grid (in Feet) Used for Oil Spill Modeling in the California Location.**

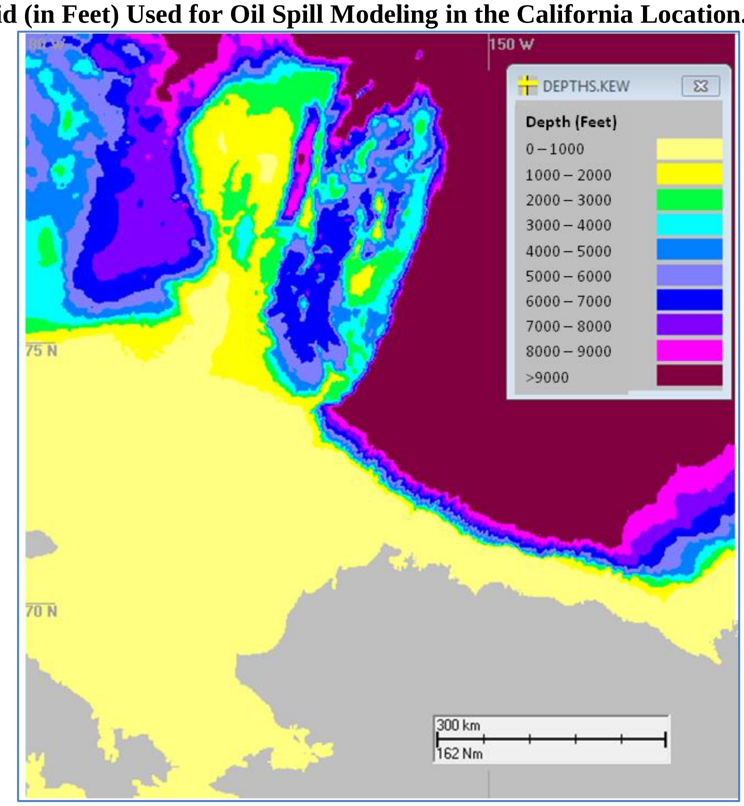


**Figure 88: Depth Grid (in Feet) Used for Oil Spill Modeling in the Arctic Location**

## D.2 Habitat Data

For geographical reference, SIMAP uses a rectilinear grid to designate the location of the shoreline, the water depth (bathymetry), and the shore or habitat type. The grid is generated from a digital coastline using the ESRI Arc/Info compatible Spatial Analyst program. The cells are then coded for depth and habitat type. Note that the model identifies the shoreline using this grid. Thus, in model outputs, the coastline map is only used for visual reference; it is the habitat grid that defines the actual location of the shoreline in the model. The source of the digital shoreline data is NOAA (2012).

Ecological habitat types (Table 48) are broadly categorized into two zones: intertidal and subtidal. Intertidal habitats are those above spring low water tide level, with subtidal being all water areas below that level. Intertidal areas may be extensive, such that they are wide enough to be represented by an entire grid cell at the resolution of the grid. These are typically either mud flats or wetlands. All other intertidal habitats are typically much narrower than the size of a grid cell. Thus, these fringing intertidal types (indicated by F in Table 48) have typical (for the region, French et al., 1996) widths associated with them in the model. Boundaries between land and water are fringing intertidal habitat types. On the waterside of fringing intertidal grid cells, there may be extensive intertidal grid cells if the intertidal zone is extensive. Otherwise, subtidal habitats border the fringing intertidal.

**Table 48: Classification of Habitats (Fringing Types Indicated by (F) Are Only as Wide as the Intertidal Zone in That Province, Others (W = Water) Are a Full Grid Cell Wide and Must Have a Fringing Type on the Land Side)**

| Ecological Habitat | F or W |
|---|---|
| **Intertidal** | |
| Rocky Shore, including sheltered riprap structures and scarps | F |
| Gravel Beach | F |
| Sand Beach | F |
| Fringing Mud Flat | F |
| Fringing Wetland (Saltmarsh) | F |
| Mollusk Reef | F |
| Other hard man-made surfaces, Artificial | F |
| Extensive Mud Flat | W |
| Extensive Wetland (Saltmarsh) | W |
| **Subtidal** | |
| Sand Bottom | W |
| Wetland (Subtidal of Saltmarsh) | W |
| Macro algal Bed | W |
| Mollusk Reef | W |
| Seagrass Bed | W |

Figure 89 through Figure 95 provide the habitat grids made for the Gulf of Mexico, Pacific, and Arctic study regions. The dark blue represents U.S. waters, whereas light blue is used for international waters.

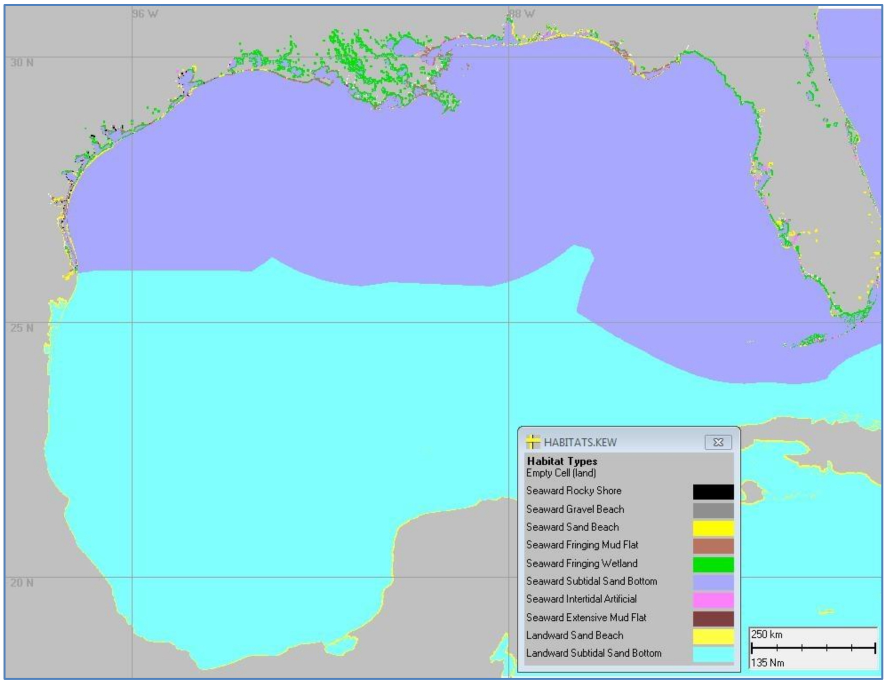


**Figure 89: Habitat Grid Used for Oil Spill Modeling in the Gulf of Mexico Location (Full Extent View)**

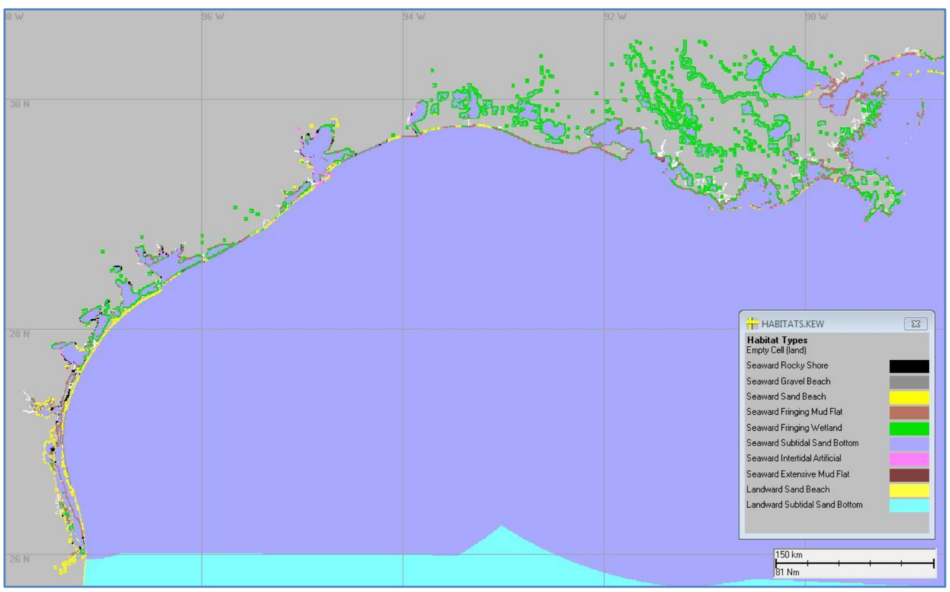


**Figure 90: Habitat Grid Used for Oil Spill Modeling in the Gulf of Mexico Location (West and Central Gulf of Mexico View)**

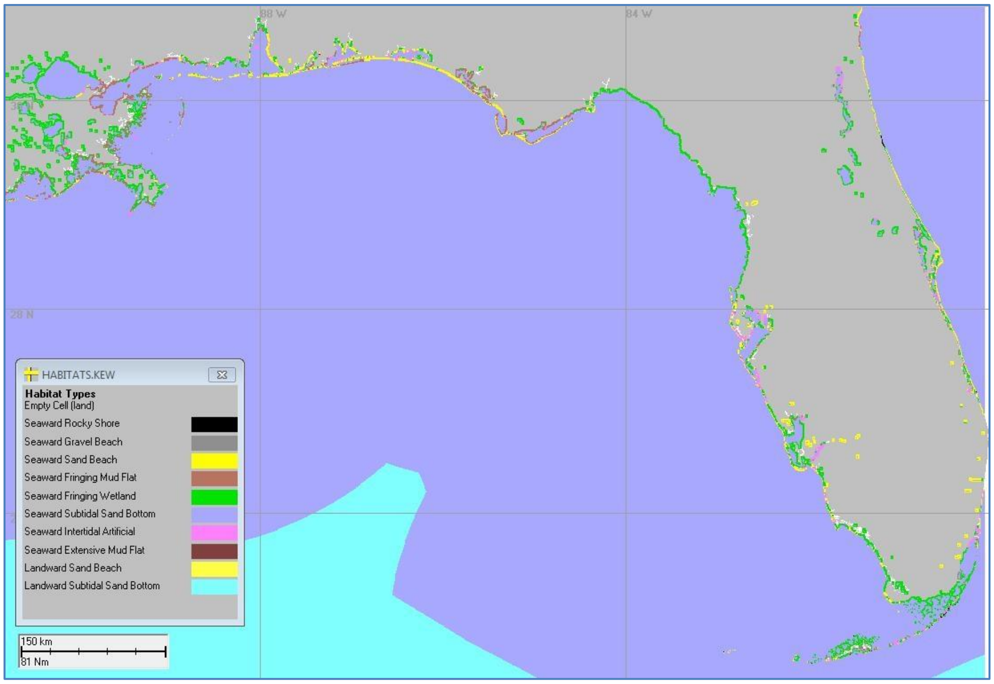


**Figure 91: Habitat Grid Used for Oil Spill Modeling in the Gulf of Mexico Location (Central and Eastern Gulf of Mexico View)**

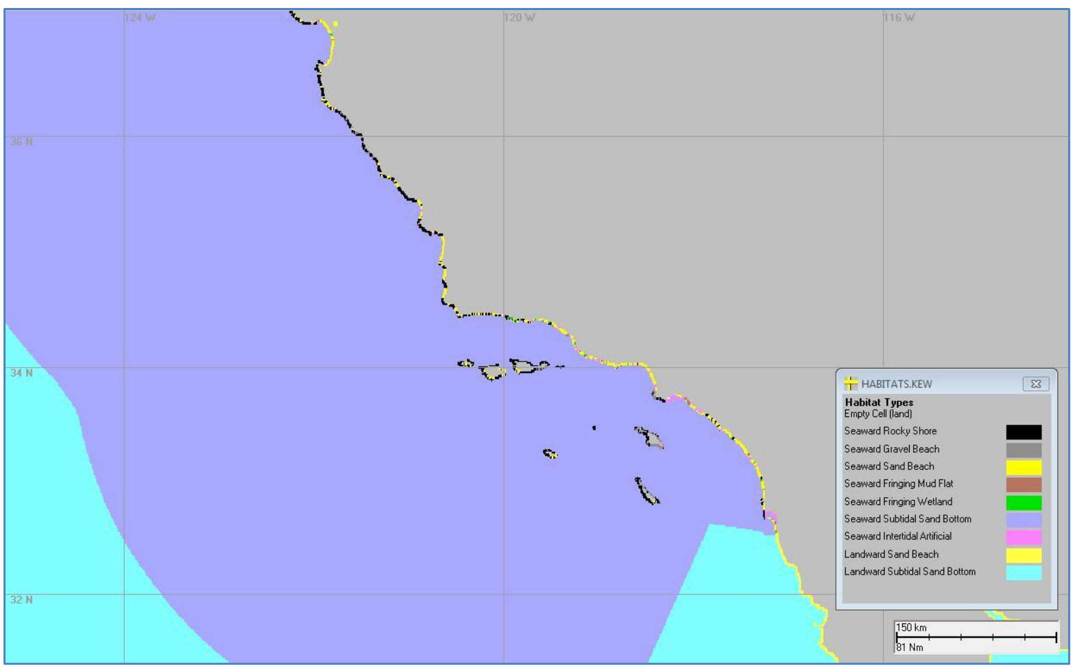


**Figure 92: Habitat Grid Used for Oil Spill Modeling in the California Location**

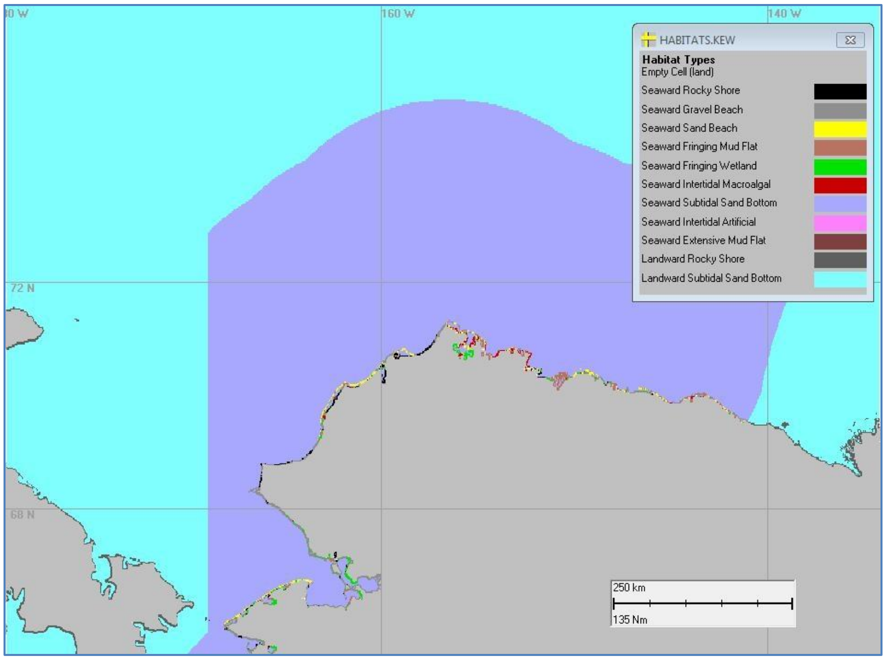


**Figure 93: Habitat Grid Used for Oil Spill Modeling in the Arctic Location (Full Extent View)**

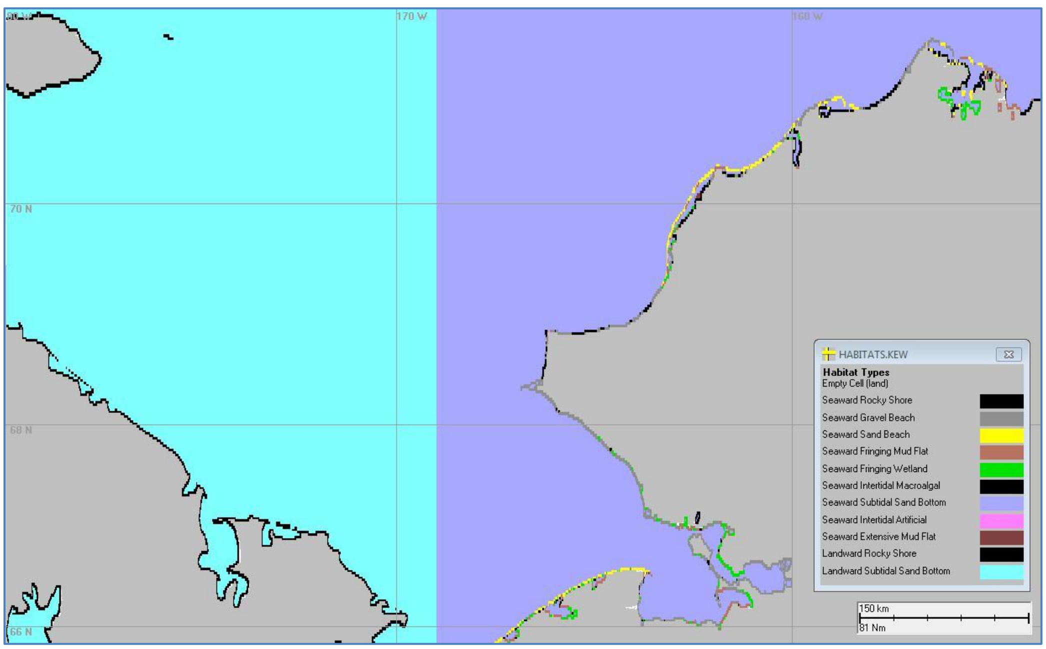


**Figure 94: Habitat Grid Used for Oil Spill Modeling in the Arctic Location (Chukchi Sea Extent)**

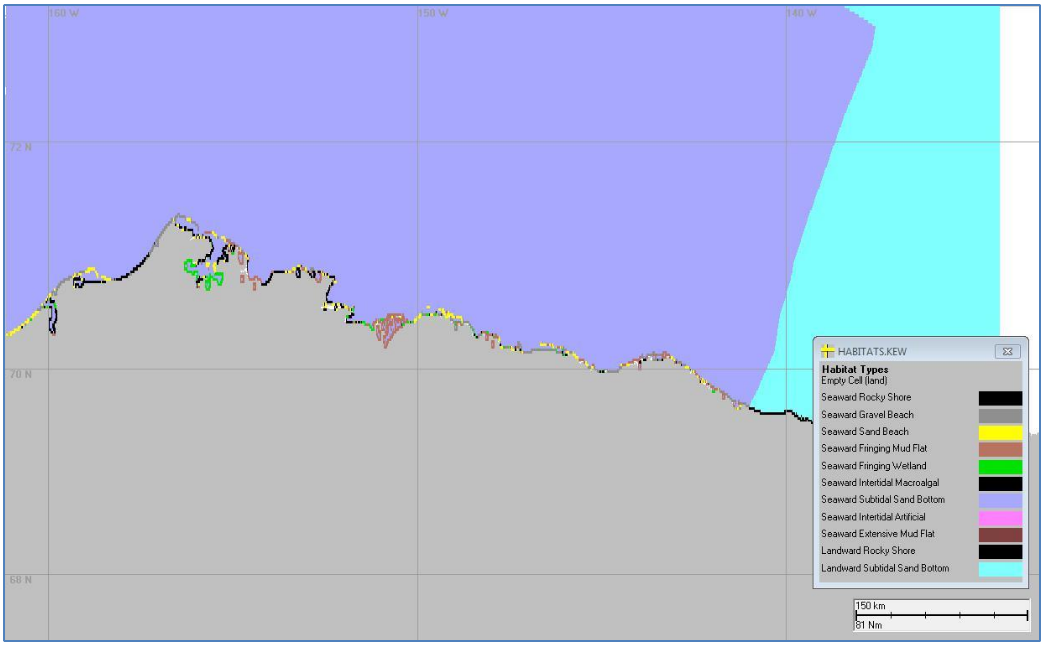


**Figure 95: Habitat Grid Used for Oil Spill Modeling in the Arctic Location (Beaufort Sea Extent)**

When oil comes ashore, the oil is deposited if the shoreline has not already reached its holding capacity for oil. The maximum holding thickness is a function of oil viscosity and shore type (CSE/ASA/BAT, 1986; Gundlach, 1987).

Table 49, Table 50, and Table 51 show the maximum oil thickness on the shore as a function of three viscosity ranges and average oil penetration depth (shore width oiled) for the shore types included in the habitat grids for each geographic region (French McCay et al. 1996). These values are from Gundlach (1987), Reed and Gundlach (1989), and Reed et al. (1988, 1989). Each shoreline cell has an oil holding capacity based on oil type, habitat type, beach slope, and beach width and shoreline grid length.

Deposition occurs when an oil spillet intersects the shore surface. Deposition ceases when the holding capacity for the shore surface is reached. Subsequent oil deposited is not allowed to remain on the shore surface, and is refloated as slicks that continue to move along shore.

**Table 49: Modeled Shore Widths and Oil Holding Capacities for Each Shore Type for the Gulf of Mexico Location**

| Type of Shore | Width (m) | Oil Holding Capacity (mm) | | |
|---|---|---|---|---|
| | | Oil Viscosity < 30 cSt | Oil Viscosity 30 - 2,000 cSt | Oil Viscosity > 2,000 cSt |
| **Rocky Shore** | 1.0 | 1.0 | 2.0 | 2.0 |
| **Gravel Beach** | 2.0 | 2.0 | 9.0 | 15.0 |
| **Sand Beach** | 10.0 | 4.0 | 17.0 | 25.0 |
| **Mud Flat (Seaward)** | 10.0 | 3.0 | 6.0 | 10.0 |
| **Mud Flat (Landward)** | 50.0 | 6.0 | 30.0 | 40.0 |
| **Wetland (Saltmarsh)** | 1.0 | 1.0 | 2.0 | 2.0 |
| **Intertidal Macroalgal** | 1.0 | 1.0 | 2.0 | 2.0 |
| **Artificial Shore** | 1.0 | 1.0 | 2.0 | 2.0 |

**Table 50: Modeled Shore Widths and Oil Holding Capacities for Each Shore Type used for the California Location**

| Type of Shore | Width (m) | Oil Holding Capacity (mm) | | |
|---|---|---|---|---|
| | | Oil Viscosity < 30 cSt | Oil Viscosity 30 - 2,000 cSt | Oil Viscosity > 2,000 cSt |
| **Rocky Shore** | 2.0 | 1.0 | 2.0 | 2.0 |
| **Gravel Beach** | 3.0 | 2.0 | 9.0 | 15.0 |
| **Sand Beach** | 10.0 | 4.0 | 17.0 | 25.0 |
| **Mud Flat (Seaward)** | 10.0 | 3.0 | 6.0 | 10.0 |
| **Mud Flat (Landward)** | 140.0 | 6.0 | 30.0 | 40.0 |
| **Wetland (Saltmarsh)** | 2.0 | 1.0 | 2.0 | 2.0 |
| **Intertidal Macroalgal** | 2.0 | 1.0 | 2.0 | 2.0 |
| **Artificial Shore** | 2.0 | 1.0 | 2.0 | 2.0 |

**Table 51: Modeled Shore Widths and Oil Holding Capacities for Each Shore Type for the Arctic Location**

| Type of Shore | Width (m) | Oil Holding Capacity (mm) | | |
|---|---|---|---|---|
| | | Oil Viscosity < 30 cSt | Oil Viscosity 30 - 2,000 cSt | Oil Viscosity > 2,000 cSt |
| **Rocky Shore** | 3.0 | 1.0 | 2.0 | 2.0 |
| **Gravel Beach** | 6.0 | 2.0 | 9.0 | 15.0 |
| **Sand Beach** | 20.0 | 4.0 | 17.0 | 25.0 |
| **Mud Flat (Seaward)** | 20.0 | 3.0 | 6.0 | 10.0 |
| **Mud Flat (Landward)** | 300.0 | 6.0 | 30.0 | 40.0 |
| **Wetland (Saltmarsh)** | 3.0 | 1.0 | 2.0 | 2.0 |
| **Intertidal Macroalgal** | 3.0 | 1.0 | 2.0 | 2.0 |
| **Artificial Shore** | 3.0 | 1.0 | 2.0 | 2.0 |

## D.3 Wind

### Gulf of Mexico

Modeled wind data for the Gulf of Mexico region from 1999-2008 were obtained from the ERA-40 (ECMWF RE-ANALYSIS) wind model. This model was developed and is operated by the European Center for Medium-range Weather Forecast (ECMWF, 2014). This model has global domain coverage with 0.75° resolution. This dataset contains 3 hourly (8 times a day) wind speed and direction readings at all grid nodes included in the region of interest.

### California

Wind data were obtained from the output of the U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS). The version of the NOGAPS dataset used for this study is originally derived from the publically available version hosted by the U.S. Global Ocean Data Assimilation Experiment (GODAE) and subsequently has a QuikSCAT correction applied by the HYCOM Consortium (NOGAPS, 2014). This dataset of winds at 10 m above the surface was provided at 0.5 degree horizontal resolution with a 3-hour time step for the same temporal period and spatial extent as the HYCOM data.

### Arctic

Modeled wind data for the Arctic region from 2008-2013 were obtained from the ERA-40 (ECMWF RE-ANALYSIS) wind model. This model was developed and is operated by the European Center for Medium-range Weather Forecast (ECMWF) (MET Norway, 2014). This model has global domain coverage with 0.75° resolution. This dataset contains 3 hourly (8 times a day) wind speed and direction readings at all grid nodes included in the region of interest.

## D.4 Currents

### Gulf of Mexico

A 3D hindcast, or statistical calculation determining probable past conditions at a given place and time, of the Gulf of Mexico Princeton Ocean Model (POM) developed by Leo Oey (Xu and Oey, 2011) was used for hydrodynamic forcing in the Gulf of Mexico locations (Figure 96).

This is a large-scale ocean circulation model that predicts high-resolution coastal ocean processes. The model includes sigma vertical coordinates (i.e., terrain-following) to handle complex topographies and shallow regions, a curvilinear grid to better handle coastlines, and a turbulence scheme to handle vertical mixing. RPS ASA has an in-house hindcast record of this model (1999-2008) adapted for use in SIMAP. POM data assimilation is based on standard optimal interpolation. Assimilation data sources include satellite sea-surface height anomaly (SSHA), sea-surface temperature (SST), moored temperatures and currents, hydrography, and drifters.

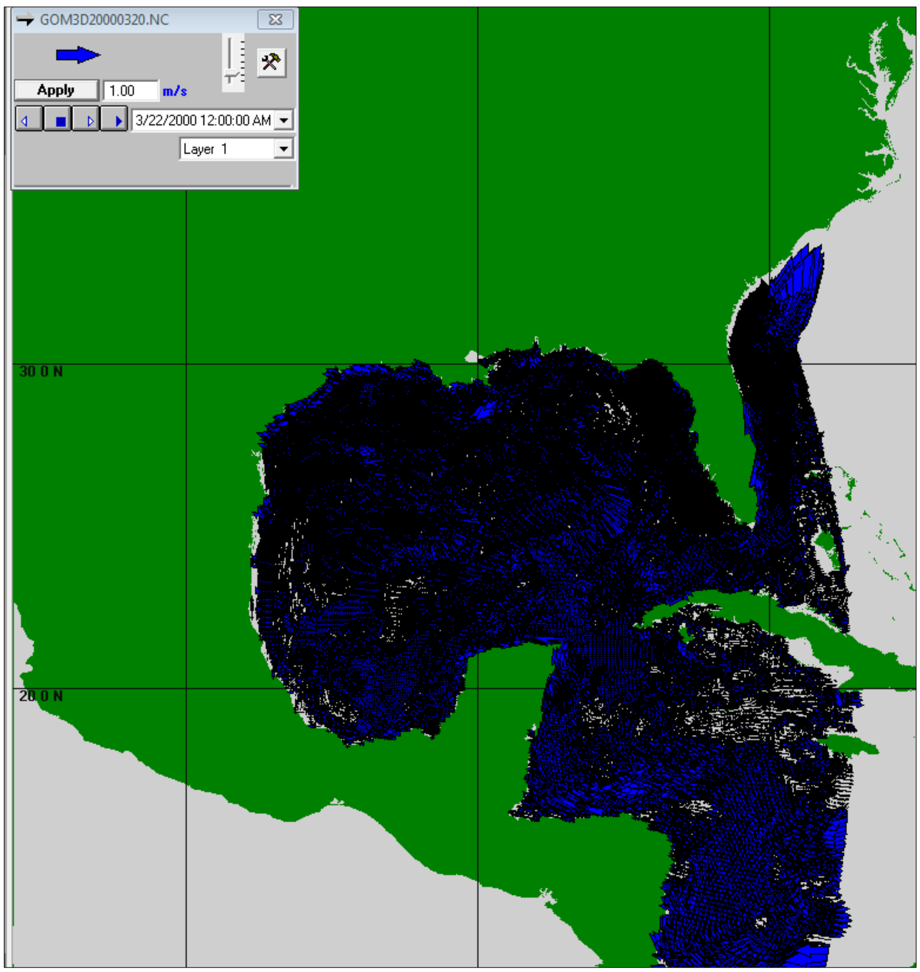


**Figure 96: Spatial Coverage of the Gulf of Mexico POM (Xu and Oey, 2011)**

### California

For the California study region, 3D currents were obtained from a hindcast analysis using inputs from the HYCOM (HYbrid Coordinate Ocean Model) global simulation assimilated with NCODA (Navy Coupled Ocean Data Assimilation) from the U.S. Naval Research Laboratory (Figure 97; Halliwell 2002; http://www.hycom.org). HYCOM is a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model. The model domain has a spatial resolution defined by a 1/12 degree grid in the horizontal direction and has a daily temporal resolution. A hindcast currents file spanning the appropriate spatial extent for the spill scenario was extracted and prepared for input to the SIMAP model. Data from the time period from 2004-2013 were used for modeling.

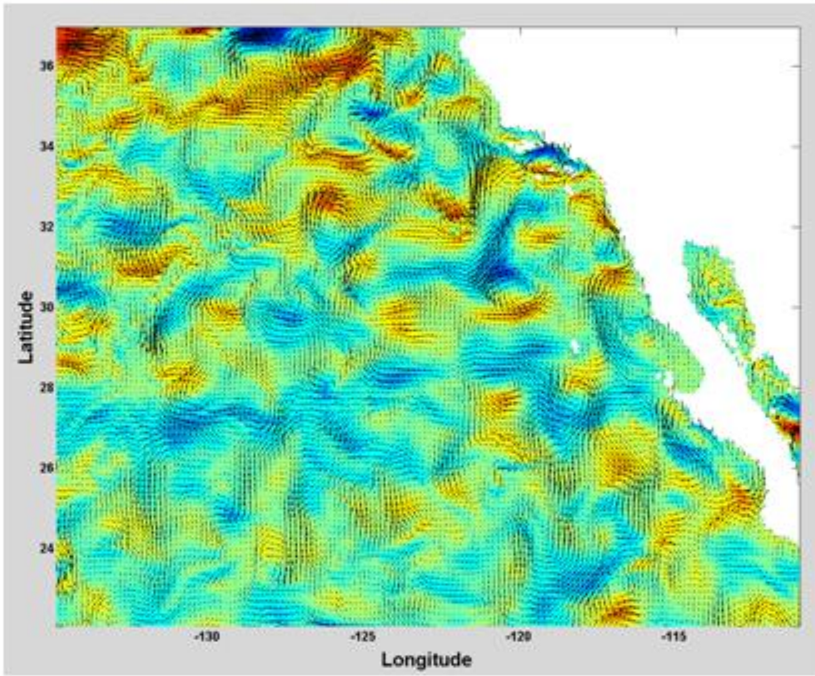


**Figure 97: Spatial Coverage of HYCOM in the California Study Region**
NOTE: model grid nodes and vectors may be strided out in this image due to the zoom. The model domain has a spatial resolution defined by a 1/12 degree grid in the horizontal direction.

### Arctic

Water and ice circulation data generated from the TOPAZ4 hydrodynamic model were used in this modelling study. TOPAZ stands for (Towards) an Operational Prediction system for the North Atlantic European coastal Zones. TOPAZ4 is a coupled ocean-sea ice data assimilation system for the North Atlantic and the Arctic. The dataset was developed by the Nansen Environmental and Remote Sensing Center (NERSC) and is publically available through the Norwegian Meteorological Institute. TOPAZ4 incorporates the hybrid coordinate ocean model (HYCOM, version 2.2) (Bleck, 2002) coupled with a sea-ice model (Hunke and Dukowicz, 1997), and a 100-member ensemble Kalman filter (EnKF) (Evensen, 1994) assimilating both *in situ* observations and satellite data. Wind stress for the TOPAZ4 model is from the ERA-40 (ECMWF RE-ANALYSIS) wind model (described in Section E.3). The EnKF assimilates remotely-sensed sea level anomalies, sea surface temperature, sea ice concentration, Lagrangian sea ice velocities (winter only), as well as temperature and salinity profiles from Argo floats. From the results of a 6-year pilot reanalysis, TOPAZ4 has been shown to produce a realistic estimate of the mesoscale ocean circulation in the North Atlantic, as well as the sea ice variability within the Arctic (Sakov et al., 2012).

In the implementation of HYCOM for the TOPAZ4 system, the vertical coordinate is isopycnal in the stratified open-ocean and z-coordinate in the unstratified surface mixed layer (Sakov et al., 2012). HYCOM was found to be the most suitable model for the large-scale Arctic water masses that span the stratified open ocean, regions of steep topography, and extensive sea ice. HYCOM is also flexible in that it provides sigma coordinates in coastal regions. However, sigma coordinates were not adopted because resolving coastal areas was not a primary objective of the TOPAZ4 project.

The model domain covers the North Atlantic and Arctic Ocean basins (Figure 98). The model grid is horizontal and created by a conformal mapping with the poles shifted to the side of the globe. This allows for a quasi-homogeneous grid size (Bentsen et al., 1999, Sakov et al., 2012). The model grid has 880 x 800 horizontal grid points and with horizontal spacing of approximately 7.5-9.9 miles (12-16 km ) in the open ocean (about 7.8 miles [12.5 km] at the north pole, equivalent to 1/8 degree). There are 28 hybrid layers (or z layers) in the vertical from the surface to a depth of 18,044 feet (5,500 m). Z-layer thickness can range from a minimum of 9.8 feet (3 m) to a maximum of 1476 feet (450 m; to resolve the deep mixed layer of the sub-polar gyre). The model bathymetry is based on the GEBCO database at 1-min resolution (GEBCO, 2009).

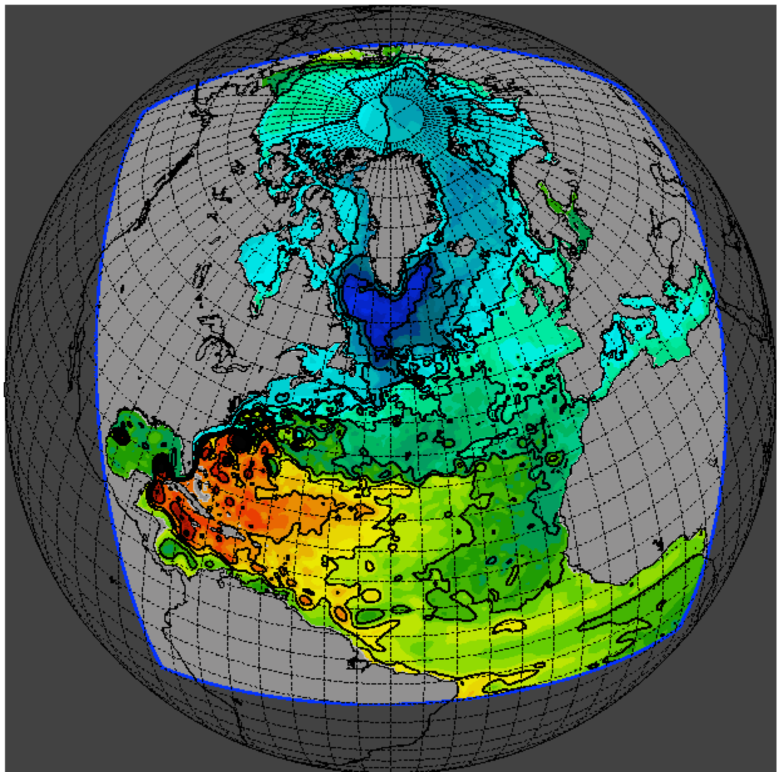

**Figure 98: The Entire Domain of the Outer Model of TOPAZ4 Arctic and Atlantic Oceans, Coloration Shows Snapshot of Sea Surface Height (Source: Samuelsen and Bertino, 2013)**

TOPAZ4 is coupled with a sea-ice model based on elastic-viscous-plastic (EVP) rheology (Hunke and Dukowicz, 1997). EVP is the standard fluid dynamics model used to predict the behavior of free moving sea ice. The EVP treats pack ice as a visco-plastic material that flows plastically under typical stress conditions, but behaves as a linear viscous fluid where strain rates are small and the ice becomes nearly rigid (Hunke and Dukowicz, 1997). Predicted currents and wind stress, together with the EVP accounting for behavior, are used to derive modelled sea ice velocities. These ice currents are then assimilated with remotely-sensed sea ice concentration (CRESAT) and Lagrangian sea ice velocities (winter only) using the EnKF. For more information, refer to Sakov et al. (2012) for detailed documentation of the complete TOPAZ4 Data Assimilation System.

The currents in the Beaufort Sea are driven by a combination of various oceanographic processes, such as, large-scale circulation features, winds, Mackenzie River discharges, and tidal forcing (IORVL, 2013). There are several large-scale circulation features in the Beaufort Sea, namely the anticyclonic Beaufort

Gyre and the Beaufort Shelf break/Slope Current. Circulation is dominated by the anticyclonic motion of the Beaufort Gyre that is driven by the Beaufort High, which results in a westward movement of the near-surface waters. The gyre transports some of the oldest and thickest ice in the Arctic from the region north of the Canadian Archipelago into the Beaufort Sea. The strength of the gyre can fluctuate annually and the ice motion can reverse for short time periods. The average winter drift is typically parallel to the coastline. The Beaufort Sea has a greater extent of landfast sea ice than the Chukchi Sea and is the largest freshwater storage area of the Arctic Ocean (Proshutinsky et al., 2009).

The principal circulation feature of the outer shelf and slope of the Beaufort Sea is the Beaufort shelf break jet, which flows along the edge of the shelf at depths of 50-200 m. This eastward flowing current transports Pacific-origin water towards the Canadian Arctic Archipelago, however, under enhanced easterly winds the current is subject to reversals to the west with current speeds up to 1 m/s (Schulze, 2012). In waters deeper than 200 m, there is an eastward movement of Atlantic Ocean water. It underlies a shallow flow regime, where the ice and upper ocean moves westward and represents the southern limb of the clockwise Beaufort gyre (Aagaard, 1989). These reversals are normally associated with upwelling onto the outer shelf and are basin-scale circulation within the Arctic Ocean. The currents over the shelf edge and continental slope are periodic with events occurring over a few days. This is due largely to the response to wind forcing as modulated by the local sea-ice cover, topographic waves, and mesoscale eddies (Carmack, 1998). Current measurements from 2009 to 2011 FDCPs identified current speeds as high as 99 cm/s in the upper 200 m of the water column and up to 47 cm/s in depths greater than 250 m (Osborne, 2012). These strong events are associated with northeasterly winds and resulted in ocean upwelling along the Beaufort Shelf edge and slope. Near the Mackenzie Trough, upwelling is enhanced and thus influences the currents along the shelf-break area.

On the inner shelf (landward of ~50 m isobaths), the circulation has a largely wind driven component, particularly in summer. During winter, the flow over the inner shelf is less energetic but still exhibits some wind influence. The main subsurface flow influence on the shelf is primarily ocean influence, while wind is of secondary importance and accounts for less than 25% of flow variance below 60 m (Aagaard, 1989). Proshutinsky et al. (2002) hypothesized that during winter, the wind drives the ice and ocean in an anticyclonic direction so that the Beaufort Gyre accumulates fresh water mechanically through a deformation of the salinity field. The strength of the horizontal salinity gradient and resultant geostrophic circulation depend on the intensity and duration of the anticyclonic winds. During summer, winds are weaker and sometimes will reverse direction, although the mean ice still rotates anticyclonically. This means that in summer the ocean geostrophic circulation prevails and may drive the ice against the wind motion (Proshutinsky et al., 2002).

The inner shelf surface currents are also influenced by the Mackenzie River plume and topography. The westerly winds result in strong alongshore currents, while easterly winds result in an offshore displacement of water from the Mackenzie River and pack ice (Carmack, 2002). The large discharges of fresh water from the Mackenzie River onto the shelf areas and beyond, plus the wind-dependent advection of these rivers waters, leads to frontal features with distance scales of tens of meters to tens of kilometers over the shelf and outer slope regions. Water from the Mackenzie River has been observed in the southern Canada Basin, as well as constrained to the coastline. The horizontal dispersion of this water depends upon the strength, frequency, and duration of northeasterly (upwelling-favorable) winds over the shelf, and has been detected along the continental slope as far west as 160°W. However, during years of frequent or strong downwelling winds, the Mackenzie River’s summer discharge is likely advected northeastward into the Canadian Archipelago (Melling, 1993). In winter, the Mackenzie shelf water is more saline due to enhanced ice production, which can alter the along-slope density gradient (Melling, 1993). Measurements related to Mackenzie River plume waters indicated strong horizontal gradients in the currents in relation to large horizontal salinity, temperature, and turbidity gradients. The upper 250 m of the water column consists of relatively cold, fresh Arctic Ocean surface water. Below the surface, from about 250 to 900 m, there is warmer and salty Atlantic water, while beneath 900 m, the water is cold and salty (Figure 99). Arctic surface water is composed of water from the Mackenzie River, melted sea ice, winter polar or surface mixed layer water, and upper halocline water that can include Pacific water (Lansard, 2012). Pacific summer water is warmer and fresher than Pacific winter water, with water temperatures reaching up to 1°C and salinity values range from 31 to 33 PSU (Lansard, 2012). The surface water is fresher in summer than winter due to the fresh water from melted sea ice and river runoff.

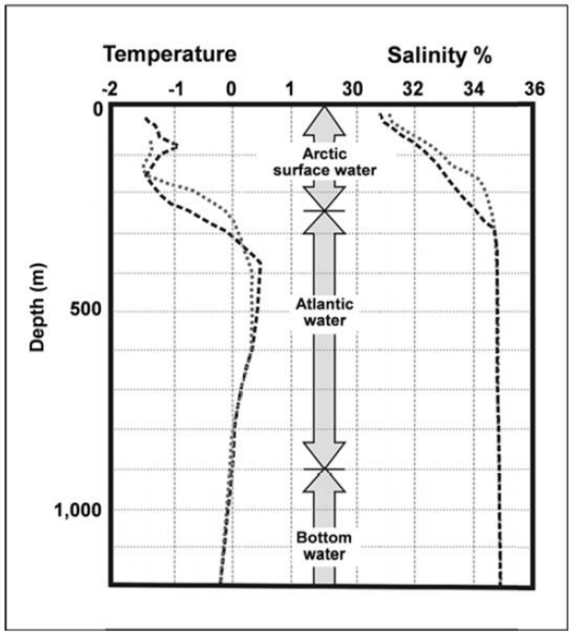


**Figure 99: Water Properties of Arctic Surface Water, Atlantic Water, and Bottom Water, Summer Profiles Are Indicated by the Dashed Black Line, While Winter Profiles Are Illustrated by the Light Dotted Line (Source: IORVL, 2013)**

For a previous project, RPS ASA downloaded the TOPAZ4 Arctic Reanalysis hindcast data product (2008-2011), and daily mean data product from the TOPAZ4 operational system (2011-2013) from the MyOcean web portal (http://myocean.met.no/) and used the same data in this project. Daily mean 3-dimensional current speed and direction, surface sea ice drift speed and direction, ice thickness, and ice coverage fraction have been acquired and processed for the period April 2008 - March 2013. Only a subset of the Arctic grid was retrieved for the region of interest (Beaufort and Chukchi Seas). The geographical coordinates of the subset are approximately 61° N to 90° N, and 170° W to 110° W (Figure 100).

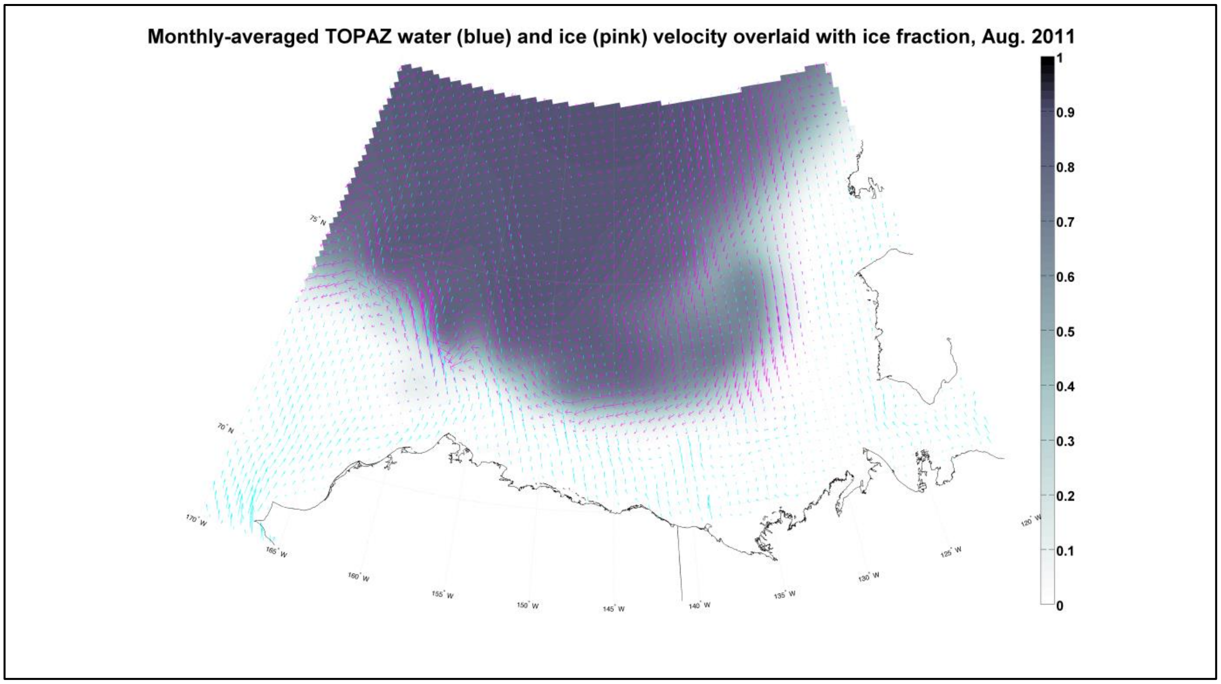


**Figure 100: TOPAZ4 Data Domain and Grid Node Resolution**
Note: Vector arrows show direction of the average monthly surface currents (blue) and ice currents (pink) for August 2011, as an example. Arrows are scaled by size to represent the average speed observed each grid node. The grey contours overlaid on the vector arrows represent the average ice coverage fraction for August 2011.

The TOPAZ4 model output also contains a variable for fraction of ice coverage, which was translated into percent ice coverage for this modeling study. Figure 101 and Figure 102 show contours in grey scale of the average spatial ice coverage for each month of 2011. All years in the TOPAZ4 dataset contain ice coverage information, but 2011 was selected to show monthly examples in this section as it best represented the general ice coverage observed across all years. In addition, the landfast ice polygons described in Appendix Care overlaid in each figure (shown in pink).

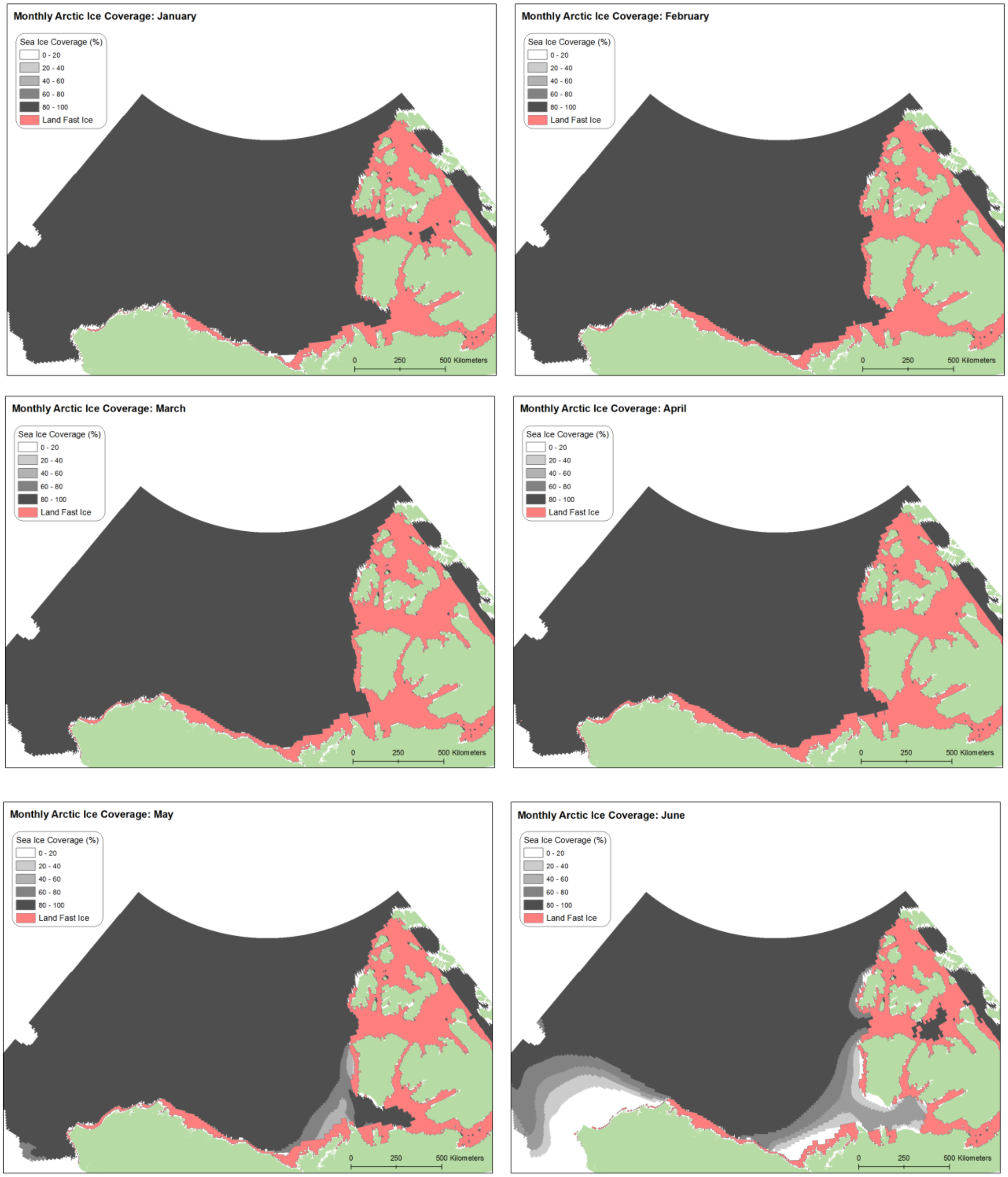


**Figure 101: North Alaska Maps Showing January - June Monthly Average Sea Ice Coverage and Landfast Ice Polygons**

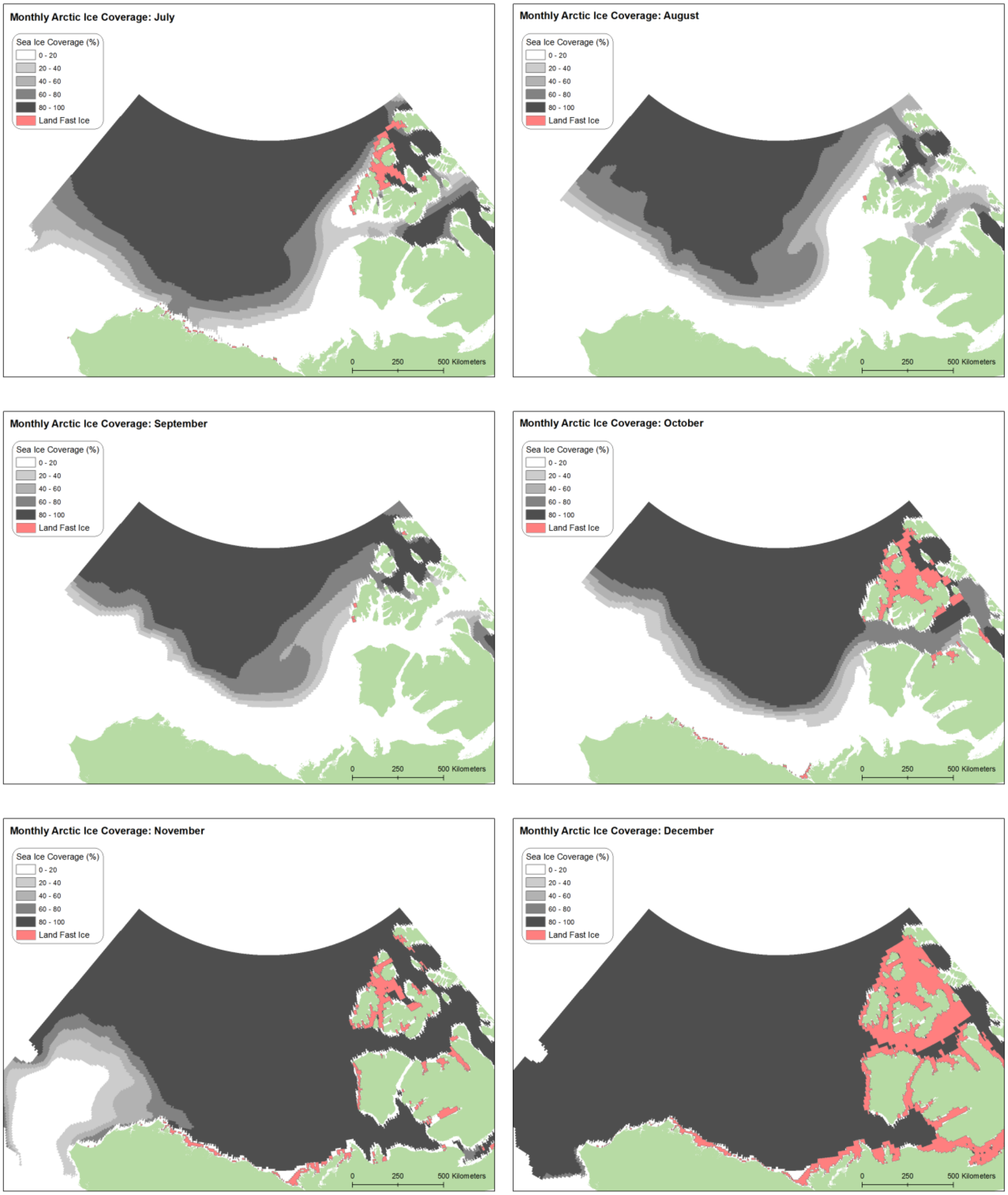


**Figure 102: North Alaska Maps Showing July - December 2011 Monthly Average Sea Ice Coverage and Landfast Ice Polygons**

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## D.5 References


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## APPENDIX E: OIL CHARACTERIZATION AND CHEMISTRY

This appendix provides the properties for the different oil types that were examined in each of the oil spill scenarios modeled.

South Louisiana Crude was selected as the representative oil for the most of the scenarios in the Gulf of Mexico location. This oil was assumed to have properties typical of oil potentially extracted from the region of interest.

**Table 52: Oil Properties of South Louisiana Crude Used in the Gulf of Mexico Location, Except for the West Cameron (WC168) Scenario**

| Oil Property | Value | Comments/References |
|---|---|---|
| **Density @ 16 deg. C (g/cm$^3$)** | 0.85241 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Viscosity @ 15 deg. C (cp)** | 10.1 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **API Gravity** | 34.5 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Surface Tension (dyne/cm)** | 30.0 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Pour Point (deg. C)** | -28.0 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Adsorption Rate to Suspended Sediment** | 0.01008 | From Kolpack et al. (1997) |
| **Adsorption Salinity Coefficient (/ppt)** | 0.023 | From Kolpack et al. (1997) |
| **Fraction monoaromatic hydrocarbons (MAHs)** | 0.01478 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Fraction 2-ring aromatics** | 0.003104 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Fraction 3-ring aromatics** | 0.005004 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Fraction Non-Aromatics: boiling point < 180ºC** | 0.16522 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) [103] |
| **Fraction Non-Aromatics: boiling point 180-264ºC** | 0.185896 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) [6] |
| **Fraction Non-Aromatics: boiling point 265-380ºC** | 0.275996 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999)[6] |

[103] Environment Canada's Oil Property Catalogue (Jokuty et al., 1999) provided total hydrocarbon data for volatile fractions of unweathered oil. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction of unweathered oil.

| Oil Property | Value | Comments/References |
|---|---|---|
| **Minimum Oil Thickness (mm)** | 0.01 | Based on McAuliffe (1987) |
| **Maximum Mousse Water Content (%)** | 75.0 | Lehr et al. (1992) |
| **Degradation Rate (/day), Surface & Shore** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (1-200 m)** | 0.1 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (>200 m)** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Oil in Sediment** | 0.001 | From French et al. (1996) |

South Louisiana Condensate was selected as the representative oil for the WC168 scenario. This oil was assumed to have properties typical of oil potentially extracted from the region of interest.

**Table 53: Oil Properties of South Louisiana Condensate Used for the West Cameron (WC168) Scenario in the Gulf of Mexico Location**

| Oil Property | Value | Comments/References |
|---|---|---|
| **Density @ 16 deg. C (g/cm$^3$)** | 0.748677 | Sleipner Condensate from: Environment Canada Oil Property Database as described in Jokuty et al. (1999) |
| **Viscosity @ 25 deg. C (cp)** | 2.0 | Sable Island Condensate from: Environment Canada Oil Property Database as described in Jokuty et al. (1999) |
| **API Gravity** | 57.5 | Sleipner Condensate from: Environment Canada Oil Property Database as described in Jokuty et al. (1999) |
| **Surface Tension (dyne/cm)** | 18.4 | Sable Island Condensate from: Environment Canada Oil Property Database as described in Jokuty et al. (1999) |
| **Pour Point (deg. C)** | -30.0 | Sleipner Condensate from: Environment Canada Oil Property Database as described in Jokuty et al. (1999) |
| **Adsorption Rate to Suspended Sediment** | 0.01008 | From Kolpack et al. (1997) |
| **Adsorption Salinity Coefficient (/ppt)** | 0.023 | From Kolpack et al. (1997) |
| **Fraction monoaromatic hydrocarbons (MAHs)** | 0.000011 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Fraction 2-ring aromatics** | 0.006745 | Henry (1997) |
| **Fraction 3-ring aromatics** | 0.002161 | Henry (1997) |

| Oil Property | Value | Comments/References |
|---|---|---|
| **Fraction Non-Aromatics: boiling point < 180ºC** | 0.729513 | Sleipner Condensate from: Environment Canada Oil Property Database as described in Jokuty et al. (1999)[104] |
| **Fraction Non-Aromatics: boiling point 180-264ºC** | 0.133143 | Sleipner Condensate from: Environment Canada Oil Property Database as described in Jokuty et al. (1999) |
| **Fraction Non-Aromatics: boiling point 265-380ºC** | 0.103427 | Sleipner Condensate from: Environment Canada Oil Property Database as described in Jokuty et al. (1999) |
| **Minimum Oil Thickness (mm)** | 0.01 | Based on McAuliffe (1987) |
| **Maximum Mousse Water Content (%)** | 0 | Assumed no emulsion formed due to chemical makeup of oil |
| **Degradation Rate (/day), Surface & Shore** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (1-200 m)** | 0.1 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (>200 m)** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Oil in Sediment** | 0.001 | From French et al. (1996) |

California Light Crude was selected as the representative oil for the scenario in the California location. This oil was assumed to have properties typical of oil potentially extracted from the region of interest.

**Table 54: Oil Properties of California Light Crude Used for the Scenario in the California Location**

| Oil Property | Value | Comments/References |
|---|---|---|
| **Density @ 16 deg. C (g/cm$^3$)** | 0.87454 | Environment Canada (2009) |
| **Viscosity @ 15 deg. C (cp)** | 22.0 | Environment Canada (2009) |
| **API Gravity** | 30.3 | Environment Canada (2009) |
| **Surface Tension (dyne/cm)** | 27.1 | Environment Canada (2009) |
| **Pour Point (deg. C)** | -22.0 | Environment Canada (2009) |
| **Adsorption Rate to Suspended Sediment** | 0.01008 | From Kolpack et al. (1997) |
| **Adsorption Salinity Coefficient (/ppt)** | 0.023 | From Kolpack et al. (1997) |

[104] Environment Canada's Oil Property Catalogue (Jokuty et al., 1999) provided total hydrocarbon data for volatile fractions of unweathered oil for Sleipner Condensate. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction of unweathered oil.

| Oil Property | Value | Comments/References |
|---|---|---|
| **Fraction monoaromatic hydrocarbons (MAHs)** | 0.026480 | Jokuty et al. (1999)[105] |
| **Fraction 2-ring aromatics** | 0.003974 | Jokuty et al. (1999)[8] |
| **Fraction 3-ring aromatics** | 0.006679 | Jokuty et al. (1999)[8] |
| **Fraction Non-Aromatics: boiling point < 180ºC** | 0.163520 | Jokuty et al. (1999)[8] |
| **Fraction Non-Aromatics: boiling point 180-264ºC** | 0.141226 | Jokuty et al. (1999)[8] |
| **Fraction Non-Aromatics: boiling point 265-380ºC** | 0.202121 | Jokuty et al. (1999)[8] |
| **Minimum Oil Thickness (mm)** | 0.05 | Environment Canada (2009) |
| **Maximum Mousse Water Content (%)** | 90.0 | Default value |
| **Degradation Rate (/day), Surface & Shore** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (1-200 m)** | 0.1 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (>200 m)** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Oil in Sediment** | 0.001 | From French et al. (1996) |

Alaskan North Slope Crude (2002) was selected as the representative oil for the Chukchi Sea location. This oil was characterized as a light to medium crude with high aromatic content and was assumed to have properties typical of oil potentially extracted from the region of interest.

**Table 55: Oil Properties of Alaskan North Slope Crude Used in the Scenario in the Chukchi Sea Location**

| Oil Property | Value | Comments/References |
|---|---|---|
| **Density @ 16 deg. C (g/cm$^3$)** | 0.87131 | Calculated density from API |
| **Viscosity @ 15 deg. C (cp)** | 11.5 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999). |
| **API Gravity** | 30.9 | Environment Canada characterization of Alaska North Slope (2002) |

[105] Calculated using the boiling curve from a reference oil (Alaskan North Slope Crude ADL) from Environment Canada database.

| Oil Property | Value | Comments/References |
|---|---|---|
| **Surface Tension (dyne/cm)** | 27.3 | Environment Canada characterization of Alaska North Slope (2002) |
| **Pour Point (deg. C)** | -32.0 | Environment Canada characterization of Alaska North Slope (2002) |
| **Adsorption Rate to Suspended Sediment** | 0.010080 | From Kolpack et al. (1977) |
| **Adsorption Salinity Coefficient (/ppt)** | 0.023000 | From Kolpack et al. (1977) |
| **Fraction monoaromatic hydrocarbons (MAHs)** | 0.02192 | Value calculated by RPS ASA from Environment Canada characterization of Alaska North Slope (2002) |
| **Fraction 2-ring aromatics** | 0.003076 | Value calculated by RPS ASA from Environment Canada characterization of Alaska North Slope (2002) |
| **Fraction 3-ring aromatics** | 0.007284 | Value calculated by RPS ASA from Environment Canada characterization of Alaska North Slope (2002) |
| **Fraction Non-Aromatics: boiling point < 180ºC** | 0.20408 | Value calculated by RPS ASA from Environment Canada characterization of Alaska North Slope (2002) |
| **Fraction Non-Aromatics: boiling point 180-264ºC** | 0.121224 | Value calculated by RPS ASA from Environment Canada characterization of Alaska North Slope (2002) |
| **Fraction Non-Aromatics: boiling point 265-380ºC** | 0.186616 | Value calculated by RPS ASA from Environment Canada characterization of Alaska North Slope (2002) |
| **Minimum Oil Thickness (mm)** | 0.05 | Based on McAuliffe (1987) |
| **Maximum Mousse Water Content (%)** | 72.9 | Value estimated by RPS ASA from Environment Canada characterization of Alaska North Slope (2002) |
| **Degradation Rate (/day), Surface & Shore** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (1-200 m)** | 0.1 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (>200 m)** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Oil in Sediment** | 0.001 | From French et al. (1996) |

Prudhoe Bay Crude-Low Volatile was selected as the representative oil for the scenario in the Beaufort Sea location. This oil was assumed to have properties typical of oil potentially extracted from the region of interest.

**Table 56: Oil Properties of Prudhoe Bay Crude – Low Volatile Used for the Scenario in the Beaufort Sea Location**

| Oil Property | Value | Comments/References |
|---|---|---|
| **Density @ 16 deg. C (g/cm$^3$)** | 0.905310 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Viscosity @ 15 deg. C (cp)** | 38.900002 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **API Gravity** | 24.8 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Surface Tension (dyne/cm)** | 30.0 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Pour Point (deg. C)** | 0.0 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Adsorption Rate to Suspended Sediment** | 0.023000 | From Kolpack et al. (1977) |
| **Adsorption Salinity Coefficient (/ppt)** | 0.02192 | Value calculated by RPS ASA from Environment Canada characterization of Alaska North Slope (2002) |
| **Fraction monoaromatic hydrocarbons (MAHs)** | 0.014620 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) |
| **Fraction 2-ring aromatics** | 0.013262 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999)[106] |
| **Fraction 3-ring aromatics** | 0.022661 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999)[8] |
| **Fraction Non-Aromatics: boiling point < 180ºC** | 0.125380 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) [8] |
| **Fraction Non-Aromatics: boiling point 180-264ºC** | 0.113738 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) [8] |
| **Fraction Non-Aromatics: boiling point 265-380ºC** | 0.194339 | Environment Canada Oil Property Database, as described in Jokuty et al. (1999) [8] |
| **Minimum Oil Thickness (mm)** | 0.1 | Based on McAuliffe (1987) |
| **Maximum Mousse Water Content (%)** | 74.0 | Lehr et al. (1992) |
| **Degradation Rate (/day), Surface & Shore** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Hydrocarbons in Water (1-200 m)** | 0.1 | From French et al. (1996) |

[106] Used ratio of Aromatic Hydrocarbon and Total Hydrocarbon boiling point < 180ºC (AR1 and TH1) to determine Aliphatic Hydrocarbon boiling point <180ºC (AL1). Used this ratio of AR1/AL1 and Total Hydrocarbons for the other boiling points (AR2, AL2, AR3, and AL3).

| Oil Property | Value | Comments/References |
|---|---|---|
| **Degradation Rate (/day), Hydrocarbons in Water (>200 m)** | 0.01 | From French et al. (1996) |
| **Degradation Rate (/day), Oil in Sediment** | 0.001 | From French et al. (1996) |

**Appendix E References**


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## APPENDIX F: WCD PORTFOLIO METADATA

The ArcGIS-10 compatible ArcMap™ document, or WCD portfolio, created for Task 1.2 of the project, displays the Worst Case Discharge points for the Gulf of Mexico, Pacific, and Alaska BSEE Regions. The worst case discharge points are displayed according to the estimated volume discharged at each location. The Official Protraction Diagrams (OPDs) are also displayed for each region. The map projection is North American Albers Equal Area Conic. This was selected as it works for all three BSEE regions, and keeps the Alaska region from being split across the International Date Line.

All the datasets (except the ESRI base map) are provided in an ESRI file geodatabase, which should reside in the same location as the ArcMap.mxd (to maintain linkage). Details about these datasets are provided below.

### Worst Case Discharge (WCD) Points

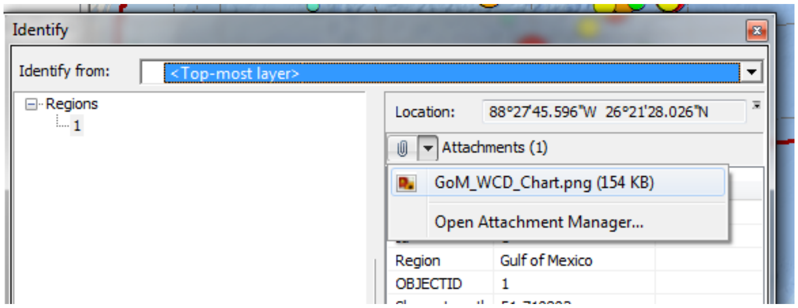
Worst Case discharge locations and information were provided by Gary Petrae from BSEE on 12/12/2014 and 7/8/15. The data were provided in an Excel spreadsheet. The spreadsheet included the latitude and longitude coordinates for most of the worst case discharge points. Those without coordinates are not included in the map. The spreadsheet was converted to an ESRI feature class and includes all the fields present in the spreadsheet as attributes.

### Official Protraction Diagrams (OPDs)

The protractions were downloaded for each BSEE region from BOEM (http://www.boem.gov/Maps-and-GIS-Data/) on 12/17/14. The format of the protraction data for each region was slightly different. All 3 regions were combined and similar fields were matched for each region. Fields that did not match other regions and did not contain any useful data were excluded. The protraction number is used as the label in the map, as it was unique and present for all regions.

### Regions

Region boundaries were generated for map display and navigation purposes, as well as to have a feature in the map to which charts could be linked. The regions were created by merging and dissolving all the protractions within each region. Attached to each region is a plot showing the Worst Case Discharge volumes versus distance to shore for that region. To access that plot use the Identify tool to click on the region. In the Identify pop-up window, it will show 1 attachment. From the dropdown menu you can select the attached image and load.




Another option to view these is to use the HTML Pop tool in ArcMap™. When you click on a region its attributes and a picture of the attached plot will load.

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## APPENDIX G: TABLE OF ACRONYMS

| Acronym | Definition |
|---|---|
| **BOEM** | Bureau of Ocean Energy Management |
| **BOP** | Blowout Preventer |
| **BSEE** | Bureau of Safety and Environmental Enforcement |
| **CERCLA** | Compensation and Liability Act of 1980 |
| **CRESAT** | With Remotely-Sensed Sea Ice Concentration |
| **CSE** | Coastal Science & Engineering, Inc. |
| **ECMWF** | For Medium-Range Weather Forecast |
| **EVP** | Elastic-Viscous-Plastic |
| **GEBCO** | General Bathymetric Chart of the Oceans |
| **GIS** | Geographic Information System |
| **GODAE** | Global Ocean Data Assimilation Experiment |
| **GOM** | Gulf of Mexico |
| **GOR** | Gas-To-Oil Ratio |
| **HFO** | Heavy Fuel Oil |
| **HTHP** | Higher Temperature and Higher Pressure |
| **IFT** | Interfacial Tension |
| **IORVL** | Imperial Oil Resources Ventures Limited |
| **ITOPF** | International Tanker Owners Pollution Federation Limited |
| **MPD** | Managed Pressure Drilling |
| **NERSC** | Nansen Environmental and Remote Sensing Center |
| **NOGAPS** | Navy Operational Global Atmospheric Prediction System |
| **NRDA** | Natural Resource Damage Assessment |
| **NRDAM/CME** | Natural Resource Damage Assessment Model For Coastal and Marine Environments |
| **NRDAM/GLE** | Assessment Model For the Great Lakes Environments |
| **NSIDC** | National Snow and Ice Data Center |
| **OCS** | Outer Continental Shelf |

| Acronym | Definition |
|---|---|
| **OSPD** | Oil Spill Preparedness Division |
| **OSRP** | Oil Spill Response Plan |
| **PAH** | Polycyclic Aromatic Hydrocarbons |
| **POM** | Princeton Ocean Model |
| **SSHA** | Sea-Surface Height Anomaly |
| **SST** | Sea-Surface Temperature |
| **THC** | Total Hydrocarbon Content |
| **TVD** | True Vertical Depth |
| **USDOI** | U.S. Department of the Interior |
| **WCD** | Worst Case Discharge |