DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL (DNREC) OIL SPILL MODELING AND IMPACTS ASSESSMENT

FINAL REPORT

Prepared by:

RPS

Jill Rowe, Stephanie Berkman, Deborah French-McCay, Joseph Zottoli, Matthew Frediani, Mahmud Monim, and Jenna Ducharme

55 Village Square Drive
South Kingstown RI 02879

T +1 401 661 8629
E Jill.Rowe@rpsgroup.com

Prepared for:

Industrial Economics (IEc) and Delaware Department of Natural Resources and Environmental Control (DNREC)

20-208409 Delaware DNREC Oil Spill Modelling

13 October 2020

This report was prepared by RPS using Federal funds under award NA19NOS4190140 from the Delaware Coastal Management Program and the Office for Coastal Management (OCM), National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the OCM, NOAA or the U.S. Department of Commerce.

Contents

Figures

Tables

EXECUTIVE SUMMARY

This modeling study explores potential impacts from hypothetical spill scenarios located offshore the U.S. Mid-Atlantic. Three of the six modeled spill locations are located 10 - 17 miles (mi) (16 - 27 kilometers [km]) offshore New Jersey, Delaware, and Virginia in areas of high vessel traffic and were chosen for simulations of vessels spills of 126 barrels (bbl); 2,240 bbl; and 200,000 bbl of crude oil (API of 37). The other three sites were located 50 - 70 mi (80 - 113 km) offshore New Jersey, Delaware, and Virginia in areas identified by the Bureau of Ocean Management and the Bureau of Safety and Environmental Enforcement (BOEM and BSEE) as potential lease sites and were chosen for subsea blowout models of 30,000 bbl/day over 30 days (900,000 bbl in total). Key conclusions of this study include:

- With one representative oil type used throughout the study, the model results are primarily controlled by the release volume, site location, and the use of response measures.
- The small and medium volume surface releases resulted in surface oil footprints that remained in nearshore waters of the state in which the spill occurred while the unmitigated high-volume surface releases resulted in larger footprints.
- When comparing the mitigated and unmitigated high-volume spill scenarios, the trajectories of the highest concentrations of floating oil followed similar paths but differences can be noted in the overall size of the surface and shoreline footprints.
- The location of the release site, relative to the shoreline was not an indicator for length of shoreline oiled; the length of shoreline oiled was primarily a result of the volume of oil released.
- The length of shoreline oiled increased with the volume for each scenario with the subsea blowouts oiling the longest stretch of shoreline, although released furthest shore.
- When response options were used for the high volume surface releases, the length of shoreline oiled dropped considerably when compared to the unmitigated scenarios.

Oil spills into offshore waters can result in trajectories that move in various directions, depending upon the winds and currents prevailing at the time. Thus, the impacts of oil spills are subject to the time sequence of environmental conditions at the time of and following the spill. The probability of various resources contacting oil was estimated using a probabilistic approach, which 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-time window. The random start time allows for the same type of spill to be analyzed under varying environmental conditions. In order to reproduce the natural variability of environmental conditions, historical wind and current data, which vary both spatially (multiple points) and temporally (changing with time), were used. In addition to presenting the probabilistic model results for each scenario, the individual deterministic model simulation resulting in the maximum shoreline length oiled (above a conservative threshold of concern) are provided; thus, representing the worst-case environmental condition for shoreline oiling. In addition, the worst case for each season from the largest (200,000 bbl releases) surface spill scenarios were modeled with spill response measures.

In general, for the modeling results from the Delaware spill location, there were low probabilities (less than 50%) for surface oiling greater than or equal to 1 grams per meter squared (g/m^2) (10 micrometer [μm], on average over a grid cell) outside of the area just around the spill sites. Probabilities greater than 1% for surface oiling exceeding 0.01 g/m^2 (0.01 μm, on average over a grid cell) consistently extended over 590 mi (950 km) to the east and outside of the model domain. Probabilities for shoreline oil contamination were highest directly west of the spill site, along the seaward southern coastline of Delaware and across Maryland, with oiling typically occurring within one day of the release. The shoreline oiling above 1 g/m^2 (1 μm, on average over a grid cell) threshold extended along the outer coast from south of Cape Lookout, NC to Cape Cod, MA.

For the modeling results from the New Jersey spill location, there were low probabilities (less than 50%) for surface oiling greater than or equal to 10 g/m^2 (10 μm, on average over a grid cell) outside of the area just around the spill sites. Probabilities greater than 1% for surface oiling exceeding 0.01 g/m^2 (0.01 μm, on average over a grid cell) consistently extended up to 450 mi (724 km) to the southeast and outside of the model domain. Probabilities for shoreline oil contamination were highest directly west of the spill site, along the seaward southern coastline of Delaware and across Maryland, with oiling typically occurring within one day of the release. The shoreline oiling above 1 g/m^2 (1 μm, on average over a grid cell) threshold extended along the outer coast from south of Martha's Vineyard, MA south to Hog Island Bay, VA.

For the modeling results from the Virginia spill location, there were low probabilities (less than 50%) for surface oiling greater than or equal to 10 g/m^2 (10 μm, on average over a grid cell) outside of the area just around the spill sites. Probabilities greater than 1% for surface oiling exceeding 0.01 g/m^2 (0.01 μm, on average over a grid cell) consistently extended over 570 mi (917 km) to the east and outside of the model domain. Probabilities for shoreline oil contamination were highest directly west of the spill site, along the seaward southern coastline of Delaware and across Maryland, with oiling typically occurring within one day of the release. The shoreline oiling above 1 g/m^2 (1 μm, on average over a grid cell) threshold extended along the outer coast from south of Cape Cod, MA to Cape Lookout, NC.

The annual and seasonal worst-case runs were selected based on the longest length of shoreline oiled above the most conservative threshold of concern (1.0 g/m^2). Table E-1 summarizes the final mass balance of the spilled oil at the end of the 30- or 75-day simulations for the Delaware location surface and blowout modeling scenarios, respectively. In all surface release cases, almost half of the released oil evaporated within the first five days of the release. Less than 1% of the released oil was predicted to remain at the end of the four 30-day surface simulations. The lengths of shoreline remaining oiled above threshold concentrations of concern are summarized in Table E-2 and the area of oiled shoreline inside or outside of the state of Delaware boundaries is summarized in Table E-3. Shoreline oiling was consistently at a maximum for cases that began in the summer, with the worst-case run for the three vessel releases occurring on June 25, 2018. Response deployment reduced the amount of shoreline oiling in a high-volume release from 354 mi (569 km) to 76 mi (123 km). Exposure to polycyclic aromatic hydrocarbons (PAHs) in the water column and maximum exposure time increase with spill volume in the unmitigated cases, with exposures at the most conservative threshold dissipating within 4 hours during the low volume release and 46 hours during the medium volume release. The degree of exposure to PAHs within the water column is higher in the mitigated high-volume case as response methods, specifically dispersant, break oil into smaller droplets, allowing for increased entrainment within the water column.

Table E-1. Mass balance at the end of the simulation for the worst-case run for shoreline oiling (on an annual basis) for each of the five scenarios at the Delaware release locations.

Spill Scenario	Season	Percent of Oil by End of Simulation				
		Surface	Atmos-phere	Shore-line	Water	Degraded
Low Volume	Summer	<1	52	29	7	11
Medium Volume	Summer	<1	49	31	8	12
High Volume (unmitigated)	Summer	<1	44	29	10	16
High Volume (mitigated)[a]	Summer	0	40	<1	16	20
Blowout[b]	Spring	8	47	19	4	19.7

[a]23% of released oil removed via response methods.
[b]2% of released oil left model domain in which it was no longer tracked.

Table E-2. Shoreline lengths oiled by >1 g/m^2 (1µm on average) for the run with maximum shoreline length oiled (on an annual basis) for each Delaware location spill scenario.

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Summer	141	44	0	227	71	0
Medium Volume	Summer	234	177	49	376	285	79
High Volume (unmitigated)	Summer	354	340	263	569	564	424
High Volume (mitigated)	Summer	76	76	48	123	122	77
Blowout	Spring	638	634	497	1,027	1,021	800

Table E-3. Shoreline area oiled by >1 g/m^2 (1µm on average) inside and outside of Delaware state boundaries for the run with maximum shoreline length oiled (on an annual basis) for each Delaware location spill scenario.

Spill Scenario	Location	Length Oiled (mi^2)			Length Oiled (km^2)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Delaware	0.2	0.0	0.0	0.4	0.0	0.0
	Outside	0.5	0.2	0.0	1.3	0.4	0.0
Medium Volume	Delaware	0.4	0.2	0.0	1.1	0.5	0.1
	Outside	2.4	0.6	0.2	6.1	1.7	0.6
High Volume (unmitigated)	Delaware	1.4	1.4	0.8	3.6	3.6	2.1
	Outside	6.6	6.3	3.1	17.1	16.4	8.0
High Volume (mitigated)	Delaware	0.1	0.1	0.0	0.3	0.3	0.0
	Outside	0.7	0.7	0.3	1.9	1.8	0.7
Blowout	Delaware	1.2	1.1	0.7	3.0	2.9	1.8
	Outside	11.5	11.2	6.8	29.7	29.0	17.5

Table E-4 summarizes the final mass balance of the spilled oil at the end of the 30- or 75-day simulations for the New Jersey location surface and blowout modeling scenarios, respectively. In all surface release cases, almost half of the released oil evaporated within the first five days of the release. Less than 4% of the released oil was predicted to remain at the end of the four 30-day surface simulations. The lengths of shoreline remaining oiled above threshold concentrations of concern are summarized in Table E-5 and the area of oiled shoreline inside or outside of the state of Delaware boundaries is summarized in Table E-6. Shoreline oiling was consistently at a maximum for cases that began in the spring, with the worst-case run for the three vessel releases occurring on May 1, 2018. Response deployment reduced the amount of shoreline oiling in a high-volume release from 307 mi (494 km) to 191 mi (307 km). Exposure to PAHs in the water column and maximum exposure time increase with spill volume in the unmitigated cases, with exposures at the most conservative threshold dissipating within 2 hours during the low volume release and 31 hours during the medium volume release. The degree of exposure to PAHs within the water column is higher in the mitigated high-volume case as response methods, specifically dispersant, break oil into smaller droplets, allowing for increased entrainment within the water column.

Table E-4. Mass balance at the end of the simulation for the worst-case run for shoreline oiling (on an annual basis) for each of the five scenarios at the New Jersey release locations.

Spill Scenario	Season	Percent of Oil by End of Simulation				
		Surface	Atmos-phere	Shore-line	Water	Degraded
Low Volume	Spring	2	53	30	6	9
Medium Volume	Spring	2	51	31	6	10
High Volume (unmitigated)	Spring	4	46	28	9	13
High Volume (mitigated)[a]	Spring	<1%	44	11	9	12.8
Blowout[b]	Spring	10	49	17	4	18

[a]23% of released oil removed via response methods.
[b]2% of released oil left model domain in which it was no longer tracked.

Table E-5. Shoreline lengths oiled by >1 g/m^2 for the run with maximum shoreline length oiled (on an annual basis), for each New Jersey spill scenario.

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Spring	140	51	0	226	82	0
Medium Volume	Spring	218	161	43	351	259	70
High Volume (unmitigated)	Spring	307	305	215	494	491	347
High Volume (mitigated)	Spring	191	190	135	307	305	217
Blowout	Spring	530	527	400	854	848	643

Table E-6. Shoreline area oiled by >1 g/m^2 inside and outside of the Delaware state territory for the run with maximum shoreline length oiled (on an annual basis), for each New Jersey spill scenario.

Spill Scenario	Location	Length Oiled (mi^2)			Length Oiled (km^2)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	0.0	0.2	0.7	1.9	0.4	0.0
Medium Volume	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	0.3	0.9	1.2	3.1	2.2	0.7
High Volume (unmitigated)	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	2.0	3.9	4.0	10.4	10.1	5.2
High Volume (mitigated)	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	1.1	1.8	1.9	5.0	4.7	2.8
Blowout	Delaware	1.1	1.5	1.5	4.0	4.0	2.9
	Outside	7.3	11.1	11.4	29.5	28.7	19.0

Table E-7 summarizes the final mass balance of the spilled oil at the end of the 30- or 75-day simulations for the Virginia location surface and blowout modeling scenarios, respectively. In all surface release cases, almost half of the released oil evaporated within the first five days of the release. Less than 5% of the released oil was predicted to remain at the end of the four 30-day surface simulations. The lengths of shoreline remaining oiled above threshold concentrations of concern are summarized in Table E-8 and the area of oiled shoreline inside or outside of the state of Delaware boundaries is summarized in Table E-9.

Shoreline oiling was at a maximum in the winter for low- and medium-volume releases and in the summer for the high-volume release and blowout. Response deployment reduced the amount of shoreline oiling in a high-volume release from 430 mi (692 km) to 225 mi (363 km). Exposure to PAHs in the water column and maximum exposure time increase with spill volume in the unmitigated cases, with exposures at the most conservative threshold not expected during the low volume release and 17 hours during the medium volume release. The degree of exposure to PAHs within the water column is higher in the mitigated high-volume case as response methods, specifically dispersant, break oil into smaller droplets, allowing for increased entrainment within the water column.

Table E-7. Mass balance at the end of the simulation for the worst-case run for shoreline oiling (on an annual basis) for each of the five scenarios at the Virginia release locations.

Spill Scenario	Season	Percent of Oil by End of Simulation				
		Surface	Atmos-phere	Shore-line	Water	Degraded
Low Volume	Winter	5	55	22	8	10
Medium Volume	Winter	3	53	22	11	11
High Volume (unmitigated)	Summer	1	46	39	6	8
High Volume (mitigated)[a]	Summer	0	43	21	8	10
Blowout[b]	Summer	3	45	19	4	22

[a]18% of released oil removed via response methods.
[b]7% of released oil left model domain in which it was no longer tracked.

Table E-8. Shoreline lengths oiled by >1 g/m^2 for the run with maximum shoreline length oiled (on an annual basis), for each spill scenario offshore Virginia.

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m²	>10g/m²	>100g/m²	>1g/m²	>10g/m²	>100g/m²
Low Volume	Winter	142	14	0	228	22	0
Medium Volume	Winter	210	173	38	338	278	62
High Volume (unmitigated)	Summer	430	415	245	692	668	395
High Volume (mitigated)	Summer	225	217	122	363	349	196

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m²	>10g/m²	>100g/m²	>1g/m²	>10g/m²	>100g/m²
Blowout	Summer	458	454	340	738	731	548

Table E-9. Shoreline area oiled by >1 g/m² inside and outside of Delaware state territory for the run with maximum shoreline length oiled (on an annual basis), for each spill scenario offshore Virginia.

Spill Scenario	Location	Length Oiled (mi²)			Length Oiled (km²)		
		>1g/m²	>10g/m²	>100g/m²	>1g/m²	>10g/m²	>100g/m²
Low Volume	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	0.9	0.1	0.0	2.2	0.2	0.0
Medium Volume	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	1.7	1.0	0.2	4.4	2.7	0.6
High Volume (unmitigated)	Delaware	0.03	0.03	0.01	0.1	0.1	0.0
	Outside	19.3	18.1	9.3	50.0	46.8	24.1
High Volume (mitigated)	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	9.0	8.2	3.4	23.3	21.3	8.9
Blowout	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	13.5	13.1	7.2	34.9	34.0	18.5

1 INTRODUCTION

For the Delaware Department of Natural Resources and Environmental Control (DNREC), RPS Ocean Science was contracted by Industrial Economics, Incorporated (IEc) to assess the trajectory and fate of released oils using RPS' SIMAP model for twelve hypothetical release scenarios off the continental shelf of Delaware, New Jersey, and Virginia both without and with spill response mitigation. The results of this analysis will be used by IEc to assess the socioeconomic impacts of oil spills to the state of Delaware. Key conclusions of this study include:

- With one representative oil type used throughout the study, the model results are primarily controlled by the release volume, site location, and the use of response measures.
- The small and medium volume surface releases resulted in surface oil footprints that remained in nearshore waters of the state in which the spill occurred while the unmitigated high-volume surface releases resulted in larger footprints.
- When comparing the mitigated and unmitigated high-volume spill scenarios, the trajectories of the highest concentrations of floating oil followed similar paths but differences can be noted in the overall size of the surface and shoreline footprints.
- The location of the release site, relative to the shoreline was not an indicator for length of shoreline oiled; the length of shoreline oiled was primarily a result of the volume of oil released.
- The length of shoreline oiled increased with the volume for each scenario with the subsea blowouts oiling the longest stretch of shoreline, although released furthest shore.
- When response options were used for the high volume surface releases, the length of shoreline oiled dropped considerably when compared to the unmitigated scenarios.

Hydrocarbon release scenarios were simulated using the SIMAP oil spill modeling system in its two different modes, in order to first evaluate the probable effects associated with varying environmental conditions (i.e., stochastic mode) and then to evaluate the details of each spill type under a set of conditions representative of a worst-case situation (i.e., deterministic mode). SIMAP simulations were performed using multiple years of wind and current condition data from across the Mid-Atlantic Bight (MAB) in order to capture the range of potential environmental conditions.

Representative worst-case spill events were identified from the suite of individual trajectories simulated in the stochastic analyses and were selected based on the greatest length of shoreline oiled above a conservative threshold of concern. These spills were used to characterize a probable event trajectory and oil mass balance. Furthermore, response modeling (i.e., surface dispersant, mechanical removal, and in-situ burning [ISB]) was conducted on selected representative spill events.

This report presents a summary of the modeling methodology and a description of the spill scenario in Section 2. Section 3 provides the model results for the hypothetical oil releases. Conclusions based on the modeling results are included in Section 4.

2 METHODS

2.1 Oil Transport and Fate Model

The SIMAP oil transport and fate model (French-McCay 2003, 2004; French-McCay et al. 2018b; summarized in Annex A of this report) quantifies oil trajectory, concentrations of oil hydrocarbon components as droplet and dissolved phases in the water column, areas swept by floating oil of varying mass concentrations and thicknesses, shorelines oiled to varying degrees, and amount of oil settling to sediments. Processes simulated by SIMAP include spreading (gravitational and by currents shearing the oil apart), evaporation of volatile oil components from surface oil, transport on the surface and in the water column, turbulent diffusion (random movements from small-scale motions, i.e., mixing), emulsification (incorporation of water droplets into the oil to form mousse), entrainment of oil as droplets into the water column due to waves (either without or facilitated by dispersant application), dissolution of soluble and semi-soluble hydrocarbon (S/SS-HC) components, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended particulate matter, adsorption of semi-soluble hydrocarbons to suspended particulate matter, sedimentation, stranding on shorelines, and degradation (based on component-specific biodegradation and photo-oxidation rates). The model tracks soluble and semi-soluble components of the oil (i.e., monoaromatic hydrocarbons [MAHs, such as benzene, toluene, ethylbenzene and xylene, BTEX], polycyclic aromatic hydrocarbons [PAHs], and soluble alkanes; i.e., S/SS-HCs), as well as insoluble volatile aliphatic hydrocarbons, separately from high-molecular weight non-volatile and insoluble components of the oil. These components are modeled in groups of hydrocarbons with similar physical-chemical properties, termed pseudo-components. Sublots of the discharged oil are represented by Lagrangian Elements ("spillets"), each characterized by location, state (floating, droplet in water, sedimented, ashore), mass of the various hydrocarbon components, water content, thickness, diameter, density, viscosity, and associated suspended particulate matter mass. A separate set of Lagrangian Elements is used to track mass and movements of the dissolved hydrocarbons. A detailed description of the model algorithms and assumptions is in French-McCay et al. (2018b). The floating oil entrainment model is also described in detail in Li et al. (2017).

The SIMAP model has been validated with data from >20 large oil spills, including the *Exxon Valdez*, *North Cape* and Deepwater Horizon (DWH) oil spills (French and Rines 1997; French-McCay 2003, 2004; French-McCay and Rowe 2004; French-McCay et al. 2015, 2016, 2018a,b), as well as test spills designed to verify the model (French et al. 1997). These studies showed that oil trajectories depended primarily on the current and wind data input to the model.

2.2 Thresholds of Concern

The model results are presented as lengths of shoreline and areas and volumes of water where oil exposure exceeds specified thresholds of concern. Thresholds of concern were reviewed by French-McCay (2009, 2016) and French-McCay et al. (2018a), based in part on work described in French-McCay (2002, 2003, 2004). Thresholds are expressed throughout this study as an area-based concentration or loading (grams per meter squared [g/m^2]; 1 g/m^2 is approximately 1 micrometer (µm) thick oil, on average, if the oil is not emulsified or up to approximately 6 µm thick if emulsified) of floating or shoreline oil that could potentially adversely affect a resource (French-McCay 2009; French-McCay 2016). The following thresholds, based on these reviews, are considered and in accordance with current practice in oil spill risk assessments.

Floating Surface Oil Thickness Thresholds: ≥0.01 g/m^2 (~0.01 µm thick on average over the grid cell) and ≥10 g/m^2 (~10 µm thick on average over the grid cell)

- Oil sheens at the minimum concentration of 0.01 g/m^2 are just barely visible (National Oceanic and Atmospheric Administration's (NOAA) 2016; Bonn 2009, 2011).
- Effects on socioeconomic resources may occur (e.g., fishing may be prohibited) if oil is visible on the water surface, i.e., ≥0.1 g/m^2.
- Effects on wildlife (birds, mammals, reptiles) may occur if oil on the water surface is ≥ 10 g/m^2.

Shoreline Thickness Thresholds: ≥1 g/m^2 (~1 µm thick on average over the grid cell) and ≥100 g/m^2 (~100 µm thick on average over the grid cell)

- The threshold 1 g/m^2 represents an oil amount that would appear as a dull brown color.
- Effects on socioeconomic resources may occur (e.g., need for shoreline cleanup) above a threshold of 1 g/m^2.
- Effects on shoreline biological resources would be expected above a threshold of 100 g/m^2.

Water Concentration Threshold: ≥1 µg/L and 10 µg/L total dissolved PAH

Effects on sensitive early life history stages of fish and invertebrates may occur at concentrations above approximately 1 microgram per liter (µg/L) (1 part per billion (ppb)) of dissolved aromatics (i.e., PAHs, compounds of which make up most of the exposure concentrations). The threshold for species of typical sensitivity is about 10 µg/L (10 ppb) of dissolved PAH. Older animals are typically not affected by dissolved PAH concentrations below 100 ppb. (See French-McCay 2002, 2016 and French-McCay et al. 2018 for further background on these thresholds).

2.3 Probabilistic Modeling

Oil spills into offshore waters can result in trajectories that move in various directions, depending upon the winds and currents prevailing at the time. Thus, the effects of oil spills are subject to the time sequence of environmental conditions at the time of and following the spill. Winds vary hour to hour with the passage of fronts and storms, and nearshore there are typically diel changes due to sea and land breezes. Tidal forces induce oscillatory currents, such that oil may move in opposite directions depending upon the timing of the release.

Probabilistic (or “stochastic”) modeling is used to evaluate the likelihood of various locations and resources being exposed to oil. It is based on a statistical analysis of results generated from many different individual trajectories of the same type of spill scenario. Each trajectory has a different spill start time sampled from a relatively long-term window. The various start times allow for the same type of spill to be analyzed under varying environmental conditions. The favored approach is to use historical observed or modeled multiple-year winds and currents and perform the simulations within the coinciding time period, as this allows reproduction of the natural variability of the wind and current directions and speeds. Optimally, the minimum time window for stochastic analysis is five or more years. Examples of such an approach are contained in oil spill risk assessments performed by the Bureau of Ocean Energy Management (BOEM; e.g., Ji et al. 2002; BOEM 2012, 2017b,c; Bejarano et al. 2013), the Bureau of Safety and Environmental Enforcement (BSEE; Buchholz et al. 2016), the U.S. Fish and Wildlife Service (e.g., Wilson et al. 2018), and French-McCay et al. 2005, 2012, 2014, 2018a).

The stochastic analysis provides two types of information: 1) areas associated with probability of oiling, and 2) the shortest time required for oil to reach any point within the areas predicted to be oiled. The predicted cumulative footprint or area and probabilities of oiling are generated by a statistical analysis of all the individual trajectories. The analysis evaluates areas affected and concentrations over a prescribed minimum threshold, and at oiling probabilities above a certain percent (e.g., >1%). Stochastic modeling results include predicted spatial distributions of hydrocarbons and probabilities that water surface, water column, and shoreline areas will be affected, as well as oil exposure levels. These exposures are described and summarized in tables of statistics for indices of interest (e.g., water surface swept by oil, shoreline oiled, water volume contaminated, etc.).

To evaluate worst-case exposure conditions, individual (“deterministic”) trajectories are selected from the stochastic parent scenario that are representative of a specific condition or exposure level (e.g., 99th percentile for shoreline oiling) to evaluate oil fate and weathering information in detail. In addition to a specific trajectory, the results of the deterministic simulations provide a time history of oil weathering over the duration of the spill (mass balance), expressed as the percentage of spilled oil on the water surface, on the shoreline, evaporated, entrained in the water column, and degraded. Deterministic model results include mass balance graphs; tabular exposure information (such as area of water surface exposed to floating oil, shoreline length/area oiled by shore/habitat type); and maps of individual trajectories showing mass of floating surface oil, water column concentrations, and shoreline oiling.

Figure 2-1 illustrates the stochastic modeling process. The left panel of Figure 2-1 shows four individual trajectories predicted by SIMAP for an example scenario. Because these trajectories started on different dates/times, they were exposed to varying environmental conditions, and travelled in different directions. To compute the stochastic results, all individual trajectories (such as the four depicted in Figure 2-1) were overlain and the number of times that a given location is reached by different trajectories was used to calculate the probability of oiling for that location. This is shown as the stacked runs in the right panel of Figure 2-1. The predicted cumulative footprint and probabilities of oiling were generated by a statistical analysis of all the individual trajectories. It is important to note that a single trajectory encountered only a relatively small portion of the overall probability footprint. Thus, the probability map depicts the likelihood that oil would reach each location given a spill of the specified magnitude occurring at some unknown time. This information may be presented for surface oil, shoreline oil, and subsurface oil. Also, the results of individual trajectories may be examined.

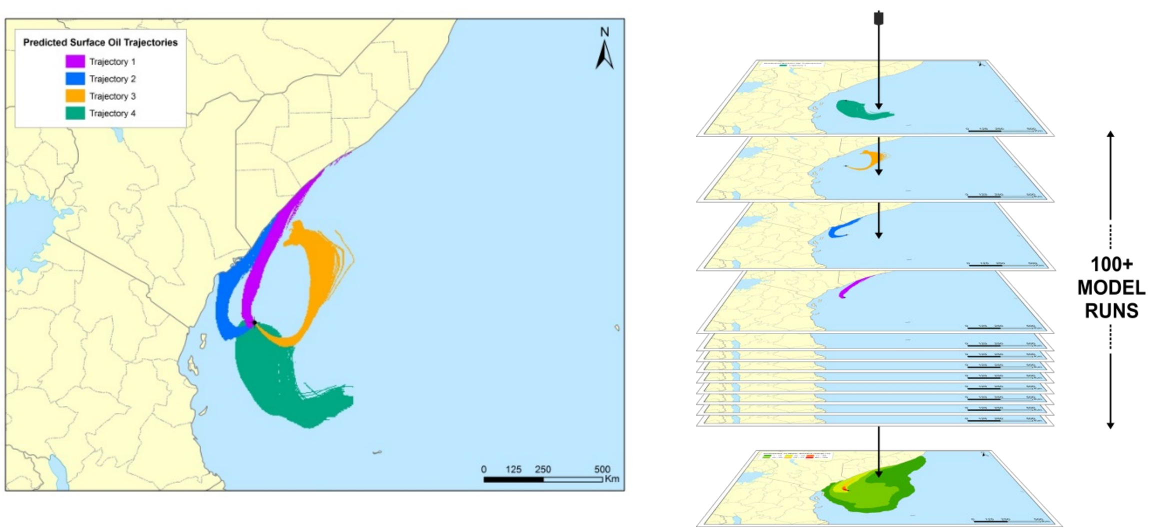


Figure 2-1. Examples of four individual spill trajectories predicted by SIMAP for a generic spill scenario. All 100+ individual trajectories are overlain (shown as the stacked runs on the right), and the frequency of contact with given locations is used to calculate the probability of being affected during a spill.

The stochastic analysis provides three types of information: 1) areas associated with probabilities of oiling; 2) the potential degree of the oil exposure (i.e., concentrations and oil loading), and 3) the shortest time required for oil to reach any point within the areas predicted to be oiled. The stochastic analysis typically evaluates probabilities, as well as areas and concentrations affected, over a minimum threshold value. Often these thresholds are based on response requirements or environmental effects endpoints. For this study, the following thresholds (based on French-McCay 2016 review) were assessed to summarize the stochastic analysis as described in Section 2.2:

- Floating Surface Oil Thickness Threshold: ≥0.01 g/m^2 (~0.01 µm thick on average) and ≥10 g/m^2 (~10 µm thick on average)
- Shoreline Thickness Threshold: ≥1 g/m^2 (~1 µm thick on average) and ≥100 g/m^2 (~100 µm thick on average)

The stochastic analysis provides insight into the probable behavior of oil spills given historic wind and current data for the region. In addition, charts of oil weathering information and mass balance provide information on the state and environmental compartments of the released oil over time. The results of individual simulations provide a time history of oil weathering over the duration of the spill (mass balance), expressed as the percentage of spilled oil on the water surface, on the shoreline, in the atmosphere (evaporated or volatilized), in the water column (either as oil droplets or dissolved), and degraded. For these mass balance charts, the individual deterministic model simulation resulting in the maximum shoreline length oiled is shown, as a worst-case.

2.4 Scenario Specifications

Twelve stochastic scenarios were modeled using six different discharge locations and four release volumes. The spill locations used for modeling were the approximate center of a primary offshore lightering track offshore Delaware Bay at 38.4875°N, 74.7334°W; Wilmington Canyon at 38.7017°N, 73.5403°W; location of high vessel traffic offshore New Jersey at 40.1113°N, 73.8329°W; Hudson Canyon at 39.2658°N, 73.1658°W; location of high vessel traffic offshore Virginia at 36.8231°N, 75.7494°W and; offshore Virginia approximately the same distance from shore and depth as Delaware and New Jersey well (canyon) sites at 37.2886°N, 74.7109°W . Separate modeling scenarios were run for each release location with one oil type (Table 2-1). For all three nearshore locations, three volumes (126 barrels [bbl]; 2,240 bbl; or 200,000 bbl) of discharged oil were simulated. For all three offshore locations, a discharge of 30,000 bbl/day over 30 days (900,000 bbl of oil in total) was simulated to represent a blowout scenario. A total of 400 runs were performed for each stochastic scenario, sampled between the period of 04/01/2018 – 04/20/2020, which corresponds to the metocean data timeseries. Each nearshore simulation was modeled for a total of 30 days and offshore simulations were modeled for 75 days. The ensemble of the stochastic scenarios is listed in Table 2-1 and results presented in Section 3.2.

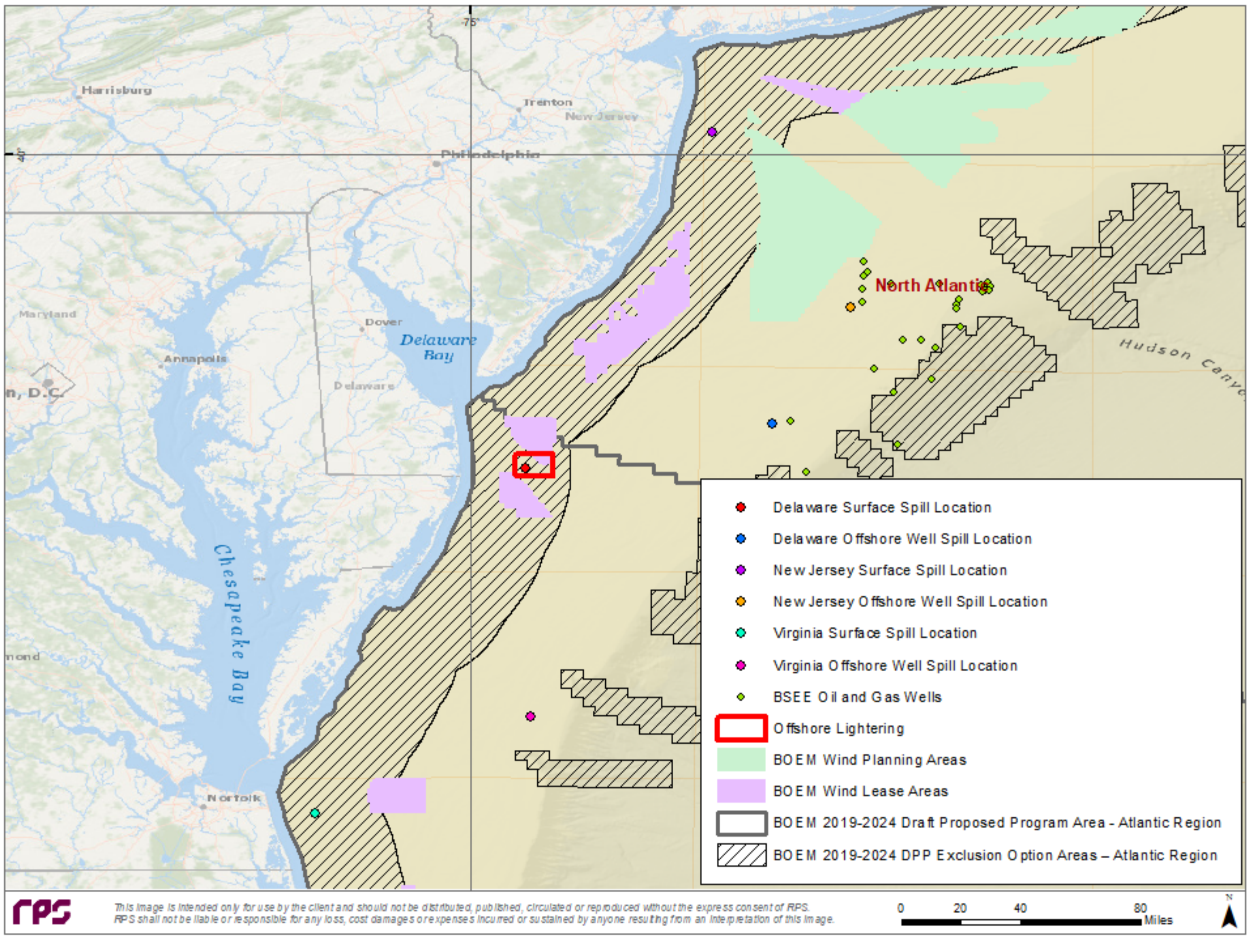


Figure 2-2. Locations of hypothetical surface and subsurface oil releases off of Delaware, New Jersey and Virginia

Representative "worst-case" (deterministic) spill events were identified for annually and for each season from the suite of individual trajectories simulated in the stochastic analyses. Worst-case spill events were selected based on the maximum length of shoreline oiled (>1.0 g/m^2). These spills were used to characterize a probable event trajectory and oil mass balance. Furthermore, response modeling (i.e., surface dispersant, mechanical removal, and ISB) was conducted on the high-volume surface release scenarios for each season. The results of the scenarios described in Table 2-2 are presented in Section 3.

2.4.1 Background for Spill Volume Development

The spill volumes for this modeling study were determined based on U.S. Coast Guard (USCG) spill response planning volumes and BOEM National Environmental Policy Act (NEPA) planning documents.

USCG Spill Response Planning Volumes

USCG Spill response planning volumes (33 CFR § 155.1020, 33 CFR § 154.1020, and 33 CFR § 155.1050) are sometimes used for oil spill risk analyses of spills into water. Planning volumes for offshore and coastal marine areas are classified as:

- Average Most-Probable Discharge (AMPD): 50 bbl or 1% of facility's worse-case discharge (WCD)
- Maximum Most-Probable Discharge (MMPD; Vessel): 2,500 bbl of oil for vessels with an oil cargo capacity equal to or greater than 25,000 barrels or 10% of fuel/cargo capacity up to 2,500 bbl
- Worst-Case Discharge (WCD; Vessel): Entire contents of oil cargo and/or fuel capacity

BOEM NEPA Practices

In its most recent NEPA planning documents for evaluating potential oil spills related to Outer Continental Shelf (OCS) oil and gas activities[1], the BOEM reported the median size of large spills (defined as those ≥1,000 bbl) that occurred during 1996-2010 as 2,240 bbl (BOEM 2017d, e). This size was calculated based on the nine spills (both platforms/rigs and pipelines) that occurred during this timeframe and did not include the DWH oil spill. BOEM (2017d, e) reported the median size of the large spills (>1000 bbl) from platforms was 5,066 bbl and from pipelines was 1,720 bbl, while spills from other sources were much smaller. BOEM (2017e) reported that the maximum spill volume from a platform (not including DWH) was 7,000 bbl, and that from a pipeline was 1,200 bbl. The median spill size for spills 50-999.9 bbl was 126 bbl (BOEM, 2017e). It should be noted that large spills are highly unlikely to occur, since most oil spills are of very small volumes (BOEM, 2017a, d, e).

BOEM (2017a) published a separate report with its analysis of catastrophic spill events, which would include high-volume extended releases (such as blowouts) due to natural (e.g., hurricane) or human (error or terrorism) cause. In their assessment, if a blowout were to occur in shallow water (<1,000 ft, 305 m), it could take 2 weeks to 3 months to stop the spillage. If a blowout were to occur in deep water (>1,000 ft), it could take 2 weeks to 4 months to stop the spillage. The floating oil could persist in the environment for 1-2 months after the release is stopped. In their assessment, BOEM (2017a) assumed 30,000 bbl/day for a

[1] https://www.boem.gov/nepaprocess

shallow water blowout and 30,000 – 60,000 bbl/day for a deep water blowout (the midpoint of which, 45,000 bbl/day, has been assumed in recent deep water modeling, French-McCay et al. 2018a, based on BOEM, 2013). Offshore of Delaware, the 60 meter (m) depth contour is approximately 30-50 nautical mi [nm] (35-58 mi) offshore. Thus, the potential area for development and a blowout would be classified as shallow water.

Tankers

The largest tankers delivering crude to the Delaware River refineries are about 150,000 dead weight ton (dwt), with vessel size varying between 85,000 and 150,000 dwt. These tankers are classified as Suezmax. However, occasionally a Very Large Crude Carrier (VLCC) or Ultra Large Carrier (ULCC) is brought into Delaware Bay in a partially laden condition and completely offloaded by barge at Big Stone Anchorage (Riker et al. 1981). One dwt is equivalent to approximately 6.3 bbl. Thus, the maximum crude oil cargo of one Suezmax vessel is ~945,000 bbl. The cargo of a VLCC is ~2 million bbl.

Oil Spill Volumes

The medium and small oil volumes were selected based on BOEM NEPA practice. The largest spill was based on a 10% loss of a tanker cargo of crude oil.

High: Worst Credible Discharge: Assuming VLCCs would be lightered off Delaware and 10% of the cargo were spilled (based on the USCG MMPD planning volume calculation method, which would be an assumption of 2 out of 20 tanks of a typical VLCC being breached), 200,000 bbl would be released (assumed over 1 hour). The spilled oil will be tracked for 30 days after the release ends.

Medium: 2,240 bbl released over 1 hour, tracked for 30 days after release ends (based on recent BOEM NEPA practice), which is similar to a MMPD as per the USCG Spill Response Plan guidance.

Low: 126 bbl released over 1 hour, tracked for 30 days after release ends (based on the median size spill for spills in the 50-999.9 bbl range; BOEM 2017d).

Well Blowout: Based on BOEM (2017a) for a shallow water blowout, 30,000 bbl/day over 30 days (900,000 bbl in total) and tracked for 45 days after release ends (the spill duration being within possible range but not worst case, based on BOEM [2017a] estimates).

2.4.2 Response Parameters for High Volume Deterministic Scenarios:

The response parameters included in this modeling study were surface dispersant, mechanical removal, and ISB. Assumptions used in this study are based on the analysis of French-McCay et al. (2017, 2018).

Surface Application of Dispersants: It was assumed that sufficient dispersant supplies are available to treat all actionable floating oil and that application is not restricted. The geographic area where surface dispersant use was assumed to occur is in pre-approval areas in Area Contingency Plans: not within a 5 nm radius exclusion zone of the release site, in less than 10 m water depth, or within 3 nm of a shoreline. Aerial dispersant application was assumed to occur beginning on day 2 of the event at an effective application rate of 1 part dispersant to 20 parts oil (dispersant-to-oil ratio [DOR] = 1:20) for 12 hours (daylight) each day. The dispersant application was assumed effective when oil thickness exceeded 8 µm (0.0003 in, NOAA, 2010) and on weathered and emulsified oil up to a viscosity of 20,000 centipoise (cP). These assumptions are consistent with a recent oil spill modeling risk assessment study conducted with industry, government and non-governmental organization stakeholders' input (French-McCay et al. 2018, Bock et al. 2018, Walker et al. 2018).

Mechanical Removal and ISB: During the DWH oil spill response, once fully mobilized, essentially all available equipment in the mainland U.S. for mechanical removal and ISB was applied. Thus, the achieved removal rates reflect performance and operational capacity. The modeled capacity will be assumed to be the maximum monthly average volume removal rate per day over the period of the DWH response, which, based on Lehr et al. (2010), was 10,829 bbl/day of oily water in June 2010, equivalent to 2,166 bbl/day of oil removed. In June 2010, ISB removed an average of 5,372 bbl of oil per day (Lehr et al. 2010). In the model, operations will be assumed to start on day 2 and to occur 12 hours a day, except for a 5 nm exclusion zone around the release site, when environmental conditions were suitable (Etkin et al. 2006) on oil > 8 µm thick (NOAA, 2010). These assumptions are consistent with a recent oil spill modeling risk assessment study conducted with industry, government and non-governmental organization stakeholders' input (French-McCay et al. 2018a; Bock et al. 2018; Walker et al. 2018).

Table 2-1. Modeled Oil Spill Stochastic Scenarios for the Offshore Mid-Atlantic

Scenario ID	Spill Region	Spill Event	Oil Type	Spill Volume	Discharge Duration	Model Duration	Location
1	Offshore Delaware	Surface Release	Crude Oil	Low (126 bbl)	1 hr	30 Days	Offshore lightering track offshore Delaware Bay at 38.4875°N, 74.7334°W
2		Surface Release		Medium (2,240 bbl)	1 hr		
3		Surface Release		High (200,000 bbl)	1 hr		
4		Subsurface Well Blowout		Well Blowout (900,000 bbl)	30 days	75 Days	Wilmington Canyon at 38.7017°N, 73.5403°W
5	Offshore New Jersey	Surface Release	Crude Oil	Low (126 bbl)	1 hr	30 Days	Location of high vessel traffic offshore New Jersey at 40.1113°N, 73.8329°W
6		Surface Release		Medium (2,240 bbl)	1 hr		
7		Surface Release		High (200,000 bbl)	1 hr		
8		Subsurface Well Blowout		Well Blowout (900,000 bbl)	30 days	75 Days	Hudson Canyon at 39.2658°N, 73.1658°W
9	Offshore Virginia	Surface Release	Crude Oil	Low (126 bbl)	1 hr	30 Days	Location of high vessel traffic offshore Virginia at 36.8231°N, 75.7494°W
10		Surface Release		Medium (2,240 bbl)	1 hr		
11		Surface Release		High (200,000 bbl)	1 hr		
12		Subsurface Well Blowout		Well Blowout (900,000 bbl)	30 days	75 Days	Potential well area offshore Virginia at 37.2886°N, 74.7109°W

Table 2-2. Modeled Oil Spill Deterministic Scenarios for the Offshore Mid-Atlantic

Scenario ID	Spill Site	Spill Event	Oil Type	Spill Volume
1	Offshore Delaware	Surface Unmitigated Release During Winter	Crude Oil	Low
2		Surface Unmitigated Release During Spring		Low
3		Surface Unmitigated Release During Summer		Low
4		Surface Unmitigated Release During Fall		Low
5		Surface Unmitigated Release During Winter		Medium
6		Surface Unmitigated Release During Spring		Medium
7		Surface Unmitigated Release During Summer		Medium
8		Surface Unmitigated Release During Fall		Medium
9		Surface Unmitigated Release During Winter		High
10		Surface Unmitigated Release During Spring		High
11		Surface Unmitigated Release During Summer		High
12		Surface Unmitigated Release During Fall		High

Scenario ID	Spill Site	Spill Event	Oil Type	Spill Volume
13		Surface Mitigated Release During Winter		High
14		Surface Mitigated Release During Spring		High
15		Surface Mitigated Release During Summer		High
16		Surface Mitigated Release During Fall		High
17		Subsurface Blowout Release During Winter		Well Blowout
18		Subsurface Blowout Release During Spring		Well Blowout
19		Subsurface Blowout Release During Summer		Well Blowout
20		Subsurface Blowout Release During Fall		Well Blowout
21	Offshore New Jersey	Surface Unmitigated Release During Winter	Crude Oil	Low
22		Surface Unmitigated Release During Spring		Low
23		Surface Unmitigated Release During Summer		Low
24		Surface Unmitigated Release During Fall		Low
25		Surface Unmitigated Release During Winter		Medium
26		Surface Unmitigated Release During Spring		Medium
27		Surface Unmitigated Release During Summer		Medium
28		Surface Unmitigated Release During Fall		Medium
29		Surface Unmitigated Release During Winter		High
30		Surface Unmitigated Release During Spring		High
31		Surface Unmitigated Release During Summer		High
32		Surface Unmitigated Release During Fall		High
33		Surface Mitigated Release During Spring		High
34		Surface Mitigated Release During Summer		High
35		Surface Mitigated Release During Summer		High
36		Surface Mitigated Release During Fall		High
37		Subsurface Blowout Release During Winter		Well Blowout
38		Subsurface Blowout Release During Spring		Well Blowout
39		Subsurface Blowout Release During Summer		Well Blowout
40		Subsurface Blowout Release During Fall		Well Blowout
41	Offshore Virginia	Surface Unmitigated Release During Winter	Crude Oil	Low
42		Surface Unmitigated Release During Spring		Low
43		Surface Unmitigated Release During Summer		Low
44		Surface Unmitigated Release During Fall		Low
45		Surface Unmitigated Release During Winter		Medium

Scenario ID	Spill Site	Spill Event	Oil Type	Spill Volume
46		Surface Unmitigated Release During Spring		Medium
47		Surface Unmitigated Release During Summer		Medium
48		Surface Unmitigated Release During Fall		Medium
49		Surface Unmitigated Release During Winter		High
50		Surface Unmitigated Release During Spring		High
51		Surface Unmitigated Release During Summer		High
52		Surface Unmitigated Release During Fall		High
53		Surface Mitigated Release During Winter		High
54		Surface Mitigated Release During Spring		High
55		Surface Mitigated Release During Summer		High
56		Surface Mitigated Release During Fall		High
57		Subsurface Blowout Release During Winter		Well Blowout
58		Subsurface Blowout Release During Spring		Well Blowout
59		Subsurface Blowout Release During Summer		Well Blowout
60		Subsurface Blowout Release During Fall		Well Blowout

2.5 Oil Properties and Degradation Rates

The same crude oil type was used in all surface spill simulations because the oil source and refinement state are expected to be similar regardless of the selected location. The primary oil type that is imported to the region is light sweet (low sulfur) crude oil. Early oil exploration in the Mid-Atlantic identified a potential for light crudes and condensates to be present (BOEM 2012). The potential oil types would likely be similar to those imported into the region. Thus, one light crude oil type is proposed to be modeled in all scenarios, whether as surface releases or as a subsea blowout.

The oil type spilled during the DWH incident from lease area MC252 was a light crude with API=37. It has been well characterized in terms of oil properties and composition. Therefore, its properties were applied for this modeling. The bulk oil properties, as well as the content of volatile and semi-volatile hydrocarbons, are described in detail in Annex B. See Annex B.1 for a definition of properties used.

Primary degradation, i.e. the loss of the hydrocarbon compounds initially in the oil via biodegradation and photo-oxidation, was modeled using a first-order degradation equation and pseudo-component specific rates. The biodegradation rates were developed as part of the research for modeling the DWH oil spill (French-McCay et al. 2015, 2018b,c). Photo-oxidation rates of PAHs by ultraviolet light (UV) were assumed to be the same as those developed by French-McCay et al. (2018d) for the Gulf of Mexico.

2.6 Model Inputs

In order to understand the behavior of a marine oil spill, it is necessary to evaluate the predominant environmental conditions in the area of interest. Winds and currents are the key forcing agents that control the transport and weathering of an oil spill. In order to reproduce the natural variability of the environment, the oil spill model requires wind and current datasets that vary both spatially and temporally. Therefore, long-term records of wind and current data were obtained from the outputs of global numerical atmospheric and circulation models for this study.

Model inputs defining the environmental conditions and geography for all scenarios are described within this report section.

2.6.1 General Dynamics and Climatology

The spill locations for this study are located over the Middle Atlantic Bight (MAB) region. MAB is the continental shelf region off the northeastern coast of the United States which extends from Cape Hatteras in the south to Nantucket Shoals in the northeast (Beardsley and Boicourt 1981). The MAB is a complex region in terms of oceanographic dynamics, where cooler and fresher shelf water is separated from warmer and saltier slope water by a shelf slope front (Csanady and Hamilton 1988).

By analyzing current measurement over the MAB continental shelf, Lentz (2007) exhibited that the mean along shelf depth-averaged flow is equatorward and increases with water depth. The mean cross-shelf circulation showed a consistent vertical structure where the near-surface flow is typically offshore while the interior flow is onshore. The near-bottom flow increases linearly with water depth from 1 centimeter per second (cm/s) onshore flow in shallow water to 4 cm/s offshore flow at the 250-m isobath over the slope, while the direction of the current reverses at ~50 m isobath.

Tidal currents account for 30 to 40 percent of the total variance of currents in the MAB region (Moody et al. 1984). The amplitude of the M2, K1 and O1 surface current is minimum at the outer edge of the continental shelf and maximum at midway across the shelf[2]. However, from midway toward the coast the amplitude

[2] For definitions of M2, K1 and O1, see https://tidesandcurrents.noaa.gov/publications/glossary2.pdf.

decreases. The variability of the tidal current estimates is largest near the shelf slope where the variation can be impacted by baroclinic tide (Moody et al. 1984).

2.6.2 Currents and Wind Data

For hydrodynamic forcing, the oil spill model uses time-varying current vectors (i.e., current speed and direction) provided by a hydrodynamic model defined on spatial grid. Surface current was obtained from "Doppio", an operational forecasting system based on Regional Ocean Modeling System (ROMS) covering the MAB and Gulf of Maine regions, developed by the Rutgers University. ROMS is a free-surface, terrain-following, primitive equation ocean model (Table 2-3, Figure 2-3). The primitive equations are a set of nonlinear differential equations that are used to approximate global current flows and include conservation of momentum, thermal energy equation, mass and a turbulence closure scheme (Shchepetkin and McWilliams 2005; Haidvogel et al. 2008). In the horizontal direction, the primitive equations are evaluated using boundary-fitted, orthogonal curvilinear coordinates, while in the vertical, the primitive equations are discretized over variable topography/bathymetry using sigma coordinate system. This system allows the vertical layers to follow the model terrain (Song and Haidvogel 1994), which results in an equal number of layers regardless of local water depth.

The configuration of Doppio (Table 2-3) is built upon two previous regional modeling programs: North East North American (NENA) shelf coupled circulation and biogeochemical model, and ESPreSSO (Experimental System for Predicting Shelf and Slope Optics) model. The moniker "Doppio" came from the fact that the Doppio domain is approximately twice the extent of ESPreSSO and extends from Cape Hatteras in the south to Gulf of Maine in the north. The average surface current speed for the period of 04/01/2018 – 04/20/2020 from Doppio ROMS is shown in Figure 2-3.

Surface forcing for Doppio ROMS comes from operational NOAA's National Centers for Environmental Prediction (NCEP) North American Mesoscale (NAM) forecasting system, while river discharges are from United States Geological Survey (USGS) and Water Survey of Canada (WSC). Harmonic tides along the open boundaries are extracted from Oregon State University (OSU) Tidal Prediction Software (Egbert and Erofeeva 2002). For open boundary condition, Doppio ROMS used daily mean data taken from the Mercator-Océan system (Drévillon et al. 2008) provided by Copernicus Marine Environment Monitoring Service (CMEMS; marine.copernicus.eu).

Table 2-3. The specifics of Doppio ROMS configuration used for modeling.

Name of Dataset	Doppio ROMS
Atmospheric Forcing	NCEP NAM
Hydrodynamic Boundary Forcing	CMEMS Mercator forecasting System

Name of Dataset	Doppio ROMS
Tides	OTPS
River Discharge	USGS and WSC
Horizontal Grid Size	7 km
Forecast Period	2018/04/01 – 2020/04/20
Output timestep	1 hour
URL	http://tds.marine.rutgers.edu/thredds/dodsC/roms/doppio/2017_da/his/History_Best.html

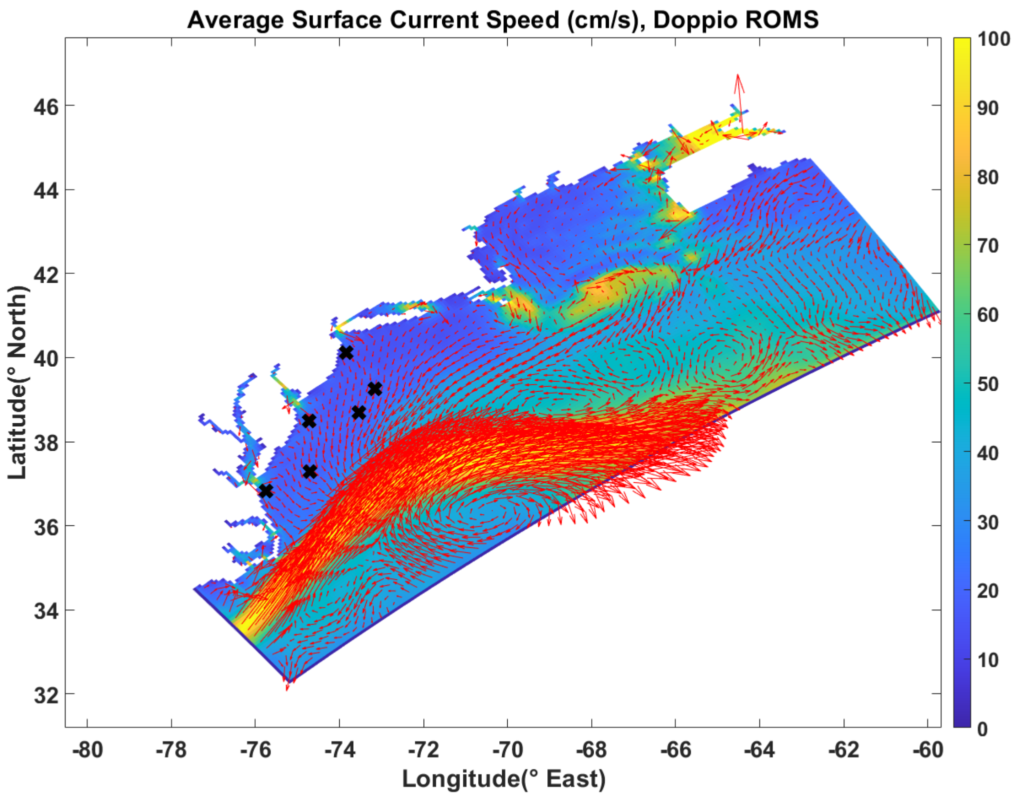


Figure 2-3. Spatial distribution of Doppio ROMS averaged surface current speeds (in cm/s) and directions for 04/01/2018 – 04/20/2020. The black crosses represent the spill locations.

The wind data used for oil spill modeling is from NAM dataset. This wind forcing is also used for forcing the hydrodynamic model used in this study, ROMS Doppio. NOAA's NCEP provides the NAM dataset, which is a high-resolution regional forecast covering North America (Janjic et al. 2005). NAM has a horizontal resolution of 12 km with data output every 3 hours. The average wind speed for the period of 04/01/2018 – 04/20/2020 from NCEP-NAM extracted for this modeling study is shown in Figure 2-4.

Table 2-4. The specifics of wind dataset used for the modeling.

Name of Dataset	NCEP NAM
Coverage	82°W - 55°W 28°N - 50°N
Owner/Provider	NCEP (US)
Horizontal Grid Size	12 km
Forecast Period	04/01/2018 – 04/20/2020
Output timestep	3 hourly
URL	https://www.ncei.noaa.gov/thredds/catalog/model-namanl/catalog.html

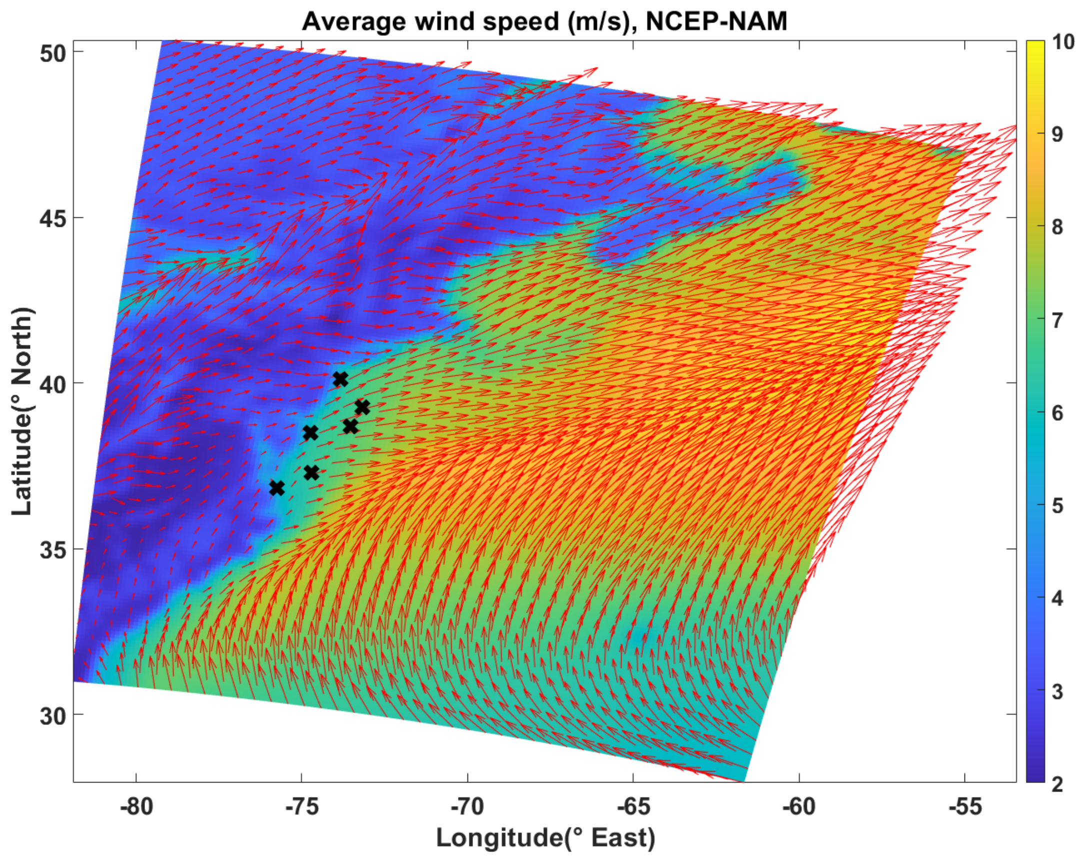


Figure 2-4. Spatial distribution of NCEP-NAM wind speeds (in meters per second [m/s]) and directions for 04/01/2018 – 04/20/2020. The black crosses represent the spill locations.

2.6.3 Temperature and Salinity Data

Temperature and salinity values throughout the water column are used by the oil spill model for oil transport and fate calculations. Temperature and salinity were obtained from the World Ocean Atlas 2018 (WOA18) (Zweng et al. 2018; Locarnini et al. 2018). The WOA18 dataset is compiled and maintained by the United

States National Oceanographic Data Center (NODC; www.nodc.noaa.gov). These data records consist of observations obtained from various global data management projects and include temperature and salinity values for 137 standardized vertical levels from the sea surface to 9,000 meters over the entire globe. After a quality control process, the data are averaged yearly, seasonally, and monthly and interpolated to fit a global grid with a 0.25° horizontal resolution. Temperature and salinity fields in the WOA18 are an average of all decades from the period 1955-2017. The dataset is available for download from the NOAA NODC (https://www.nodc.noaa.gov/cgi-bin/OC5/woa18/woa18.pl). Figure 2-5 presents the monthly variation of surface temperature and salinity at one of the spill sites offshore Delaware, from WOA 2018. Two seasons can be clearly distinguished on the plot, including summer with high temperature and lower salinity and winter with low temperature and higher salinity.

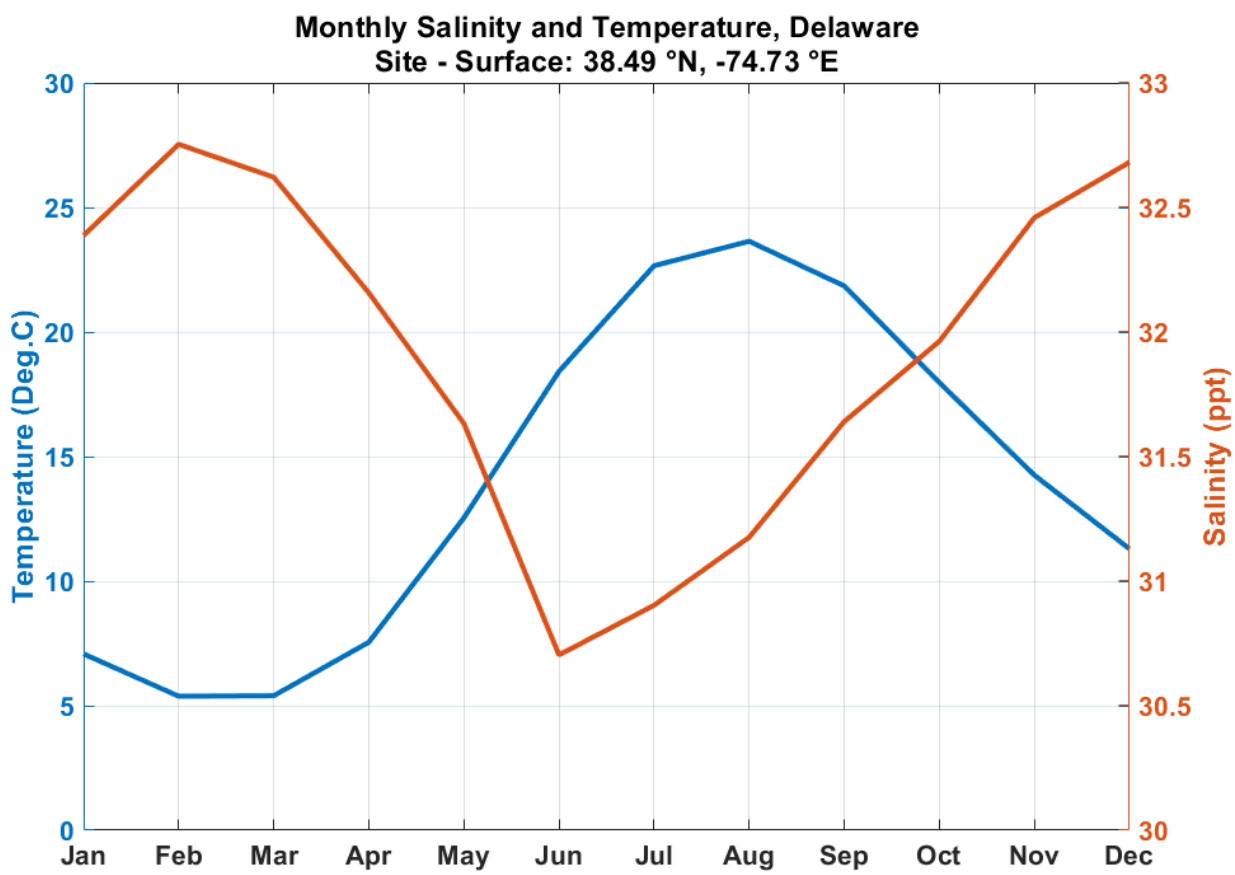


Figure 2-5. Monthly sea surface temperature (deg. C) in blue and salinity (ppt) in red at the spill site of surface release offshore Delaware, from WOA 2018 (Zweng et al. 2018 and Locarnini et al. 2018).

2.6.4 Geographical Data

For geographical reference, SIMAP uses rectilinear grids to designate the location of the shoreline, the water depth (bathymetry), and the shore or habitat type. The grids were generated from a digital shoreline using ESRI geoprocessing and Spatial Analyst Extension tools. The cells were coded for depth and habitat type. The digital shoreline was developed using the most current NOAA Environmental Sensitivity Index (ESI) hydrography data layers for applicable states (NOAA 2020). Habitat data were used to define the bottom type and vegetation found in subtidal areas, areas of extensive mud flats and wetlands, and the shoreline type (e.g., sandy beach, rocky shoreline, etc.).

The SIMAP model used these grids to identify the location of the shoreline and amount of oil that may adhere once oil contacted the shoreline (Figure 2-6). Retention of oil on a shoreline depends on the shoreline type, physical and chemical properties (e.g., viscosity) of the oil, tidal amplitude in estuarine areas, and wave energy. The resolution of the habitat grid was approximately 0.3 mi north-south by 0.2 mi east-west (0.00413° on each side). Bathymetry data define the water depths within the modelled extent. The General Bathymetric Chart of the Oceans (GEBCO) one arc-minute interval grid was used, but was resampled into a grid with the same resolution as the habitat grid (GEBCO 2003; Figure 2-6).

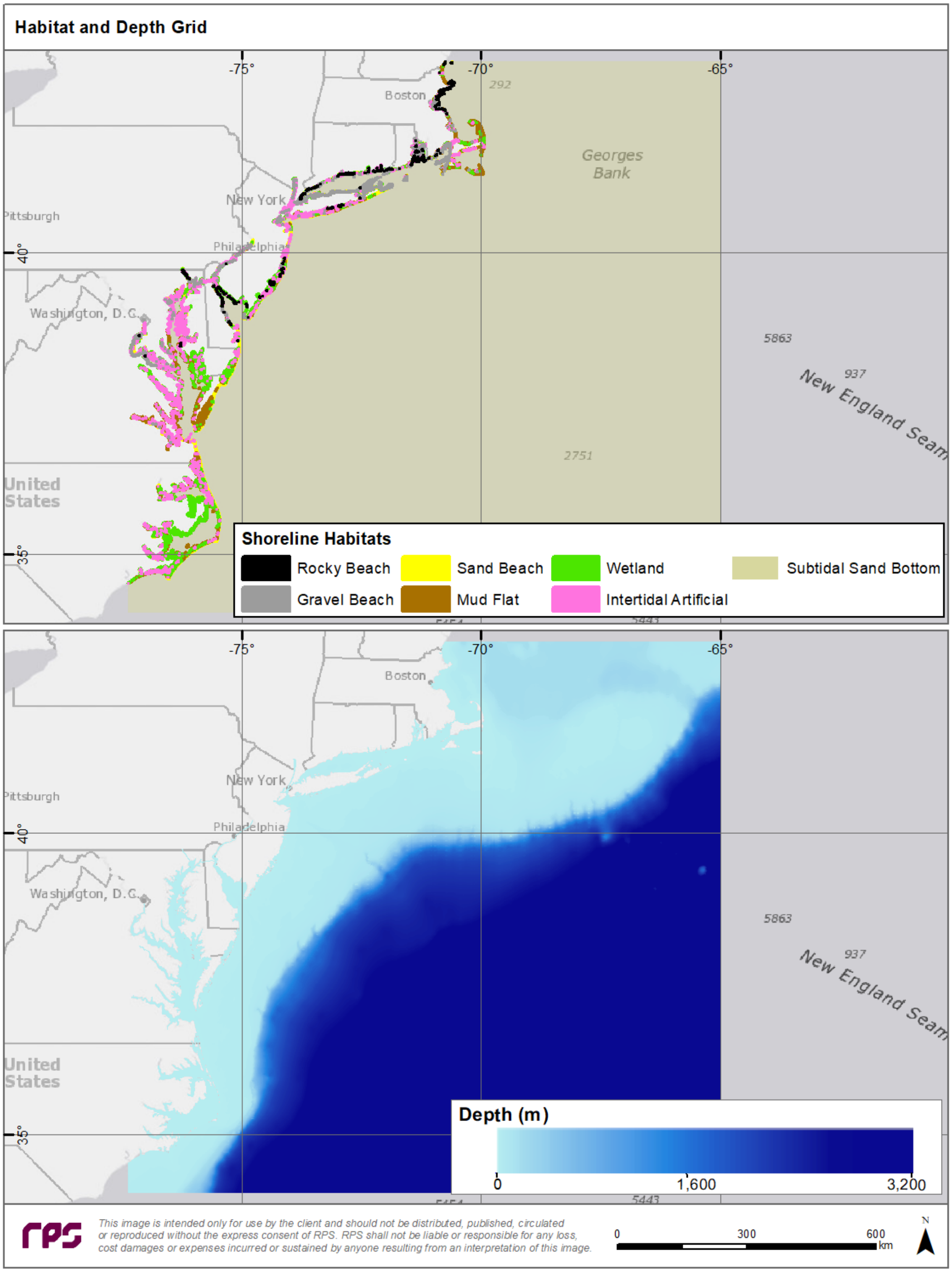


Figure 2-6. Habitat grid (top; from NOAA 2020) and bathymetry data (bottom; GEBCO 2003) used in the modeling study.

3 RESULTS

3.1 Key to Interpretation of Results

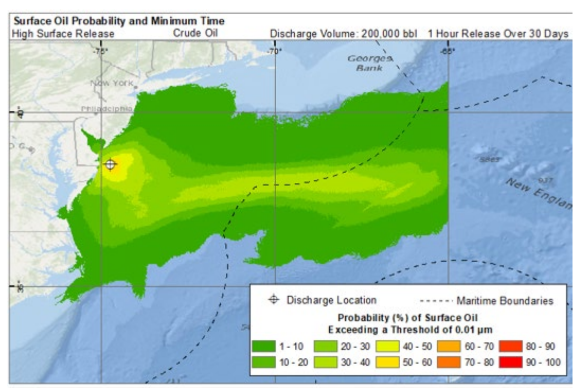
Both thresholds of surface and shoreline oil exposure were used for displaying model results. For surface oil, 0.01 g/m^2 (~0.01 µm thick on average) and ≥10 g/m^2 (~10 µm thick on average) were used to evaluate distributions and probabilities of oil contamination. For shoreline oiling, ≥1 g/m^2 (~1 µm thick on average) and ≥100 g/m^2 (~100 µm thick on average) were used. In past studies, these oiling levels have been found to potentially affect socioeconomic activities, wildlife and shoreline biota (see Section 2.2).

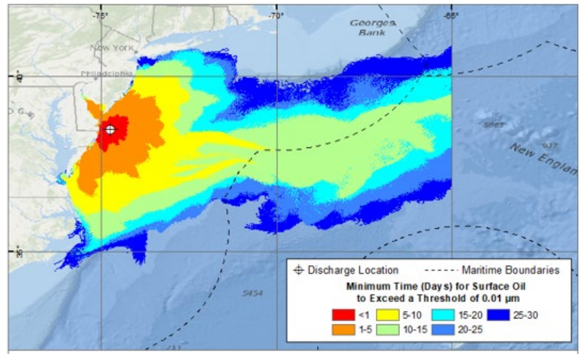
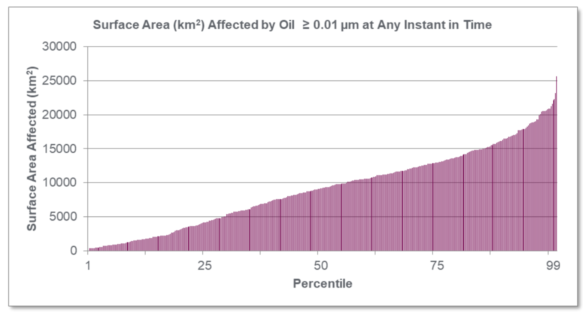
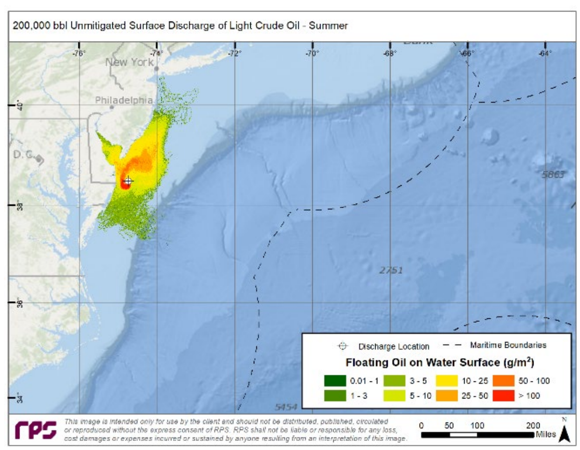
Two types of model results are presented, as summarized in Table 3-1. The figures presented for the stochastic (probabilistic) modeling results (Section 3.2) illustrate the possible locations where surface floating oil and shoreline oil contamination could occur, mapping both the probabilities and associated minimum times to threshold exceedance for the hypothetical release scenarios. The probability maps define the area of potential exposure, given an unknown hypothetical spill date and time, and the associated probability with which sea surface oil or shoreline oil are expected to exceed the specified thresholds at any point of time throughout the modeled durations. The colored delineations in the stochastic maps signify the probability percentiles of areas that may experience oil at or above the specified threshold for the release scenario. Note that the darkest green represents areas where oil would exceed the specified threshold in only 1-5% of release simulations. In other words, the likelihood that any oil exceeding the identified threshold would leave the area bounded within the dark green area is < 5%. The area between this bin and the next (10%) bin has between a 5-10% probability of exceeding the threshold, given a release of the modeled scenario occurred.

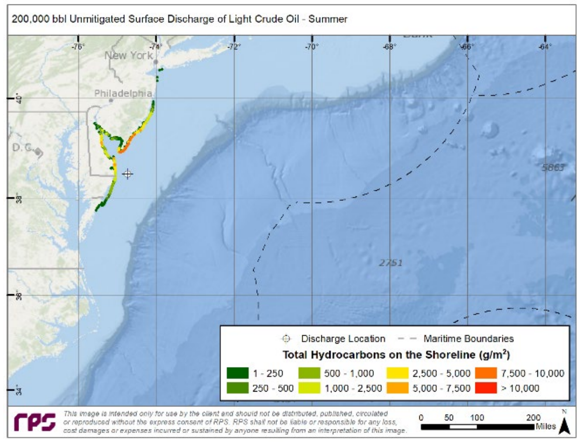
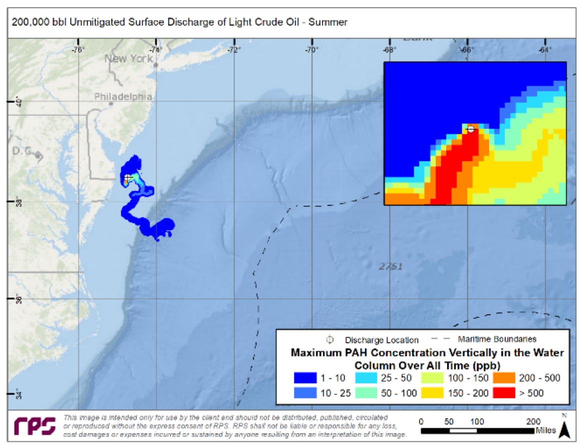
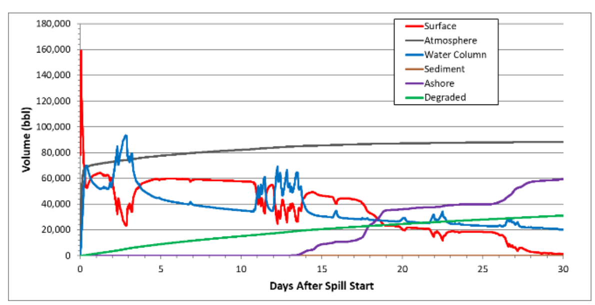
The probabilities of oil exposure were calculated from a statistical analysis of the ensemble of individual trajectories modeled for each release scenario. As stated previously, the fundamental assumption for this modeling was that an unmitigated release did occur. Therefore, probability contours should be interpreted as, “In the unlikely event of a release, the probability that any one specific area may experience contamination above the specified threshold is X%.” Stochastic figures do not imply that the entire contoured area would be covered with oil in the event of a single release, nor do they provide any information on the quantity of oil in a given area. Additionally, these figures do not provide the likelihood of an oil spill occurring in any given year. Rather, these stochastic figures denote the probability of oil exceeding identified thresholds at any modeled time step (over entire model duration), for each point within the modeled domain, assuming a release were to occur at some point in time.

In addition to presenting the probabilistic model results for each scenario, the individual deterministic model simulation resulting in the maximum shoreline length oiled was examined further as the worst-case environmental conditions. The maps presented in Section 3.3 present the cumulative maximum surface oil exposure concentrations, maximum shoreline concentrations, and vertical maximum concentrations of water column exposure to dissolved aromatics (i.e., PAHs, milligrams per cubic meter [mg/m^3] = ppb) occurring at each location at any time during the model simulation. Note that these maps are cumulative, and do not depict the extent of oil contamination at any instant in time. The concentrations on the water surface and in the water column are highly variable in space and over time (i.e., patchy in space and ephemeral in any given location). In addition, the dissolved aromatic (PAH) figures show the vertical maxima, whereas the vertical distribution is not uniform from the surface to the seafloor. The contaminants move with currents, dilute, and degrade over time. Thus, the summary footprint maps are only an indication of the highest concentrations of oil and of PAH that would occur at each location at some time after the spill, given the environmental conditions after the spill. Mass balance plots of the amount of oil in each environmental compartment (i.e., on the surface, in the atmosphere, in the water column, on the shoreline, etc.) over time are presented for each deterministic simulation. Note that "degraded" in the mass balance plots refers to primary degradation, i.e. the loss of the hydrocarbon compounds initially in the oil via biodegradation and photo-oxidation.

Table 3-1. List and examples of the model output products provided for simulations

Stochastic Simulations	Probability of Oil Contamination	Map of the probability of oil contamination on the sea surface (or shoreline) above a defined threshold, assuming an unmitigated release occurs at some unknown date and time in the future	

<table>
<tr>
<td rowspan="2"></td>
<td>Minimum Time to Oil Contamination</td>
<td>Map of the minimum time to exceed the threshold for sea surface (or shoreline) oil contamination, assuming an unmitigated release occurs at some unknown date and time in the future</td>
<td>
</td>
</tr>
<tr>
<td>Summary Plots</td>
<td>Frequency distribution of degree of surface (or shoreline) oil exposure</td>
<td>
</td>
</tr>
<tr>
<td>Individual Deterministic Simulations</td>
<td>Maximum Surface Exposure</td>
<td>Map of the maximum oil exposure (mass per unit area) on the water surface at any point in time during the simulation</td>
<td>
</td>
</tr>
</table>

	Maximum Shoreline Exposure	Map of the maximum oil exposure (mass per unit area) on shorelines at any point in time during the simulation	
	Maximum Water Column Exposure	Map of the cumulative vertical maximum concentrations of water column dissolved aromatics at any point in time during the simulation	
	Mass Balance	Chart presenting the amount of oil (volume and percentage) in each environmental compartment over time	

3.2 Stochastic (Probabilistic) Results

3.2.1 Offshore Delaware

Surface crude oil discharges of three different volumes at a high traffic location offshore Delaware and a subsea blowout in Wilmington Canyon were modeled throughout all seasons over multiple years. The following stochastic result figures illustrate the spatial extent of surface and shoreline oiling probabilities (footprint) and associated minimum travel times to reach any point within the footprint. For the spill scenario, the stochastic and time contour footprints were calculated assuming two thresholds for minimum surface and shoreline oil thickness. In addition, figures are presented in a Web Mercator Auxiliary Sphere Projection for visualization purposes because it preserves angles. Measurements are provided in North America Albers Equal Area Conic projection, as it maintains distance in the east-west direction along the eastern U.S. coastline.

3.2.1.1 Surface Release (Low Volume)

For the unmitigated 126 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) was primarily located within ~10 mi (16 km) of the discharge location (Figure 3-1, top panel). Surface oil exceeding 0.01 g/m^2 required a minimum of less than 1 day to reach the coast (Figure 3-1, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~0.6 mi (1 km) (Figure 3-2, top panel) and oil did not reach the coast (Figure 3-2, bottom panel). The 0.01 g/m^2 surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 15-20 days of the discharge. The 10 g/m^2 surface oil exposure footprint above 1% probability was not predicted to extend past U.S. waters. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 extended over roughly 175 mi (282 km) to the southeast. The 1% probability for the 10 g/m^2 threshold extended 1 mi (1.6 km) northeast of the discharge location. The shoreline oiling above 1 g/m^2 threshold extended along the outer coast from south of Cape Hatteras, North Carolina to Long Island, New York and oiling above the 100 g/m^2 threshold was patchy but extended almost as far south as Cape Hatteras, North Carolina and almost as far north as New York harbor (Figure 3-3 and Figure 3-4). The probabilities for shoreline oiling are generally 0-40% with a few small locations of higher probabilities occurring directly west of the discharge location in the vicinity of the Delaware/Virginia border. Approximately 75% of possible trajectories have < 11.5 mi^2 (30 km^2) of surface waters exceeding 0.01 g/m^2, and 100% of simulations have surface oil exposure footprints of < 0.4 mi^2 (1 km^2) exceeding 10 g/m^2 (Figure 3-5 and Figure 3-6). Approximately 50% of possible trajectories have >6 mi (10 km) of shoreline oiling exceeding 1 g/m^2 and 93% of simulations have shoreline exposure footprints of <1 mi (1.6 km) exceeding

100 g/m^2 (Figure 3-7 and Figure 3-8). The maximum amount of shoreline oiled (>1 g/m^2) for any simulation was 142 mi (228 km). This worst-case simulation is examined in more detail in Section 3.3.

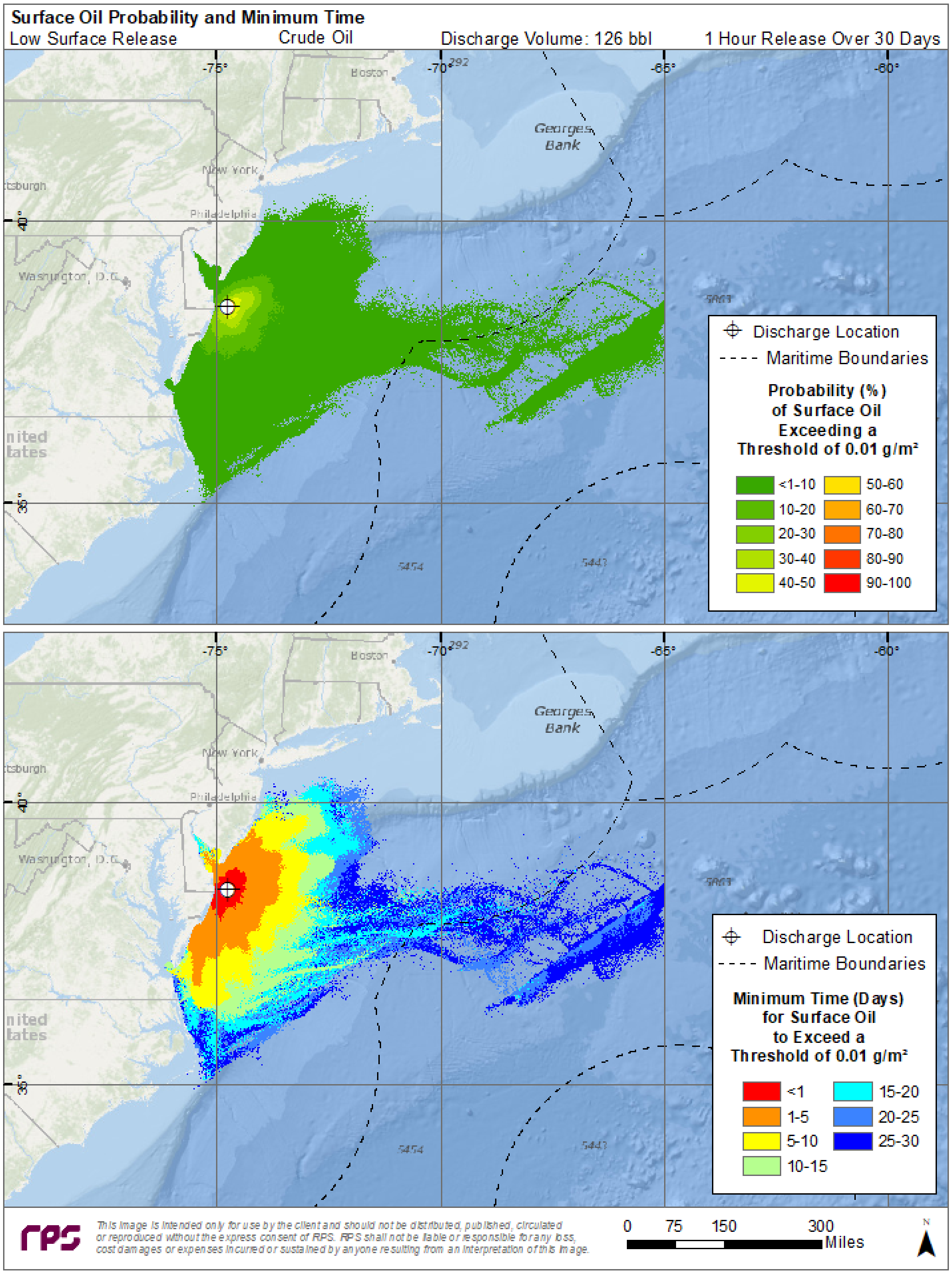


Figure 3-1. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore Delaware.

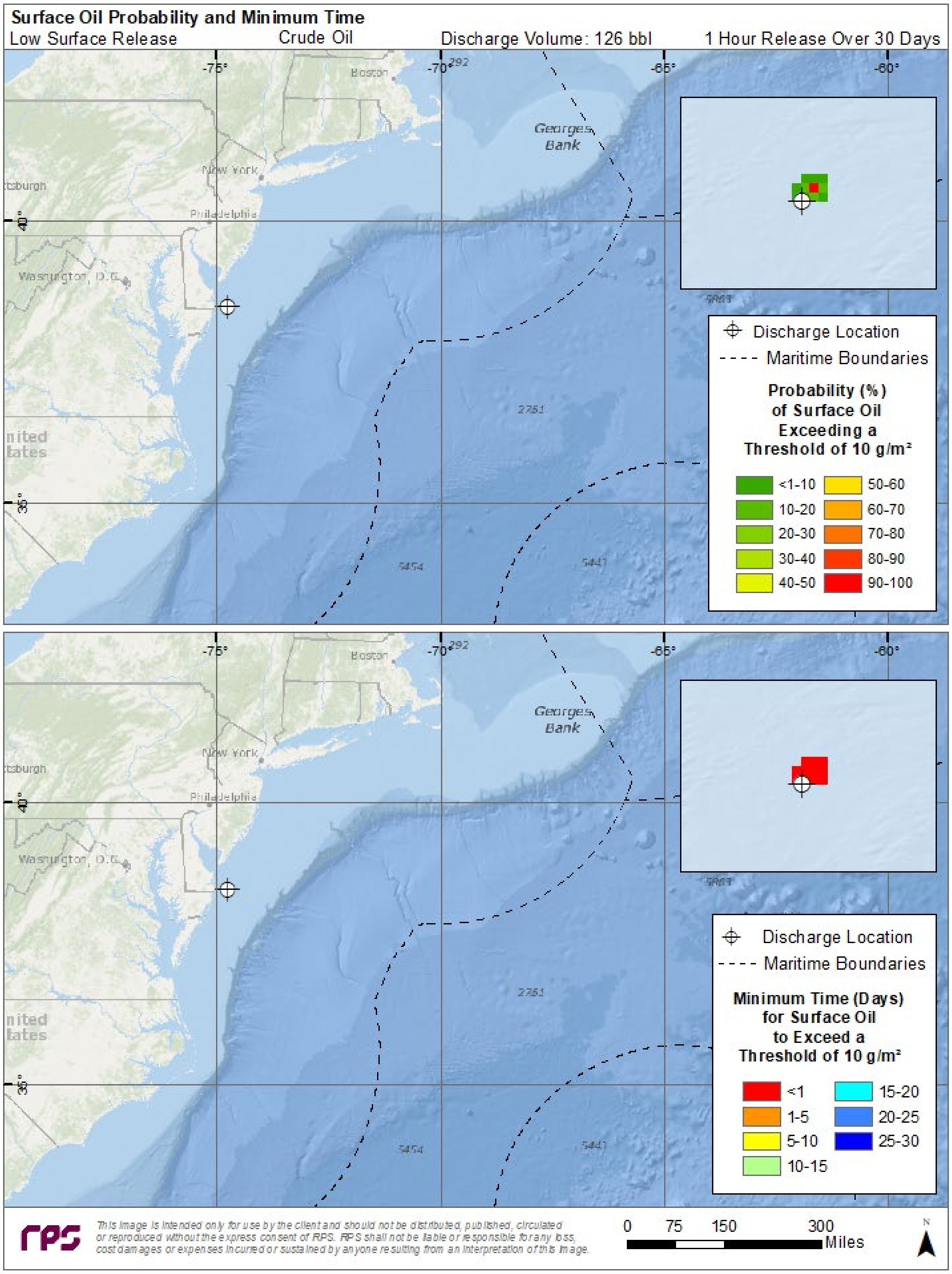


Figure 3-2. Top panel displays probability of surface oiling ≥10 μm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 μm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore Delaware.

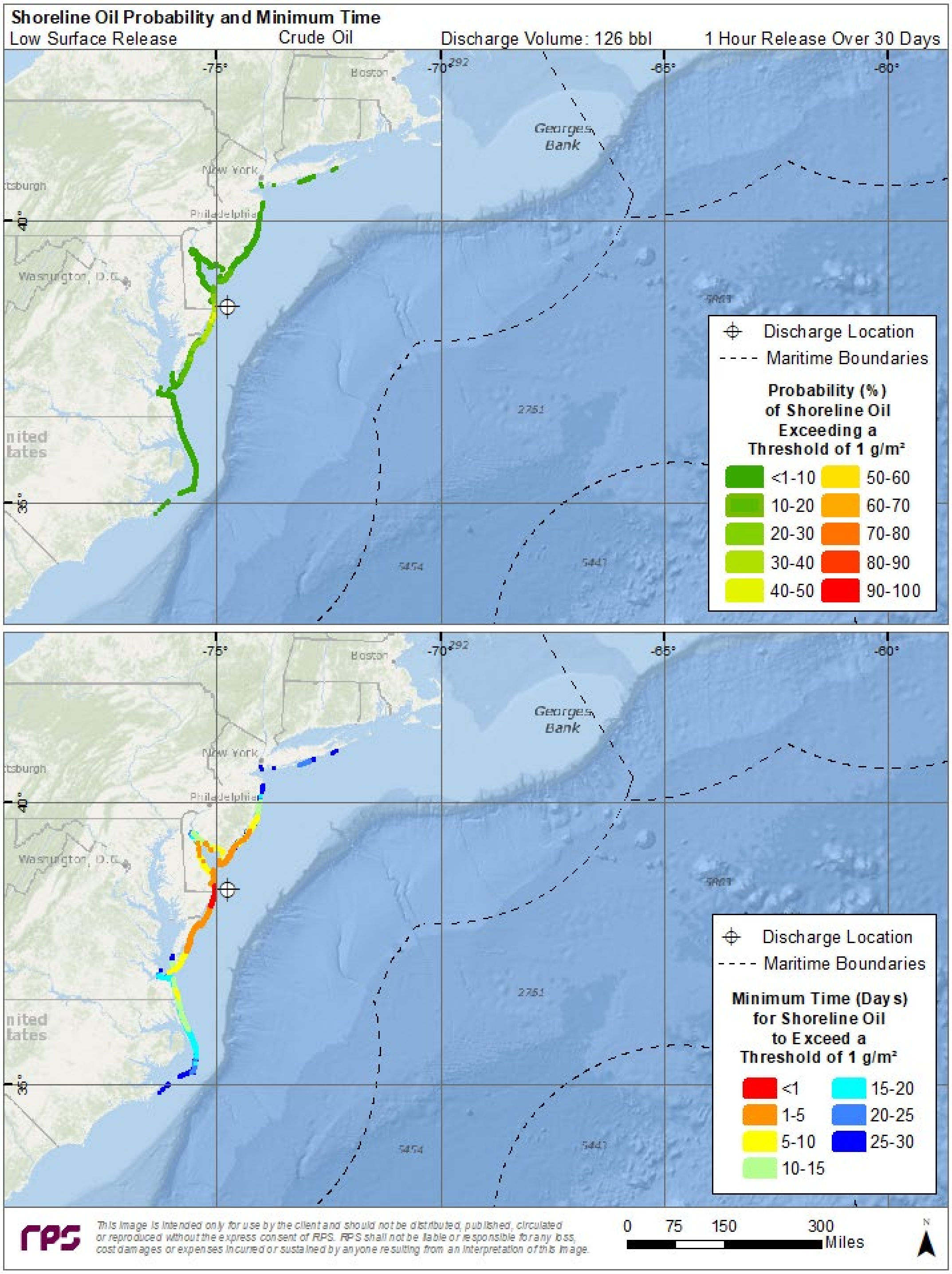


Figure 3-3. Top panel displays probability of shoreline oiling ≥1 µm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore Delaware.

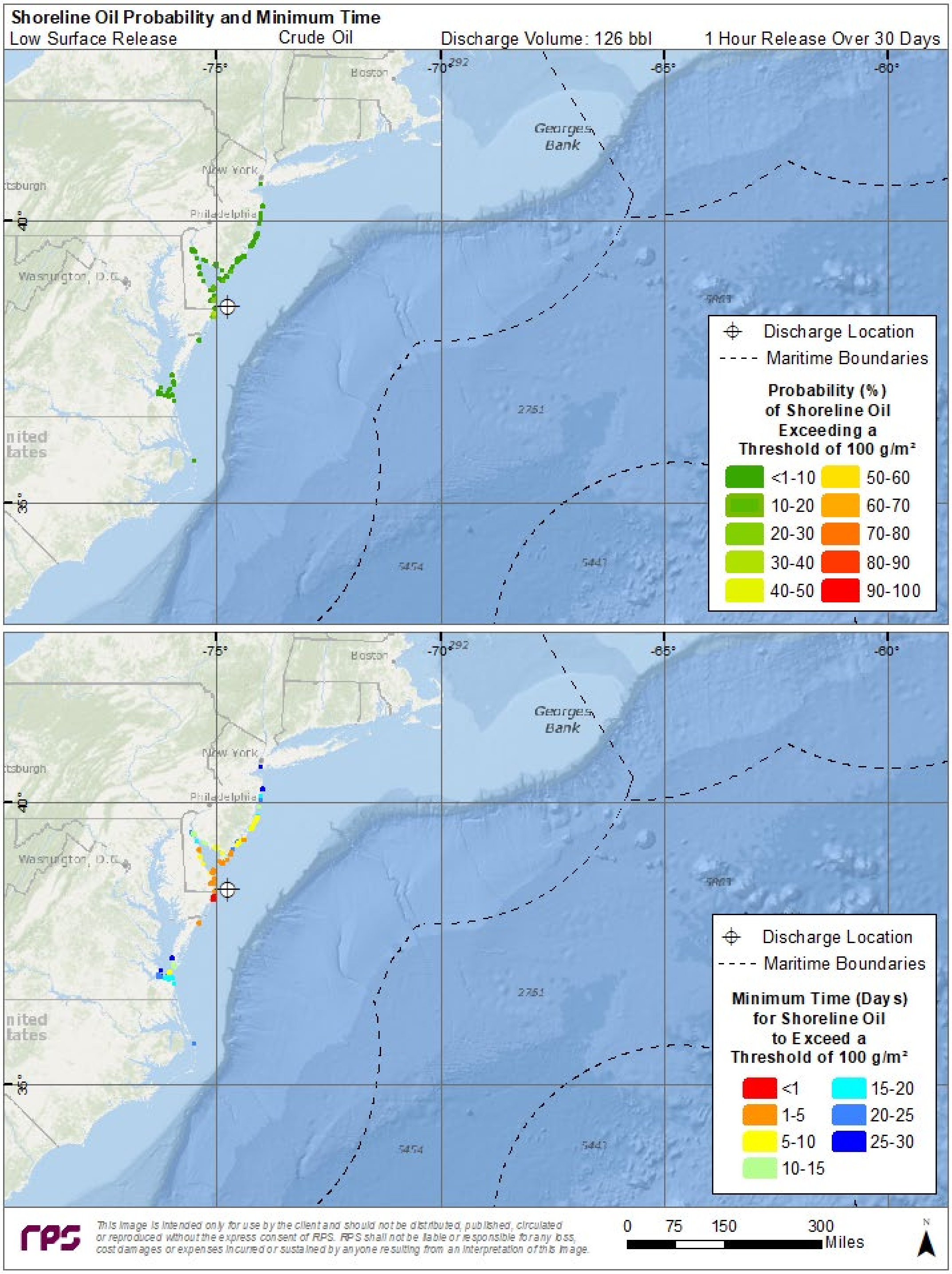


Figure 3-4. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore Delaware.

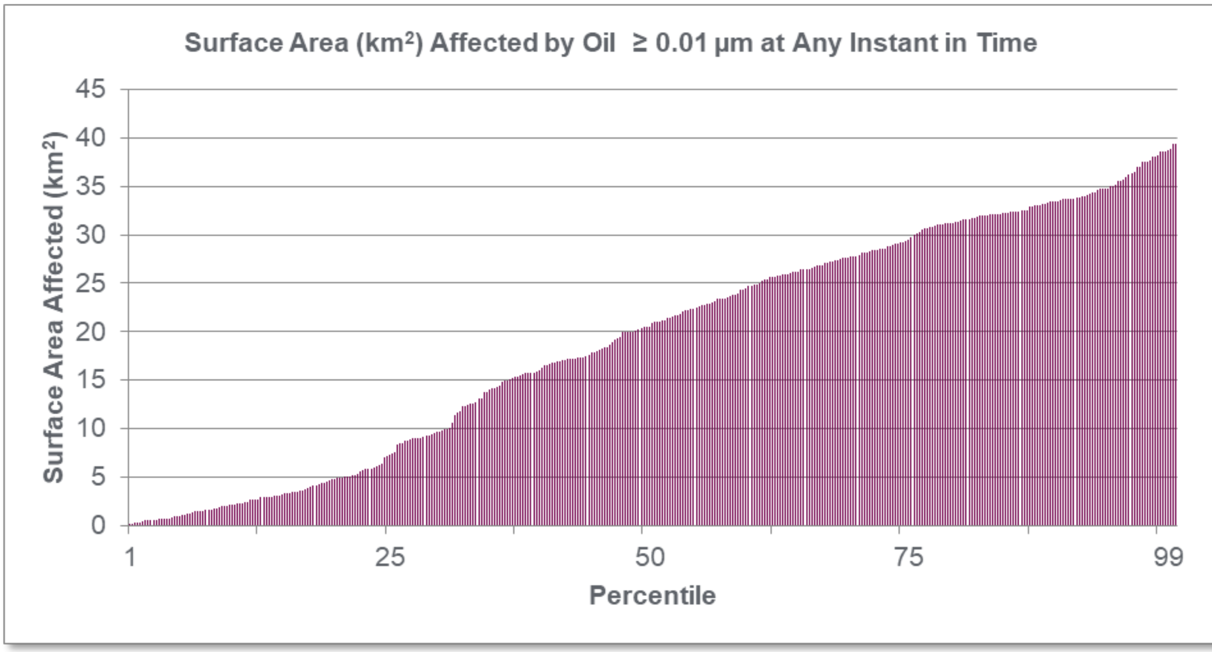


Figure 3-5. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore Delaware.

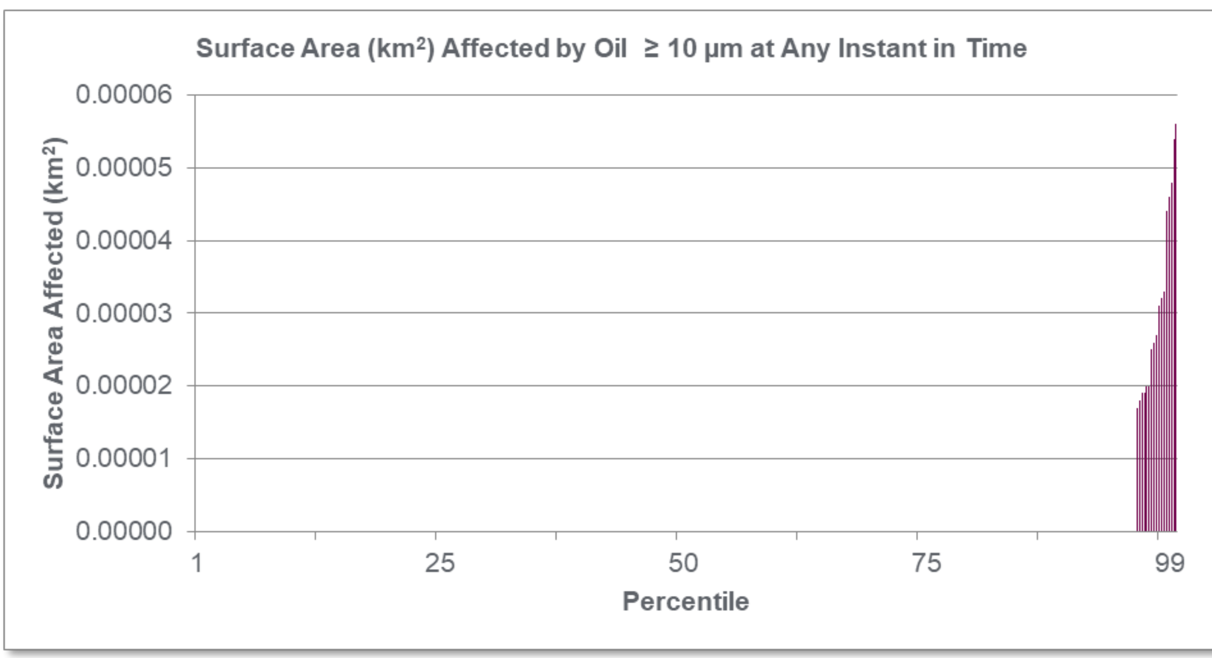


Figure 3-6. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore Delaware.

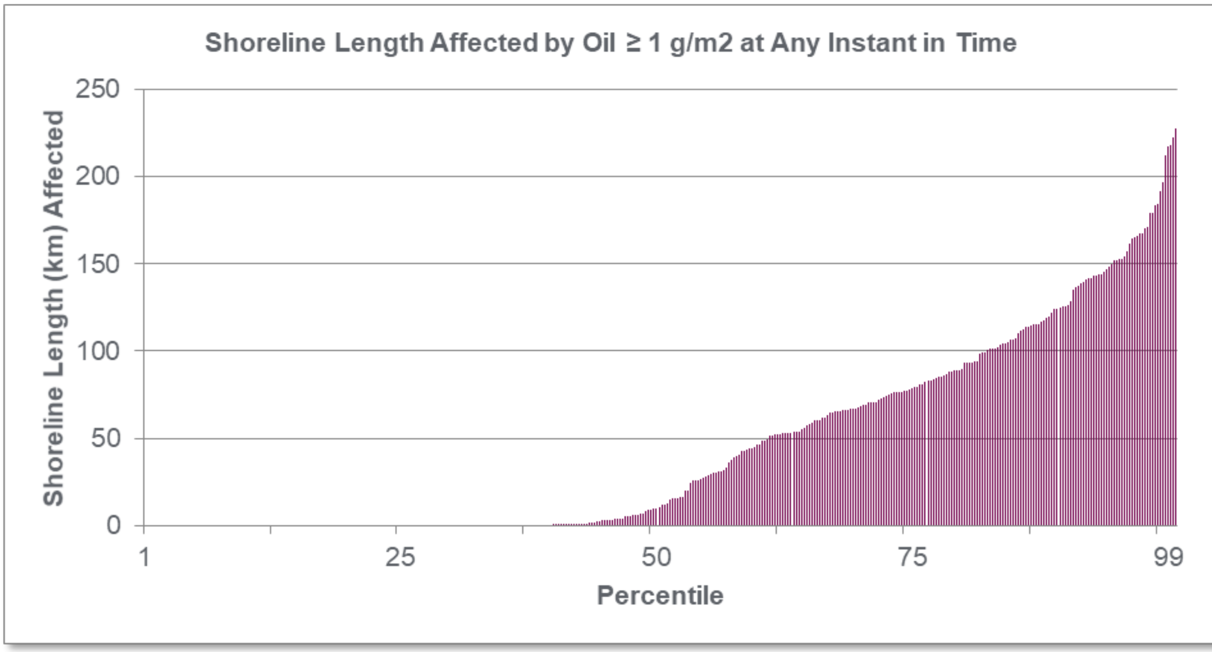


Figure 3-7. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore Delaware.

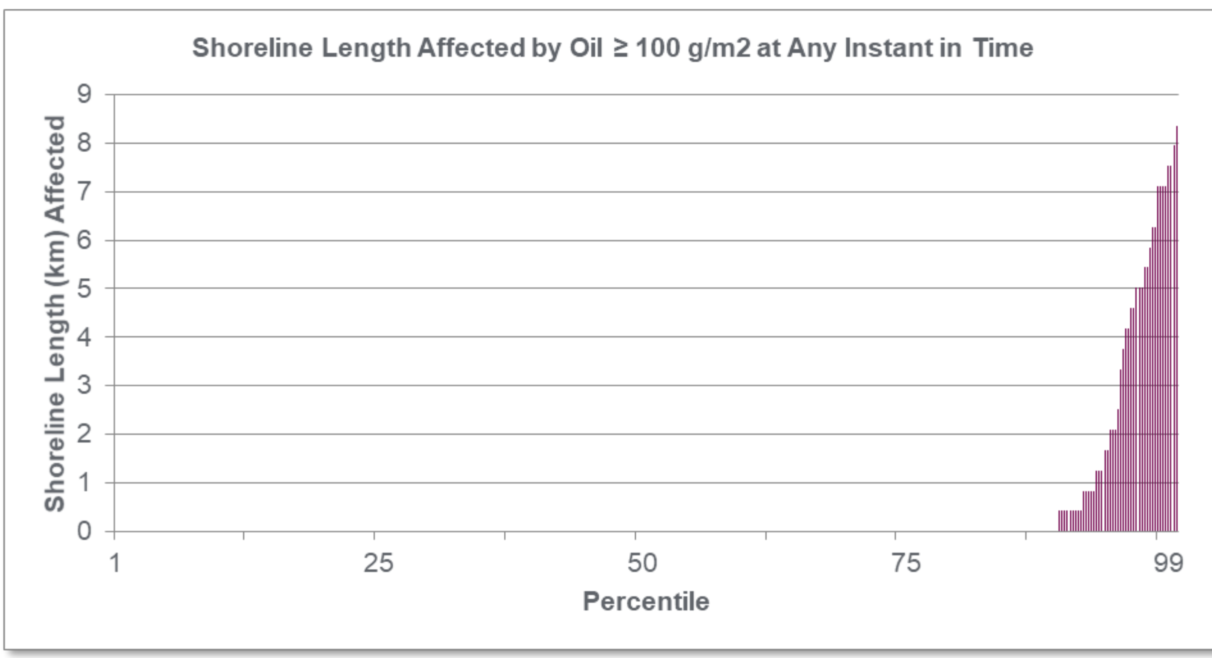


Figure 3-8. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore Delaware.

3.2.1.2 Surface Release (Medium Volume)

For the unmitigated 2,240 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) was primarily located within ~84 mi (135 km) of the discharge location (Figure 3-9, top panel). Surface oil exceeding 0.01 g/m^2 (0.01 µm, on average) required a minimum of < 1 day to reach the coast (Figure 3-9, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~1 mi (1.6 km) (Figure 3-10, top panel), and oil did not reach the coast (Figure 3-10, bottom panel). The 0.01 g/m^2 surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 10-15 days of the discharge. The 10 g/m^2 surface oil exposure footprint was not predicted to extend past U.S. waters. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 and 10 g/m^2 thresholds extended over 520 mi (837 km) east of the discharge location and outside of the model domain. The shoreline oiling above 1 g/m^2 threshold extended along the outer coast from south of Cape Hatteras, North Carolina to Long Island, New York and oiling above the 100 g/m^2 threshold was patchy but extended as far south as Cape Hatteras, North Carolina and almost as far north as western Long Island, New York (Figure 3-11 and Figure 3-12). The probabilities for shoreline oiling are generally 0-40% with a few small locations of higher probabilities occurring directly west of the discharge location around the Delaware/Virginia border. Approximately 58% of possible trajectories had < 154 mi^2 (400 km^2) of surface waters exceeding 0.01 g/m^2 and 61% of simulations have surface oil exposure footprints of < 0.4 mi^2 (1 km^2) exceeding 10 g/m^2 (Figure 3-13 and Figure 3-14). Approximately 50% of possible trajectories had < 23 mi (37 km) of shoreline oiling exceeding 1 g/m^2, while 77% of simulations had shoreline exposure footprints of < 23 mi (37 km) exceeding 100 g/m^2 (Figure 3-15 and Figure 3-16). The maximum amount of shoreline oiled for any simulation was 229 mi (368 km). This worst-case simulation is examined in more detail in Section 3.3.

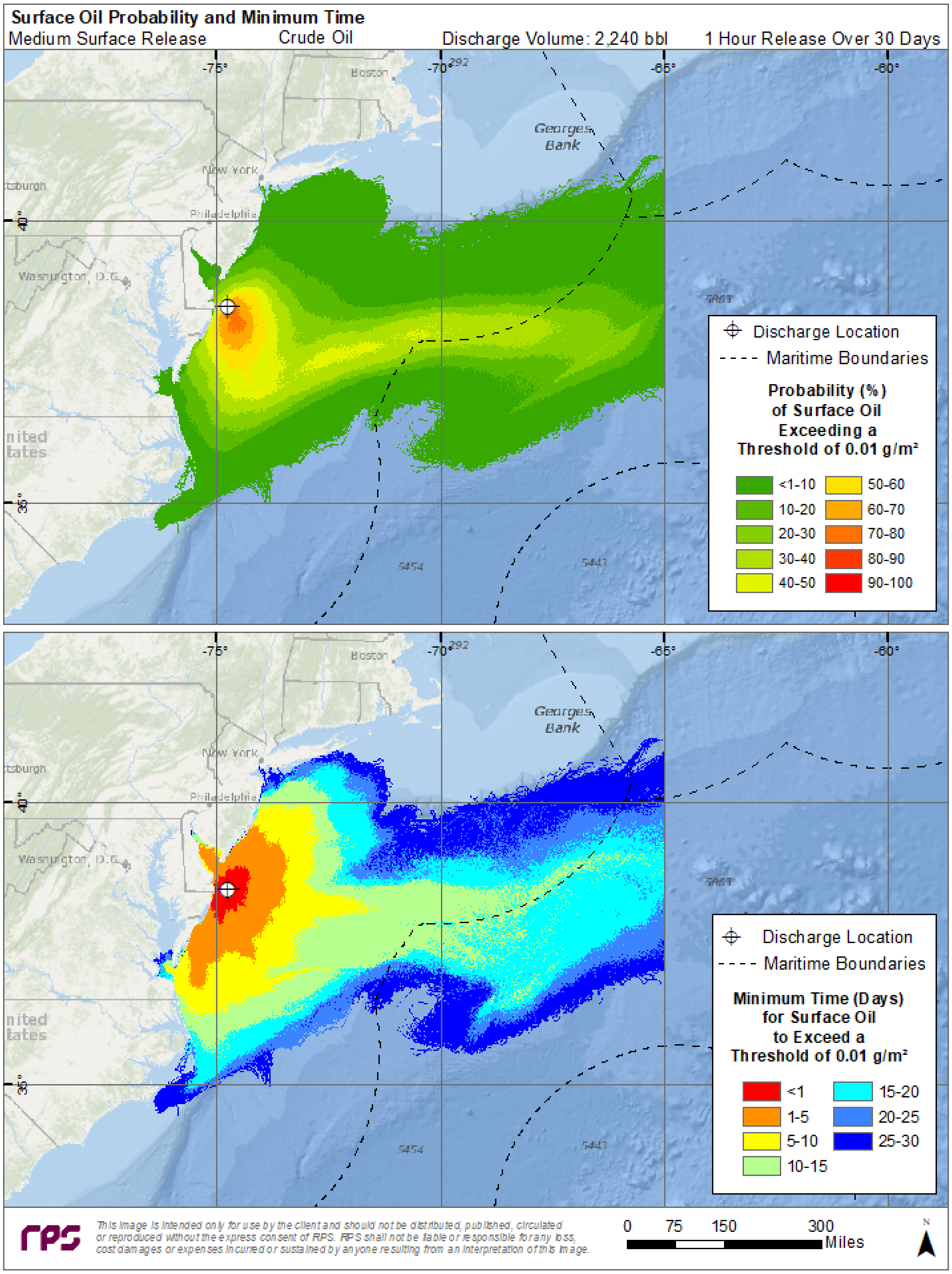


Figure 3-9. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore Delaware.

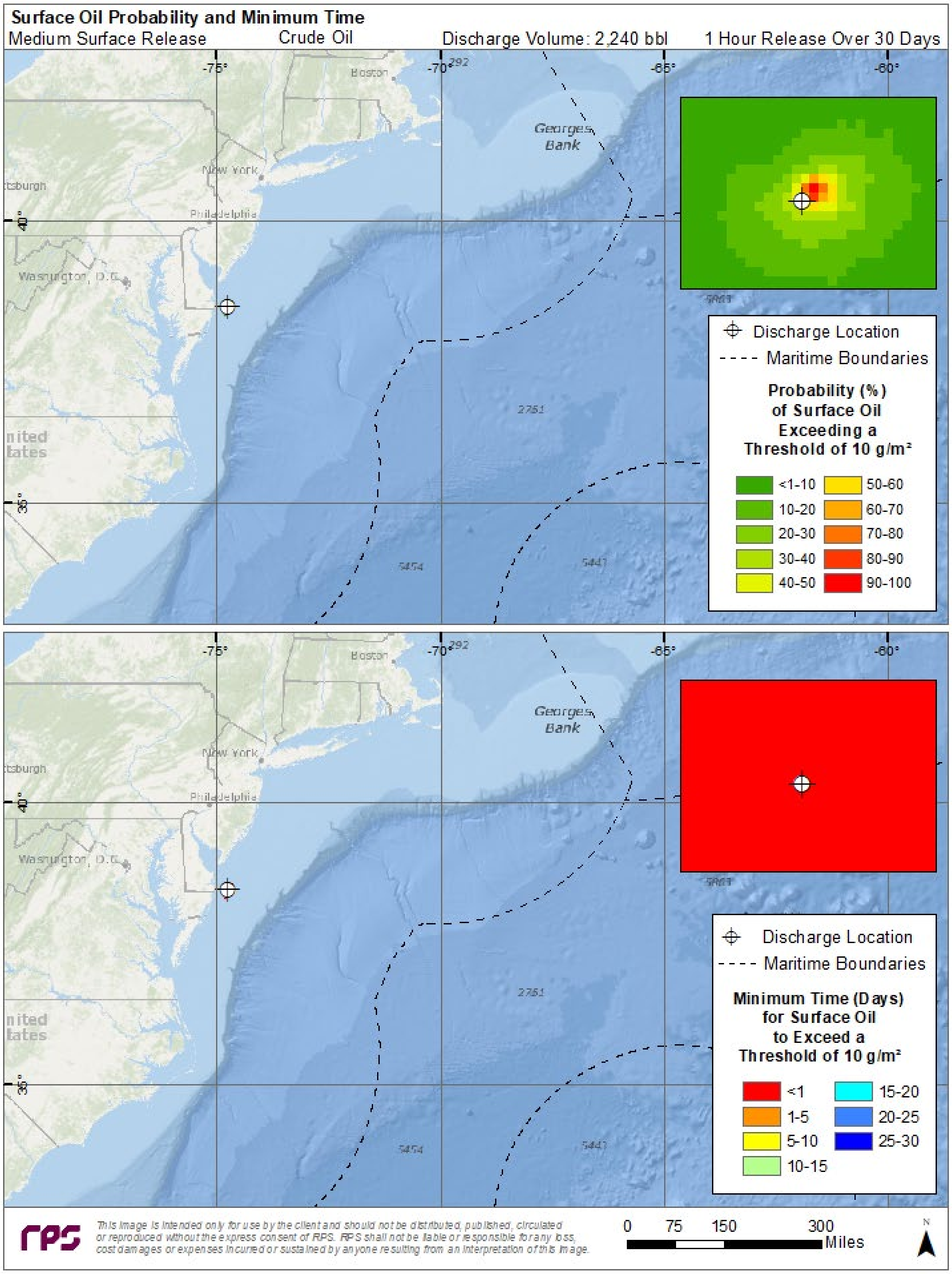


Figure 3-10. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore Delaware.

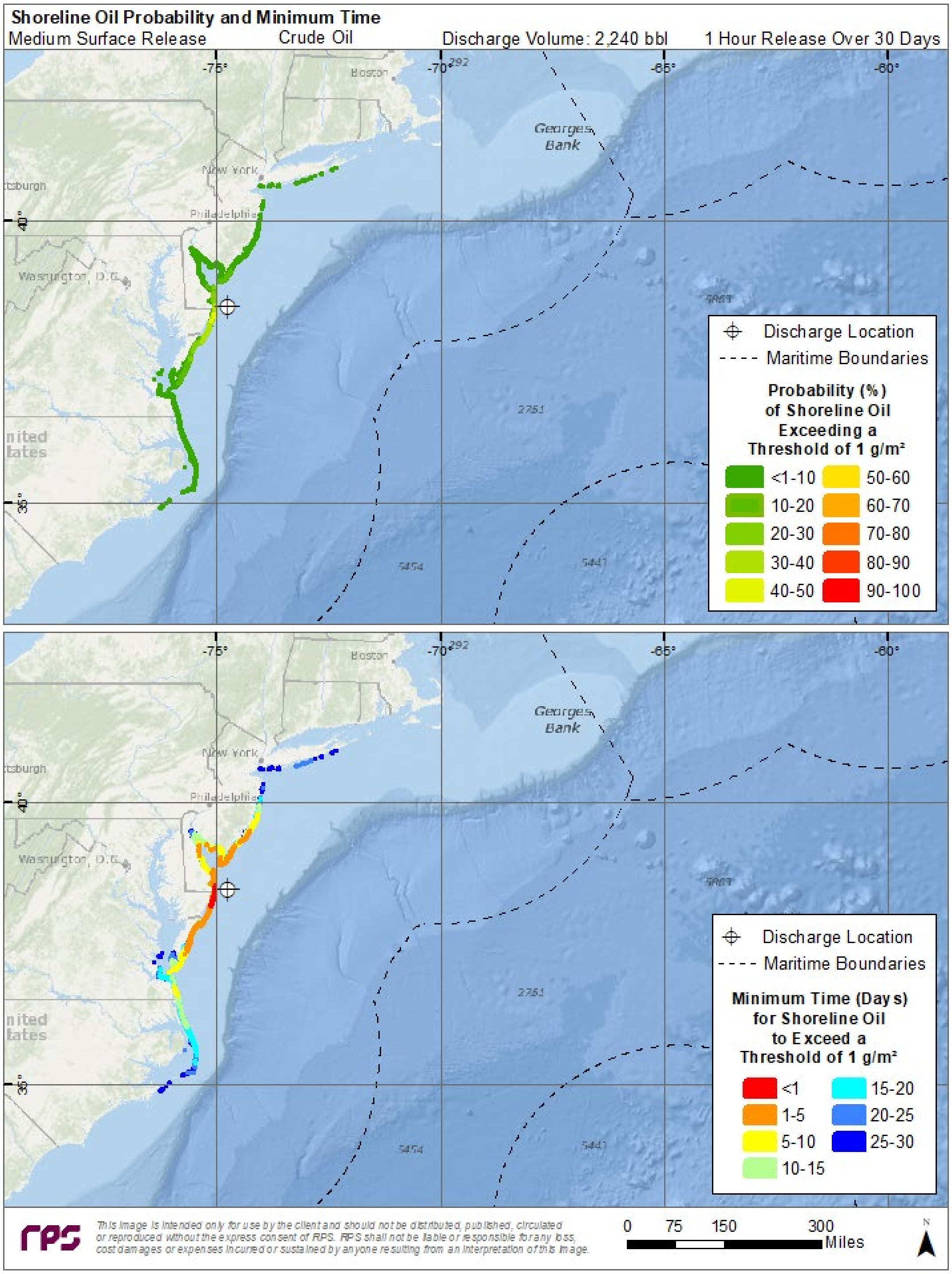


Figure 3-11. Top panel displays probability of shoreline oiling ≥1 µm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore Delaware.

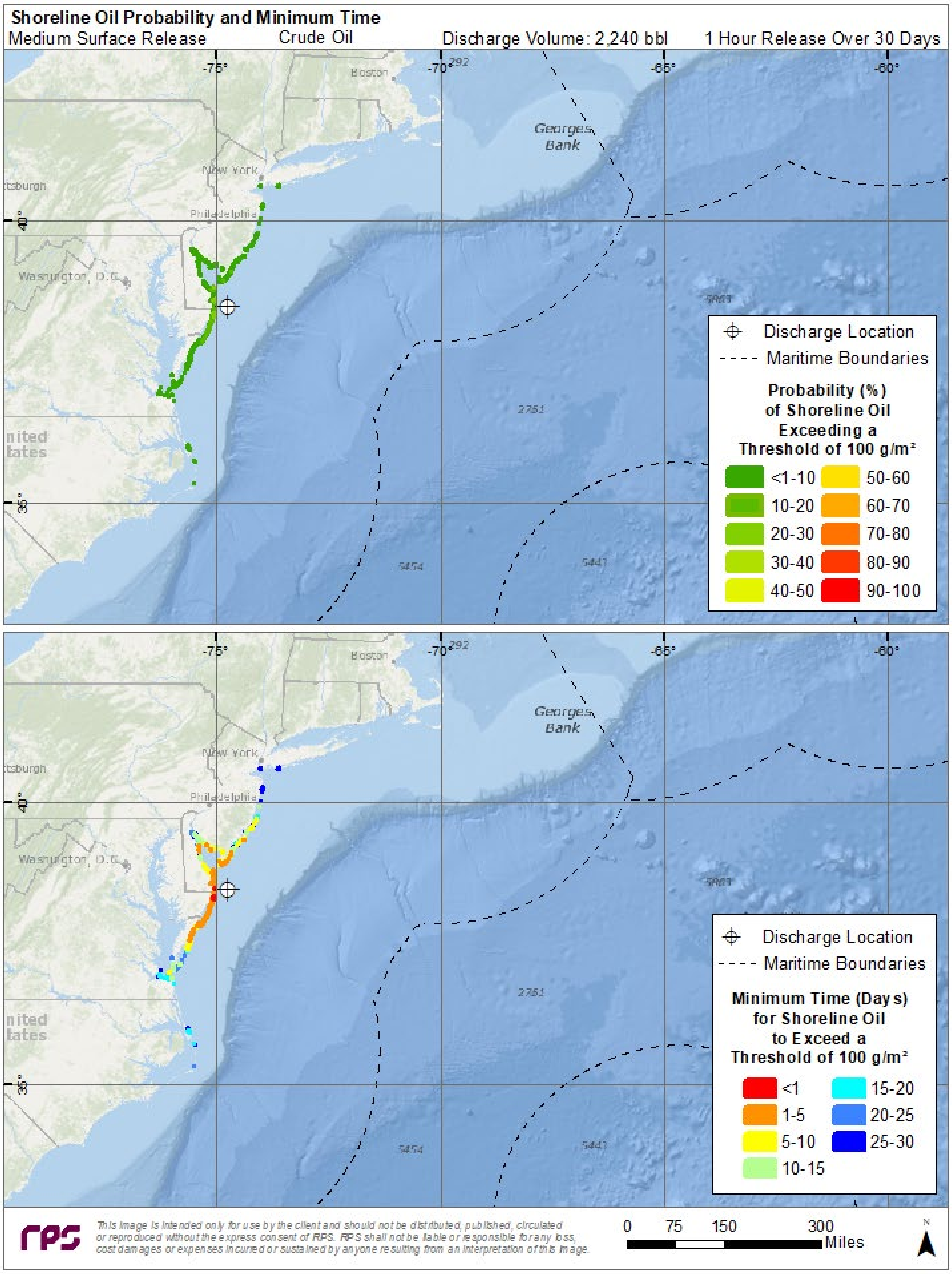


Figure 3-12. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore Delaware.

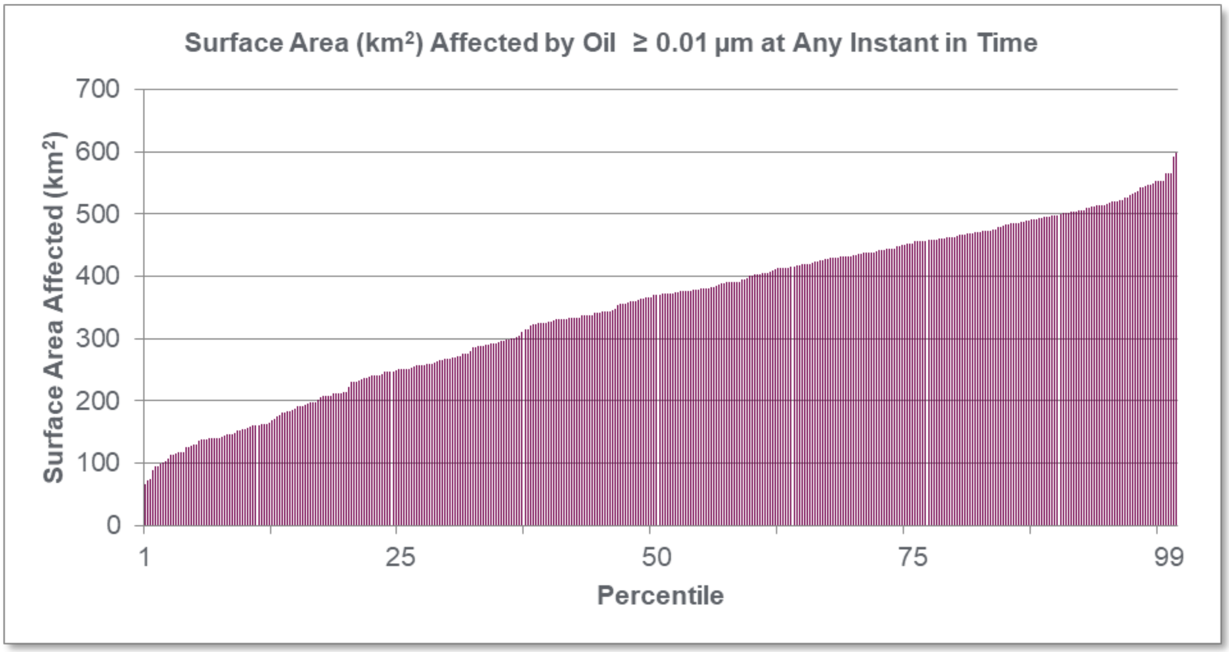


Figure 3-13. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore Delaware.

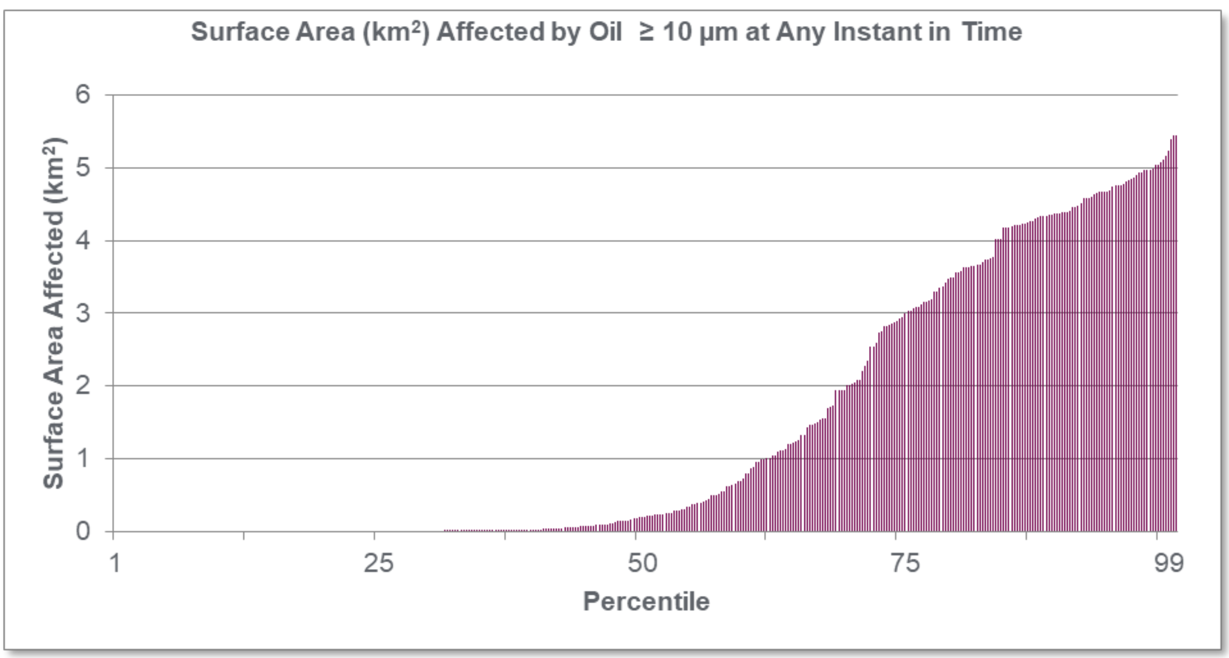


Figure 3-14. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore Delaware.

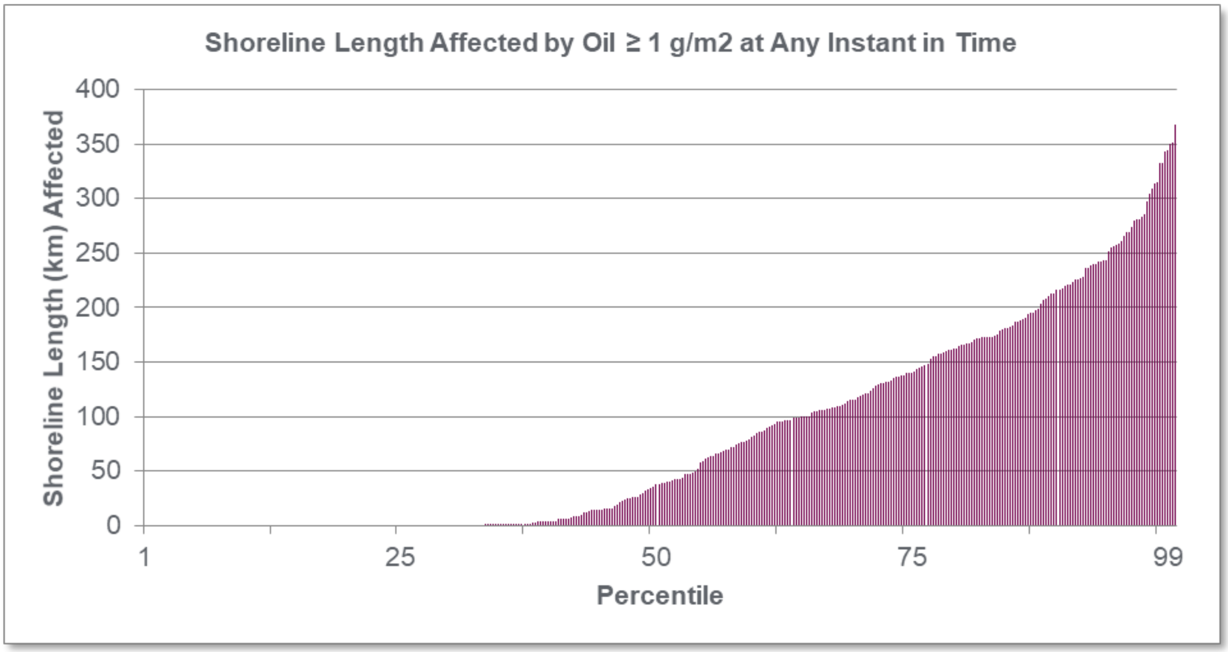


Figure 3-15. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore Delaware.

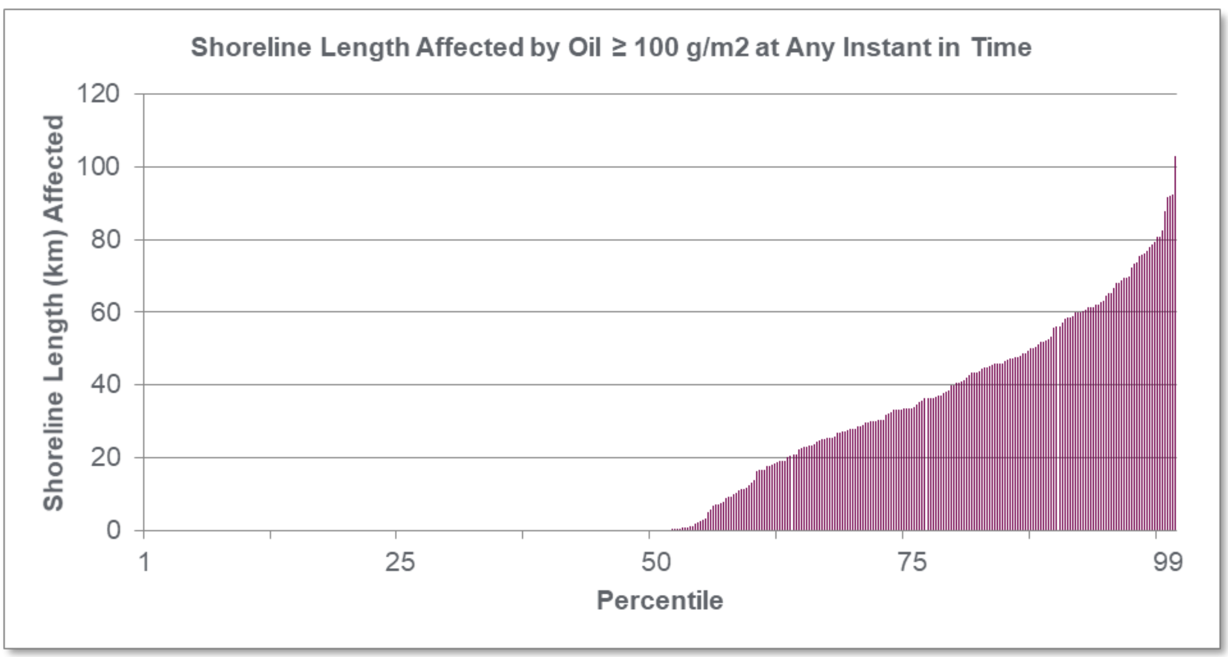


Figure 3-16. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore Delaware.

3.2.1.3 Surface Release (High Volume)

For the unmitigated 200,000 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 μm, on average] threshold) was primarily located within ~108 mi (174 km) of the discharge location (Figure 3-17, top panel). Surface oil exceeding 0.01 g/m^2 required a minimum of <1 days to reach the coast (Figure 3-17, bottom panel). Using the 10 g/m^2 (10 μm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~17 mi (27 km) (Figure 3-18, top panel) and required a minimum of < 1 days to reach the coast at any probability (Figure 3-18, bottom panel). The 0.01 g/m^2 (0.01 μm, on average) surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 5-10 days of the discharge. The 10 g/m^2 (10 μm, on average) surface oil exposure footprint above 1% probability was also predicted to extend past U.S. waters within a minimum of 10-15 days. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 and 10 g/m^2 thresholds extended over 500 mi (805 km) east of the discharge location and outside of the model domain (Figure 3-19 and Figure 3-20). The shoreline oiling above 1 g/m^2 and 100 g/m^2 thresholds extended along the outer coast from Cape Hatteras, North Carolina to Long Island, New York (Figure 3-21 and Figure 3-22). The probabilities for shoreline oiling do not exceed 50% for either threshold with the highest probabilities (40-50%) occurring directly west of the discharge location just south of the Delaware/Virginia border. Of the 400 trajectories simulated for the stochastic scenario, 50% had < 3,336 mi^2 (8,640 km^2) of surface waters exceeding 0.01 g/m^2 while 50% of simulations have surface oil exposure footprints of < 89 mi^2 (231 km^2) exceeding 10 g/m^2 (Figure 3-21 and Figure 3-22). Approximately 75% of possible trajectories had <146 mi (235 km) of shoreline oiling exceeding 1 g/m^2 while 75% of simulations had shoreline exposure footprints of <118 mi (190 km) exceeding 100 g/m^2 (Figure 3-23 and Figure 3-24). The maximum amount of shoreline oiled for any simulation was 354 mi (570 km). This worst-case simulation is examined in more detail in Section 3.3.

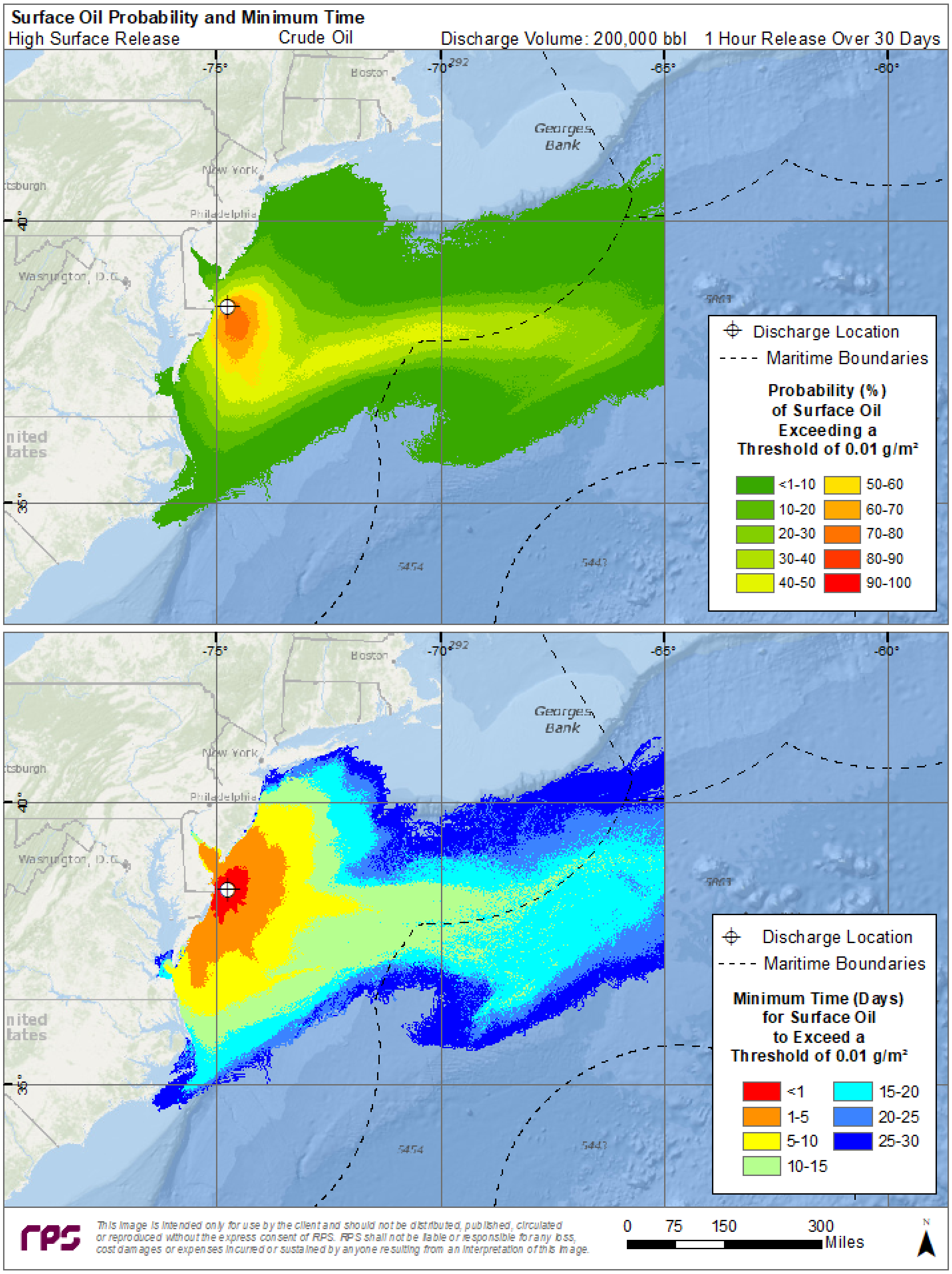


Figure 3-17. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore Delaware.

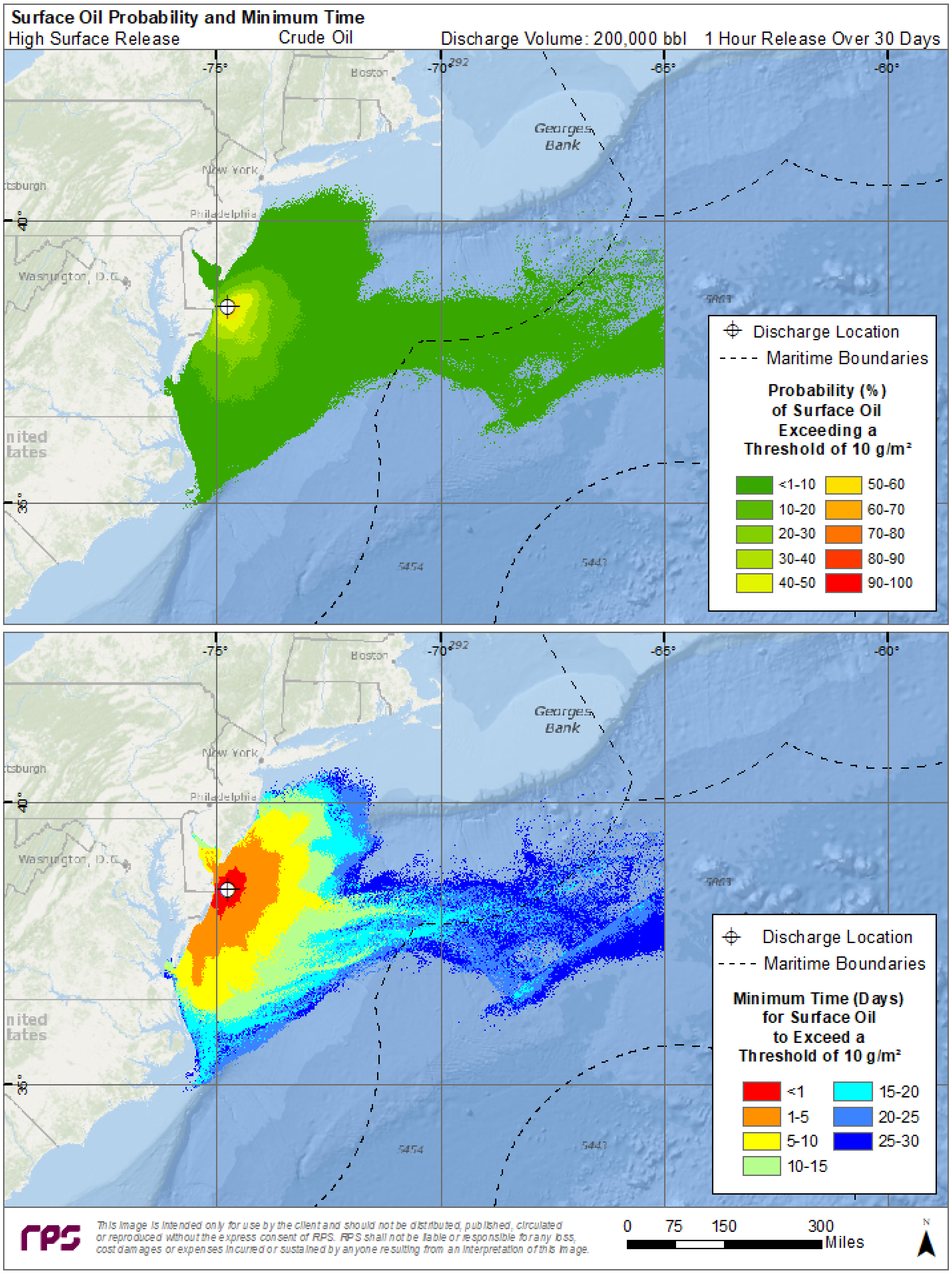


Figure 3-18. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore Delaware.

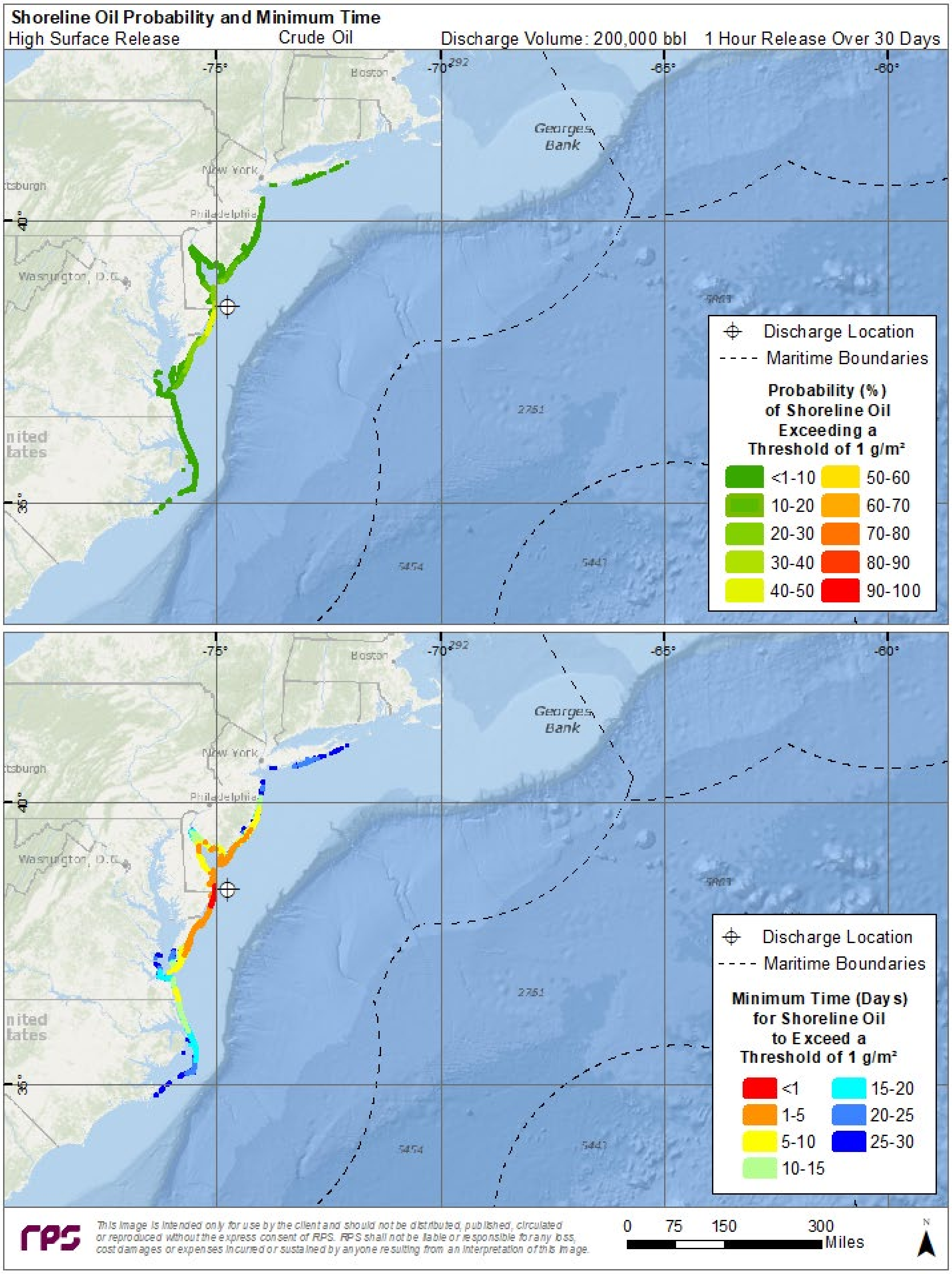


Figure 3-19. Top panel displays probability of shoreline oiling ≥1 µm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore Delaware.

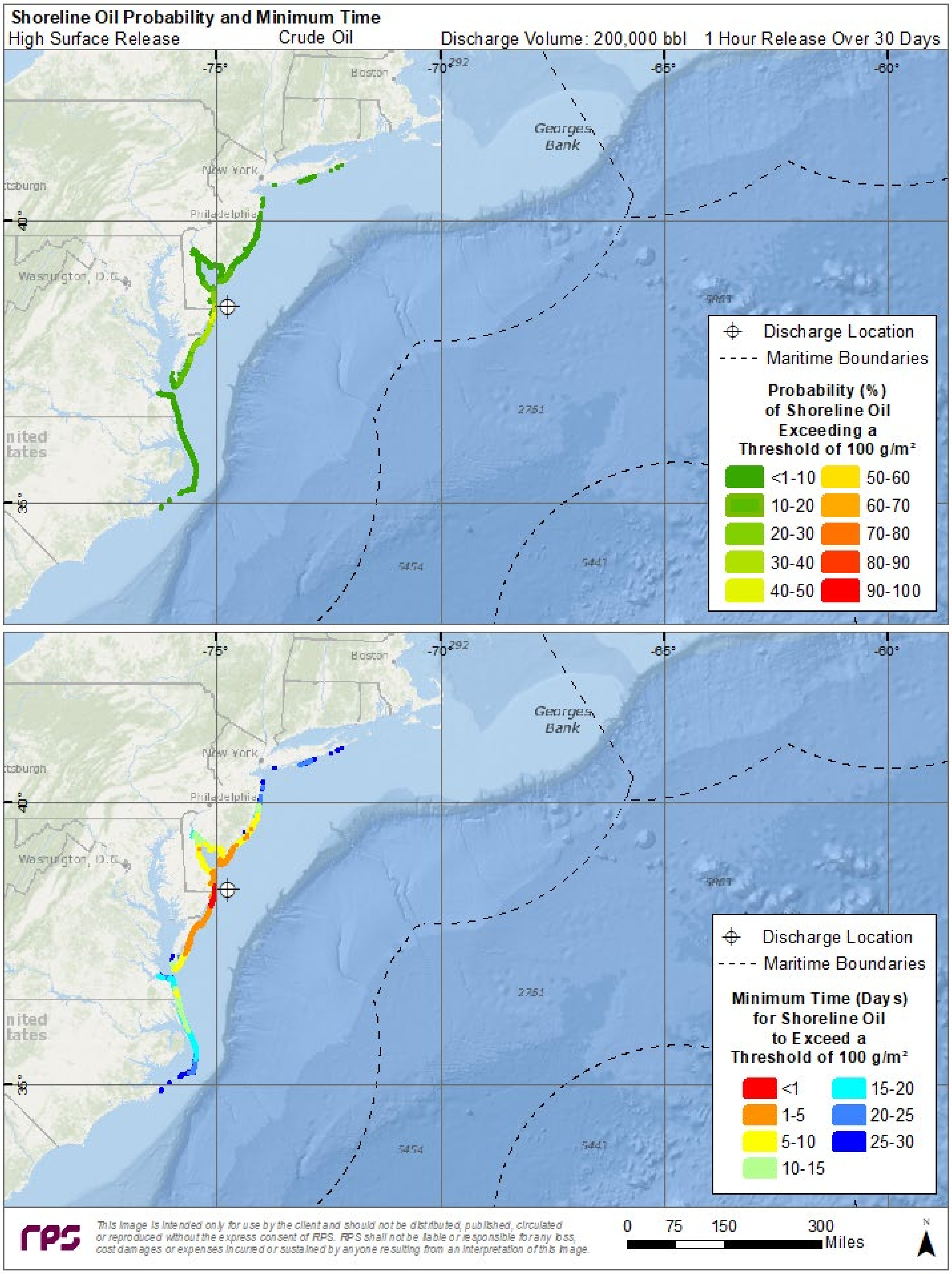


Figure 3-20. Top panel displays probability of shoreline oiling ≥100 μm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 μm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore Delaware.

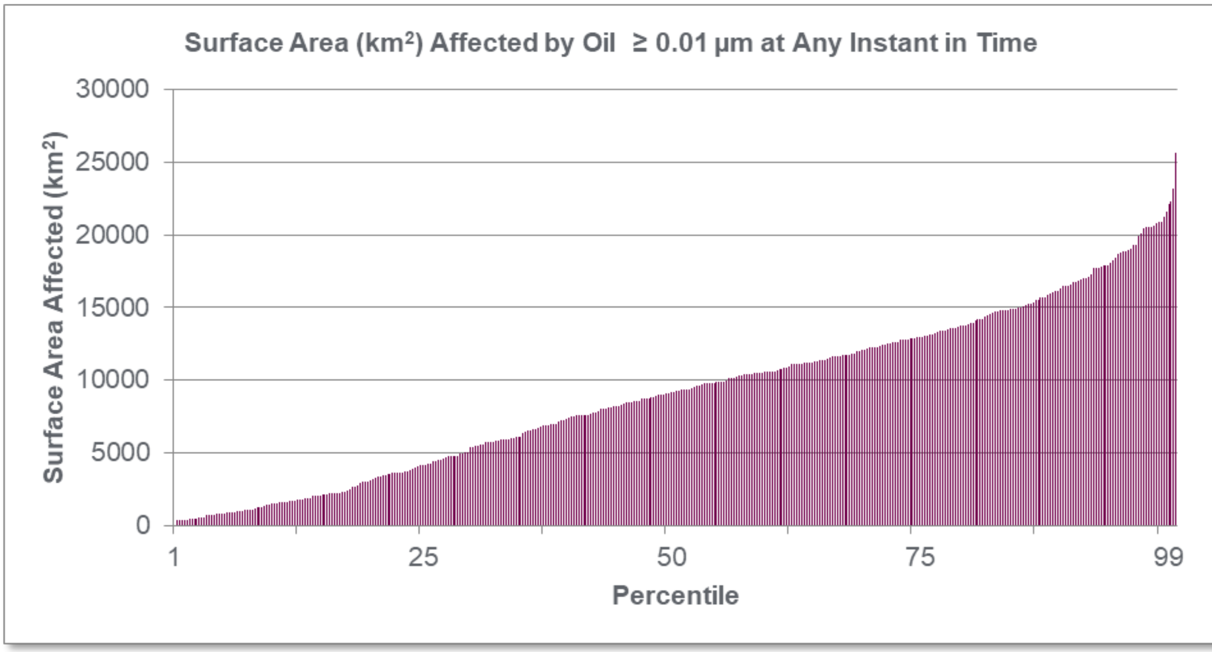


Figure 3-21. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore Delaware.

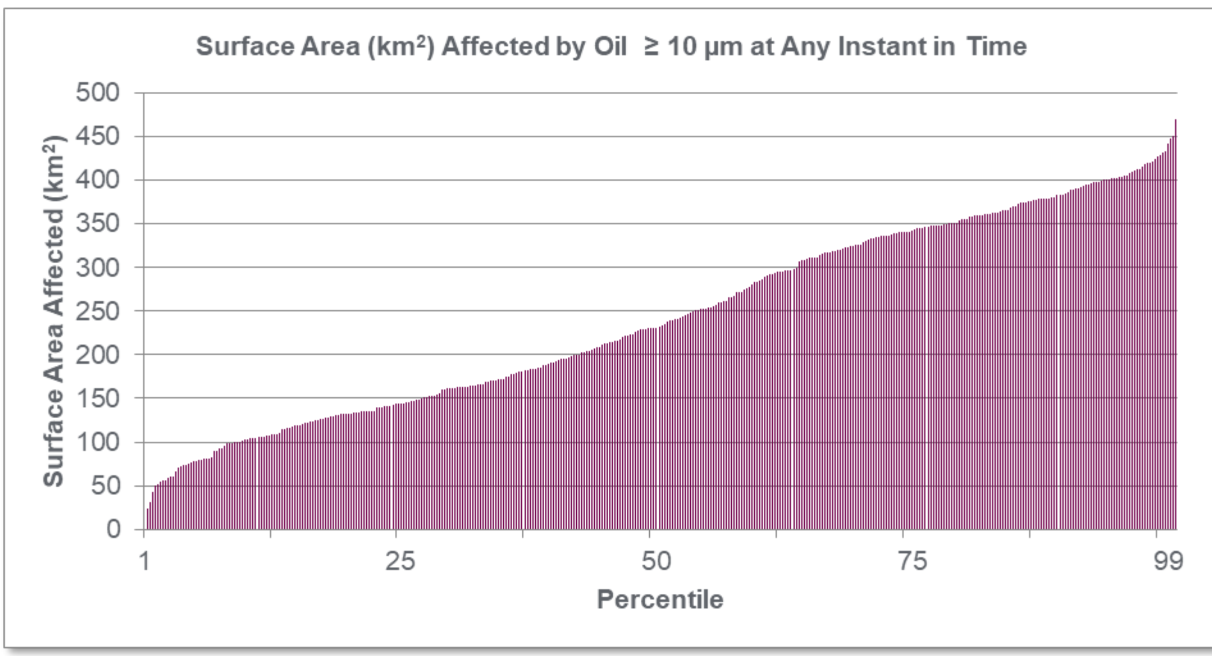


Figure 3-22. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore Delaware.

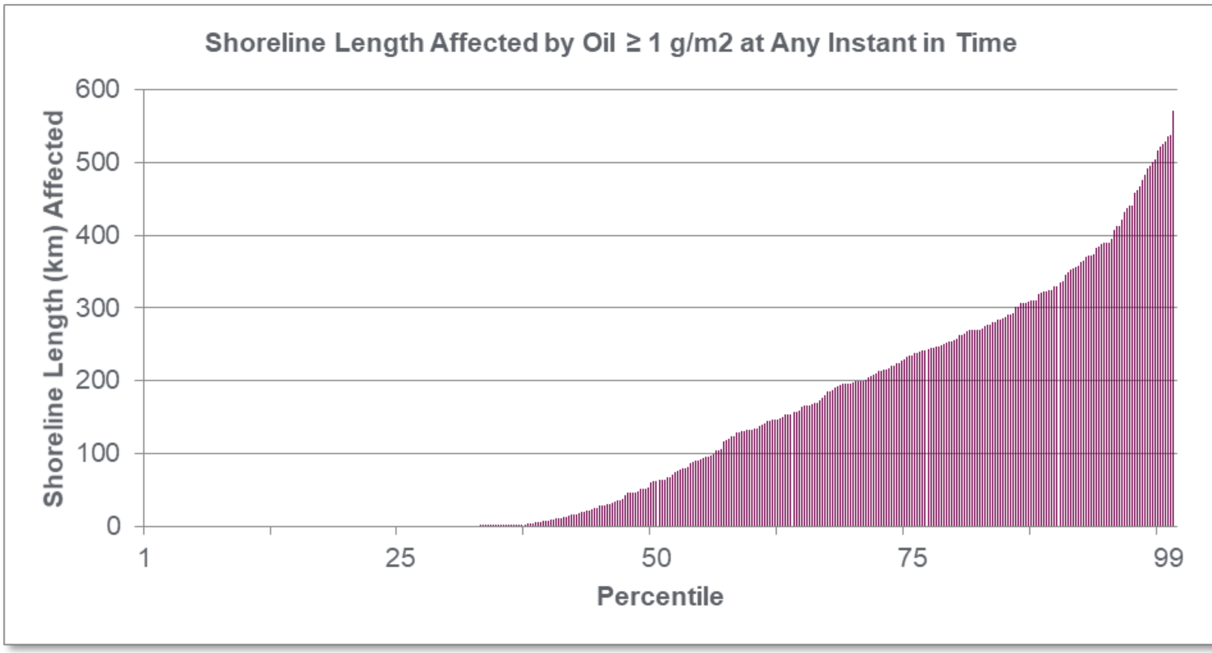


Figure 3-23. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore Delaware.

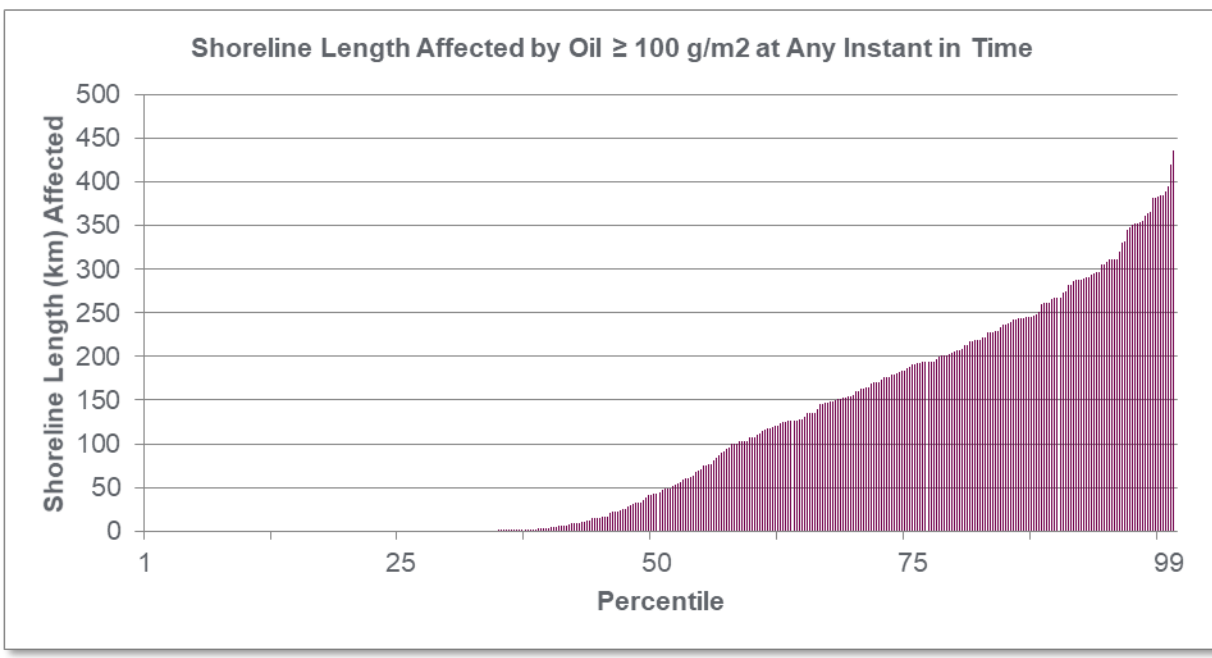


Figure 3-24. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore Delaware.

3.2.1.4 Subsurface Release (Well Blowout)

For the unmitigated 900,000 bbl subsurface blowout of crude oil, the surface oil exposure footprint exceeding 70% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) extended over 900 mi (1,448 km) east of the release location the discharge location and outside of the model domain (Figure 3-25, top panel). High probabilities for surface oiling (>70%) above the conservative threshold (0.01 g/m^2 [0.01 µm, on average]) also extended approximately 200 mi (322 km) south. Surface oil exceeding 0.01 g/m^2 [0.01 µm, on average] required a minimum of 5-10 days to reach the coast (Figure 3-25, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 70% probability threshold was primarily within ~450 mi (724 km) of the release site, with these higher probabilities also occurring further offshore and outside of the model domain (Figure 3-26, top panel). Surface oil exceeding 10 g/m^2 also required a minimum of 5-10 days to reach the coast (Figure 3-26, bottom panel). At both thresholds, the surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 5-10 days of the discharge. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 and 10 g/m^2 thresholds extended over 494 mi (795 km) east of the discharge location and outside of the model domain (Figure 3-27 and Figure 3-28). Of all trajectories simulated for the stochastic scenario, 50% had < 10,889 mi^2 (28,203 km^2) of surface waters exceeding 0.01 g/m^2 while 50% of simulations have surface oil exposure footprints of < 269 mi^2 (696 km^2) exceeding 10 g/m^2 (Figure 3-29 and Figure 3-30). The shoreline oiling stochastic footprint above the 1 g/m^2 and 100 g/m^2 [100 µm, on average] thresholds were similar in extent, stretching along the outer coast from Cape Lookout, North Carolina to Cape Cod, Massachusetts (Figure 3-29 and Figure 3-30). The probabilities for shoreline oiling do not exceed 40% for either threshold with the highest probabilities (30-40%) occurring west of the discharge location just north and south the Delaware Bay. Approximately 60% of possible trajectories had < 30 mi (49 km) of shoreline oiling exceeding both the 1 g/m^2 and 100 g/m^2 thresholds (Figure 3-31 and Figure 3-32). The maximum amount of shoreline oiled exceeding 1 g/m^2 for any simulation was 608 mi (978 km). This worst-case simulation is examined in more detail in Section 3.3.

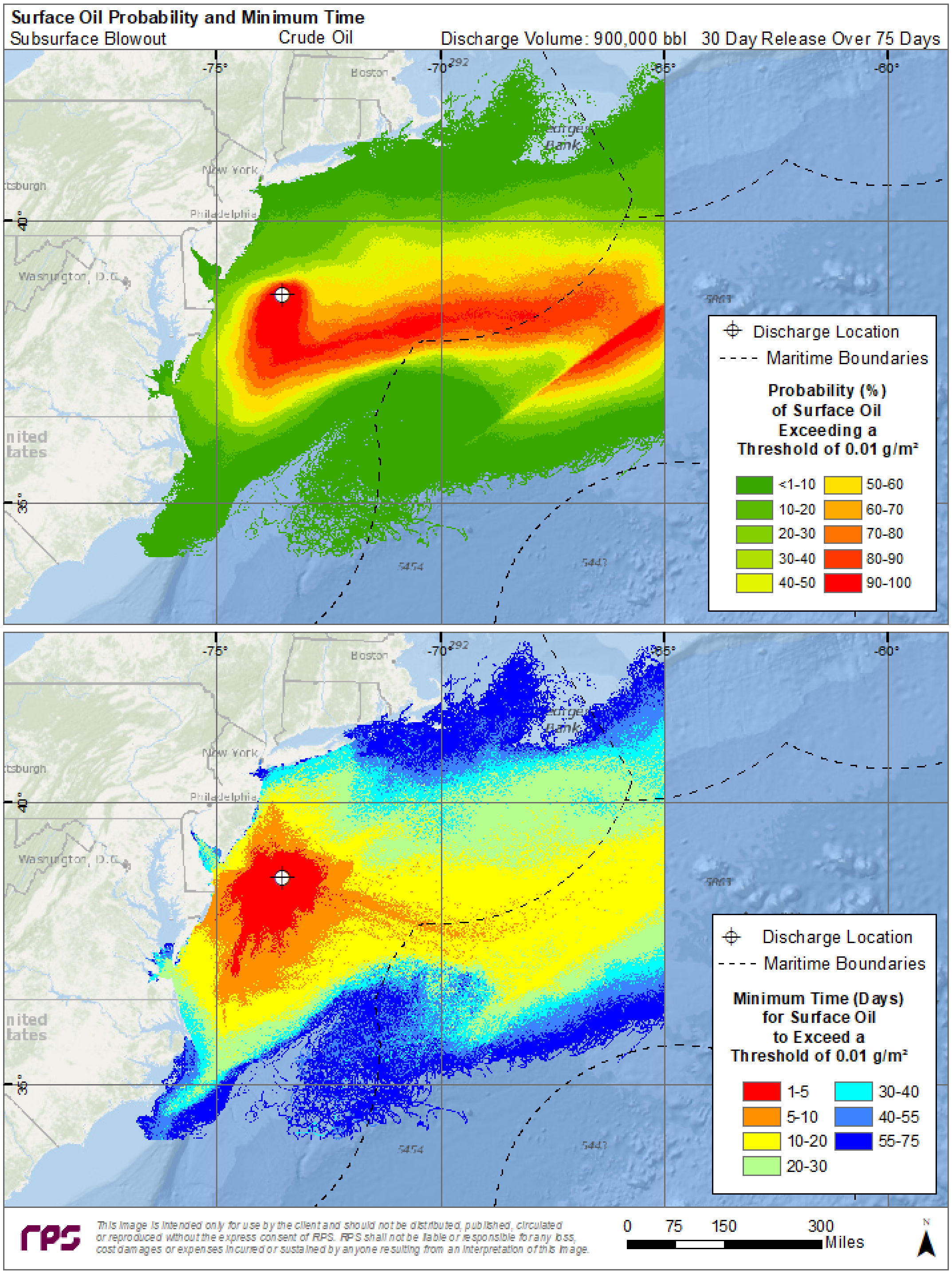


Figure 3-25. Top panel displays probability of surface oiling ≥0.01 µm and bottom panel displays minimum time for surface oil to exceed 0.01 µm, based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore Delaware.

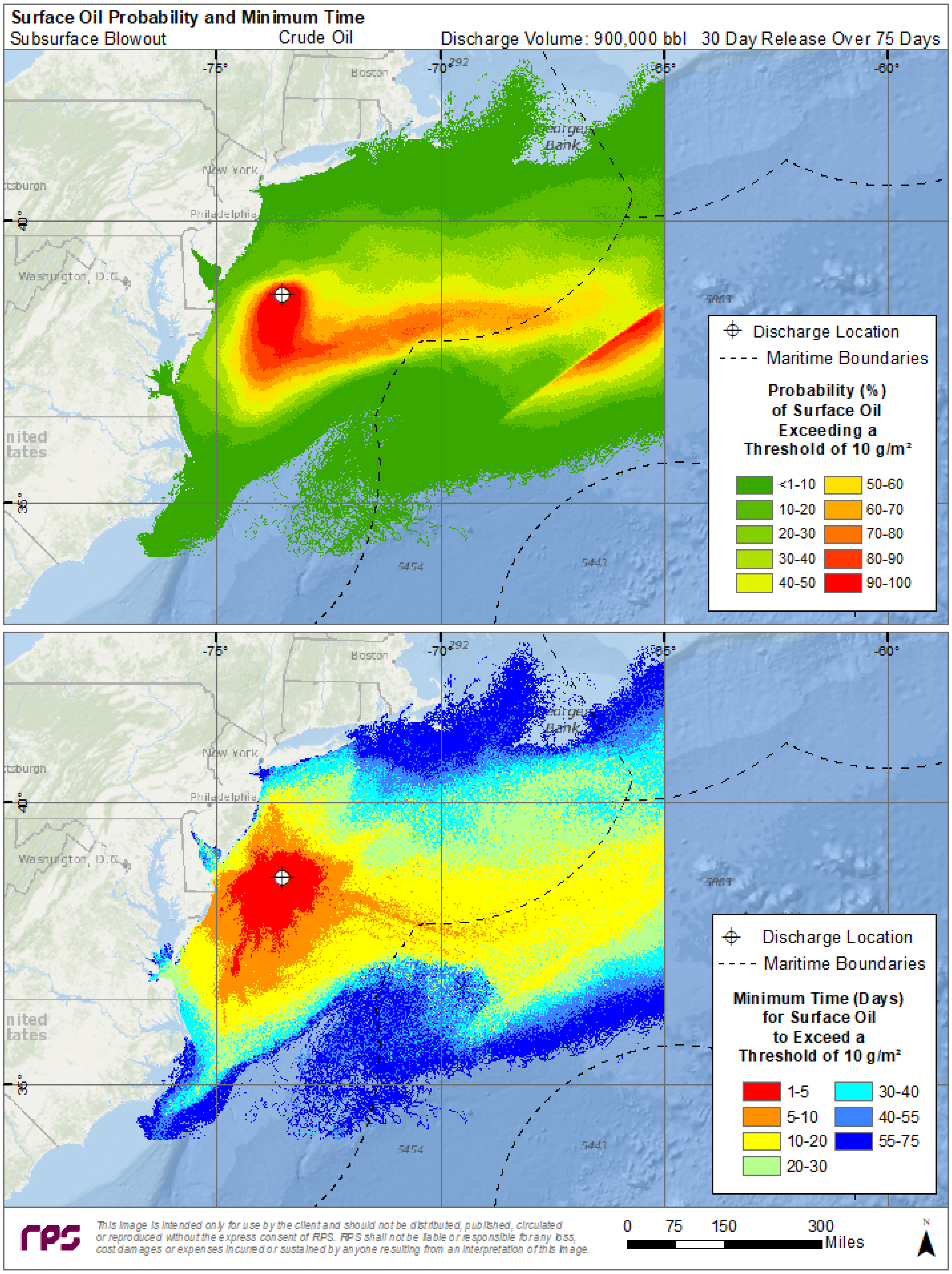


Figure 3-26. Top panel displays probability of surface oiling ≥10 µm and bottom panel displays minimum time for surface oil to exceed 10 µm, based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore Delaware.

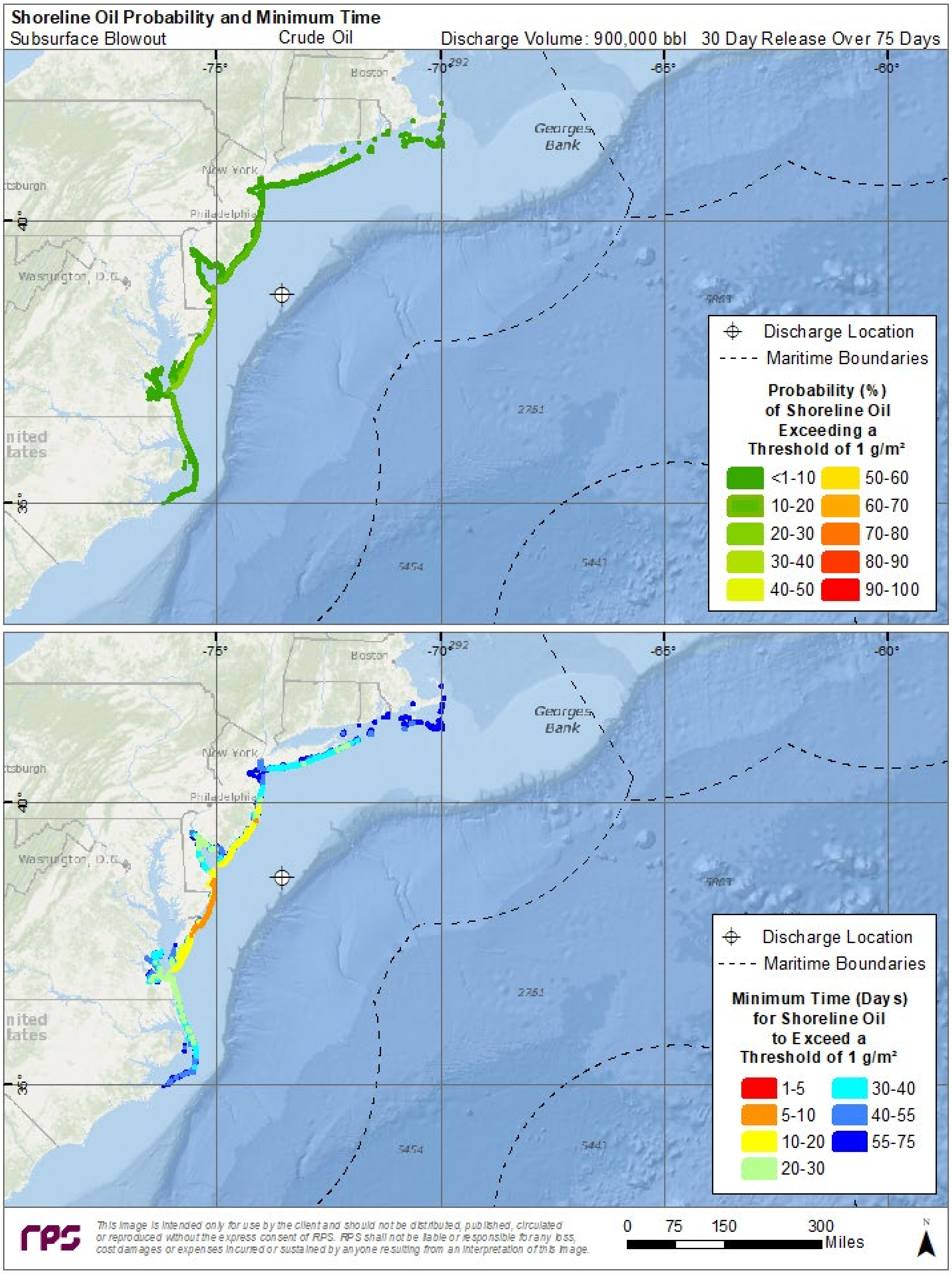


Figure 3-27. Top panel displays probability of shoreline oiling ≥1 µm and bottom panel displays minimum time for shoreline oil to exceed 1 µm, based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore Delaware.

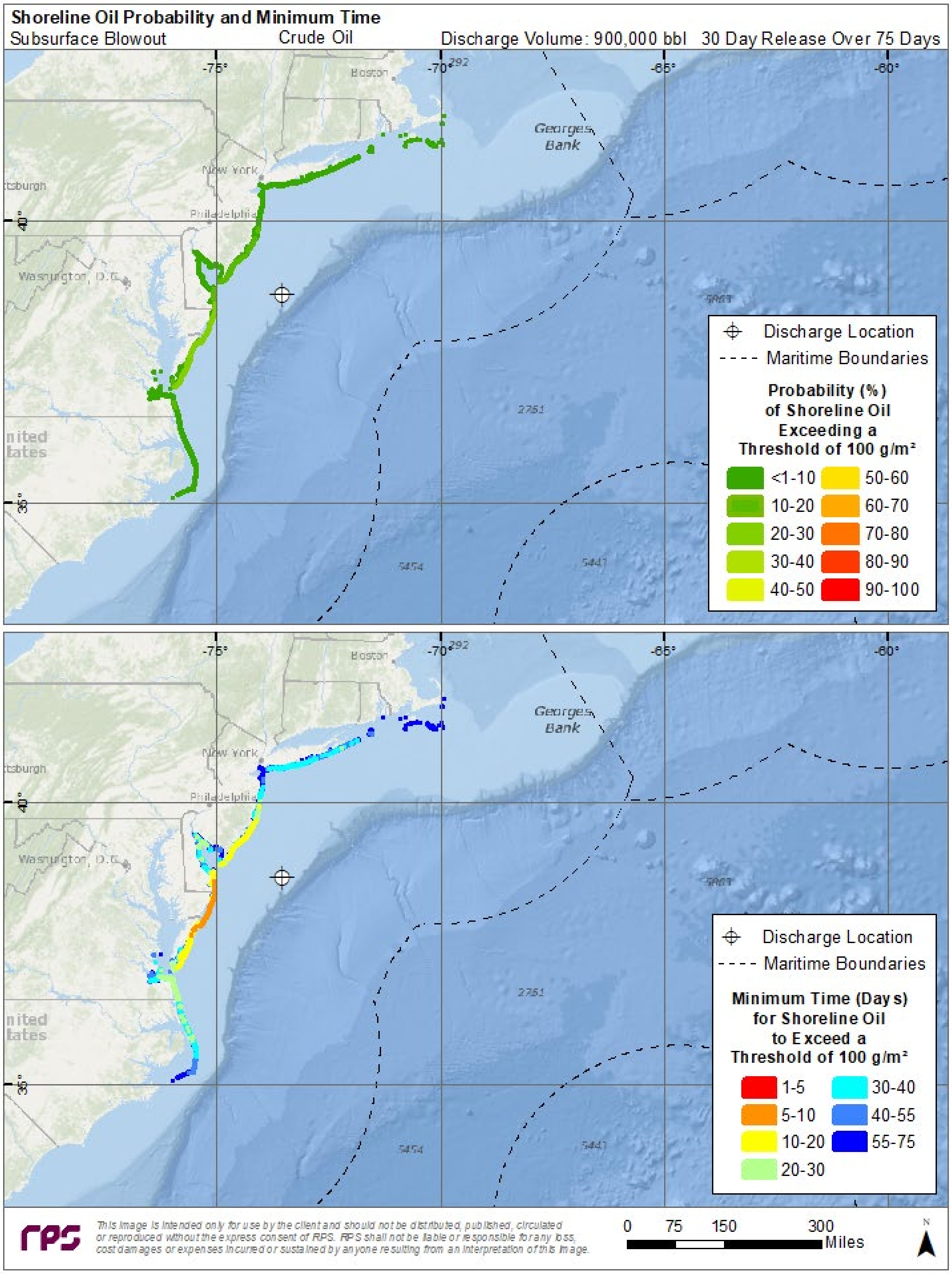


Figure 3-28. Top panel displays probability of shoreline oiling ≥100 µm and bottom panel displays minimum time for shoreline oil to exceed 100 µm, based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore Delaware.

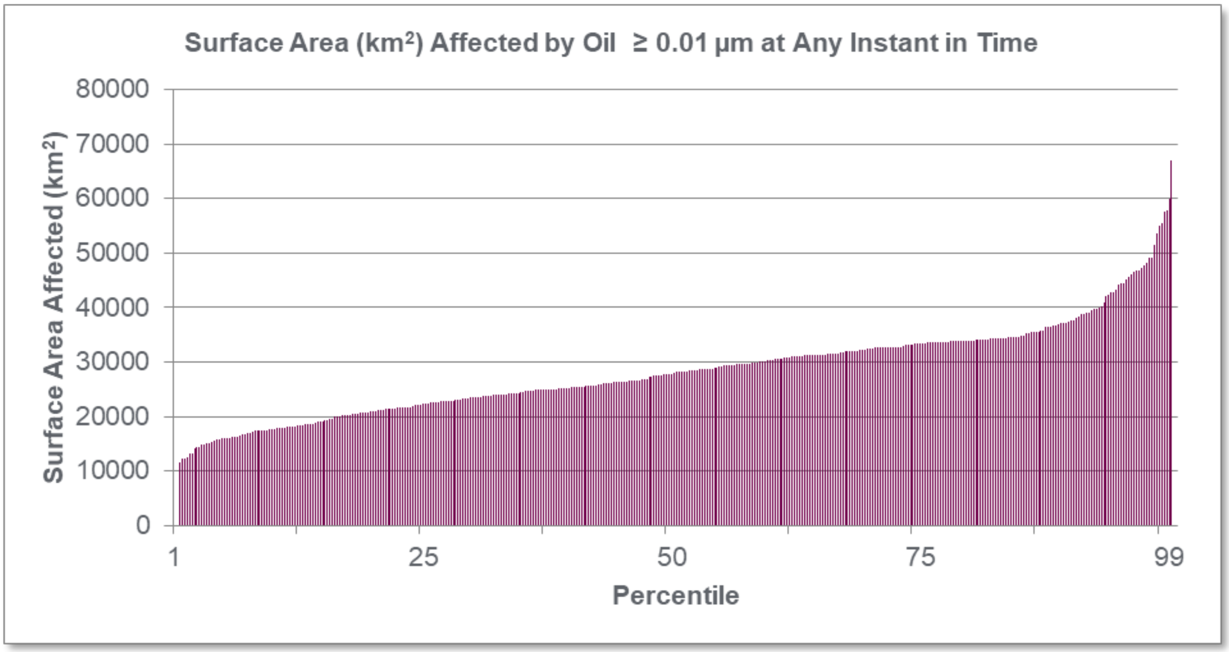


Figure 3-29. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore Delaware.

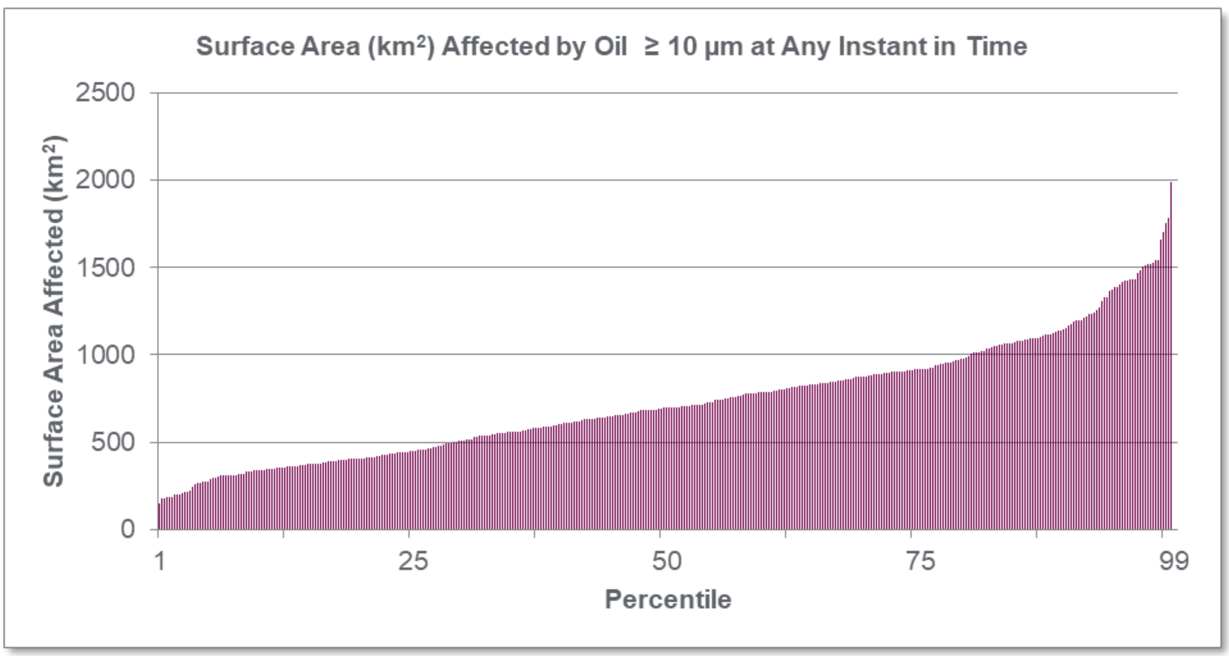


Figure 3-30. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore Delaware.

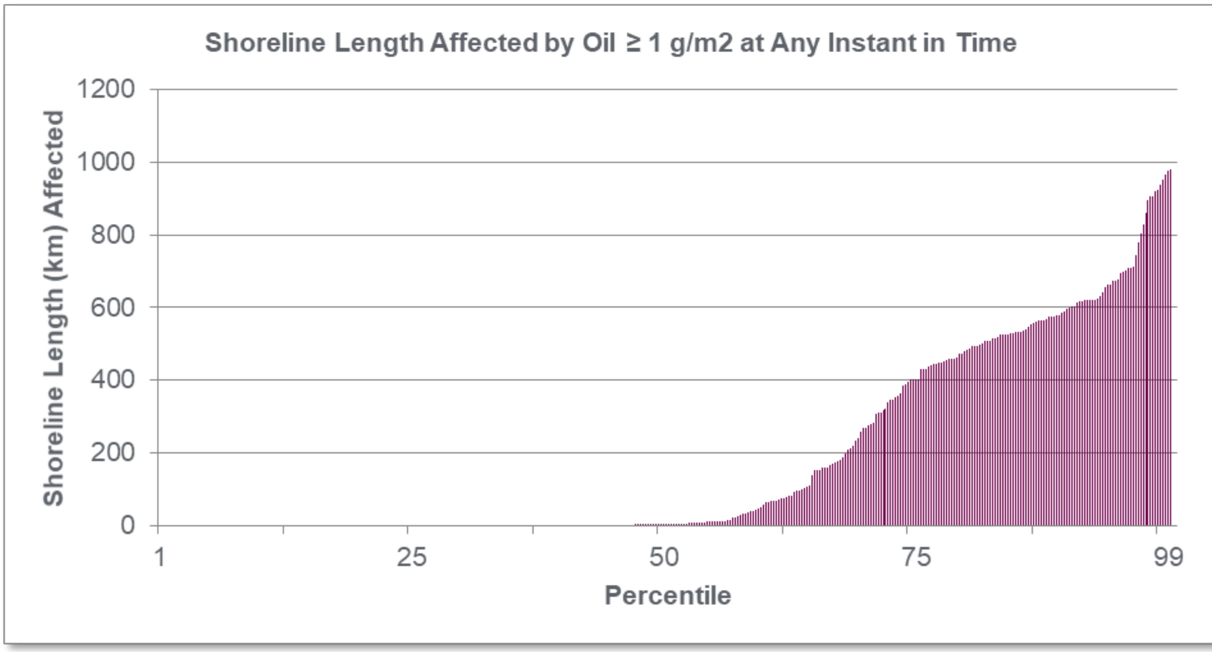


Figure 3-31. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore Delaware.

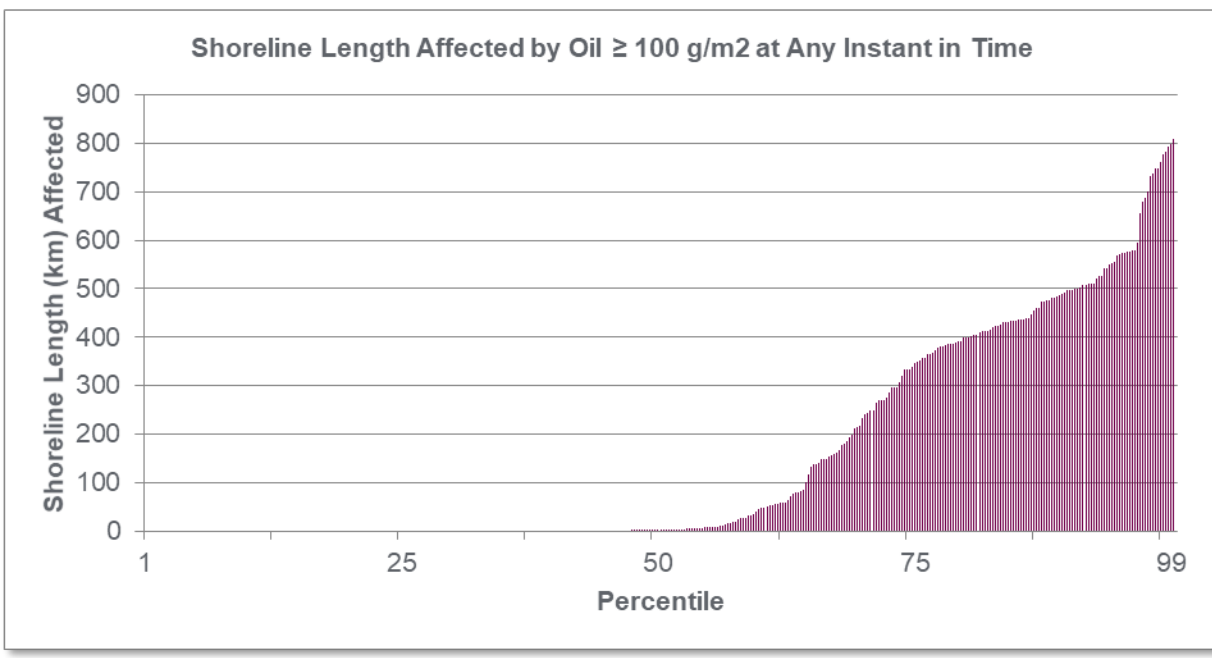


Figure 3-32. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore Delaware.

3.2.2 Offshore New Jersey

Surface crude oil discharges of three different volumes at a high traffic location offshore New Jersey and a subsea blowout in Hudson Canyon were modeled throughout all seasons over multiple years. The following stochastic result figures illustrate the spatial extent of surface and shoreline oiling probabilities (footprint) and associated minimum travel times to reach any point within the footprint. For the spill scenario, the stochastic and time contour footprints were calculated assuming two thresholds for minimum surface and shoreline oil thickness. In addition, figures are presented in a Web Mercator Auxiliary Sphere Projection for visualization purposes, as this projection preserves angles. Measurements are provided in North America Albers Equal Area Conic projection, as it maintains distance in the east-west direction along the eastern U.S. coastline.

3.2.2.1 Surface Release (Low Volume)

For the unmitigated 126 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) was primarily located within ~7 mi (11 km) of the discharge location (Figure 3-65, top panel). Surface oil exceeding 0.01 g/m^2 required a minimum of less than 1 day to reach the coast (Figure 3-65, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~0.5 mi (0.8 km) (Figure 3-66, top panel) and oil did not reach the coast (Figure 3-66, bottom panel). The 0.01 g/m^2 surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 25-30 days of the discharge. The 10 g/m^2 surface oil exposure footprint above 1% probability was not predicted to extend past U.S. waters. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 extended over roughly 190 mi (305 km) to the southeast. The 1% probability for the 10 g/m^2 threshold extended 1 mi (1.6 km) northeast of the discharge location. The shoreline oiling above 1 g/m^2 threshold extended along the east coast from Block Island, Rhode Island to south of Assateague Island National Seashore, Maryland and oiling above the 100 g/m^2 threshold was predicted along a similar extent but was patchy to the north and south of the release location (Figure 3-67 and Figure 3-68). The probabilities for shoreline oiling are generally 0-50% with a few small locations of higher probabilities occurring directly west and south of the discharge location in the vicinity of the Toms River, New Jersey. Approximately 75% of possible trajectories have < 11.5 mi^2 (30 km^2) of surface waters exceeding 0.01 g/m^2, and 100% of simulations have surface oil exposure footprints of < 0.4 mi^2 (1 km^2) exceeding 10 g/m^2 (Figure 3-69 and Figure 3-70). Approximately 50% of possible trajectories have > 24 mi (39 km) of shoreline oiling exceeding 1 g/m^2 and 80% of simulations have shoreline exposure footprints of < 1.2 mi (2 km) exceeding 100 g/m^2 (Figure 3-71 and Figure 3-72). The maximum amount of shoreline oiled (>1 g/m^2) for any simulation was 141 mi (227 km). This worst-case simulation is examined in more detail in Section 3.3.

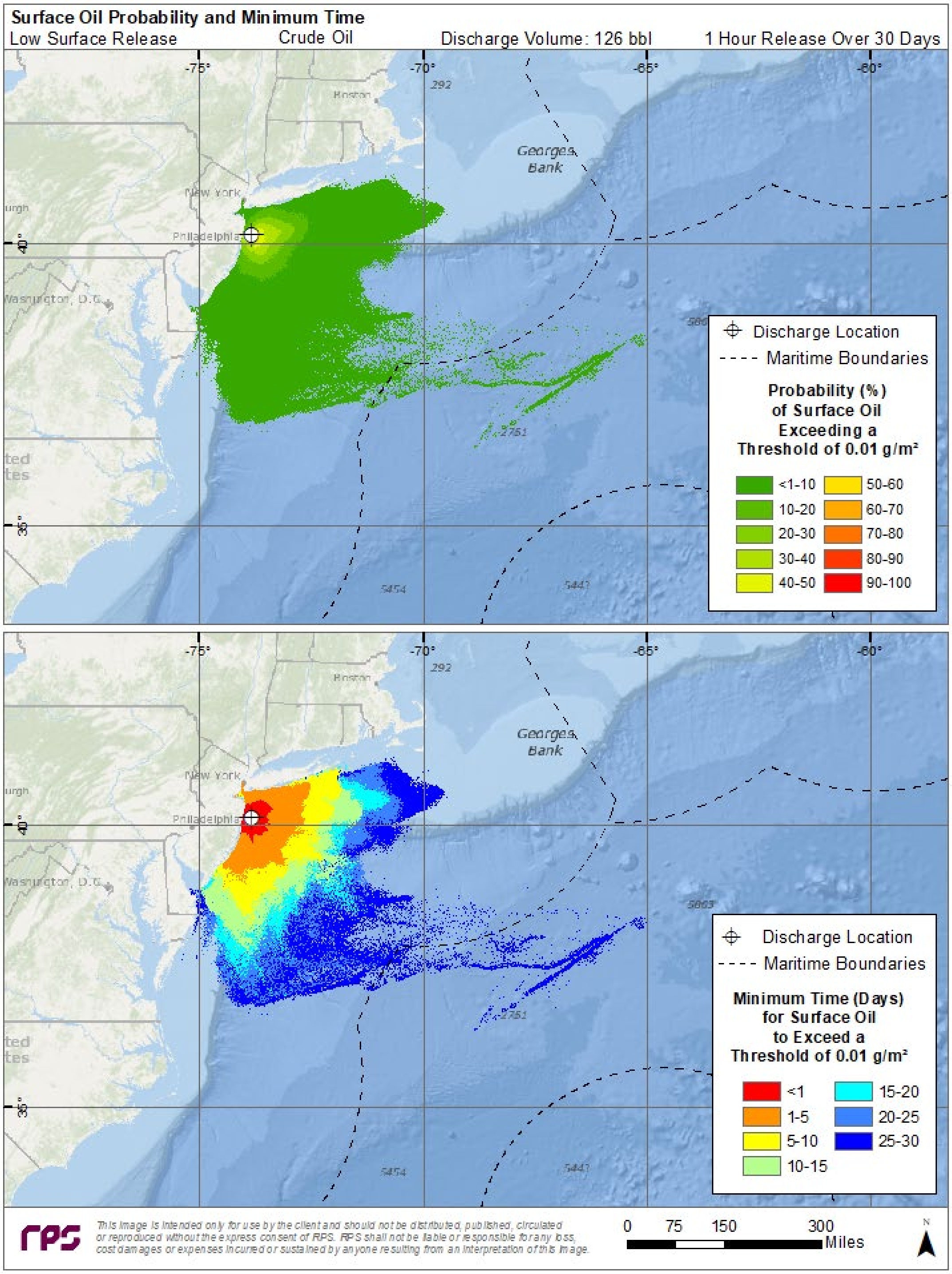


Figure 3-33. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore New Jersey.

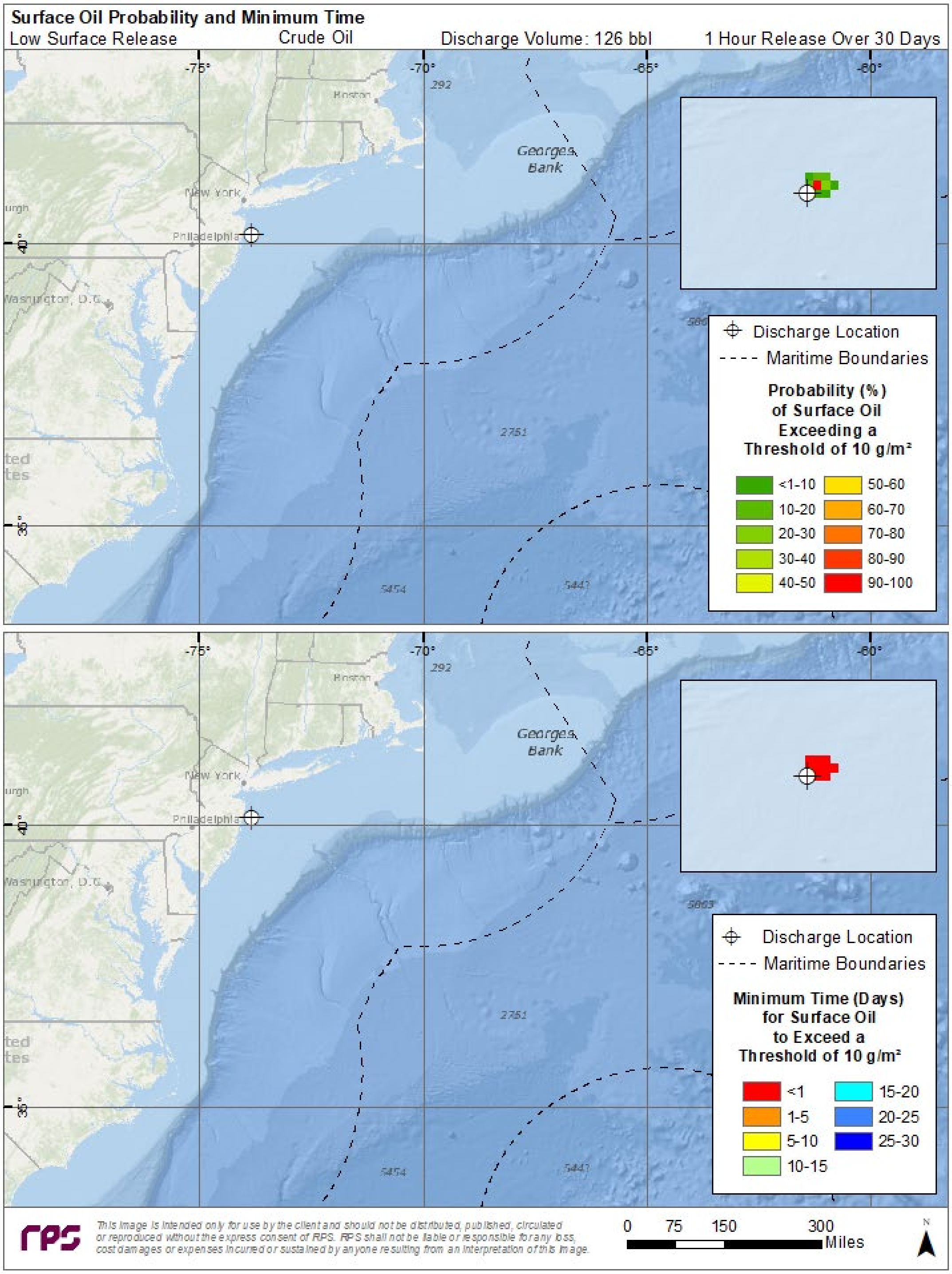


Figure 3-34. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore New Jersey.

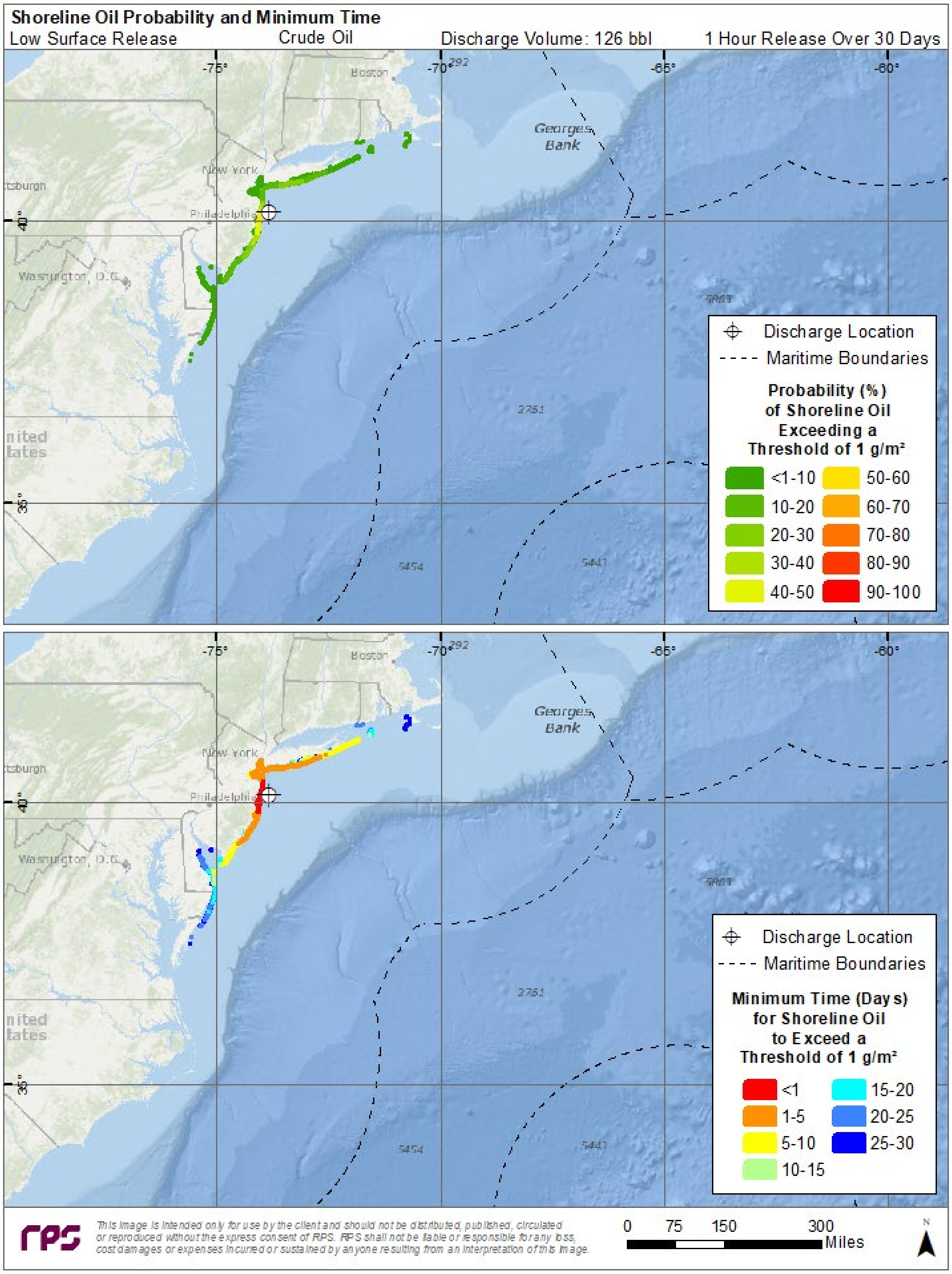


Figure 3-35. Top panel displays probability of shoreline oiling ≥1 µm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore New Jersey.

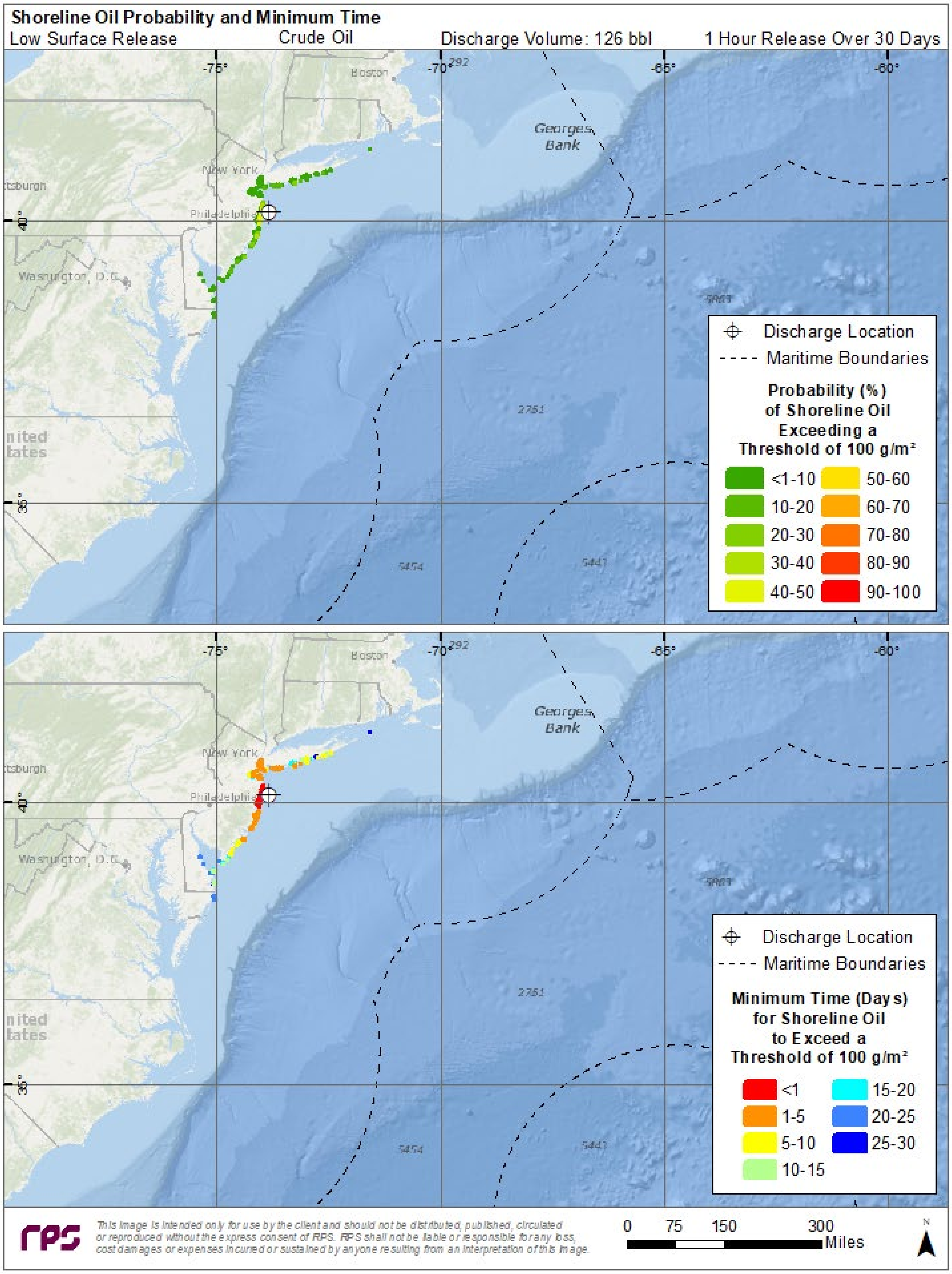


Figure 3-36. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore New Jersey.

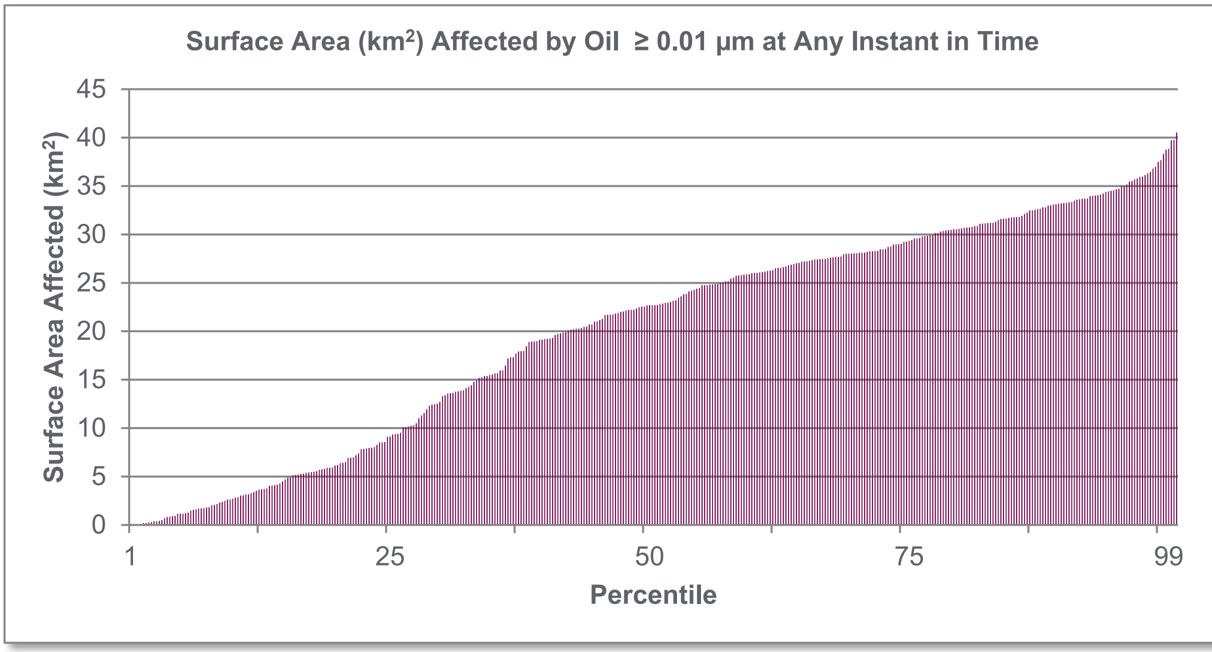


Figure 3-37. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore New Jersey.

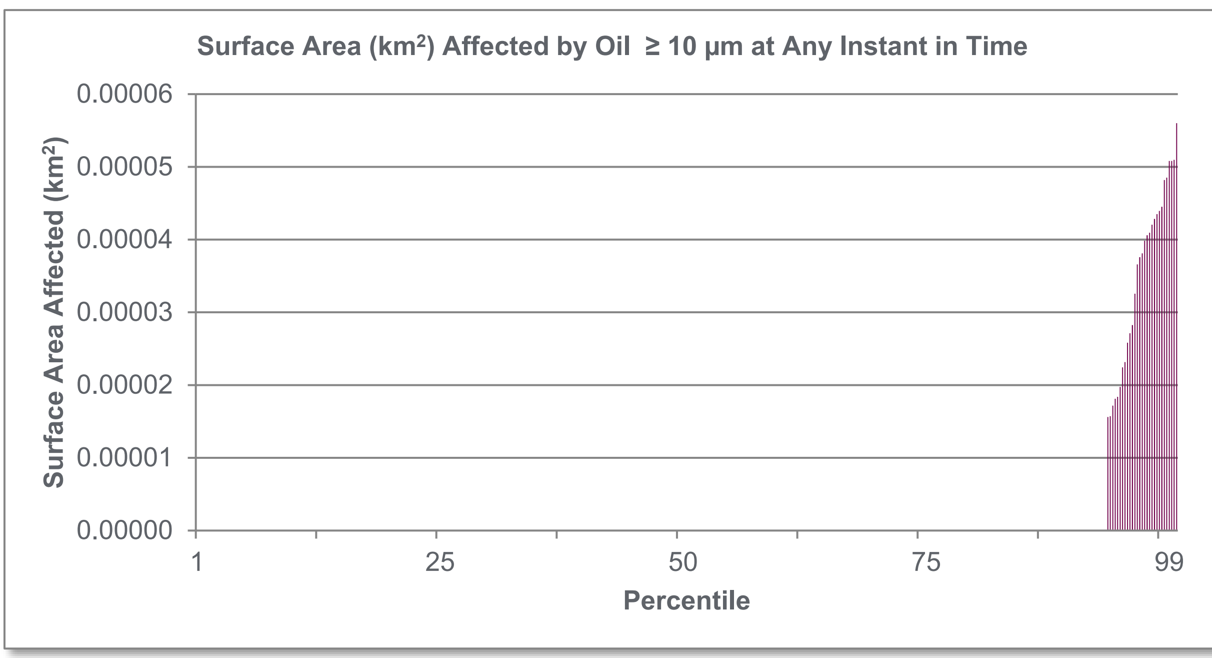


Figure 3-38. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore New Jersey.

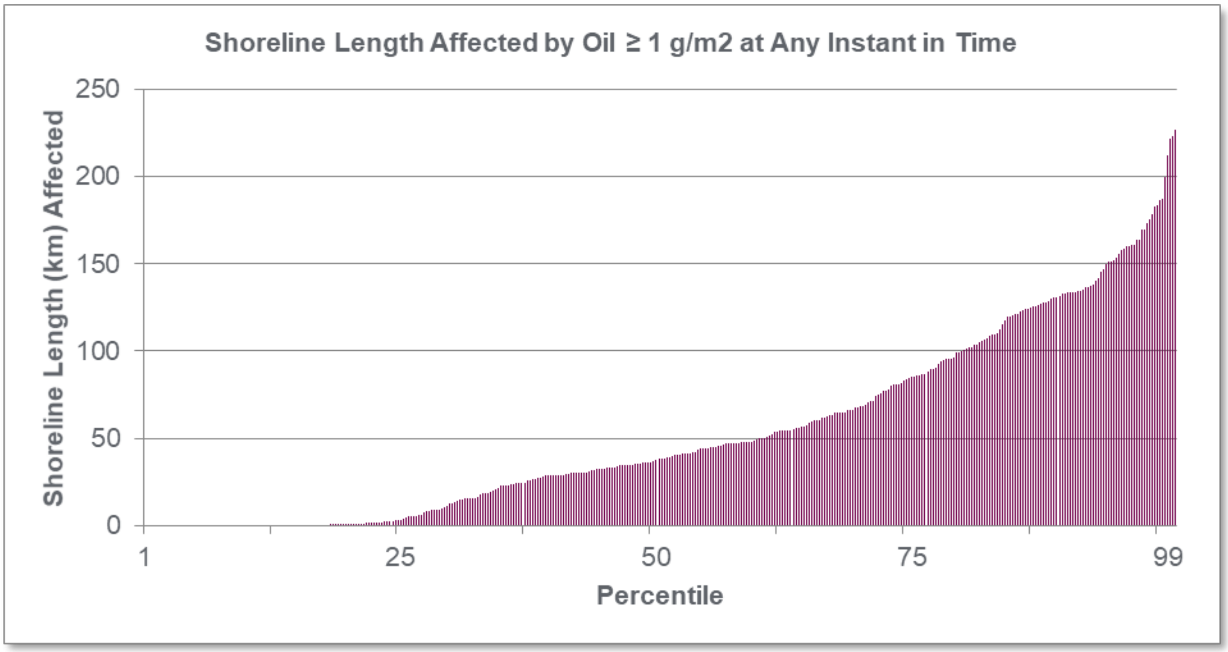


Figure 3-39. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore New Jersey.

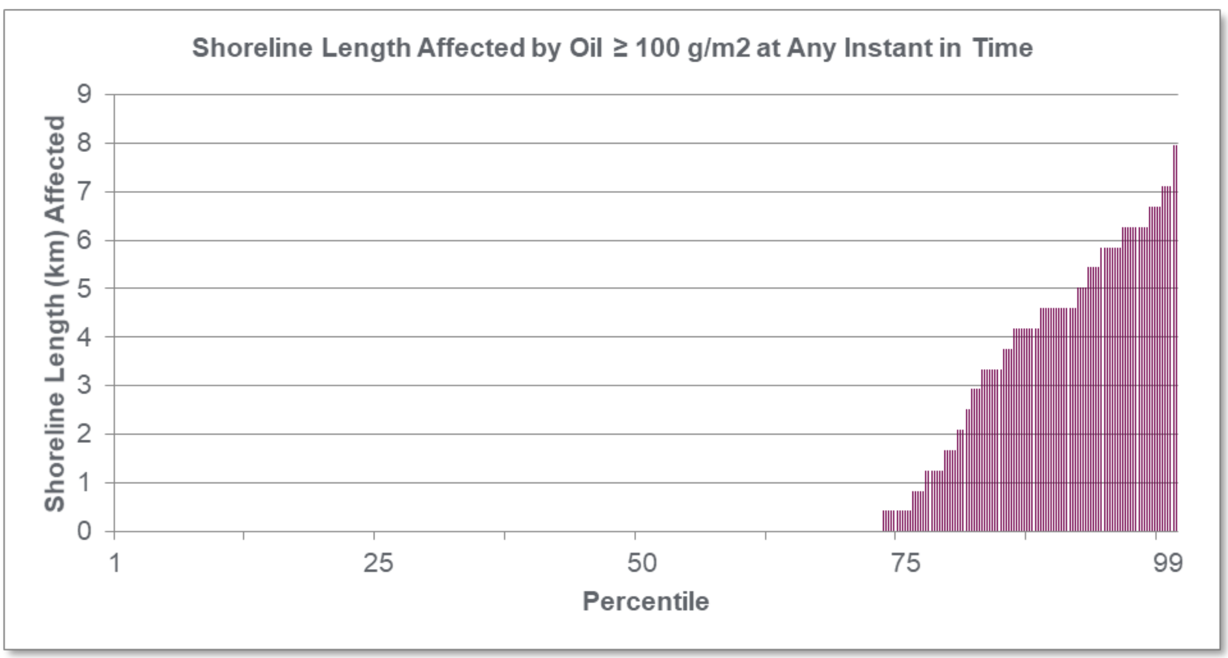


Figure 3-40. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore New Jersey.

3.2.2.2 Surface Release (Medium Volume)

For the unmitigated 2,240 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) was primarily located within ~86 mi (138 km) of the discharge location (Figure 3-73, top panel). Surface oil exceeding 0.01 g/m^2 (0.01 µm, on average) required a minimum of < 1 day to reach the coast (Figure 3-73, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~1 mi (1.6 km) (Figure 3-74, top panel), with surface oil reaching the shore within 1-2 day of release (Figure 3-74, bottom panel). The 0.01 g/m^2 surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 15-20 days of the discharge. The 10 g/m^2 surface oil exposure footprint was not predicted to extend past U.S. waters. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 threshold extended over 450 mi (724 km) east (out of model domain) of the discharge location. The shoreline oiling above 1 g/m^2 threshold extended from Martha's Vineyard, Massachusetts south to Burtons Bay, Virginia and oiling above the 100 g/m^2 threshold was patchy, extending along similar coastlines from Long Island, New York to the Virginia/Maryland border Figure 3-75 and Figure 3-76). The probabilities for shoreline oiling are generally 0-40% with a few small locations of higher probabilities occurring directly west and south of the discharge location around Toms River, New Jersey. Approximately 75% of possible trajectories had < 154 mi^2 (400 km^2) of surface waters exceeding 0.01 g/m^2 and 75 % of simulations have surface oil exposure footprints of < 1 mi^2 (2.5 km^2) exceeding 10 g/m^2 (Figure 3-77 and Figure 3-78). Approximately 50% of possible trajectories had < 37 mi (60 km) of shoreline oiling exceeding 1 g/m^2, while 50% of simulations had shoreline exposure footprints of < 9 mi (15 km) exceeding 100 g/m^2 (Figure 3-79 and Figure 3-80). The maximum amount of shoreline oiled for any simulation was 206 mi (331 km). This worst-case simulation is examined in more detail in Section 3.3.

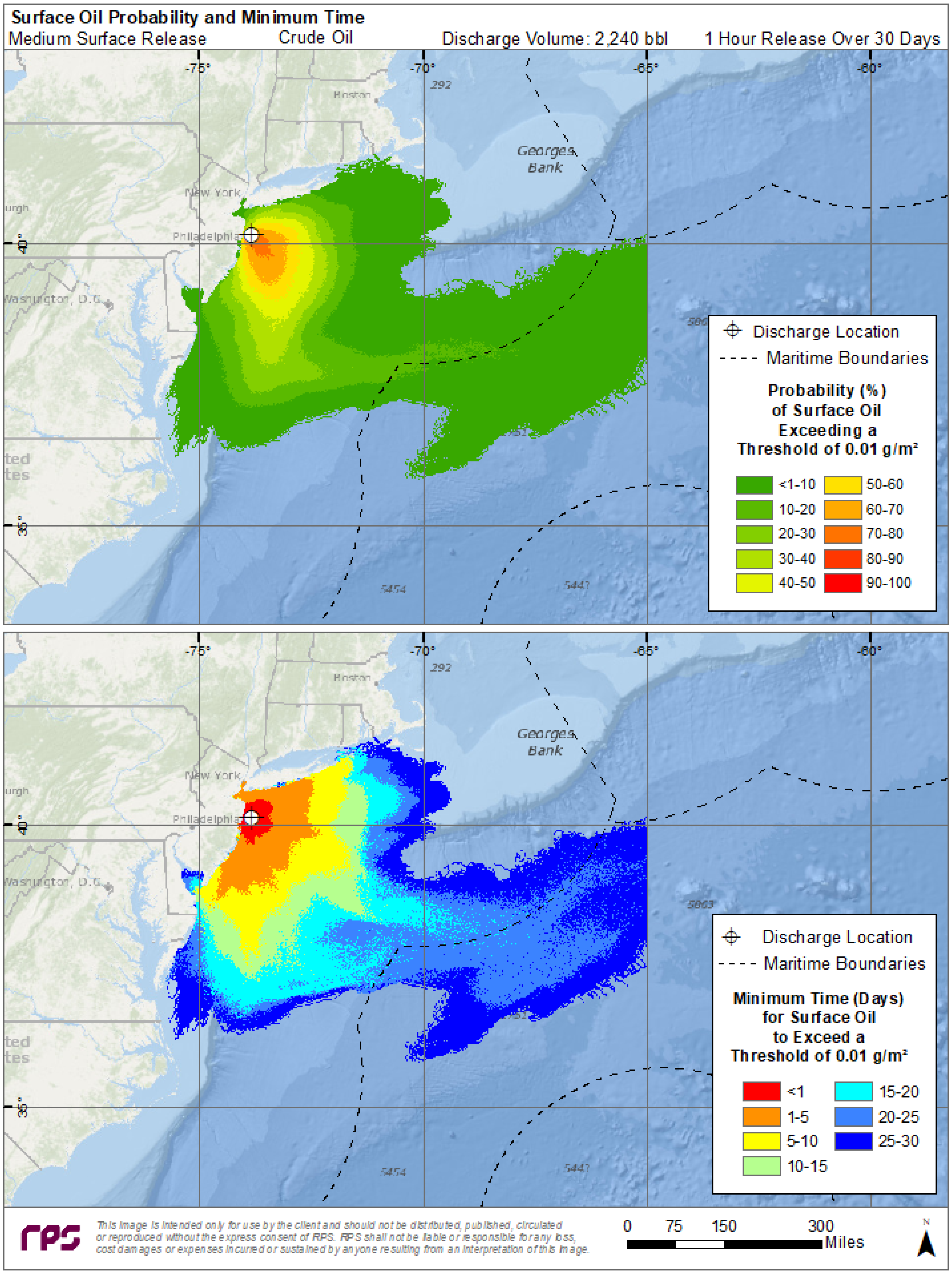


Figure 3-41. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore New Jersey.

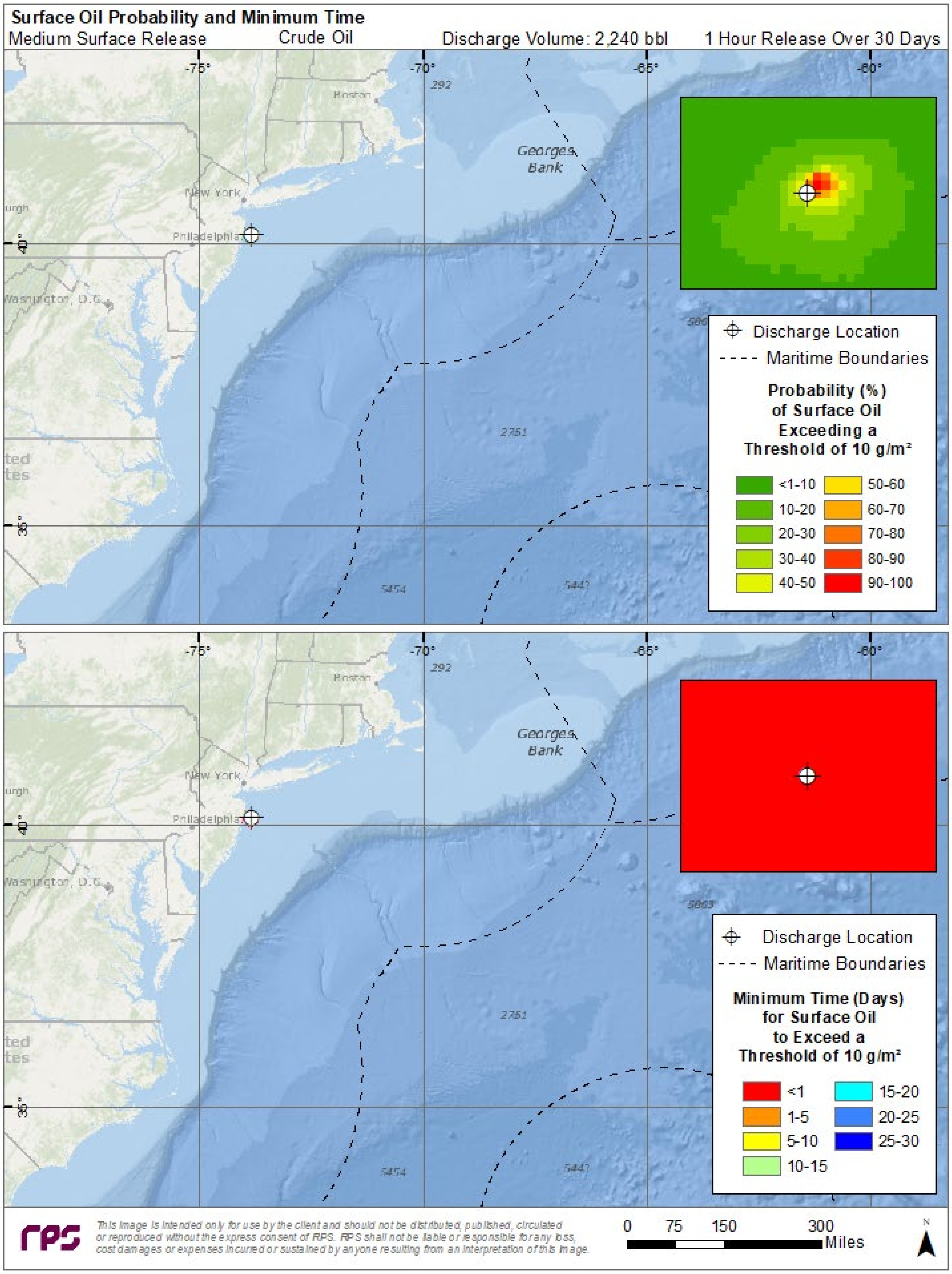


Figure 3-42. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore New Jersey.

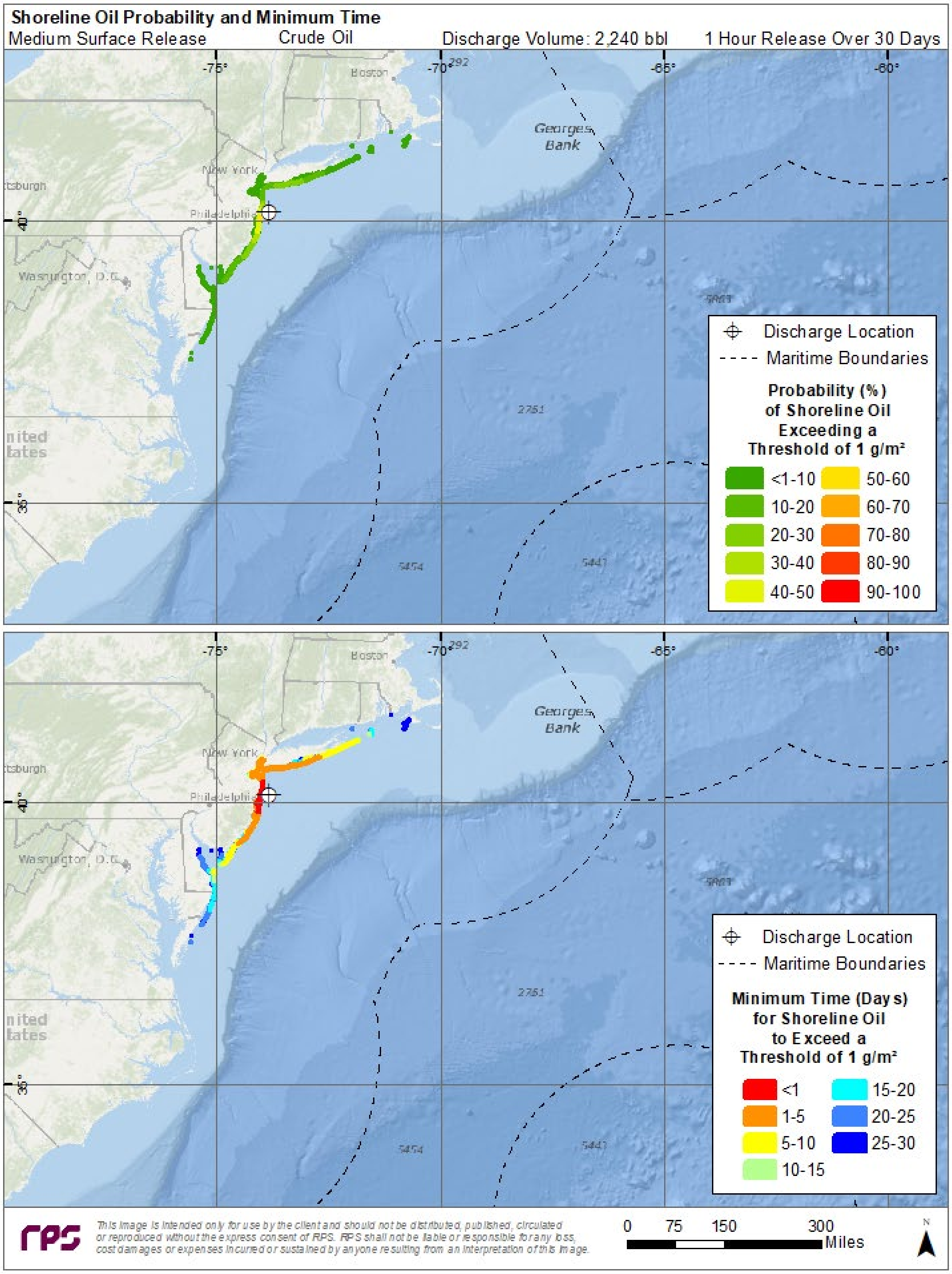


Figure 3-43. Top panel displays probability of shoreline oiling ≥1 µm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore New Jersey.

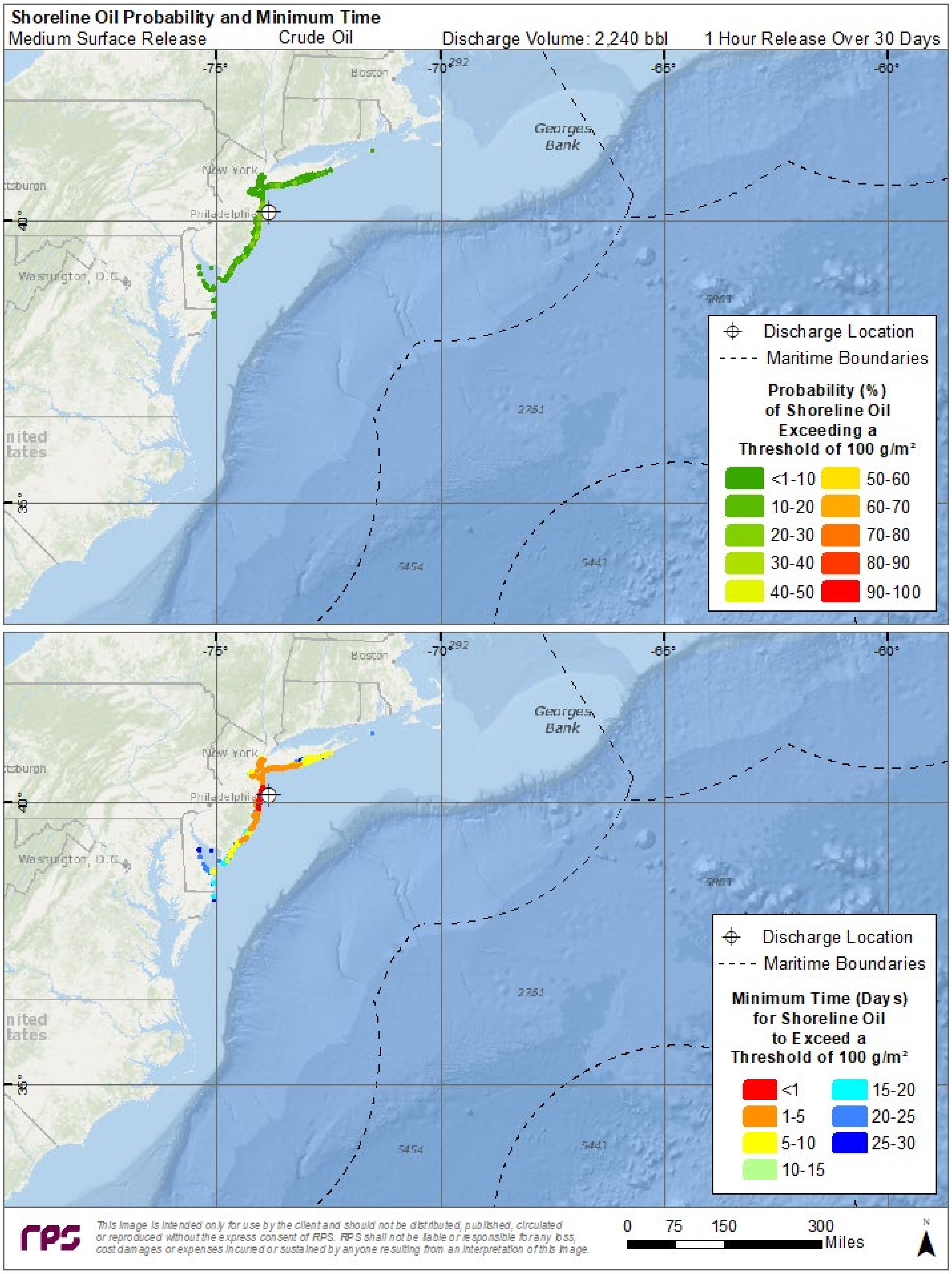


Figure 3-44. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore New Jersey.

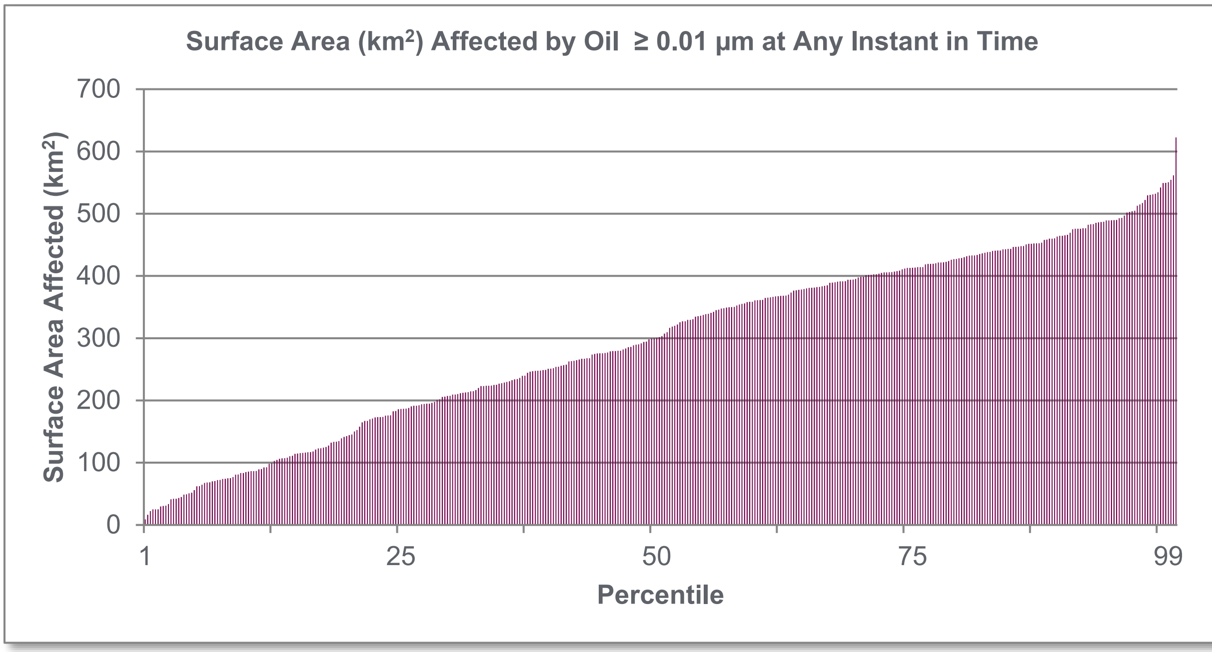


Figure 3-45. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore New Jersey.

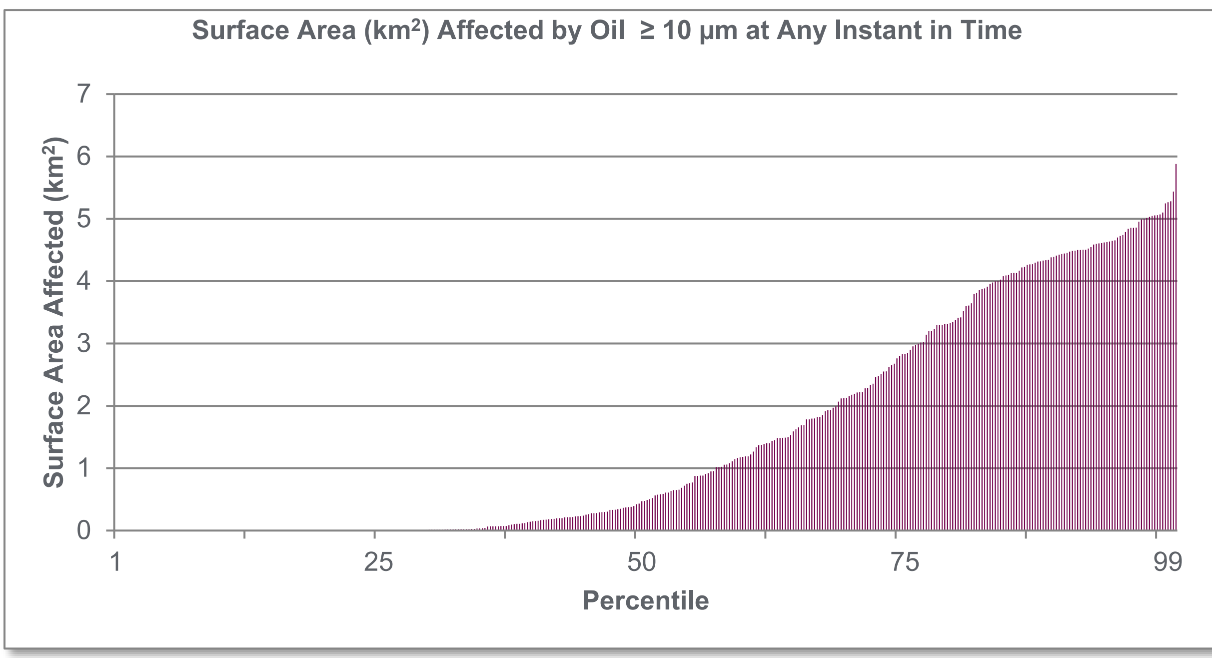


Figure 3-46. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore New Jersey.

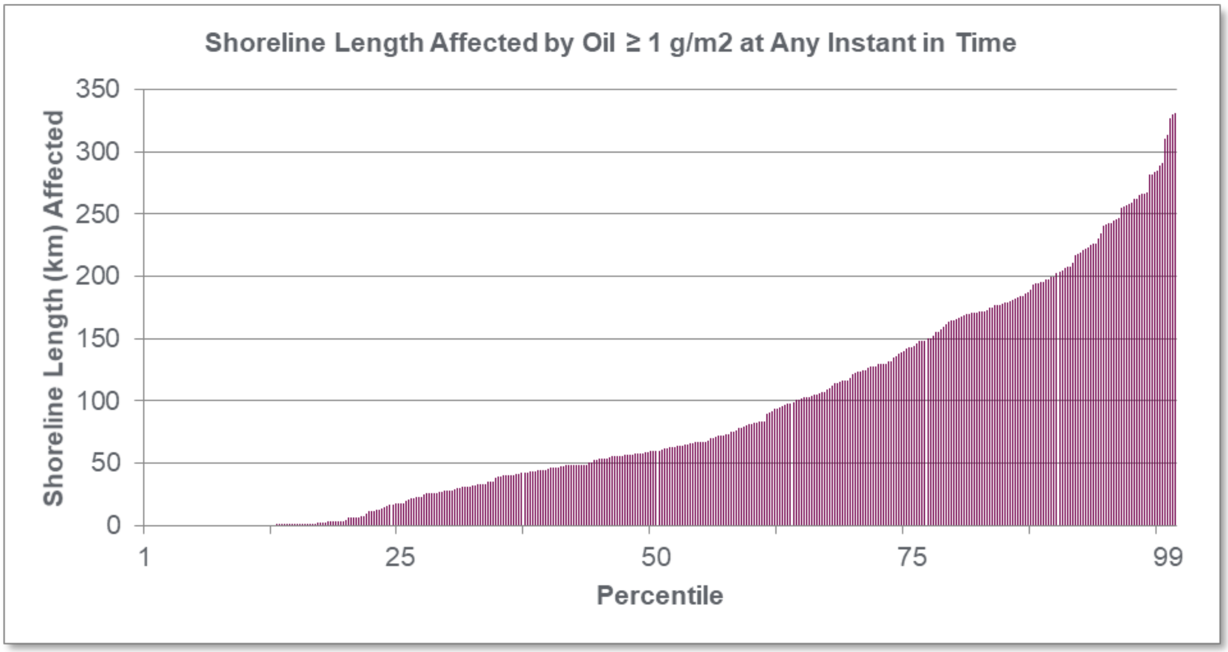


Figure 3-47. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore New Jersey.

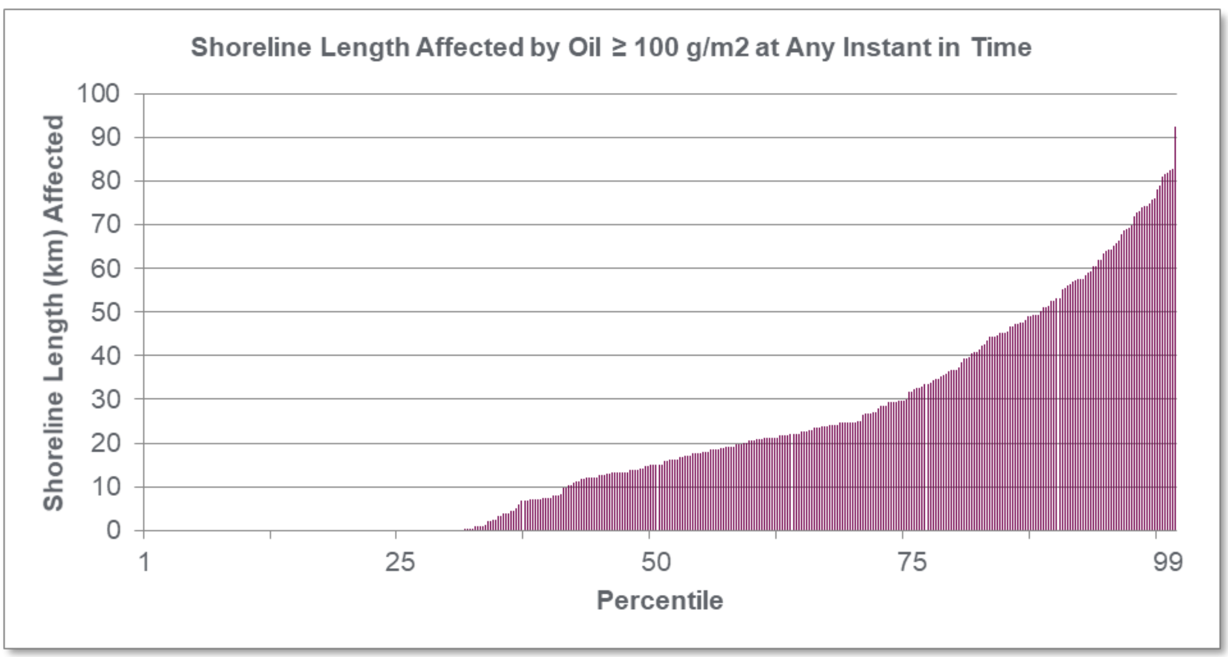


Figure 3-48. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore New Jersey.

3.2.2.3 Surface Release (High Volume)

For the unmitigated 200,000 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) was primarily located within ~90 mi (145 km) of the discharge location (Figure 3-81, top panel). Surface oil exceeding 0.01 g/m^2 and required a minimum of < 1 day to reach the coast (Figure 3-81, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~28 mi (45 km) (Figure 3-82, top panel) and required a minimum of <1 day to reach the coast at any probability (Figure 3-82, bottom panel). The 0.01 g/m^2 (0.01 µm, on average) surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 15-20 days of the discharge. The 10 g/m^2 (10 µm, on average) surface oil exposure footprint above 1% probability was also predicted to extend past U.S. waters within a minimum of 20-25 days. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 threshold extended over 450 mi (724 km) east of the discharge location and outside of the model domain and the 10 g/m^2 threshold extends approximately 240 mi (386 km) southeast of the discharge location (Figure 3-81 and Figure 3-82). The shoreline oiling above 1 g/m^2 and 100g/m^2 thresholds extends from Martha's Vineyard, Massachusetts to Hog Island Bay, Virginia (Figure 3-83 and Figure 3-84). The probabilities for shoreline oiling do not exceed 60% for either threshold with the highest probabilities (55-60%) occurring directly west and south of the discharge location. Of all trajectories simulated for the stochastic scenario, 75% had < 3,861 mi^2 (10,000 km^2) of surface waters exceeding 0.01 g/m^2 while 100% of simulations have surface oil exposure footprints of < 193 mi^2 (500 km^2) exceeding 10 g/m^2 (Figure 3-85 and Figure 3-86). Approximately 75% of possible trajectories had < 162 mi (261 km) of shoreline oiling exceeding 1 g/m^2 while 75% of simulations had shoreline exposure footprints of < 116 mi (187 km) exceeding 100 g/m^2 (Figure 3-87 and Figure 3-88). The maximum amount of shoreline oiled for any simulation was 318 mi (512 km). This worst-case simulation is examined in more detail in Section 3.3.

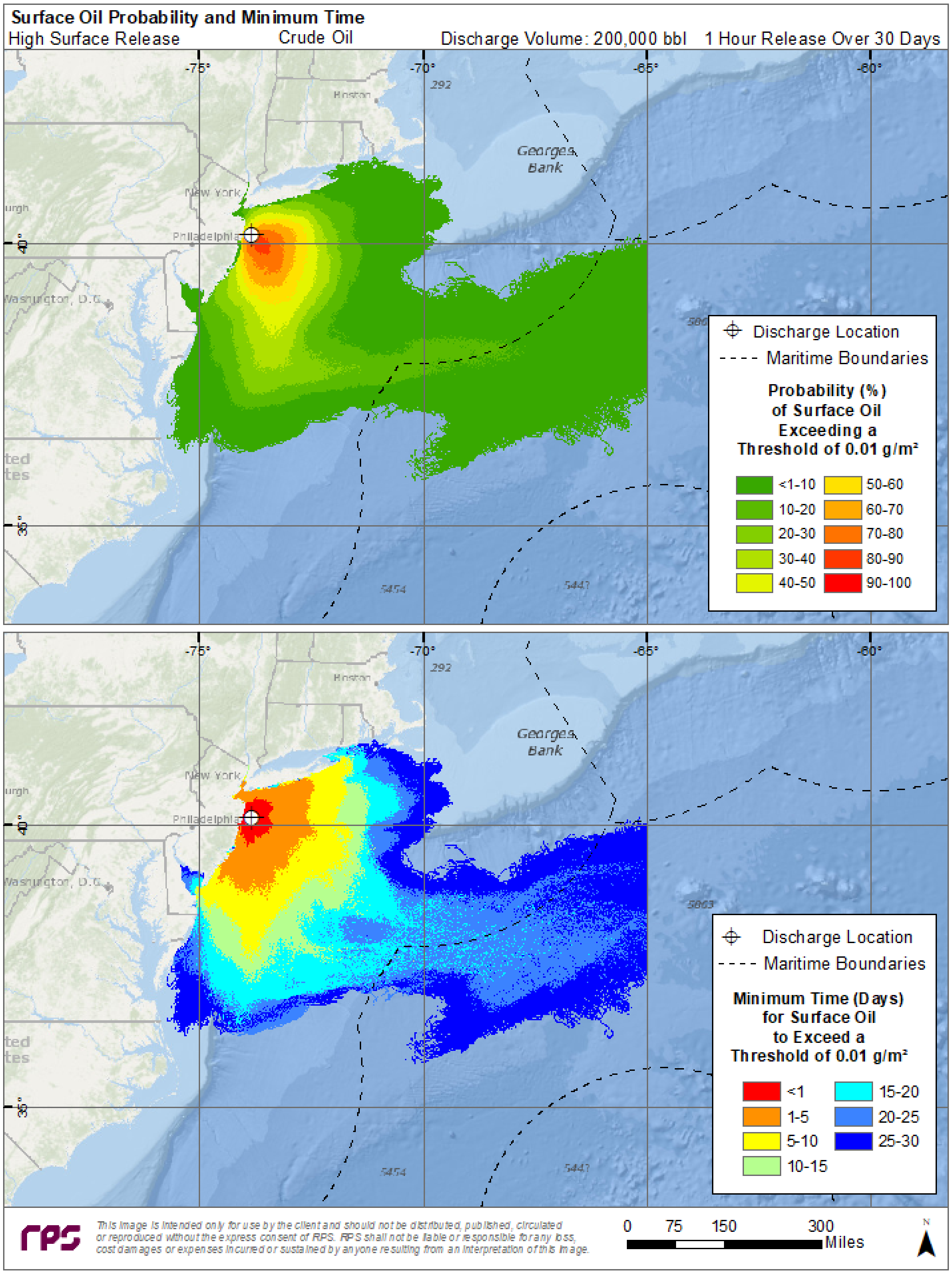


Figure 3-49. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore New Jersey.

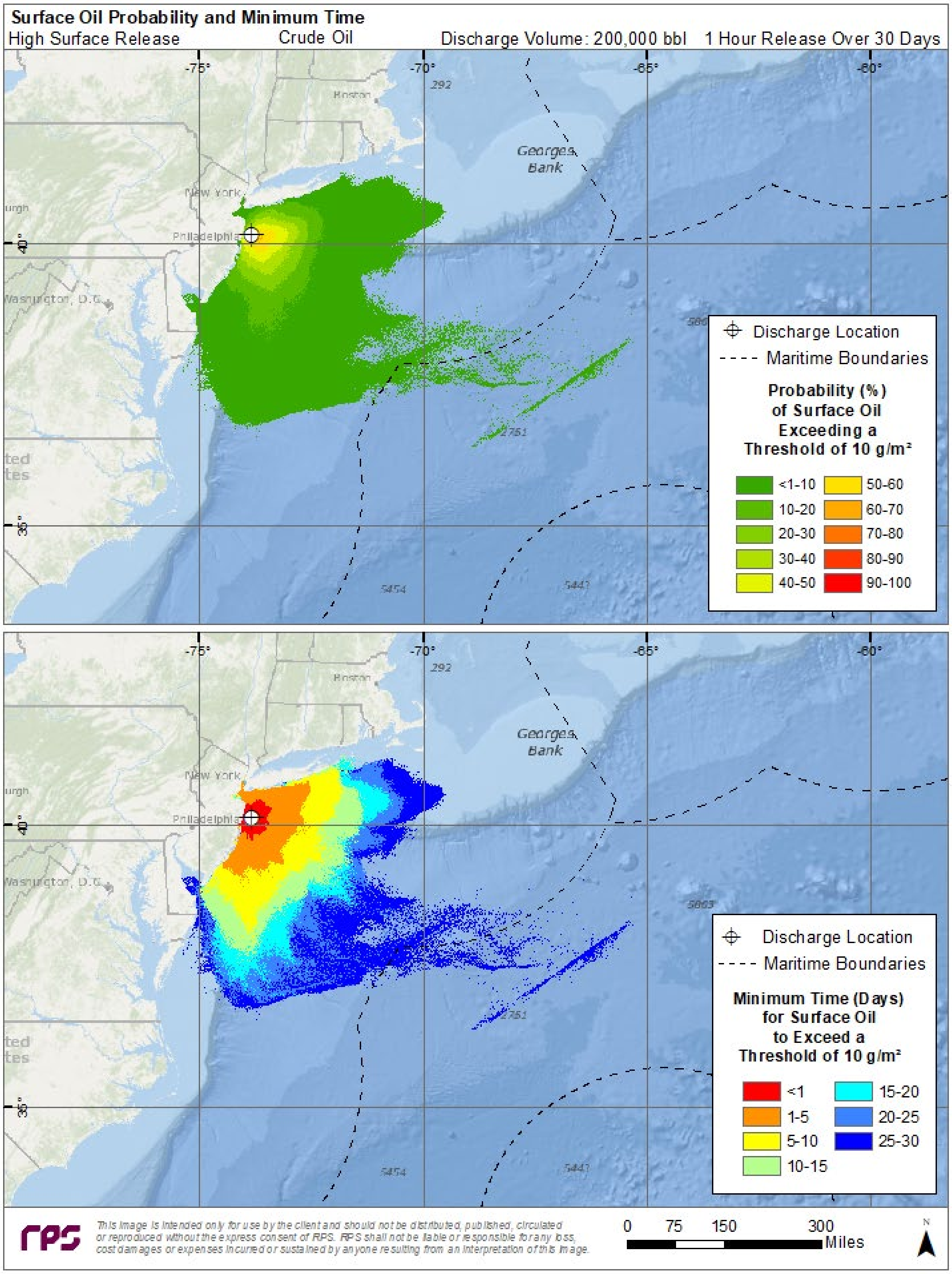


Figure 3-50. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore New Jersey.

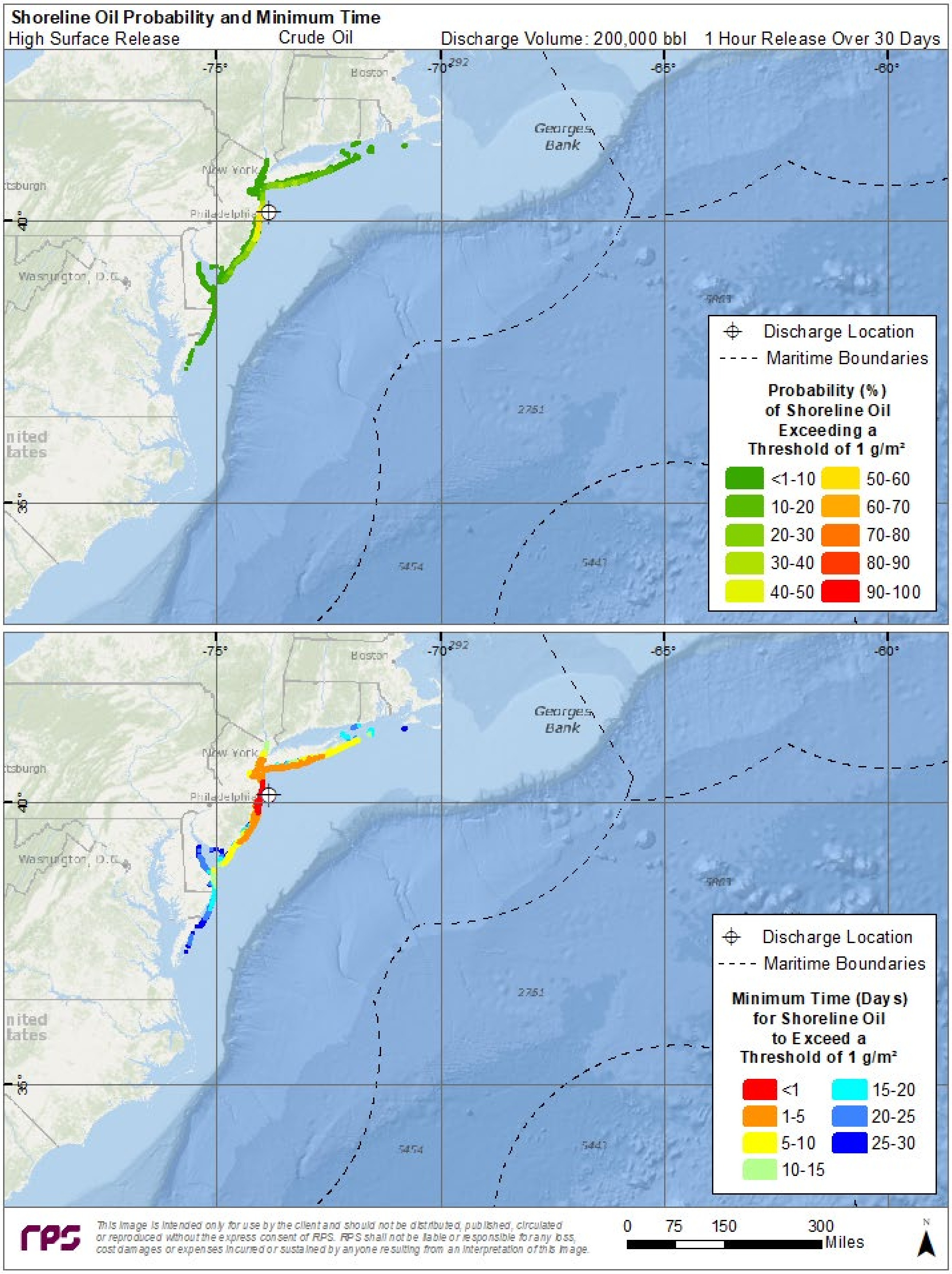


Figure 3-51. Top panel displays probability of shoreline oiling ≥1 μm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 μm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore New Jersey.

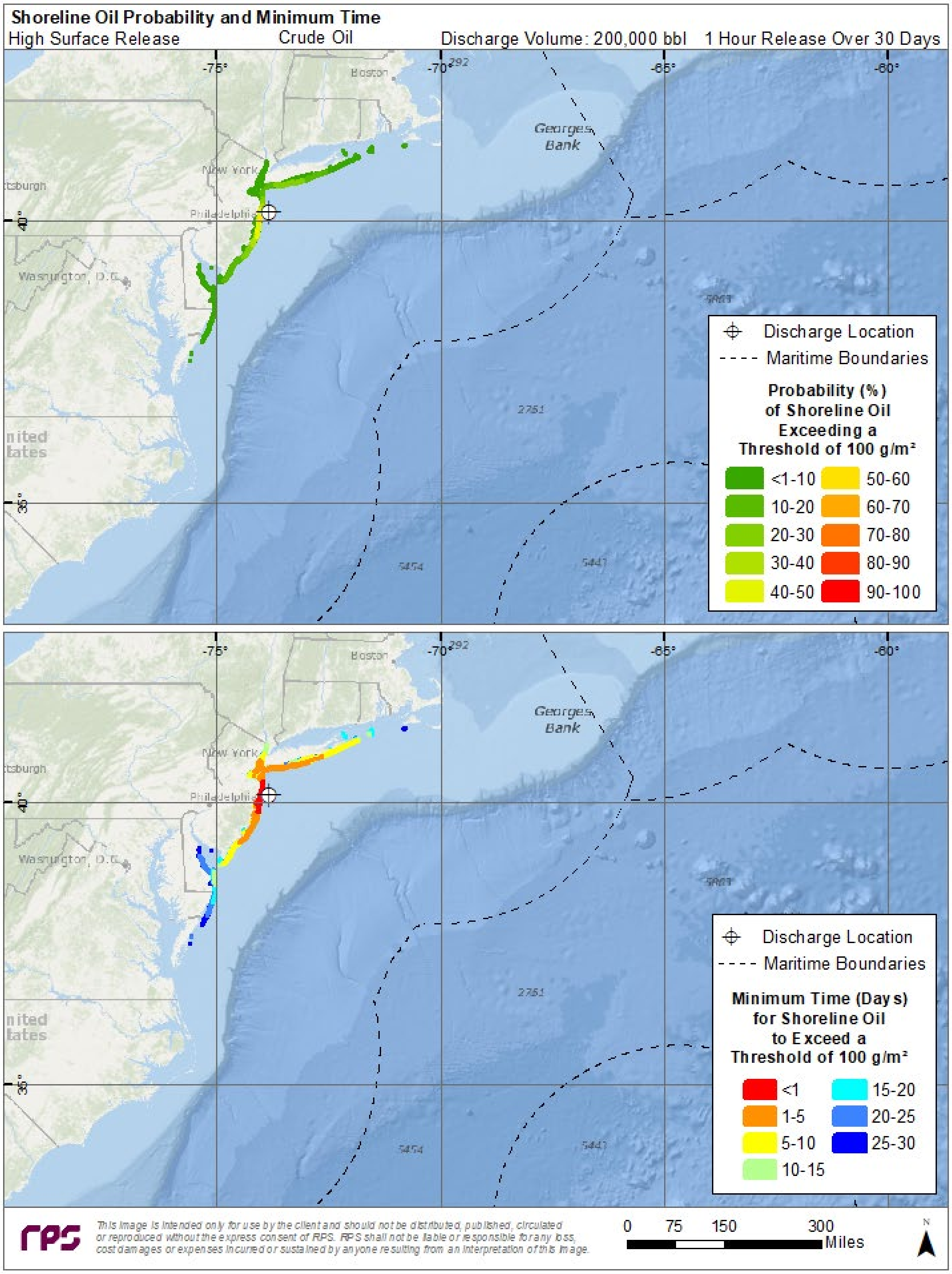


Figure 3-52. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore New Jersey.

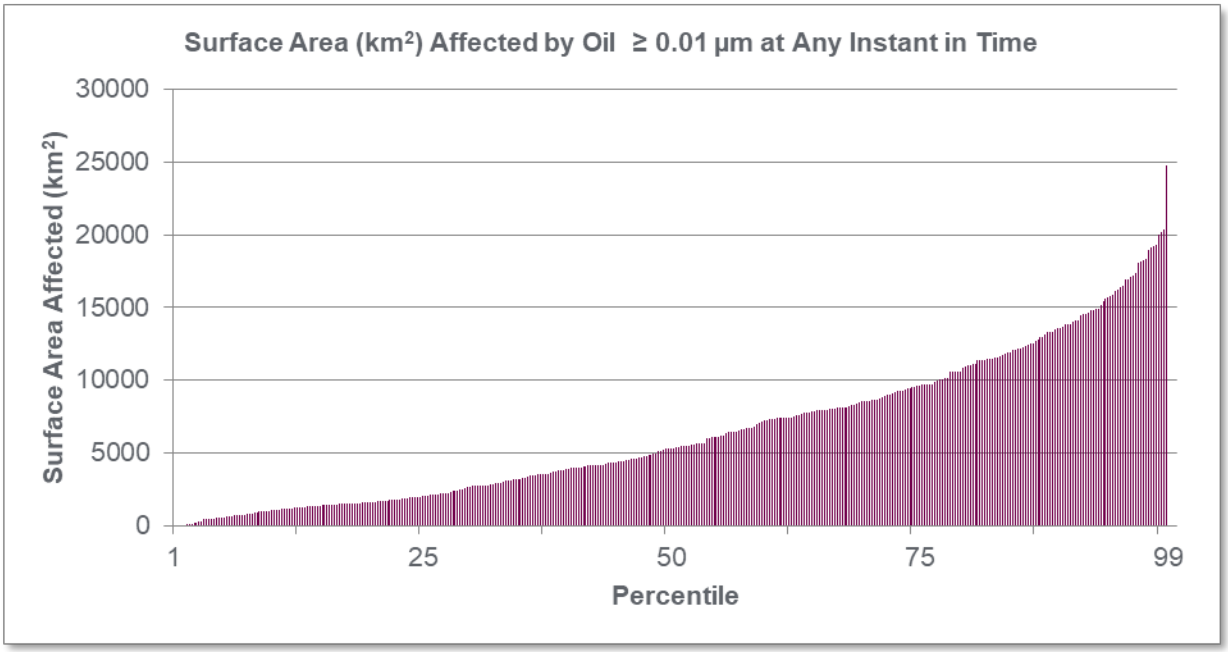


Figure 3-53. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore New Jersey.

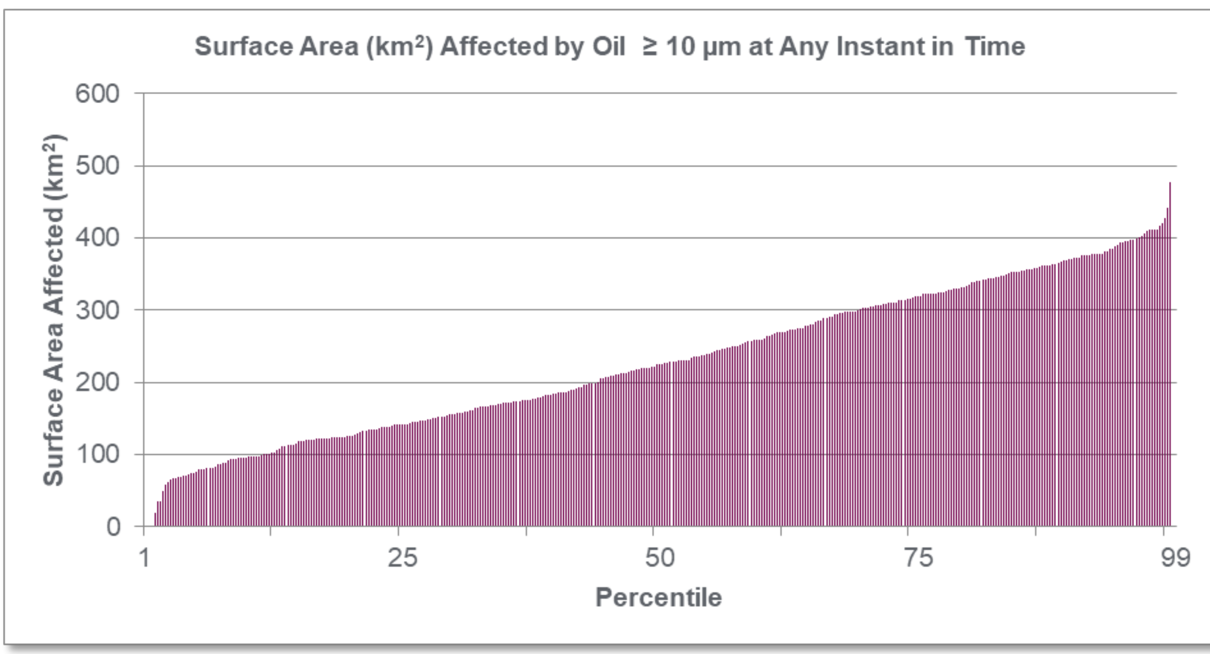


Figure 3-54. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore New Jersey.

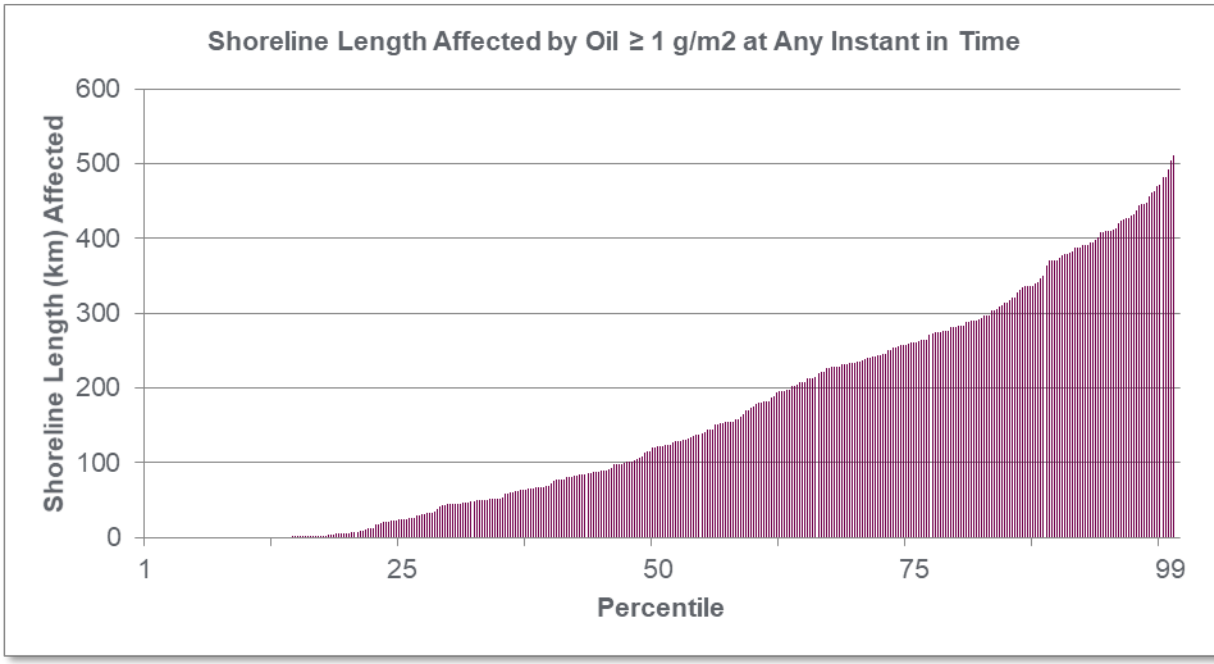


Figure 3-55. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore New Jersey.

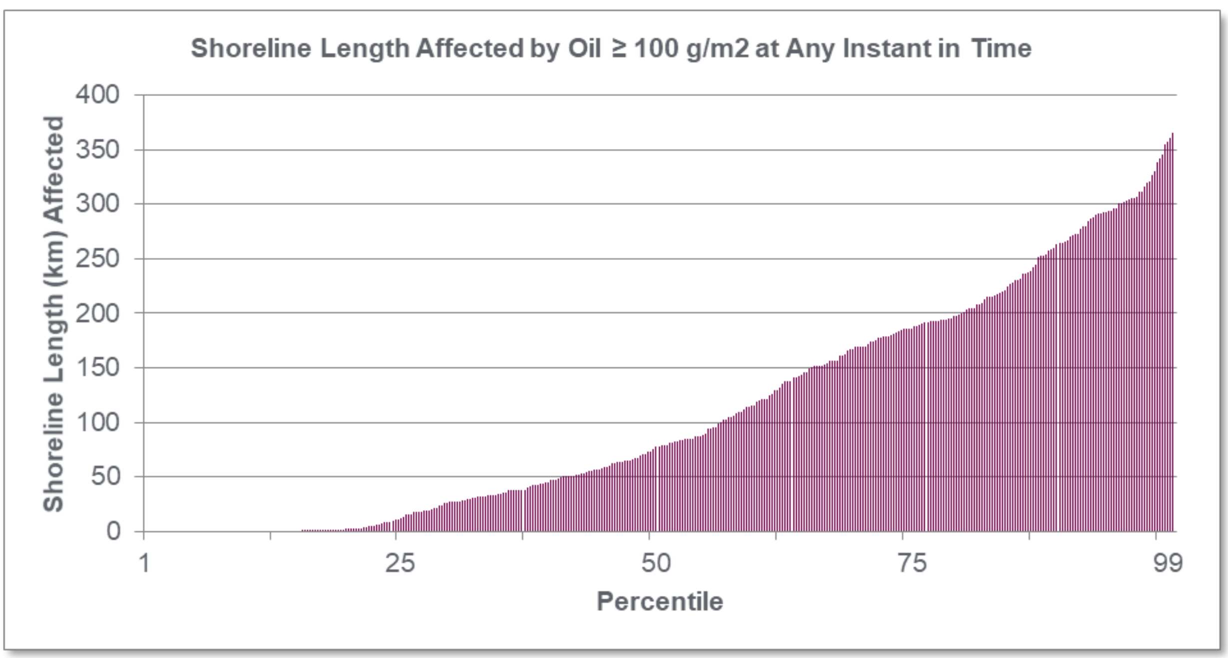


Figure 3-56. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore New Jersey.

3.2.2.4 Subsurface Release (Well Blowout)

For the unmitigated 900,000 bbl subsurface blowout of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) extended over 130 mi (209 km) south of the discharge location (Figure 3-89, top panel). Surface oil exceeding 0.01 g/m^2 [0.01 µm, on average] required a minimum of 10 days to reach the coast (Figure 3-89, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~100 mi (161 km) of the release site (Figure 3-90, top panel). Surface oil exceeding 10 g/m^2 also required a minimum of 10-20 days to reach the coast (Figure 3-90, bottom panel). At both thresholds, the surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 10-20 days of the discharge. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 and 10 g/m^2 thresholds extended outside of the model domain, over 450 mi (724 km) east of the discharge location (Figure 3-89 and Figure 3-90). Of all trajectories simulated for the stochastic scenario, 50% had < 10,278 mi^2 (26,620 km^2) of surface waters exceeding 0.01 g/m^2 while 50% of simulations have surface oil exposure footprints of < 275 mi^2 (712 km^2) exceeding 10 g/m^2 (Figure 3-93 and Figure 3-94). The shoreline oiling stochastic footprint above the 1 g/m^2 and 100 g/m^2 [100 µm, on average] thresholds were similar in extent, stretching roughly from Cape Cod, Massachusetts to Avon, North Carolina (Figure 3-91 and Figure 3-92). The probabilities for shoreline oiling do not exceed 35% for either threshold with the highest probabilities (25-35%) occurring west of the discharge location along southern New Jersey and Delaware. Approximately 50% of possible trajectories had < 4 mi (6 km) and < 3 mi (5 km) of shoreline oiling exceeding the 1 g/m^2 and 100 g/m^2 thresholds, respectively (Figure 3-95 and Figure 3-96). The maximum amount of shoreline oiled exceeding 1 g/m^2 for any simulation was 585 mi (941 km). This worst-case simulation is examined in more detail in Section 3.3.

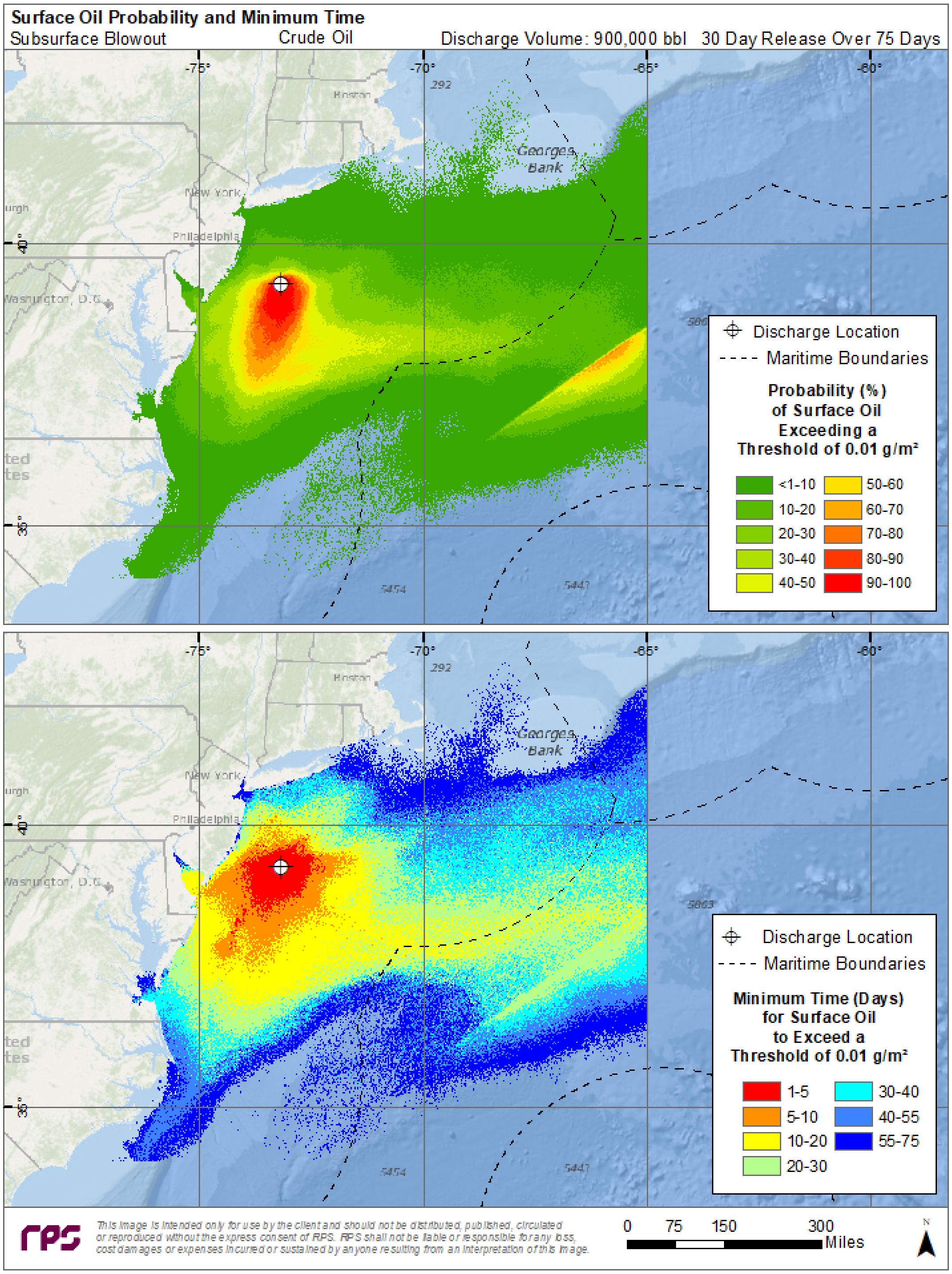


Figure 3-57. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore New Jersey.

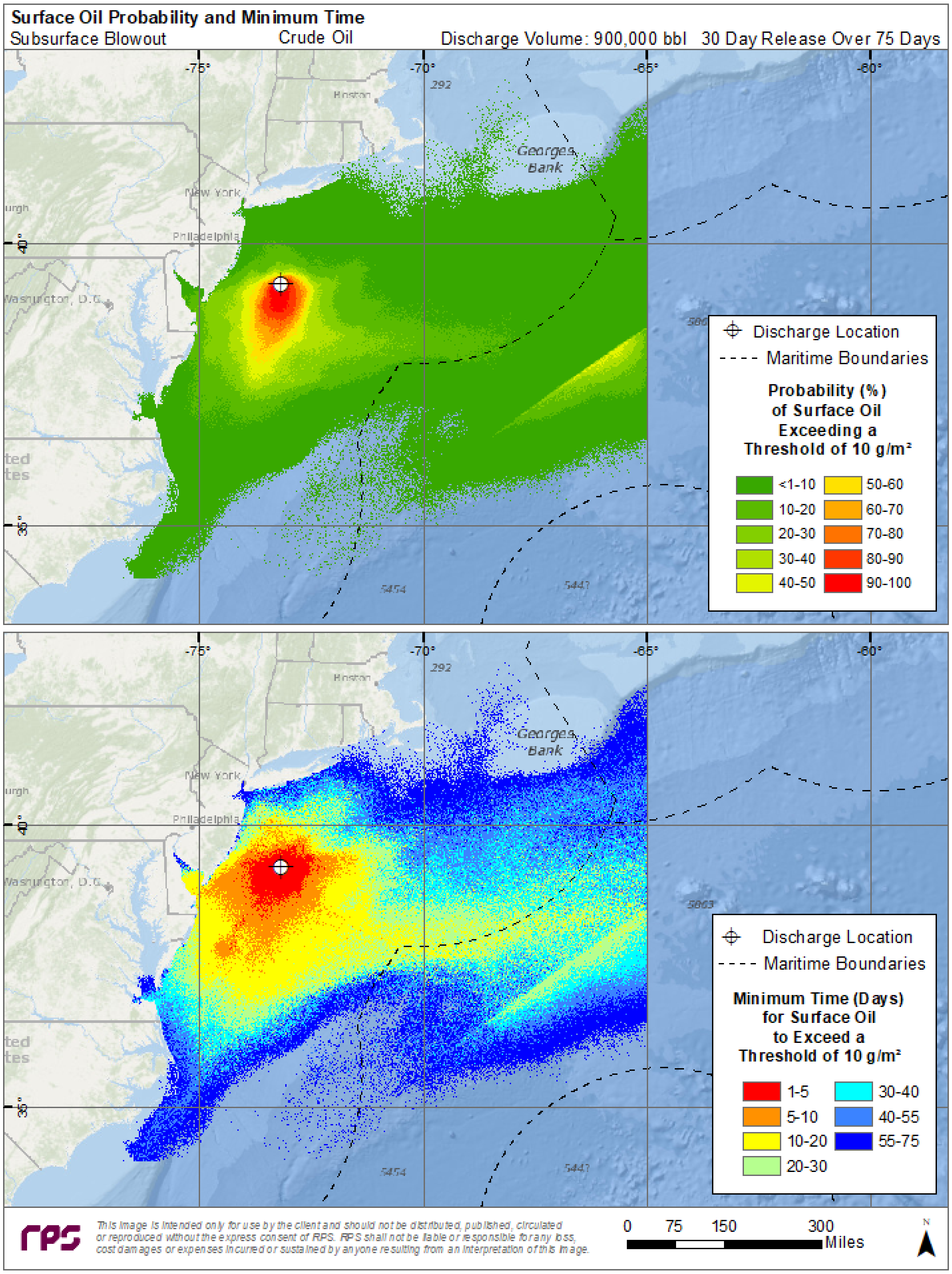


Figure 3-58. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore New Jersey.

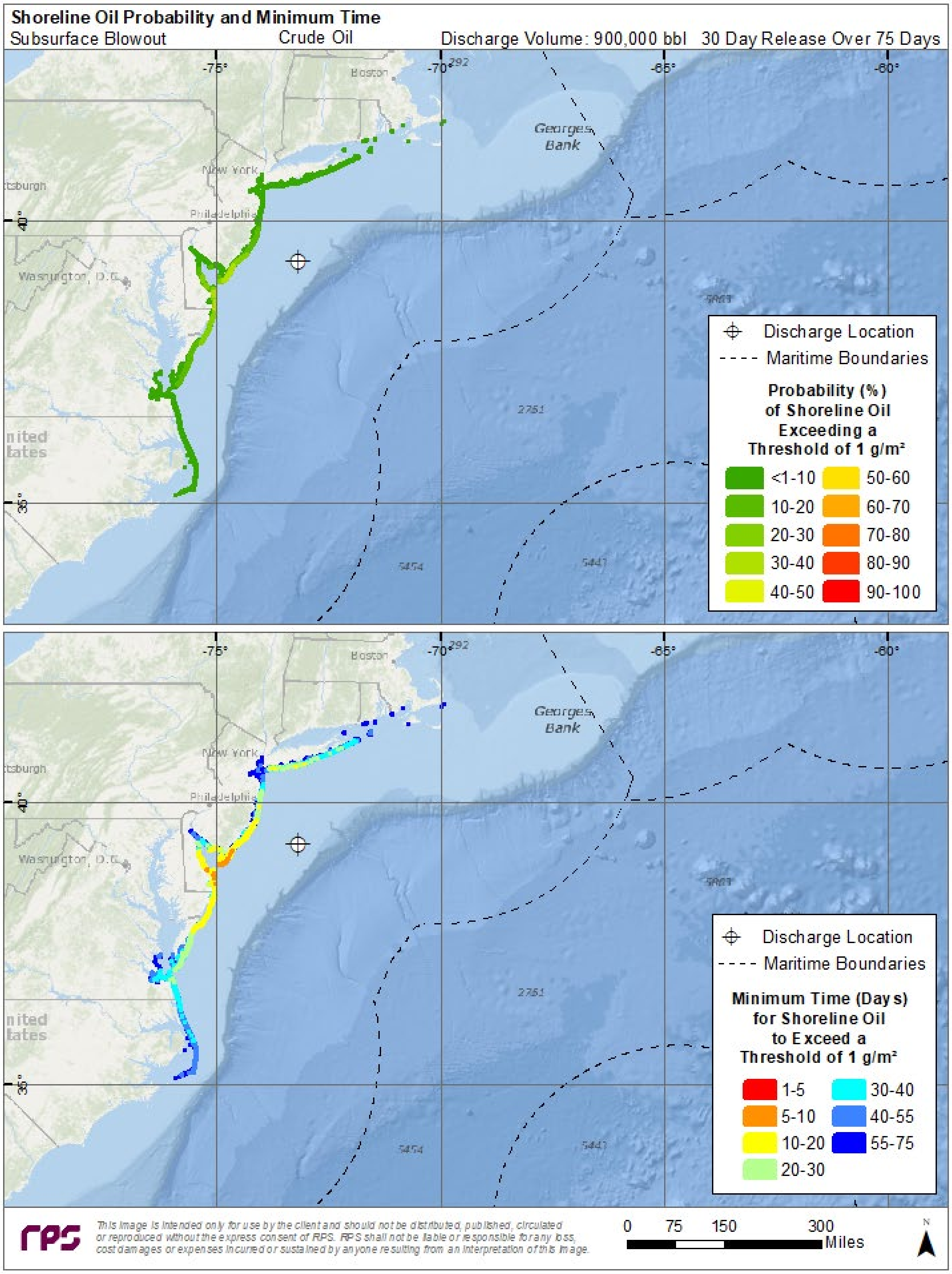


Figure 3-59. Top panel displays probability of shoreline oiling ≥1 µm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore New Jersey.

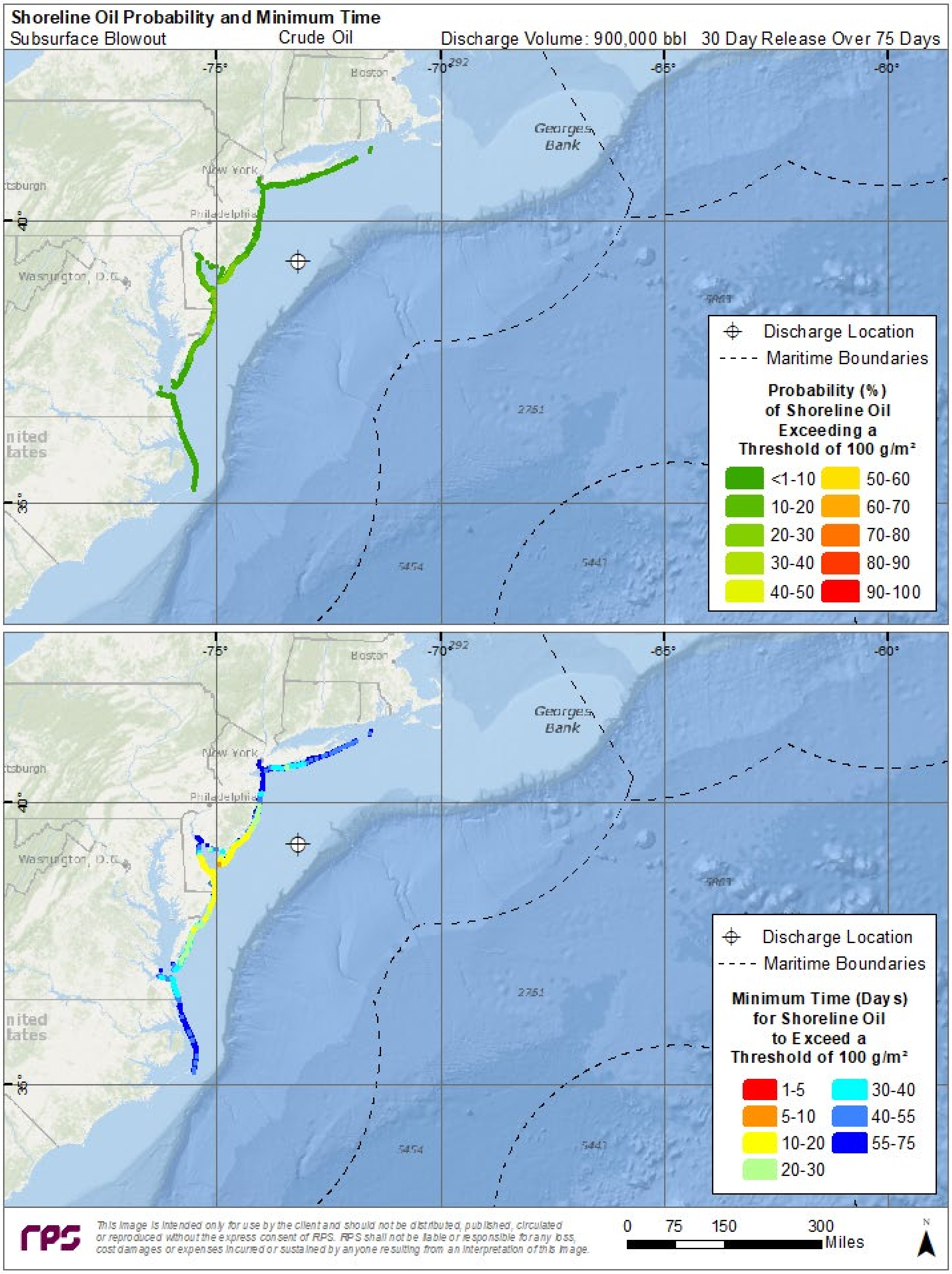


Figure 3-60. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore New Jersey.

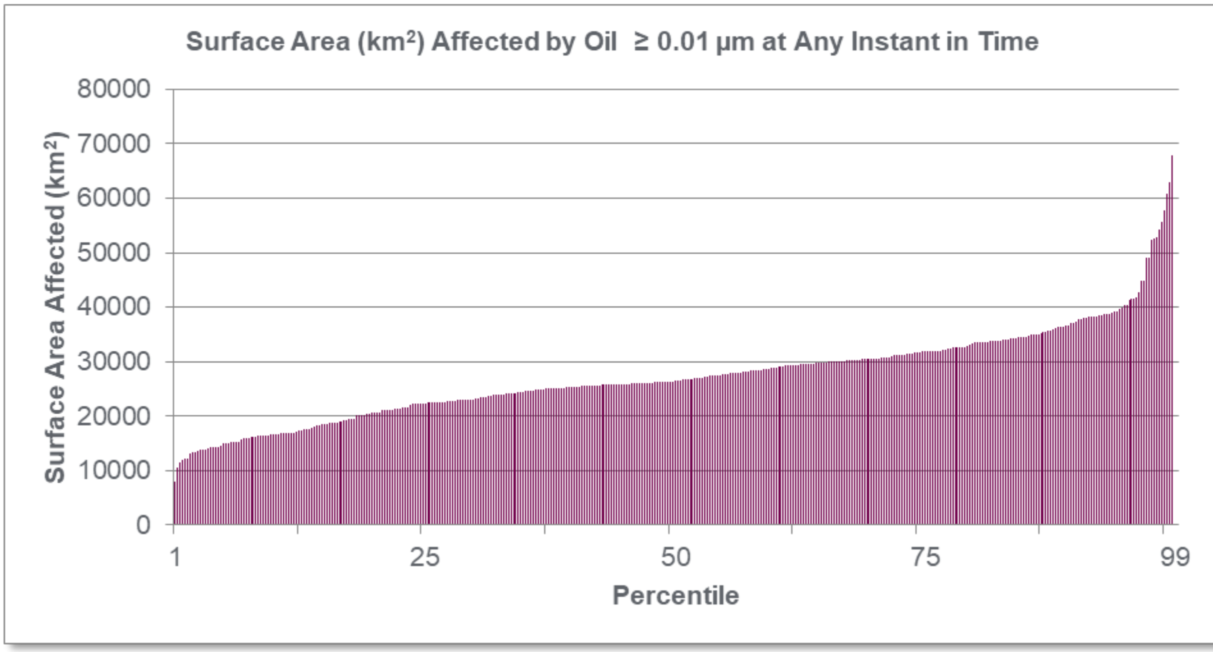


Figure 3-61. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore New Jersey.

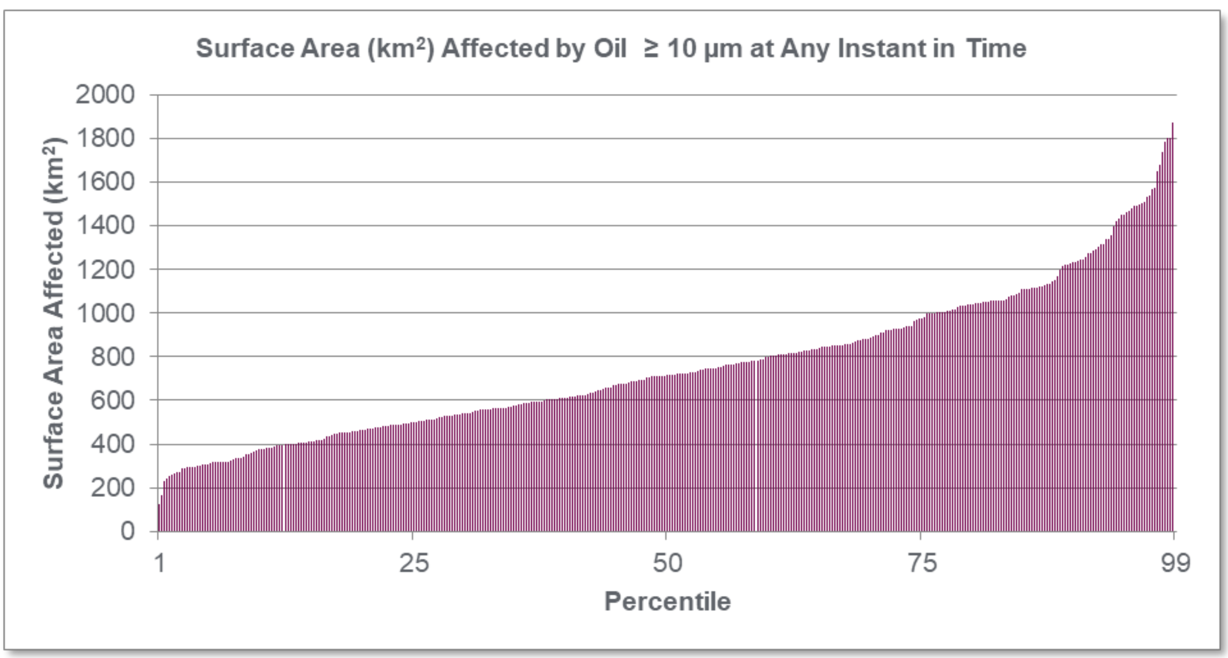


Figure 3-62. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore New Jersey.

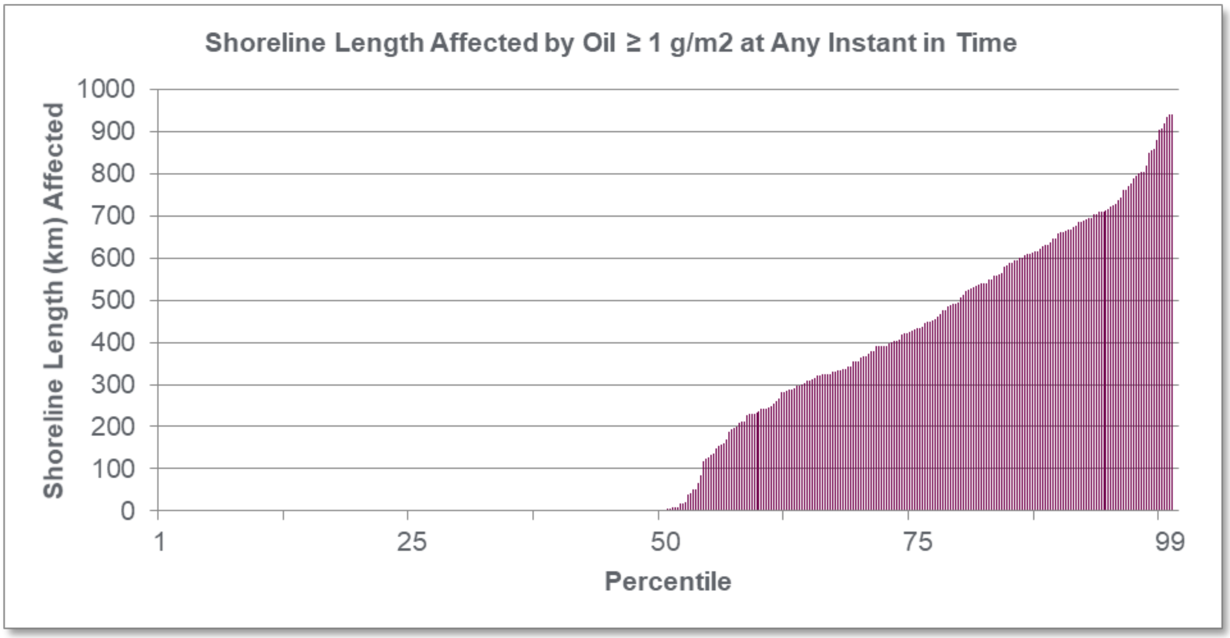


Figure 3-63. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore New Jersey.

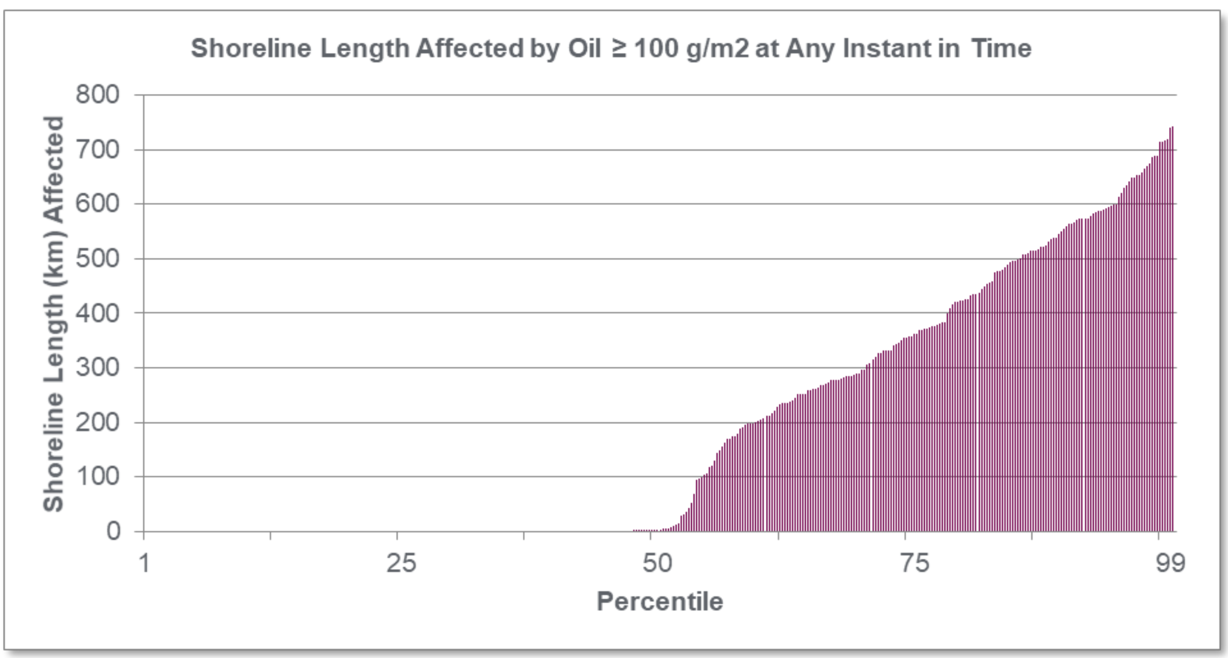


Figure 3-64. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore New Jersey.

3.2.3 Offshore Virginia

Surface oil discharges of three different volumes at a high traffic location offshore Virginia and a subsea blowout on the edge of the continental shelf were modeled throughout all seasons over multiple years. The following stochastic result figures illustrate the spatial extent of surface and shoreline oiling probabilities (footprint) and associated minimum travel times to reach any point within the footprint. For the spill scenario, the stochastic and time contour footprints were calculated assuming two thresholds for minimum surface and shoreline oil thickness. In addition, figures are presented in a Web Mercator Auxiliary Sphere Projection for visualization purposes, as this projection preserves angles. Measurements are provided in North America Albers Equal Area Conic projection, as it maintains distance in the east-west direction along the eastern U.S. coastline.

3.2.3.1 Surface Release (Low Volume)

For the unmitigated 126 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) was primarily located within ~5 mi (8 km) of the discharge location (Figure 3-65, top panel). Surface oil exceeding 0.01 g/m^2 required a minimum of less than 1 day to reach the coast (Figure 3-65, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~0.7 mi (1.1 km) (Figure 3-66, top panel) and oil did not reach the coast (Figure 3-66, bottom panel). The 0.01 g/m^2 surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 10-15 days of the discharge. The 10 g/m^2 surface oil exposure footprint above 1% probability was not predicted to extend past U.S. waters. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 extended over roughly 570 mi (917 km) to the east. The 1% probability for the 10 g/m^2 threshold extended 1 mi (1.6 km) northeast of the discharge location. The shoreline oiling above 1 g/m^2 threshold extended along the outer coast from south of Atlantic City, New Jersey to Emerald Isle, North Carolina and oiling above the 100 g/m^2 threshold was predicted along a similar extent but was patchy to the north and south of the release location (Figure 3-67 and Figure 3-68). The probabilities for shoreline oiling are generally 0-50% with a few small locations of higher probabilities occurring directly west and south of the discharge location in the vicinity of the Virginia/North Carolina border. Approximately 75% of possible trajectories have < 11.5 mi^2 (30 km^2) of surface waters exceeding 0.01 g/m^2, and 100% of simulations have surface oil exposure footprints of < 0.4 mi^2 (1 km^2) exceeding 10 g/m^2 (Figure 3-69 and Figure 3-70). Approximately 50% of possible trajectories have > 31 mi (50 km) of shoreline oiling exceeding 1 g/m^2 and 80% of simulations have shoreline exposure footprints of < 1 mi (1.6 km) exceeding 100 g/m^2 (Figure 3-71 and Figure 3-72). The maximum amount of shoreline oiled (>1 g/m^2) for any simulation was 144 mi (232 km). This worst-case simulation is examined in more detail in Section 3.3.

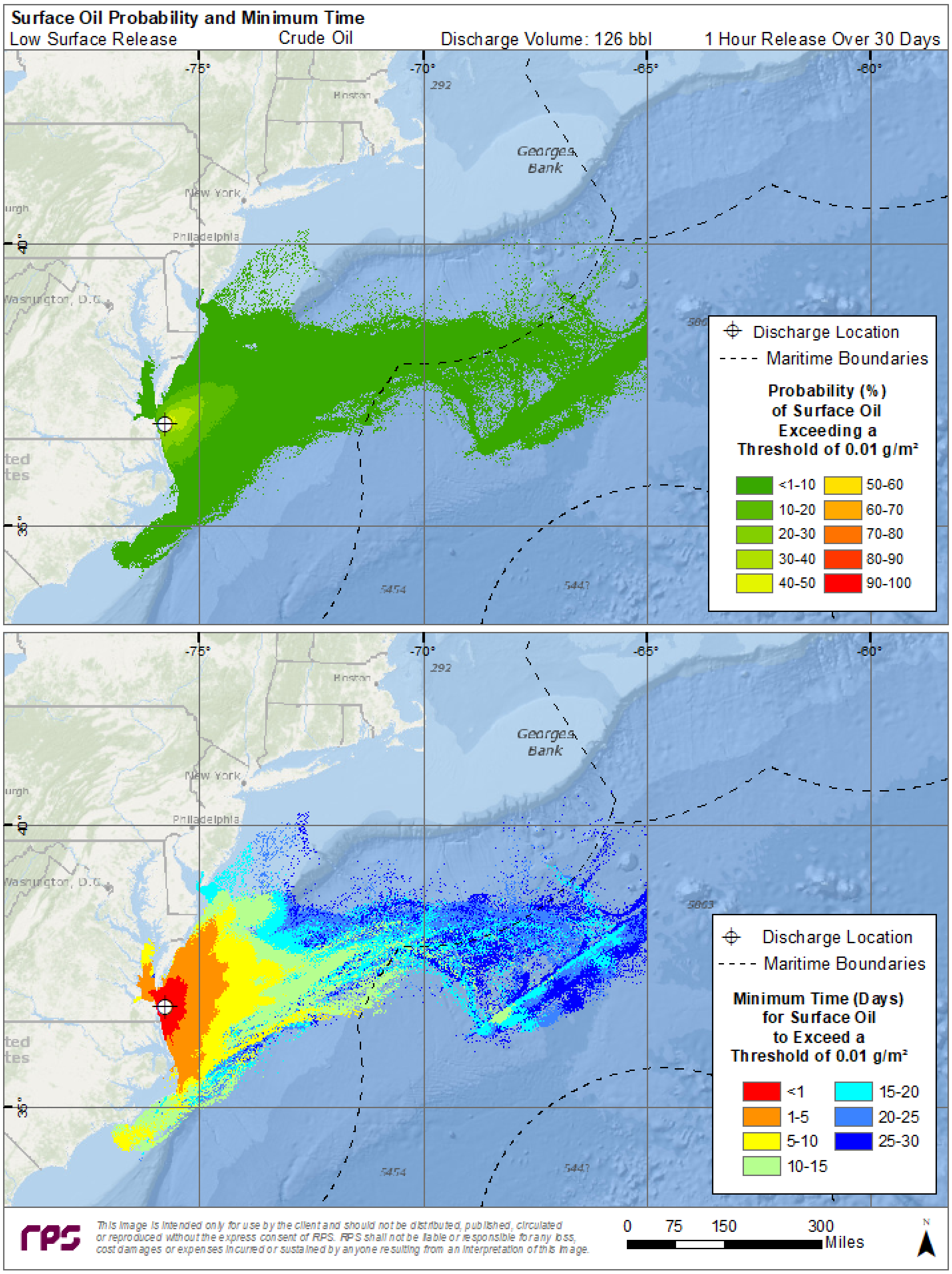


Figure 3-65. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore Virginia.

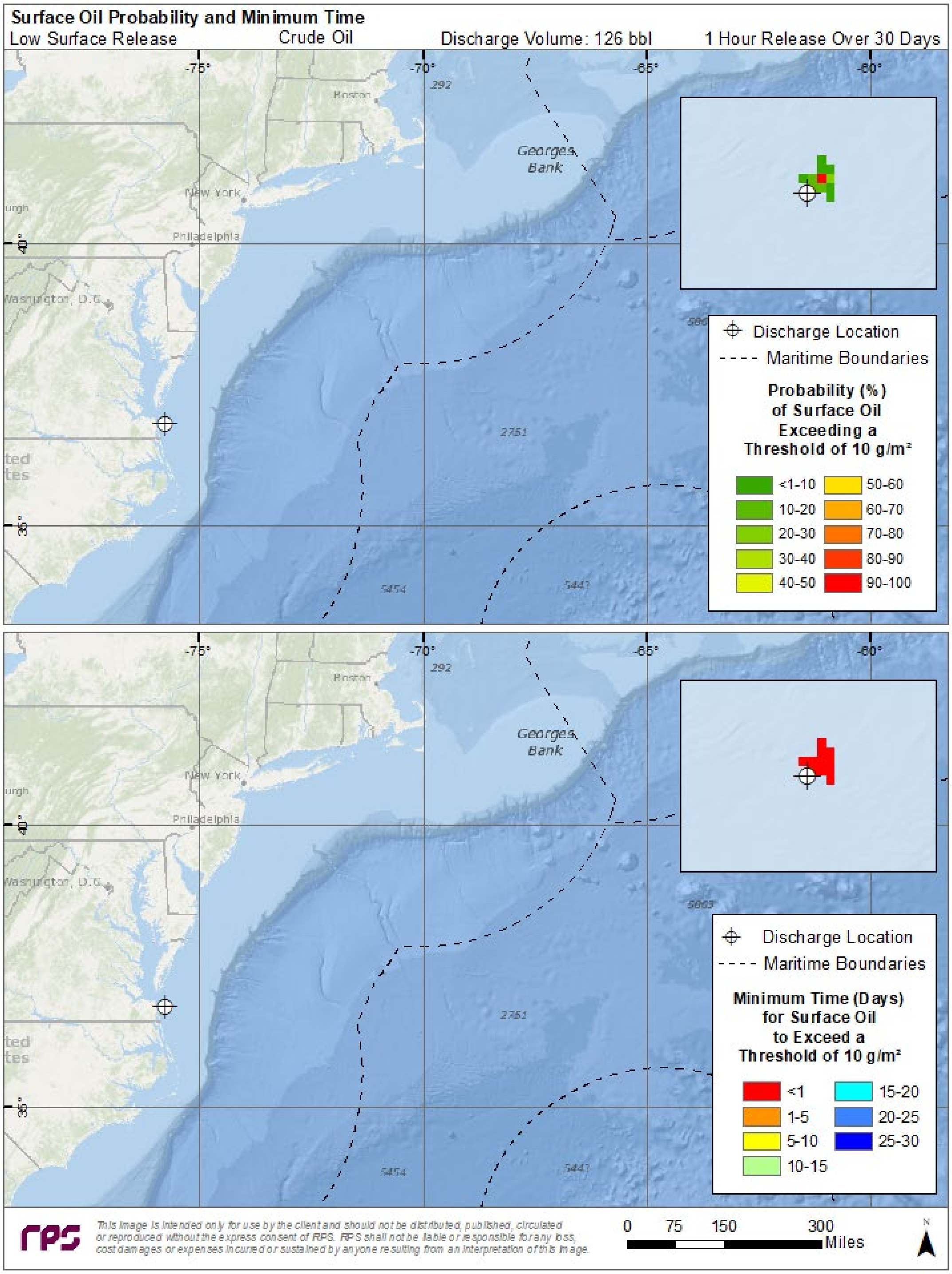


Figure 3-66. Top panel displays probability of surface oiling ≥10 μm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 μm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore Virginia.

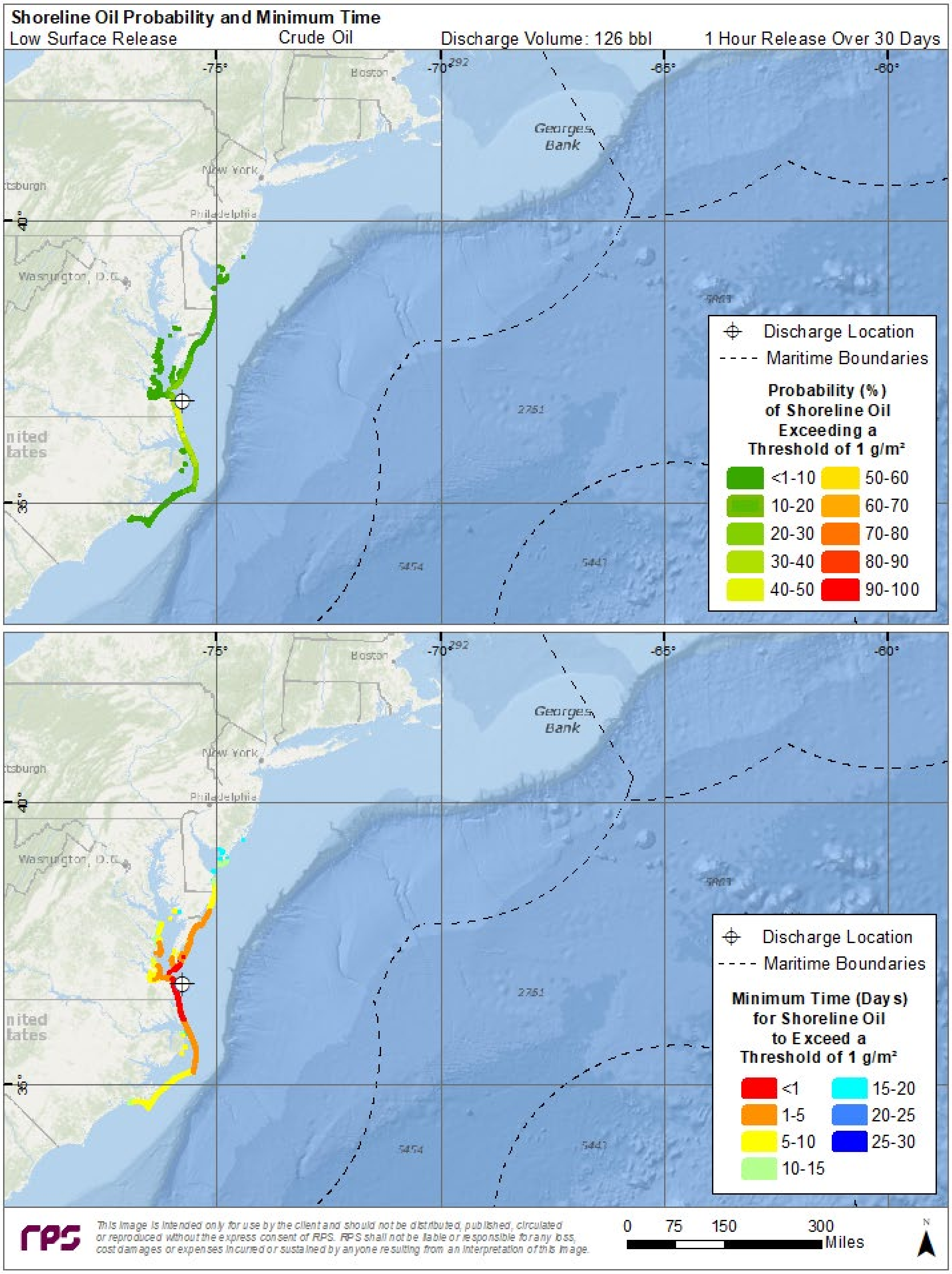


Figure 3-67. Top panel displays probability of shoreline oiling ≥1 μm (1 g/m²) and bottom panel displays minimum time for shoreline oil to exceed 1 μm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore Virginia.

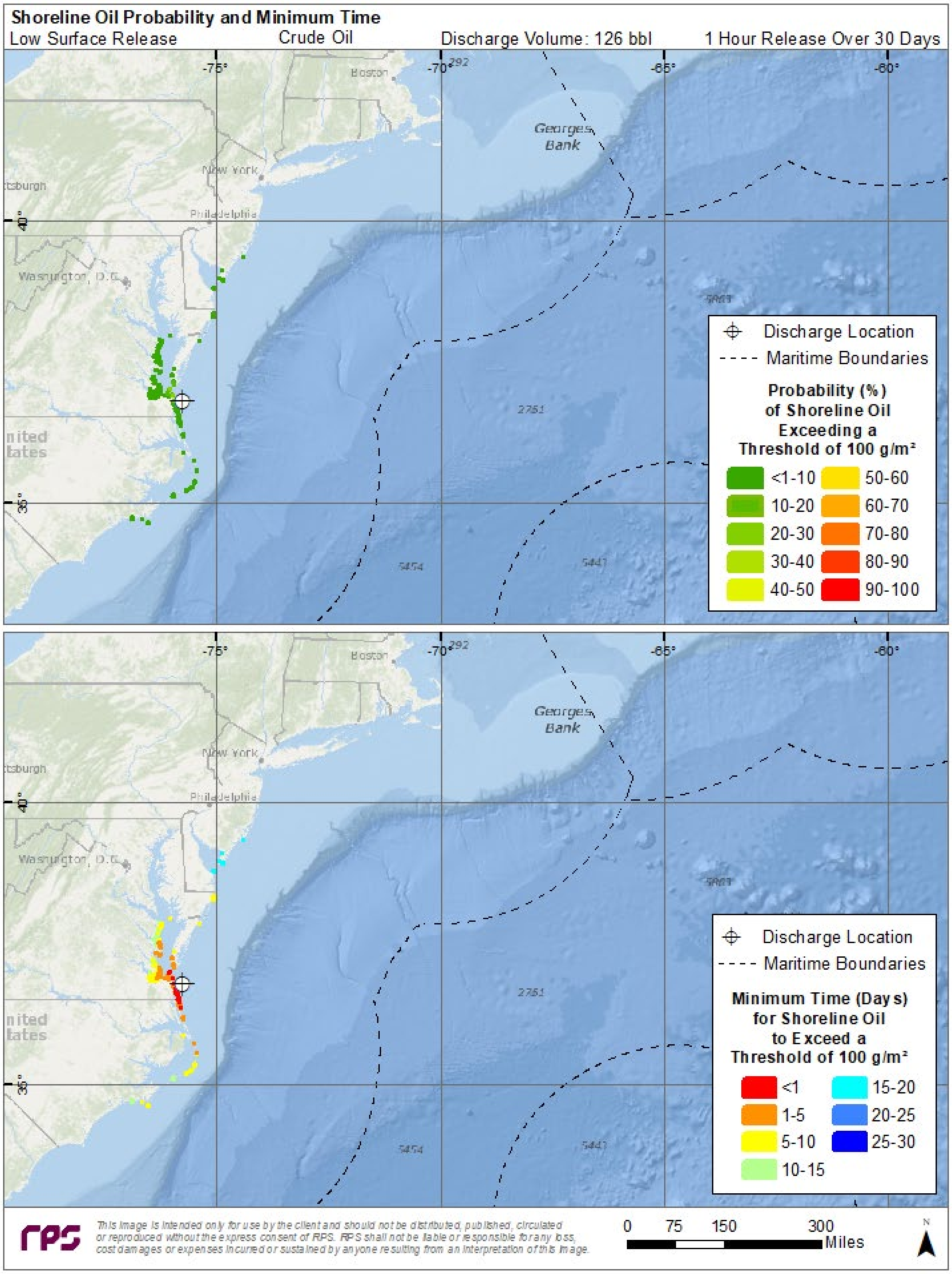


Figure 3-68. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 126 bbl of crude oil offshore Virginia.

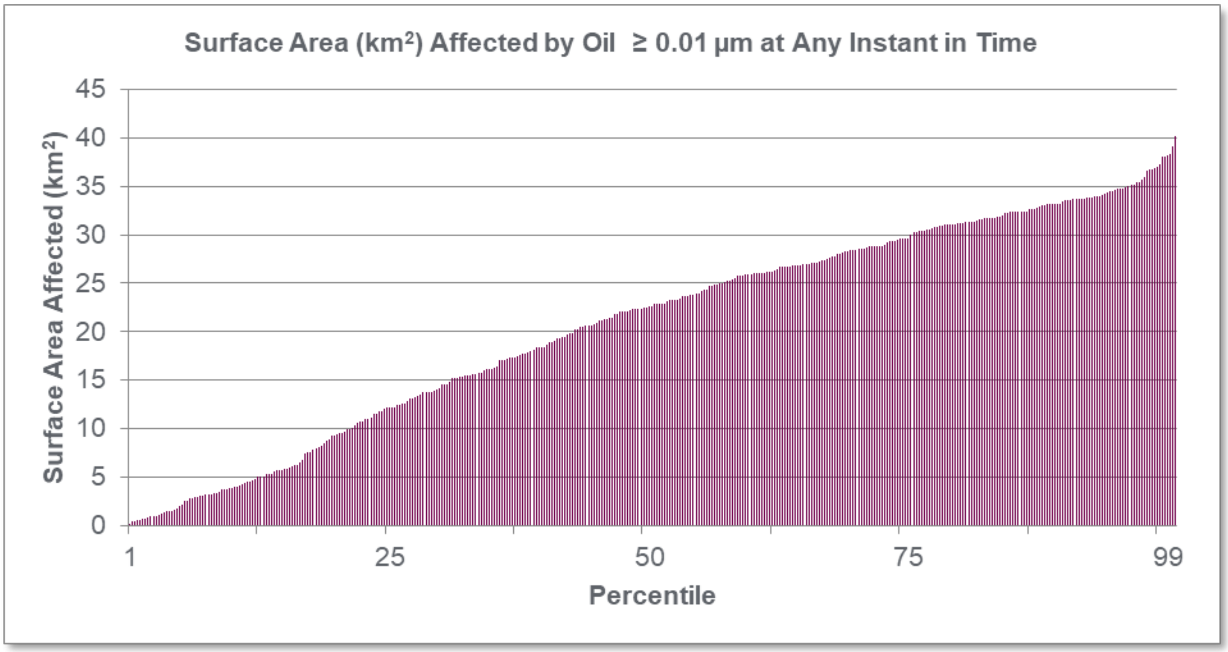


Figure 3-69. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore Virginia.

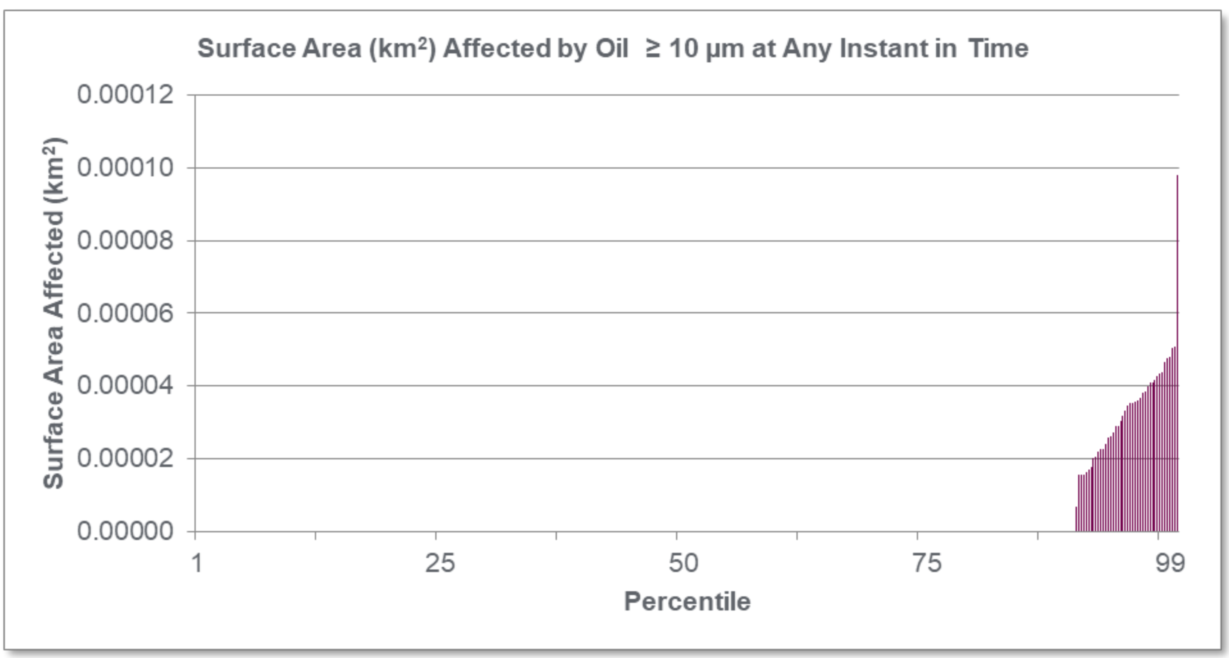


Figure 3-70. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore Virginia.

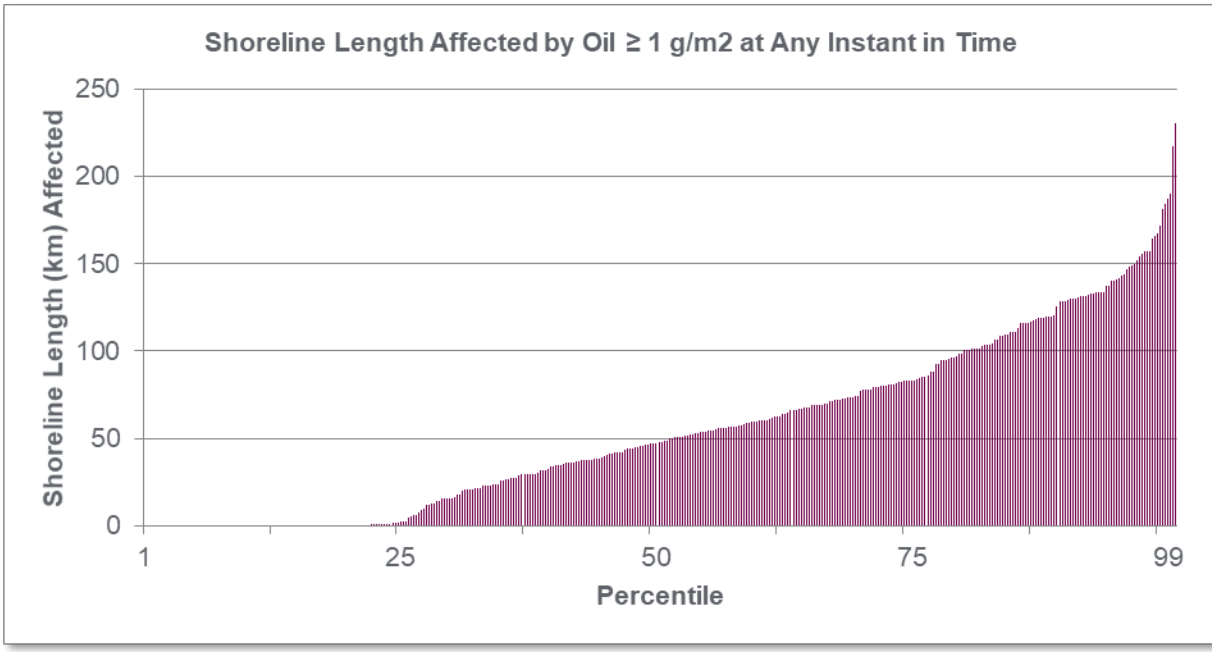


Figure 3-71. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore Virginia.

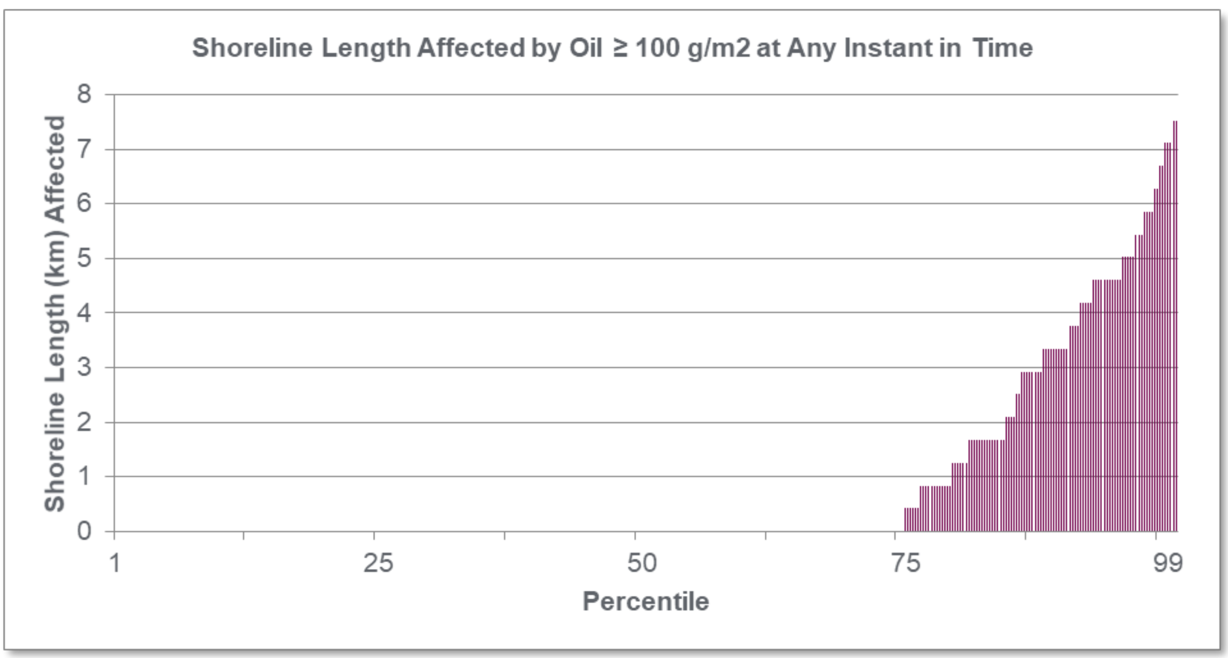


Figure 3-72. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 126 bbl of crude oil offshore Virginia.

3.2.3.2 Surface Release (Medium Volume)

For the unmitigated 2,240 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) was primarily located within ~288 mi (463 km) of the discharge location (Figure 3-73, top panel). Surface oil exceeding 0.01 g/m^2 (0.01 µm, on average) required a minimum of < 1 day to reach the coast (Figure 3-73, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~1 mi (1.6 km) (Figure 3-74, top panel), with surface oil reaching the shore within 1 day of release (Figure 3-74, bottom panel). The 0.01 g/m^2 surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 5-10 days of the discharge. The 10 g/m^2 surface oil exposure footprint was not predicted to extend past U.S. waters. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 and 10 g/m^2 thresholds extended over 570 mi (917 km) east (out of model domain) of the discharge location. The shoreline oiling above 1 g/m^2 threshold extended throughout much of Chesapeake Bay and along the outer coast from southern New Jersey to Emerald Isle, North Carolina and oiling above the 100 g/m^2 threshold was patchy, extending along similar coastlines Figure 3-75 and Figure 3-76). The probabilities for shoreline oiling are generally 0-40% with a few small locations of higher probabilities occurring directly west and south of the discharge location around the Virginia/North Carolina border. Approximately 75% of possible trajectories had < 162 mi^2 (420 km^2) of surface waters exceeding 0.01 g/m^2 and 75 % of simulations have surface oil exposure footprints of < 1.5 mi^2 (3.9 km^2) exceeding 10 g/m^2 (Figure 3-77 and Figure 3-78). Approximately 50% of possible trajectories had < 54 mi (87 km) of shoreline oiling exceeding 1 g/m^2, while 50% of simulations had shoreline exposure footprints of < 14 mi (22 km) exceeding 100 g/m^2 (Figure 3-79 and Figure 3-80). The maximum amount of shoreline oiled for any simulation was 209 mi (336 km). This worst-case simulation is examined in more detail in Section 3.3.

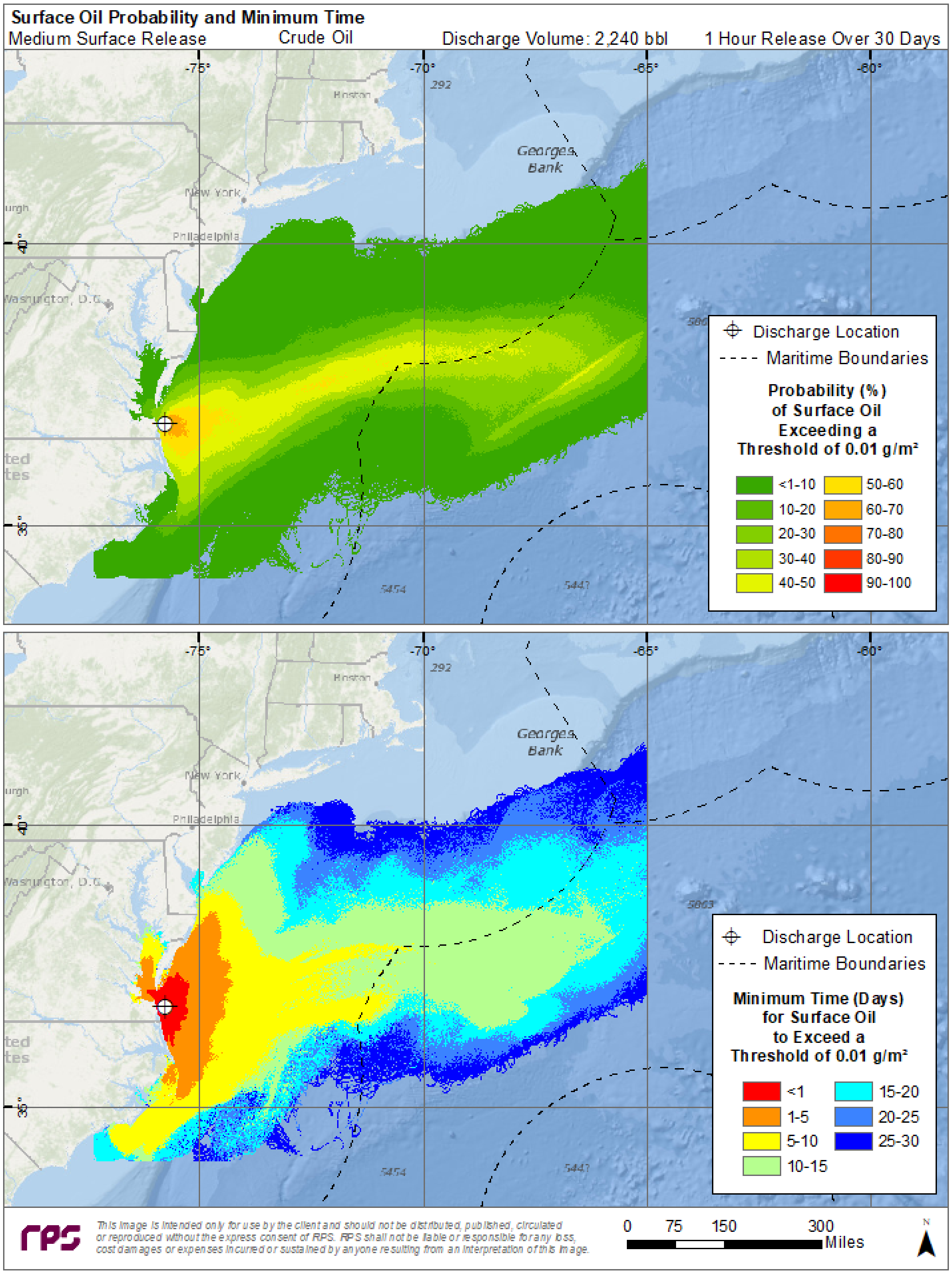


Figure 3-73. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m²) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore Virginia.

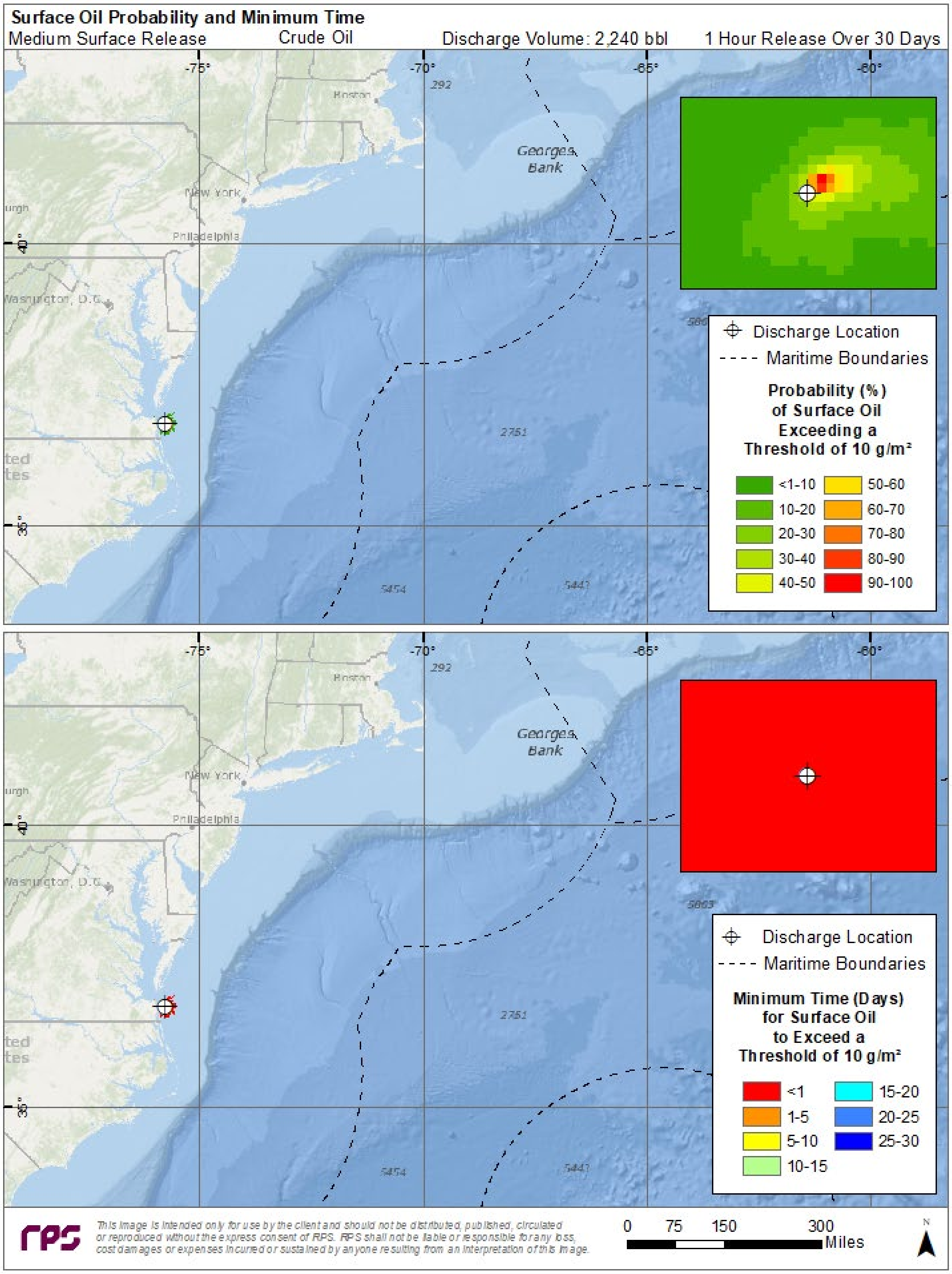


Figure 3-74. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore Virginia.

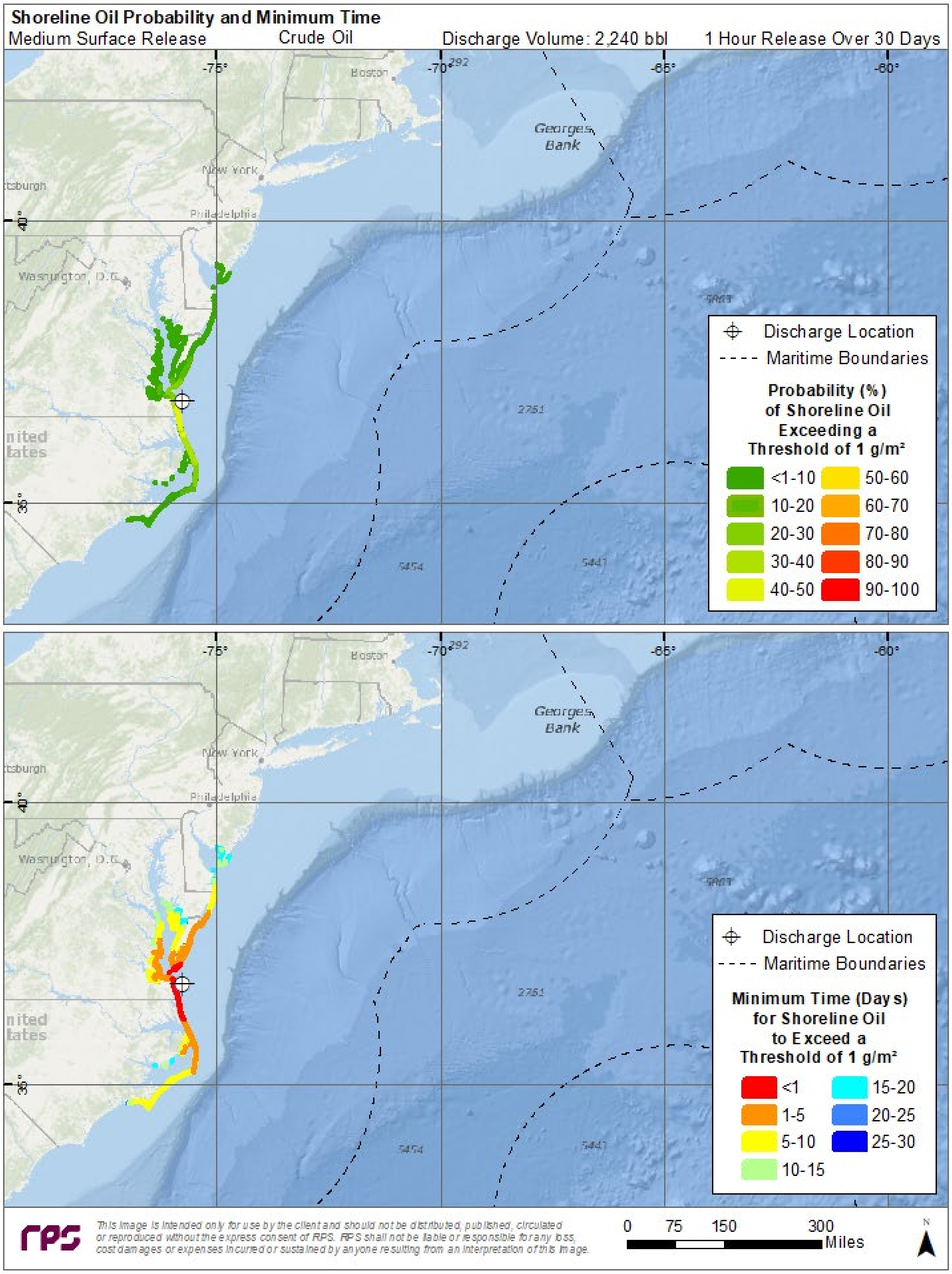


Figure 3-75. Top panel displays probability of shoreline oiling ≥1 μm (1 g/m²) and bottom panel displays minimum time for shoreline oil to exceed 1 μm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore Virginia.

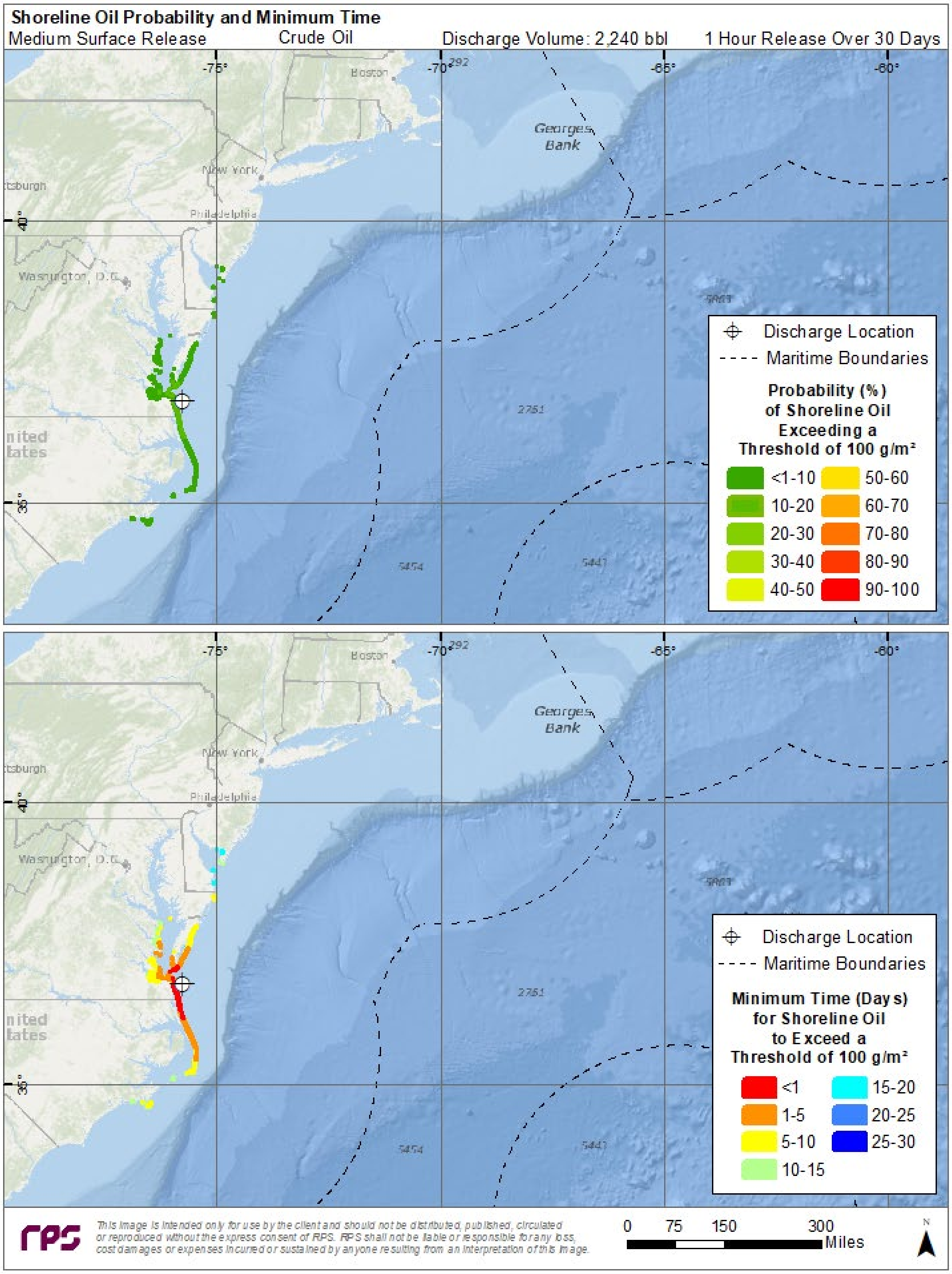


Figure 3-76. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 2,240 bbl of crude oil offshore Virginia.

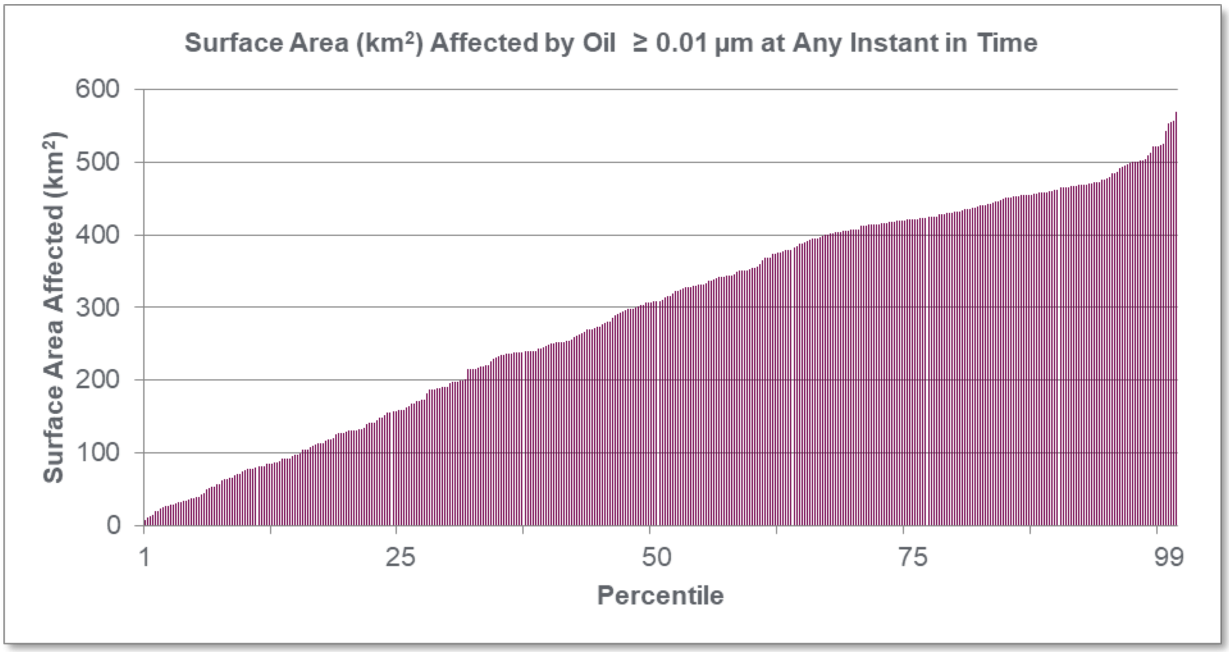


Figure 3-77. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore Virginia.

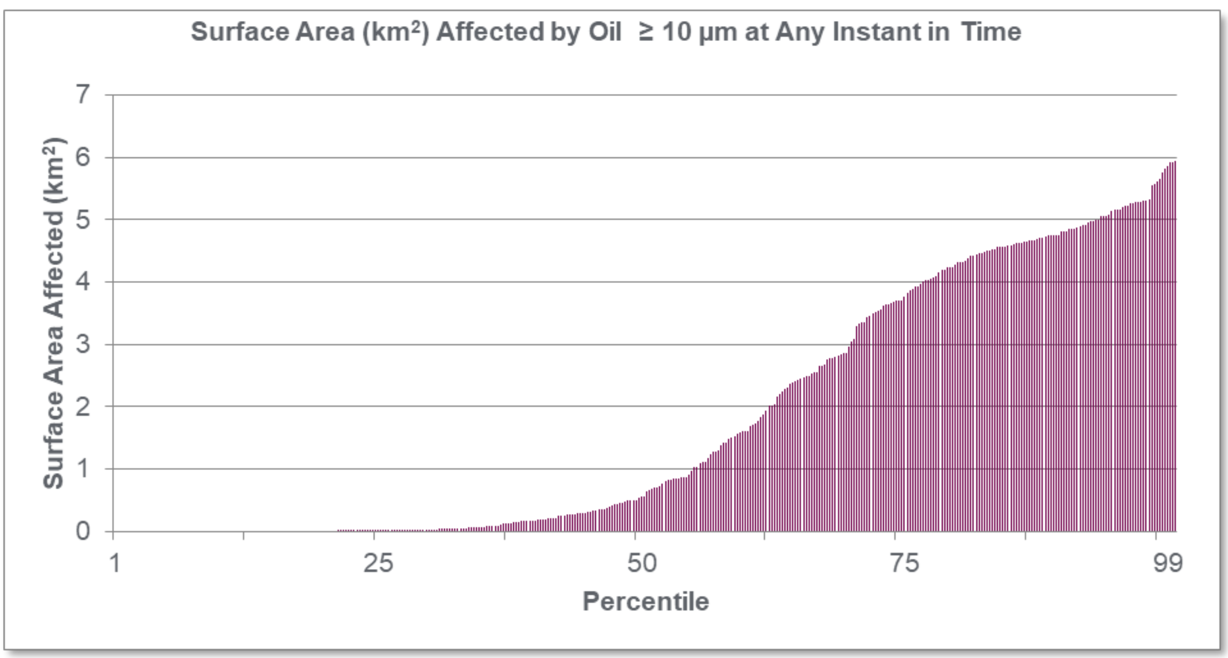


Figure 3-78. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore Virginia.

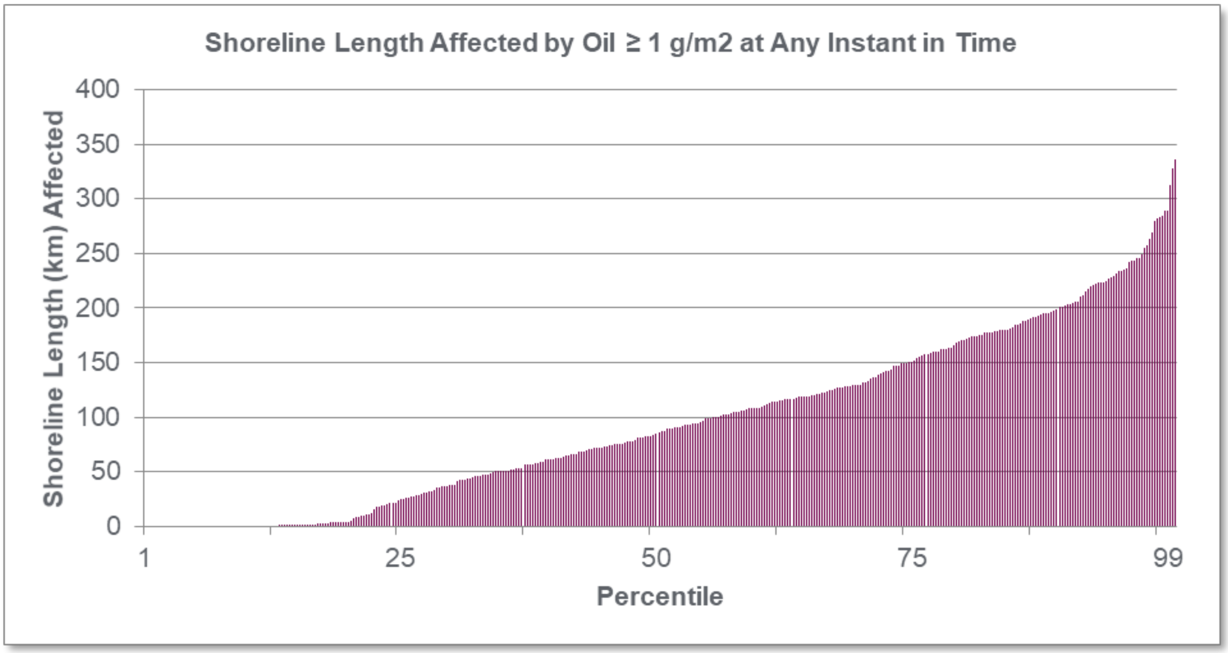


Figure 3-79. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore Virginia.

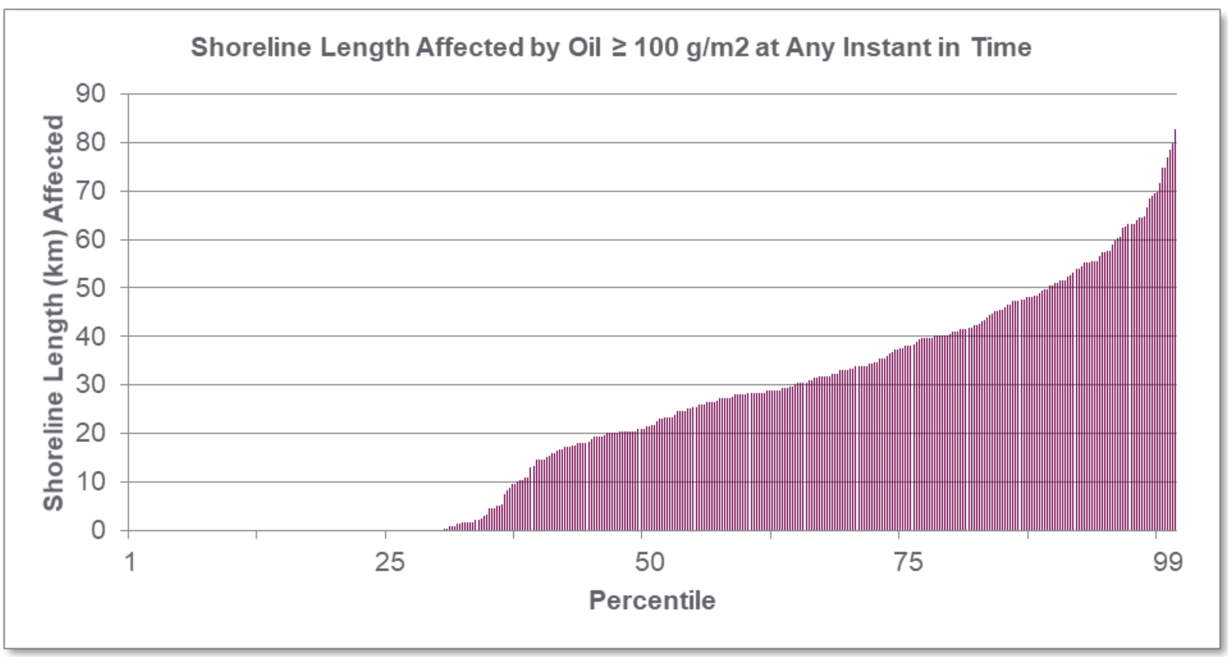


Figure 3-80. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 2,240 bbl of crude oil offshore Virginia.

3.2.3.3 Surface Release (High Volume)

For the unmitigated 200,000 bbl surface spill of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 µm, on average] threshold) was primarily located within ~507 mi (816 km) of the discharge location (Figure 3-81, top panel). Surface oil exceeding 0.01 g/m^2 and required a minimum of <1 days to reach the coast (Figure 3-81, bottom panel). Using the 10 g/m^2 (10 µm, on average) threshold, the area exceeding the 50% probability threshold was primarily within ~15 mi (24 km) (Figure 3-82, top panel) and required a minimum of < 1 days to reach the coast at any probability (Figure 3-82, bottom panel). The 0.01 g/m^2 (0.01 µm, on average) surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 5-10 days of the discharge. The 10 g/m^2 (10 µm, on average) surface oil exposure footprint above 1% probability was also predicted to extend past U.S. waters within a minimum of 5-10 days. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 and 10 g/m^2 thresholds extended over 570 mi (917 km) east of the discharge location and outside of the model domain (Figure 3-81 and Figure 3-82). The shoreline oiling above 1 g/m^2 and 100g/m^2 thresholds extended throughout much of Chesapeake Bay and along the outer coast from Atlantic City, New Jersey to Emerald Isle, North Carolina (Figure 3-83 and Figure 3-84). The probabilities for shoreline oiling do not exceed 50% for either threshold with the highest probabilities (40-50%) occurring directly west and south of the discharge location across the Virginia/North Carolina border. Of all trajectories simulated for the stochastic scenario, 50% had < 3,278 mi^2 (8,490 km^2) of surface waters exceeding 0.01 g/m^2 while 50% of simulations have surface oil exposure footprints of < 88 mi^2 (228 km^2) exceeding 10 g/m^2 (Figure 3-85 and Figure 3-86). Approximately 75% of possible trajectories had <155 mi (250 km) of shoreline oiling exceeding 1 g/m^2 while 75% of simulations had shoreline exposure footprints of < 128 mi (206 km) exceeding 100 g/m^2 (Figure 3-87 and Figure 3-88). The maximum amount of shoreline oiled for any simulation was 413 mi (665 km). This worst-case simulation is examined in more detail in Section 3.3.

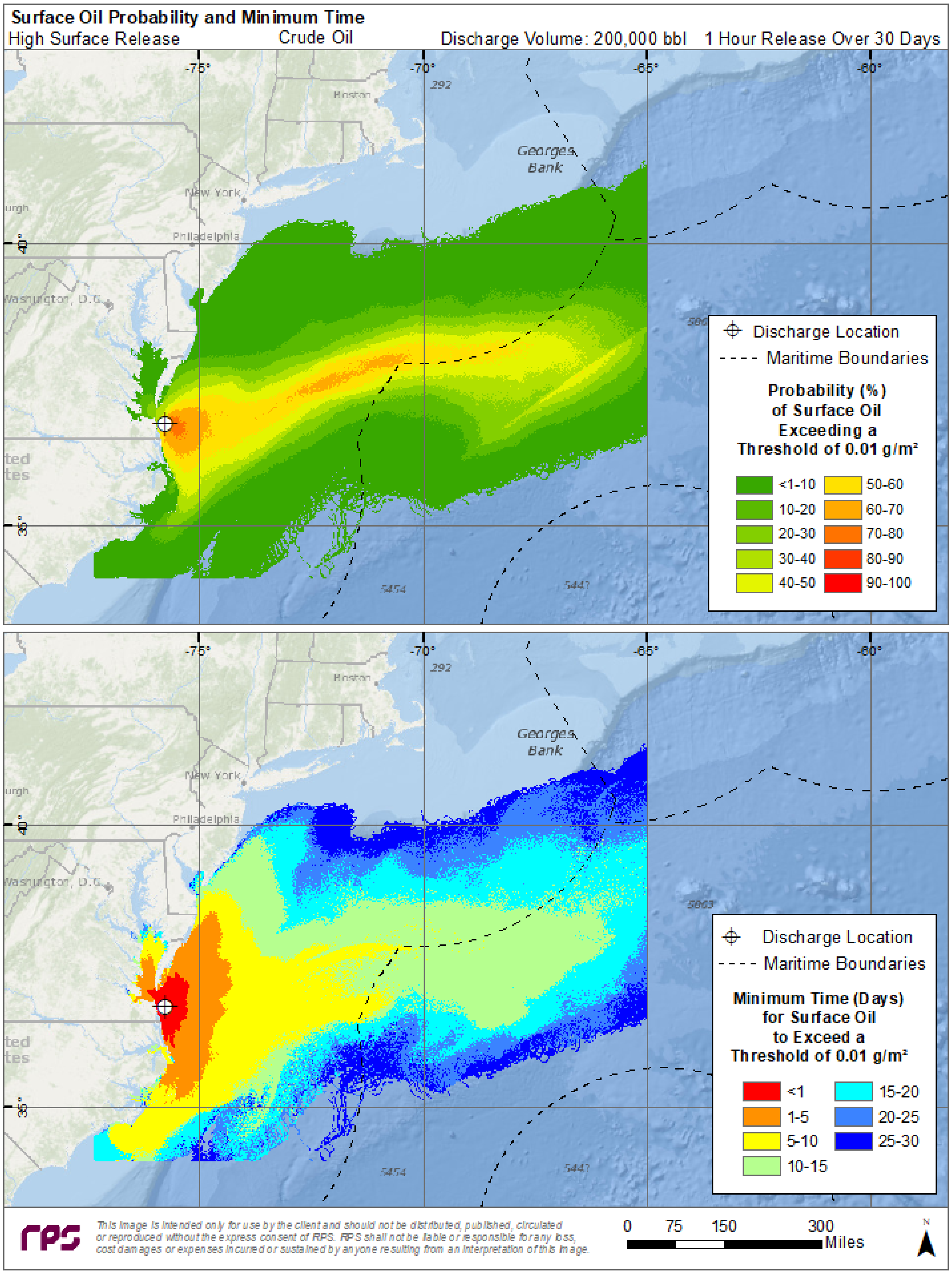


Figure 3-81. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore Virginia.

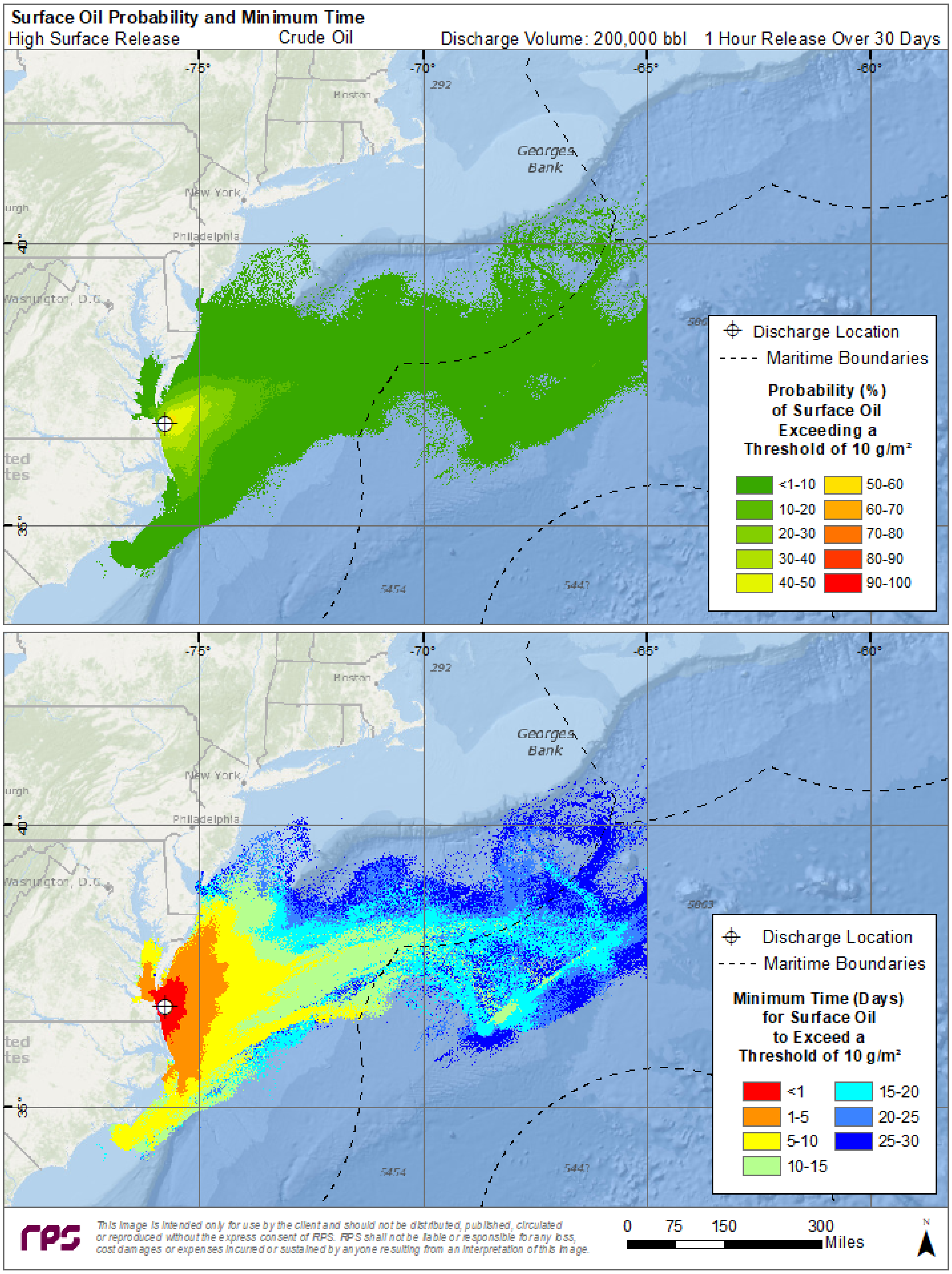


Figure 3-82. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore Virginia.

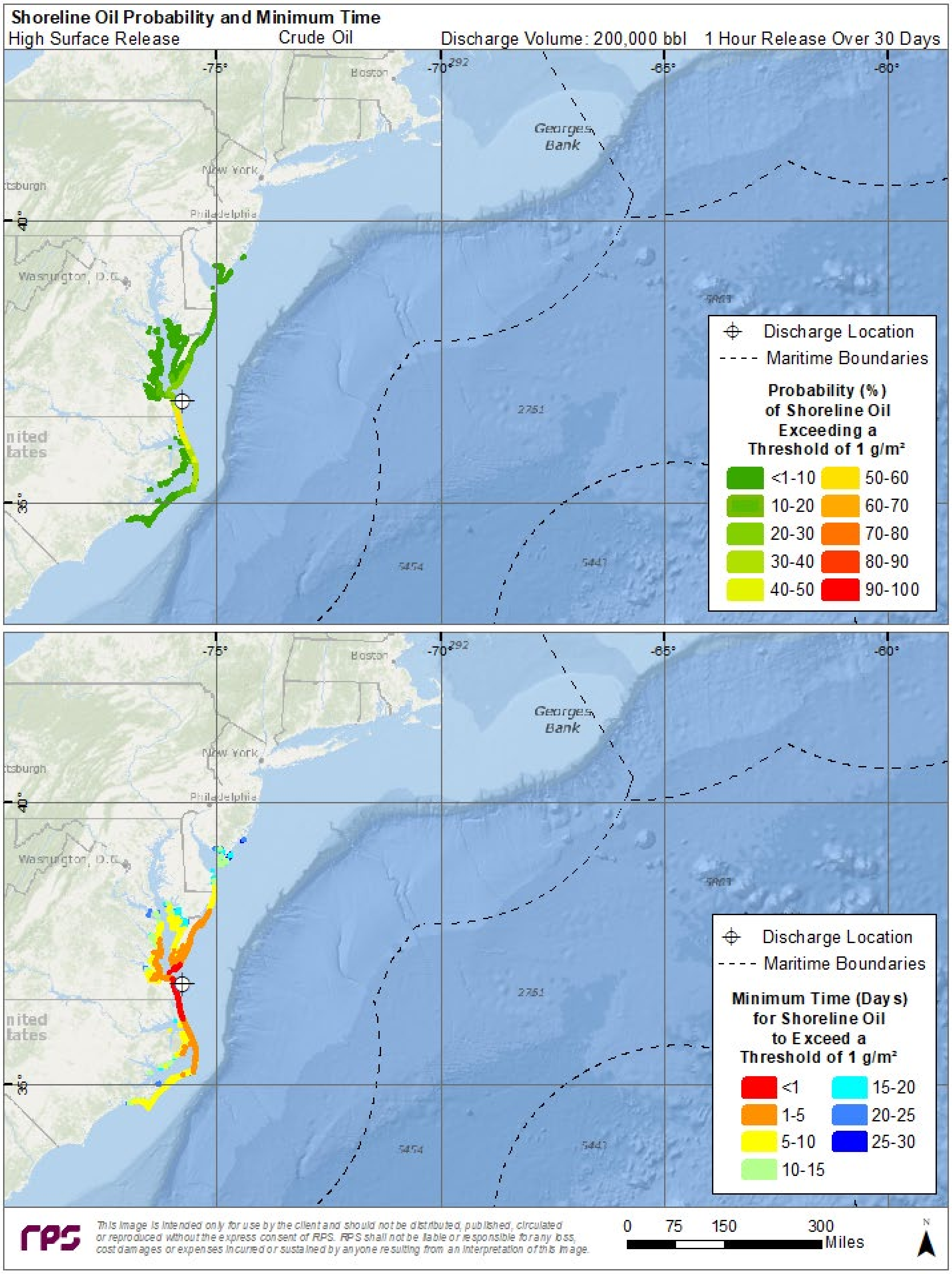


Figure 3-83. Top panel displays probability of shoreline oiling ≥1 µm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore Virginia.

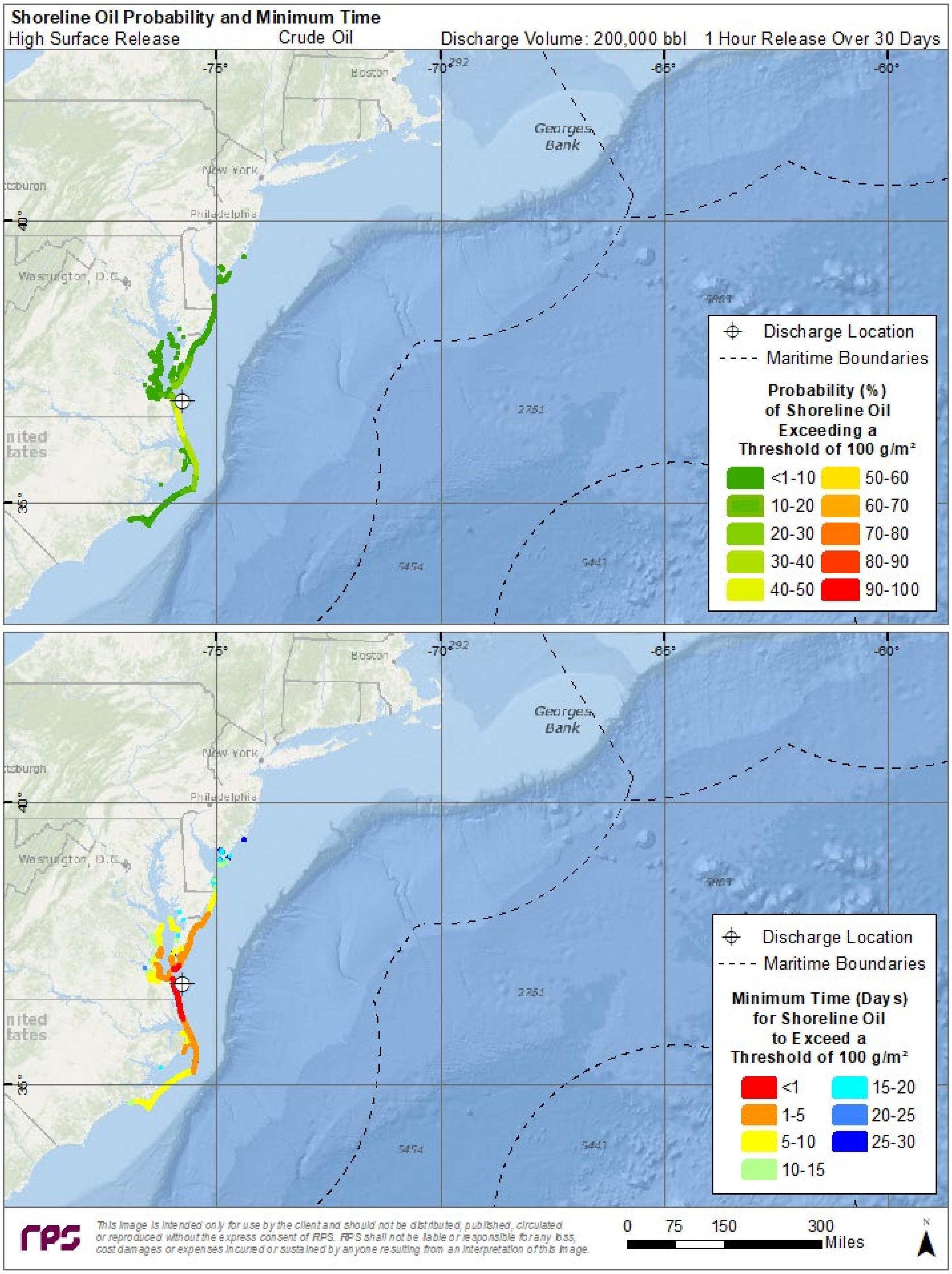


Figure 3-84. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 200,000 bbl of crude oil offshore Virginia.

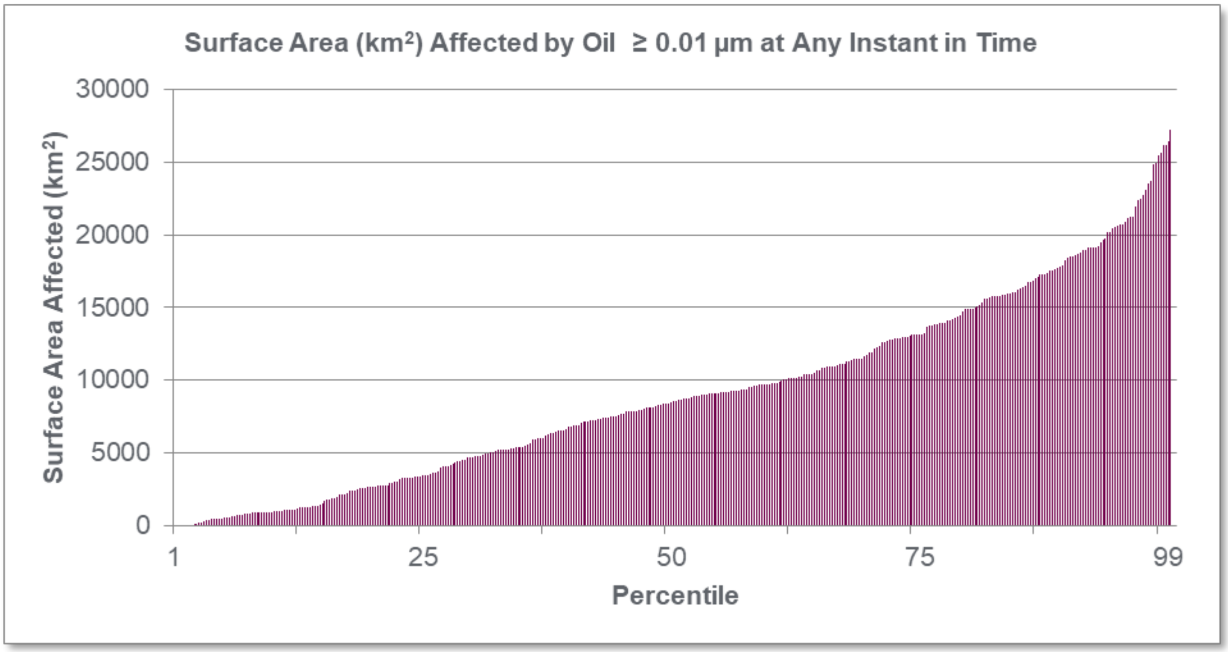


Figure 3-85. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore Virginia.

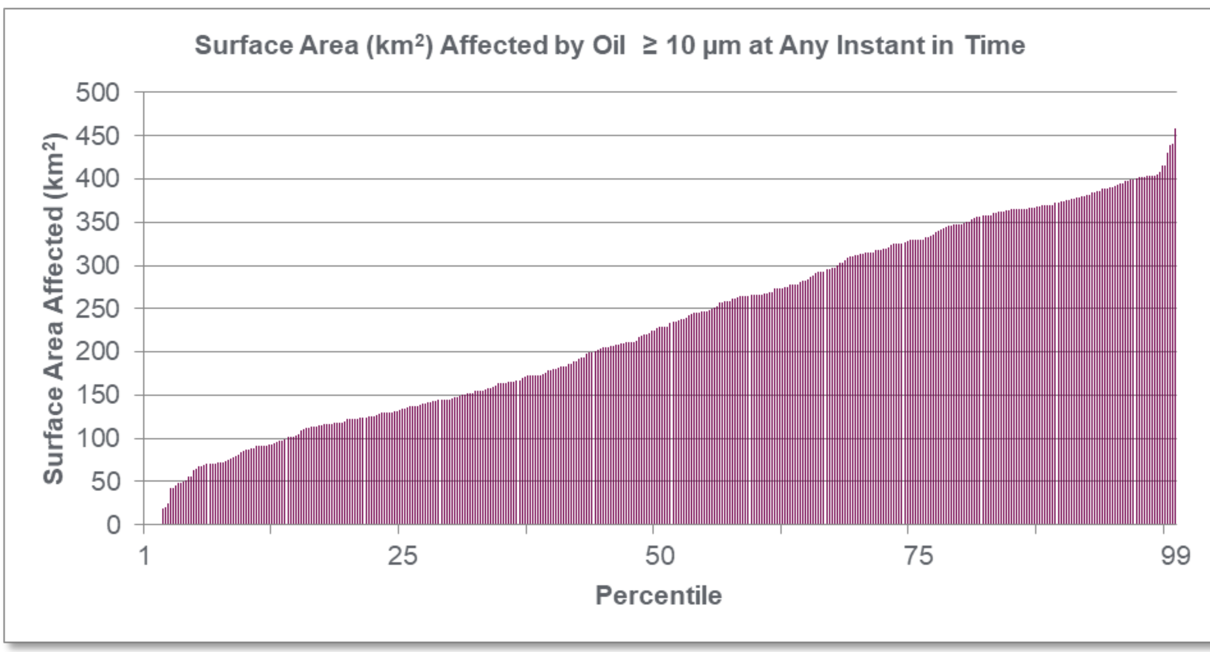


Figure 3-86. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore Virginia.

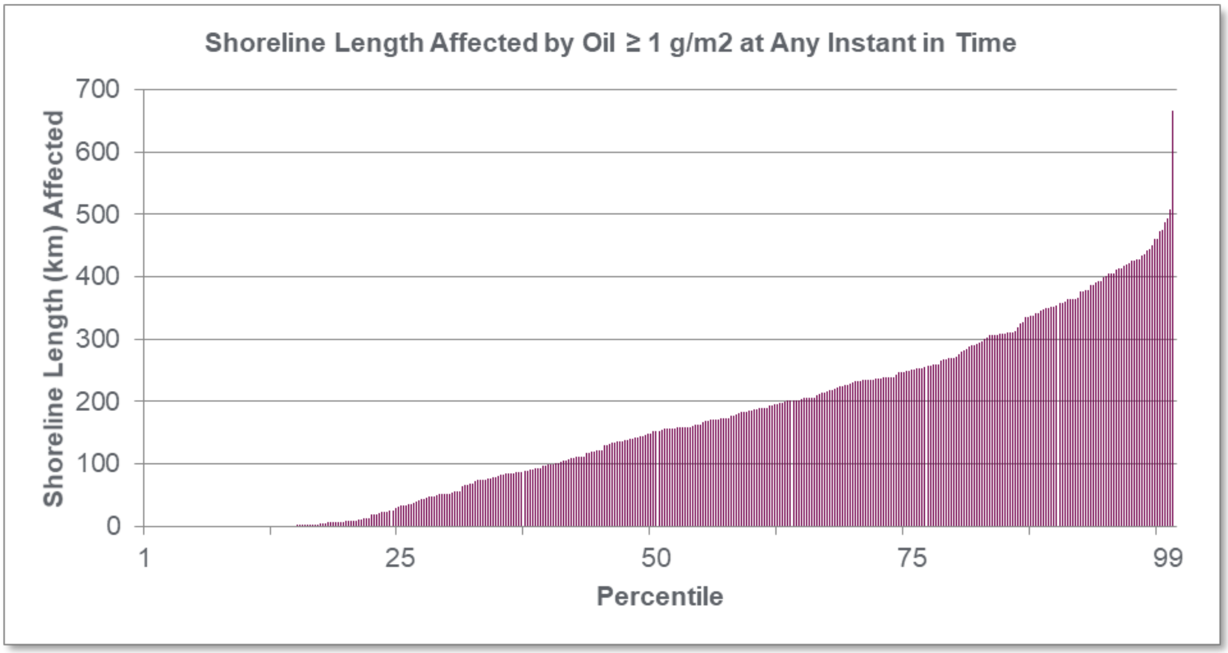


Figure 3-87. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore Virginia.

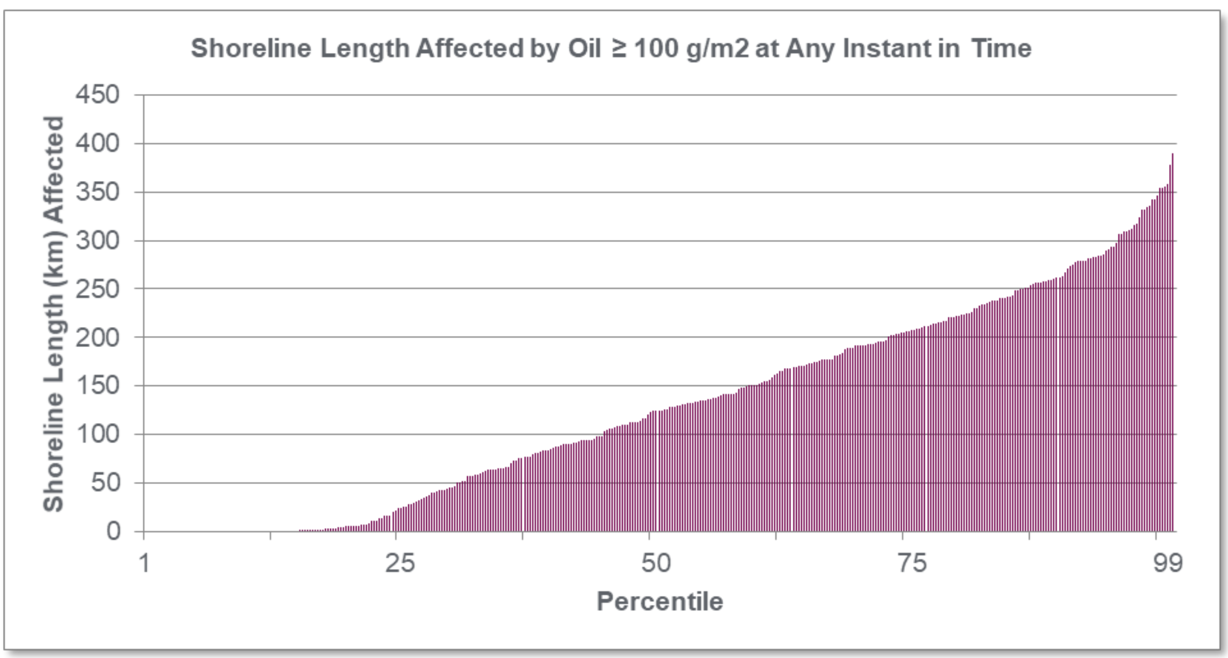


Figure 3-88. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 30-day simulations of an unmitigated surface discharge of 200,000 bbl of crude oil offshore Virginia.

3.2.3.4 Subsurface Release (Well Blowout)

For the unmitigated 900,000 bbl subsurface blowout of crude oil, the surface oil exposure footprint exceeding 50% probability (above the 0.01 g/m^2 [0.01 μm, on average] threshold) extended over 510 mi (821 km) east of the release location the discharge location and outside of the model domain (Figure 3-89, top panel). Surface oil exceeding 0.01 g/m^2 [0.01 μm, on average] required a minimum of 1-5 days to reach the coast (Figure 3-89, bottom panel). Using the 10 g/m^2 (10 μm, on average) threshold, the area exceeding the 70% probability threshold was primarily within ~450 mi (724 km) of the release site, with these higher probabilities also occurring further offshore and outside of the model domain (Figure 3-90, top panel). Surface oil exceeding 10 g/m^2 also required a minimum of 1-5 days to reach the coast (Figure 3-90, bottom panel). At both thresholds, the surface oil exposure footprint above 1% probability was predicted to extend past U.S. waters, i.e., there is a chance > 1% of oil reaching international waters within 5-10 days of the discharge. Considering the entire model duration, the 1% probability contour for the 0.01 g/m^2 and 10 g/m^2 thresholds extended outside of the model domain, over 510 mi (821 km) east of the discharge location (Figure 3-89 and Figure 3-90). Of all trajectories simulated for the stochastic scenario, 50% had < 11,187 mi^2 (28,975 km^2) of surface waters exceeding 0.01 g/m^2 while 50% of simulations have surface oil exposure footprints of < 228 mi^2 (591 km^2) exceeding 10 g/m^2 (Figure 3-93 and Figure 3-94). The shoreline oiling stochastic footprint above the 1 g/m^2 and 100 g/m^2 [100 μm, on average] thresholds were similar in extent, stretching along the outer coast from Cape Lookout, North Carolina to Cape Cod, Massachusetts (Figure 3-91 and Figure 3-92). The probabilities for shoreline oiling do not exceed 40% for either threshold with the highest probabilities (30-40%) occurring west of the discharge location along the Virginia coastline. Approximately 60% of possible trajectories had < 11 mi (18 km) and < 7 mi (11 km) of shoreline oiling exceeding the 1 g/m^2 and 100 g/m^2 thresholds, respectively (Figure 3-95 and Figure 3-96). The maximum amount of shoreline oiled exceeding 1 g/m^2 for any simulation was 440 mi (708 km). This worst-case simulation is examined in more detail in Section 3.3.

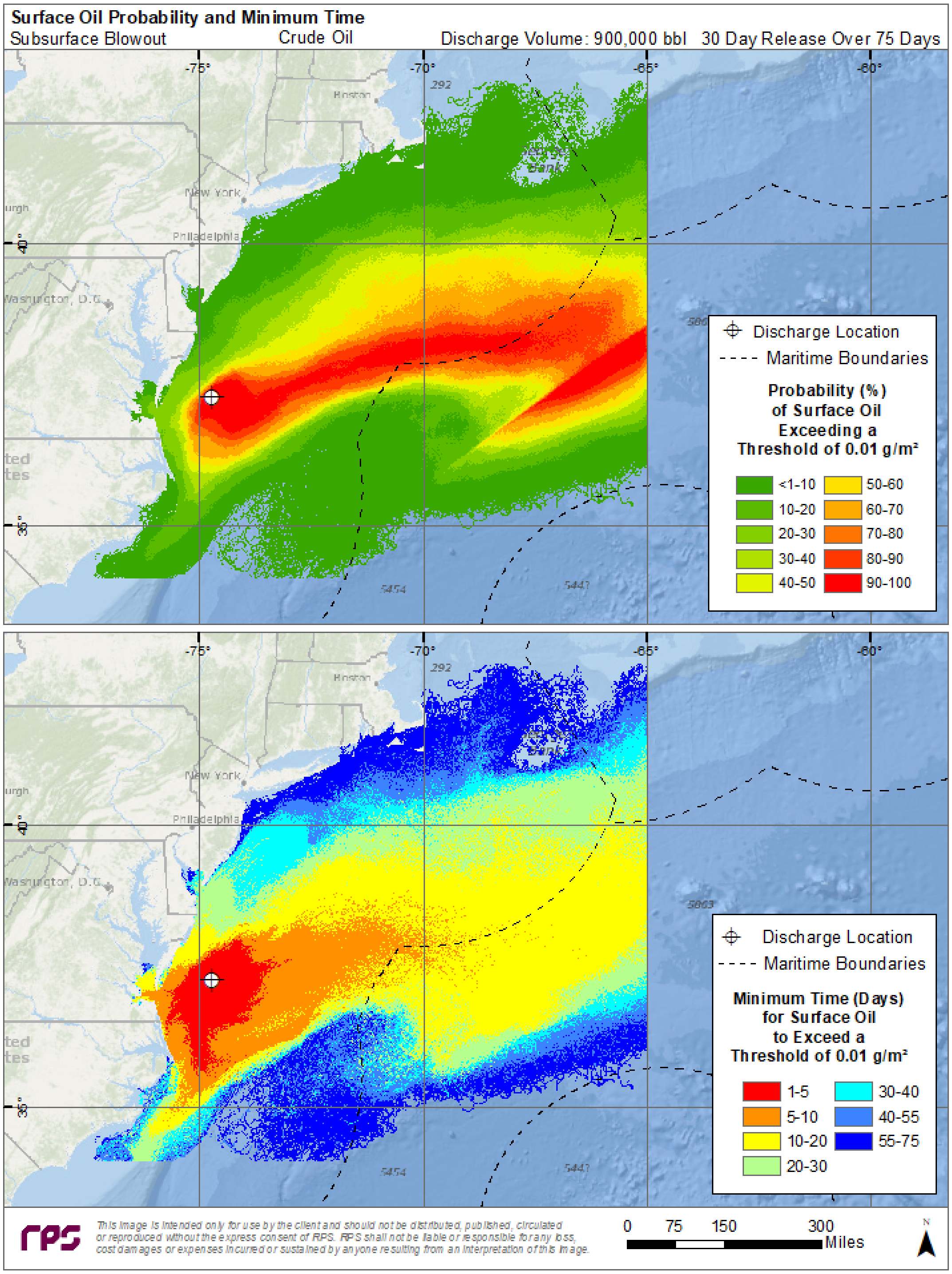


Figure 3-89. Top panel displays probability of surface oiling ≥0.01 µm (0.01 g/m^2) and bottom panel displays minimum time for surface oil to exceed 0.01 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore Virginia.

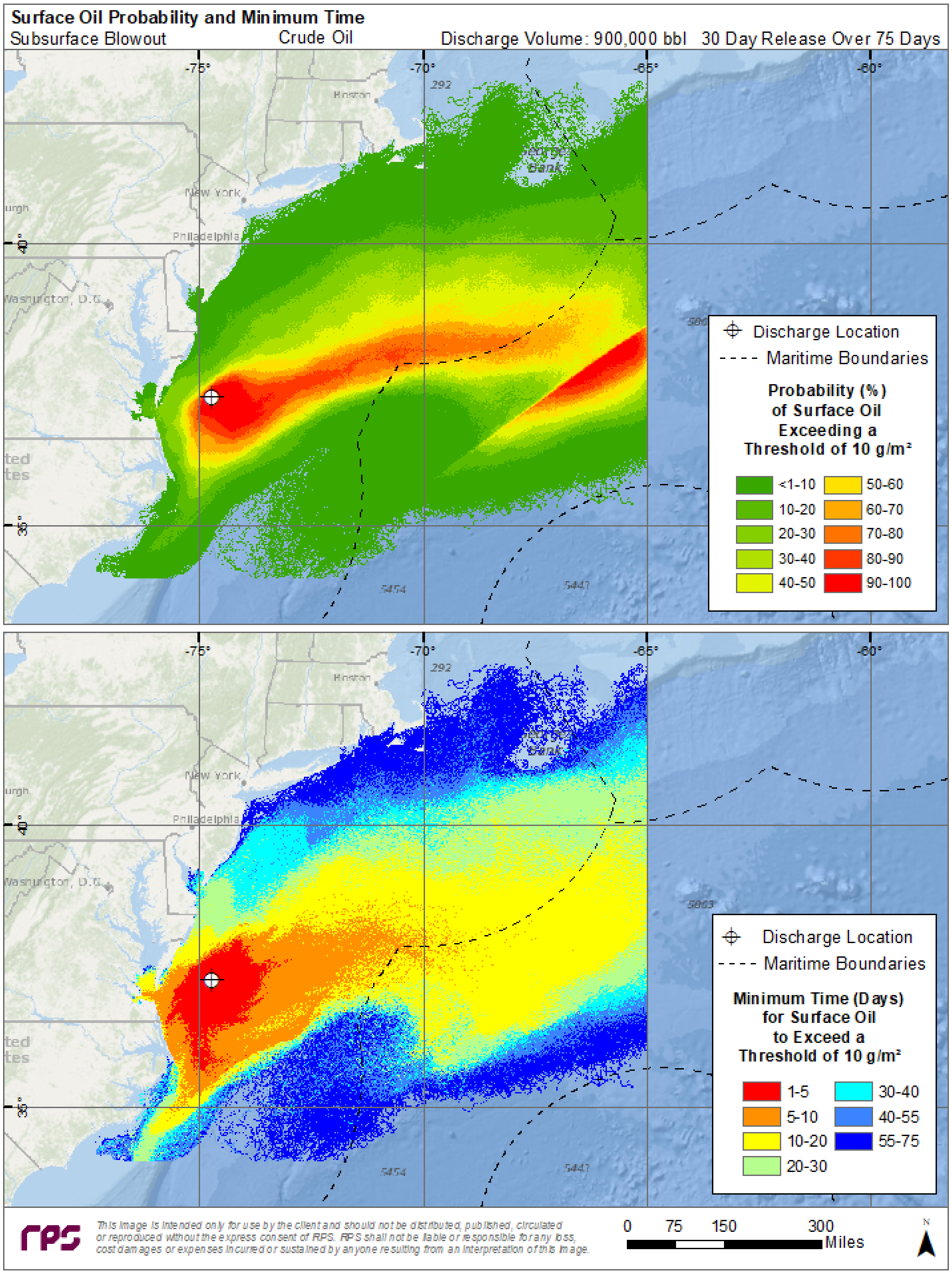


Figure 3-90. Top panel displays probability of surface oiling ≥10 µm (10 g/m^2) and bottom panel displays minimum time for surface oil to exceed 10 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore Virginia.

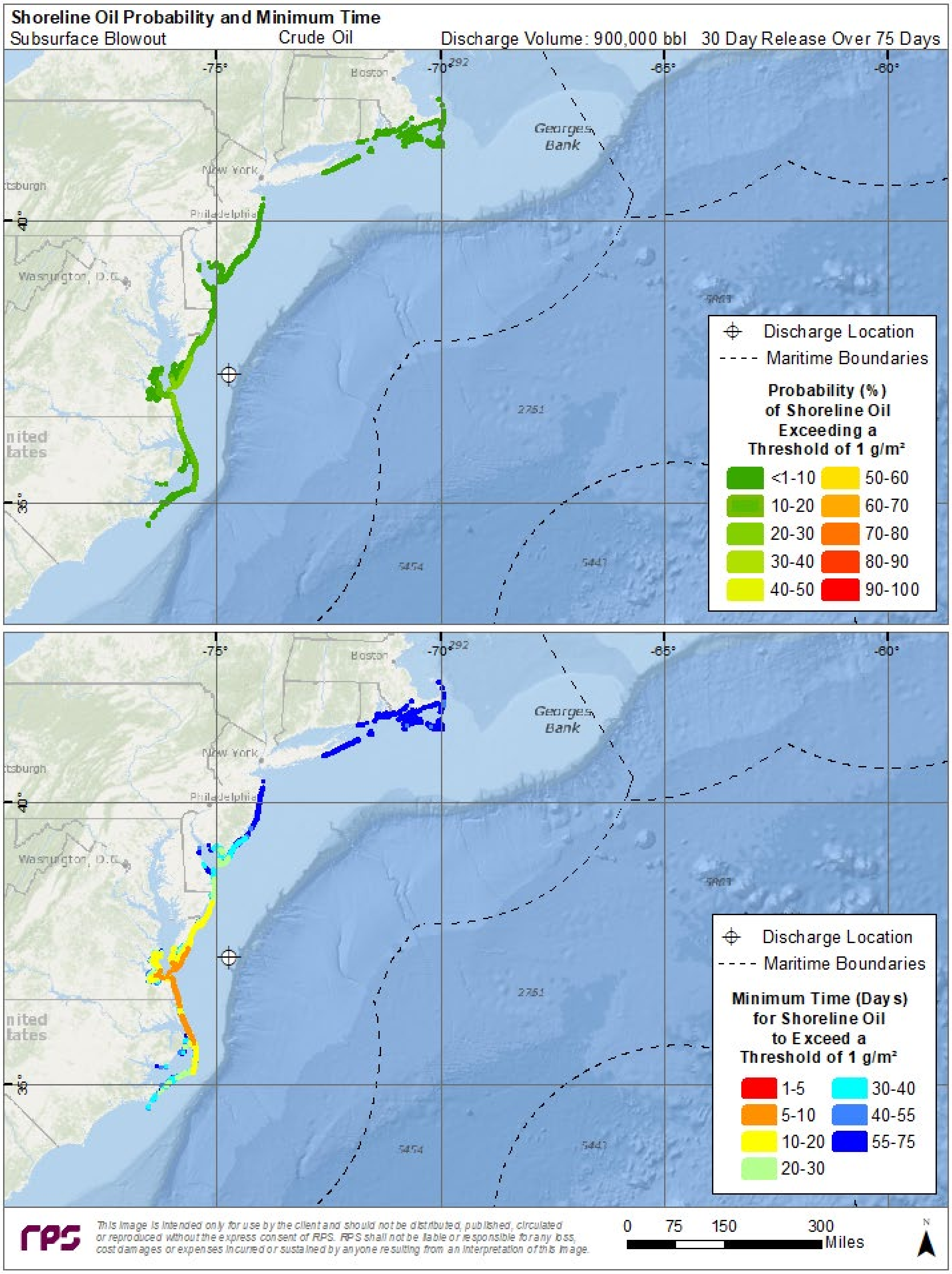


Figure 3-91. Top panel displays probability of shoreline oiling ≥1 µm (1 g/m^2) and bottom panel displays minimum time for shoreline oil to exceed 1 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore Virginia.

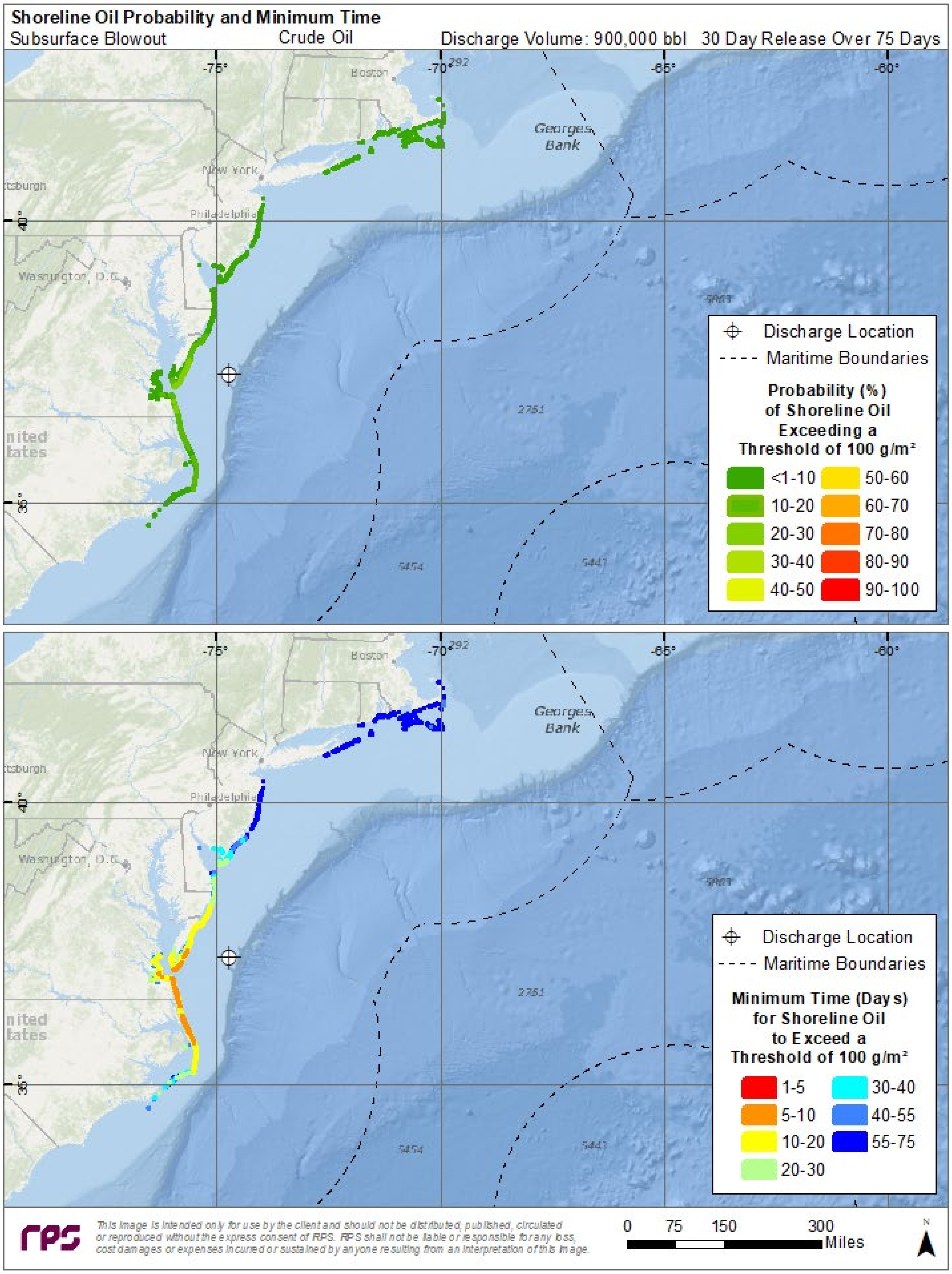


Figure 3-92. Top panel displays probability of shoreline oiling ≥100 µm (100 g/m²) and bottom panel displays minimum time for shoreline oil to exceed 100 µm (averaged over the grid cell), based on a range of possible trajectories for an unmitigated discharge of 900,000 bbl of crude oil offshore Virginia.

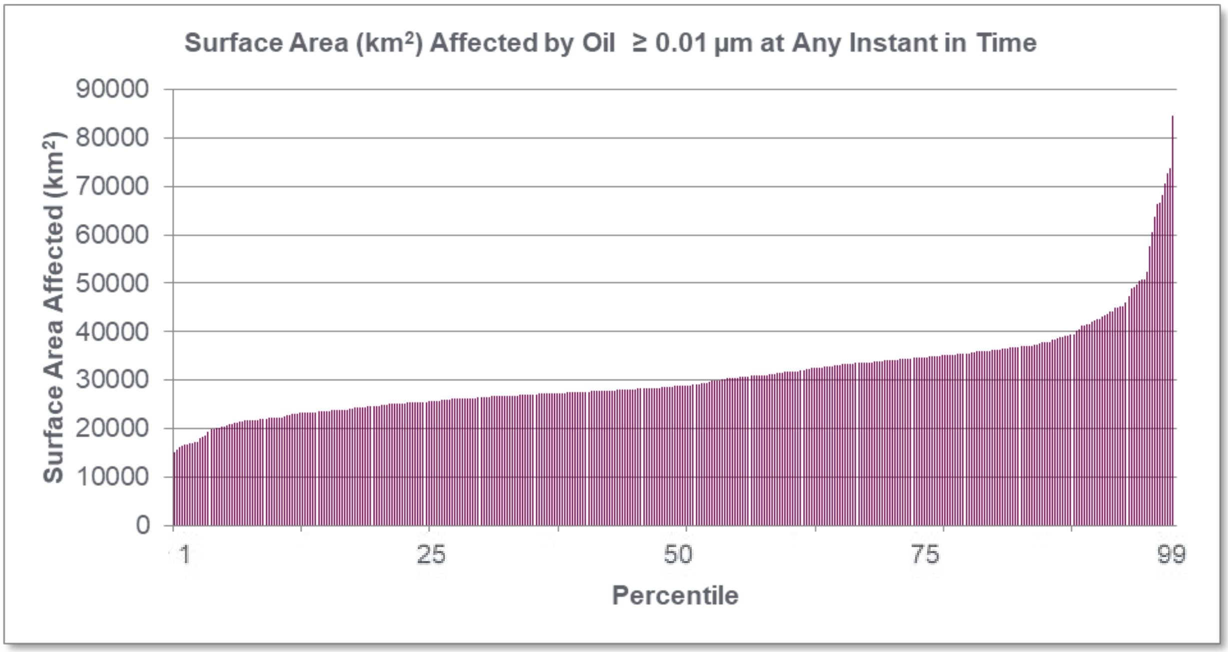


Figure 3-93. Frequency distribution of possible water surface areas exposed to oil ≥ 0.01 g/m^2 (0.01 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore Virginia.

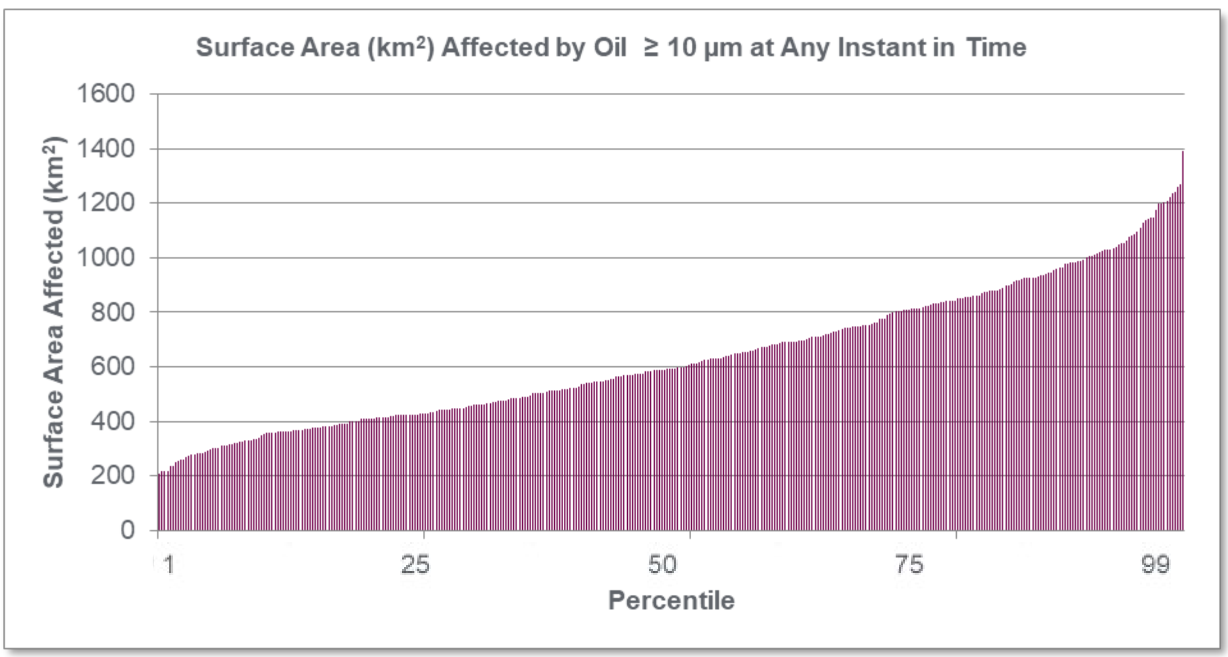


Figure 3-94. Frequency distribution of possible water surface areas exposed to oil ≥ 10 g/m^2 (10 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore Virginia.

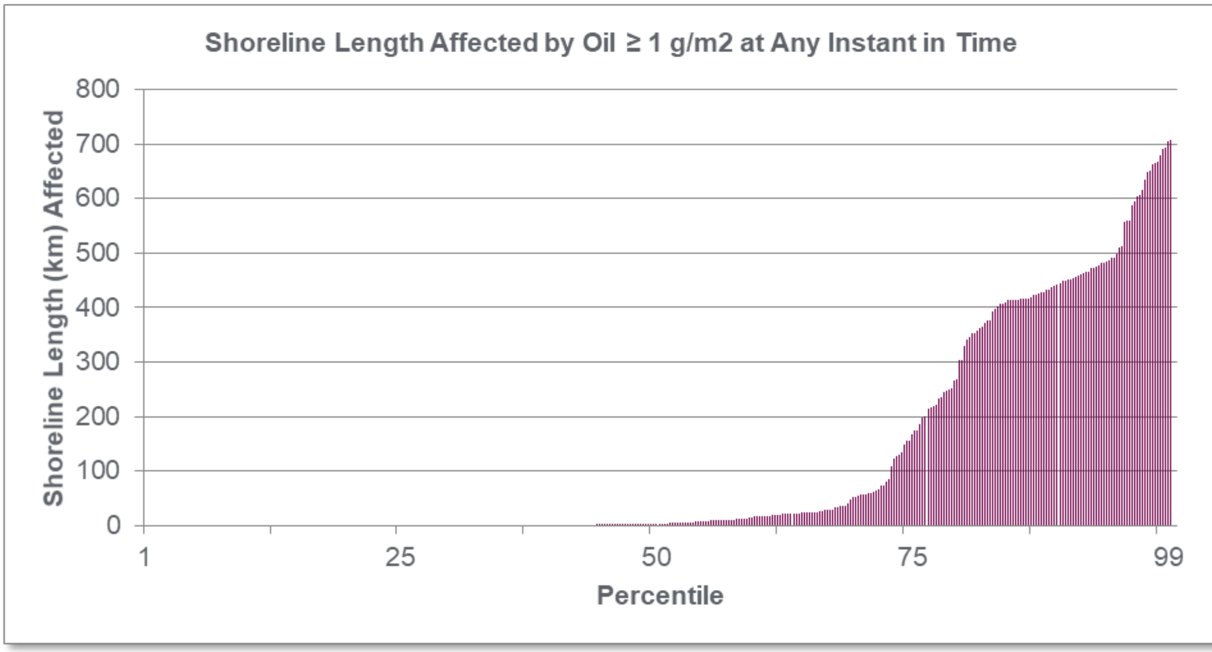


Figure 3-95. Frequency distribution of possible shoreline lengths exposed to oil ≥ 1 g/m^2 (1 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore Virginia.

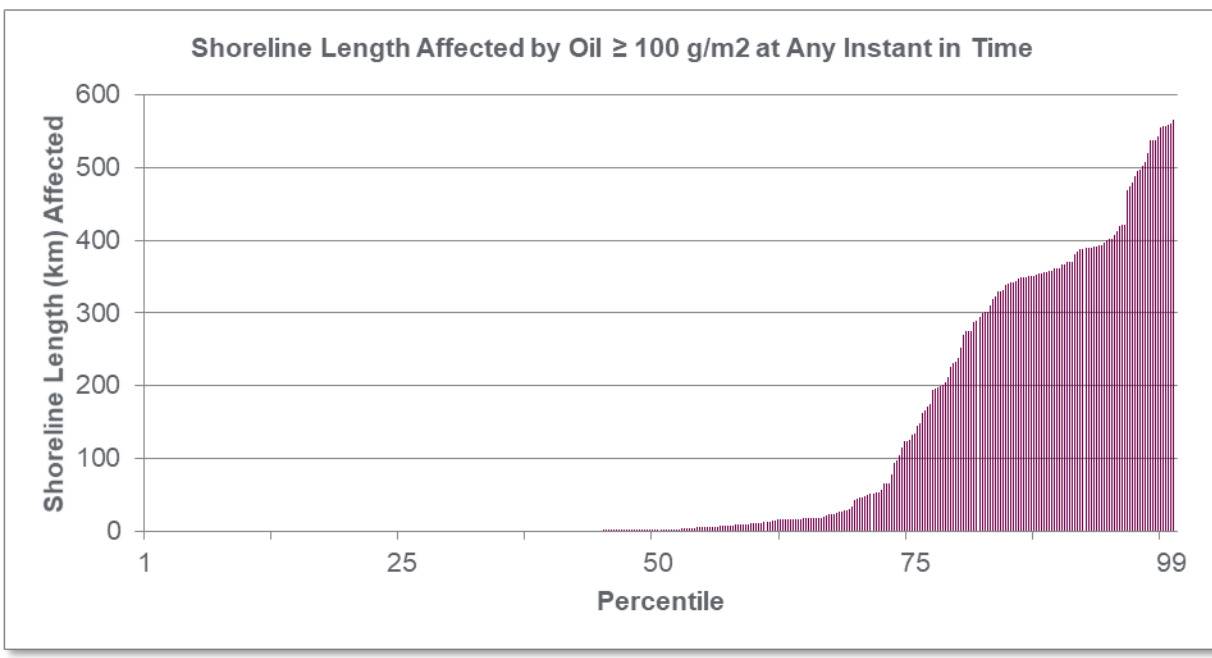


Figure 3-96. Frequency distribution of possible shoreline lengths exposed to oil ≥ 100 g/m^2 (100 µm, on average) at any point in time over 75-day simulations of an unmitigated subsurface discharge of 900,000 bbl of crude oil offshore Virginia

3.3 Individual Simulations – Worst Case for Shoreline Oiling

Individual simulations representing the run with maximum shoreline length oiled on an annual basis were identified from the stochastic scenario results for each regional spill location. The modeled dates are presented in Table 3-2 for sites offshore of Delaware, Table 3-12 for sites offshore of New Jersey, and Table 3-22 for sites offshore of Virginia. Low, medium, and high-volume surface releases were simulated for 30 days after the initial release. For the well blowout, a release of 30,000 bbl of crude oil per day for 30 days (900,000 bbl total) was simulated for 75 days. The surface oil, shoreline oil, and water column exposure figures in this section show *cumulative* exposure over the entire model simulation. At any instant in time, oil would not be in all the depicted locations. Results figures are also presented for the worst case of each of the other seasons (winter, December – February; spring, March – May; summer, June – August; fall, September – November).

3.3.1 Offshore Delaware

The spill locations used for modeling in Delaware waters were the approximate center of a primary offshore lightering track offshore Delaware Bay at 38.4875°N, 74.7334°W (vessel releases) and Wilmington Canyon at 38.7017°N, 73.5403°W (blowout) (Figure 2-2). The annual and seasonal worst-case runs were selected based on the longest length of shoreline oiling (>1.0 g/m^2) and model start dates are presented in Table 3-2.

Table 3-2. Modeled start dates for the runs offshore Delaware with worst case shoreline oiling on an annual basis and for each of four seasons. The annual worst case for each scenario is presented with an "*" and bolded.

Scenario ID	Spill Site	Spill Event	Spill Volume	Start Date of Worst Case
1	Offshore Delaware	Surface Unmitigated 126 bbl Release During Winter	Low	2/28/2019
2		Surface Unmitigated 126 bbl Release During Spring	Low	5/25/2018
3		Surface Unmitigated 126 bbl Release During Summer	Low	**6/25/2018***
4		Surface Unmitigated 126 bbl Release During Fall	Low	10/3/2019
5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	2/28/2019
6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	5/15/2018
7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	**6/25/2018***
8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	10/1/2019
9		Surface Unmitigated 200k bbl Release During Winter	High	2/28/2019
10		Surface Unmitigated 200k bbl Release During Spring	High	5/15/2019
11		Surface Unmitigated 200k bbl Release During Summer	High	**6/25/2018***
12		Surface Unmitigated 200k bbl Release During Fall	High	10/1/2019
13		Surface Mitigated 200k bbl Release During Winter	High	2/28/2019
14		Surface Mitigated 200k bbl Release During Spring	High	5/15/2019
15		Surface Mitigated 200k bbl Release During Summer	High	**6/25/2018***

Scenario ID	Spill Site	Spill Event	Spill Volume	Start Date of Worst Case
16		Surface Mitigated 200k bbl Release During Fall	High	10/1/2019
17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/28/2019
18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	**5/26/2018***
19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	6/2/2018
20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2018

Table 3-3 summarizes the final mass balance of the spilled oil at the end of the 30- or 75-day simulations for the Delaware location surface and blowout modeling scenarios, respectively. In all surface release cases, almost half of the released oil evaporated within the first five days of the release.

Table 3-3. Mass balance at the end of the simulation for the worst-case run for shoreline oiling (on an annual basis) for each of the five scenarios at the Delaware release locations.

Spill Scenario	Season	Percent of Oil by End of Simulation				
		Surface	Atmos-phere	Shore-line	Water	Degraded
Low Volume	Summer	<1	52	29	7	11
Medium Volume	Summer	<1	49	31	8	12
High Volume (unmitigated)	Summer	<1	44	29	10	16
High Volume (mitigated)[a]	Summer	0	40	<1	16	20
Blowout[b]	Spring	8	47	19	4	19.7

[a]23% of released oil removed via response methods.
[b]2% of released oil left model domain in which it was no longer tracked.

The length of shoreline oiled by habitat type and area of shoreline oiled inside and outside of Delaware for each of the annual worst-case scenarios, including an unmitigated and mitigated trajectory for the high-volume surface release, is presented in Table 3-4 and Table 3-5. Shoreline oiling was consistently at a maximum for cases that began in the summer, with the worst-case run for the three vessel releases occurring on June 25, 2018. Table 3-6 summarizes the water column exposure results for all four worst-case scenarios and the mitigated high-volume release. Note that the PAH concentrations in the water column are highly variable in space and over time. Thus, durations of exposure are summarized to give some sense of the ephemeral nature of the exposures above thresholds of concern. PAH exposure in the water column and max exposure time increase with spill volume in the unmitigated cases, with exposures at the most conservative threshold dissipating within 4 hours during the low volume release and 46 hours during the medium volume release. The degree of exposure to PAH within the water column is higher in the mitigated high-volume case as response methods, specifically dispersant, break oil into smaller droplets, allowing for increased entrainment within the water column.

Table 3-4. Shoreline lengths oiled by >1 g/m^2 for the run with maximum shoreline length oiled (on an annual basis), for each Delaware location spill scenario.

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Summer	141	44	0	227	71	0
Medium Volume	Summer	234	177	49	376	285	79
High Volume (unmitigated)	Summer	354	340	263	569	564	424
High Volume (mitigated)	Summer	76	76	48	123	122	77
Blowout	Spring	638	634	497	1,027	1,021	800

Table 3-5. Shoreline area oiled by >1 g/m^2 inside and outside of Delaware state territory for the run with maximum shoreline length oiled (on an annual basis), for each Delaware location spill scenario.

Spill Scenario	Location	Length Oiled (mi^2)			Length Oiled (km^2)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Delaware	0.2	0.0	0.0	0.4	0.0	0.0
	Outside	0.5	0.2	0.0	1.3	0.4	0.0
Medium Volume	Delaware	0.4	0.2	0.0	1.1	0.5	0.1
	Outside	2.4	0.6	0.2	6.1	1.7	0.6
High Volume (unmitigated)	Delaware	1.4	1.4	0.8	3.6	3.6	2.1
	Outside	6.6	6.3	3.1	17.1	16.4	8.0
High Volume (mitigated)	Delaware	0.1	0.1	0.0	0.3	0.3	0.0
	Outside	0.7	0.7	0.3	1.9	1.8	0.7
Blowout	Delaware	1.2	1.1	0.7	3.0	2.9	1.8
	Outside	11.5	11.2	6.8	29.7	29.0	17.5

Table 3-6. Modeling results of dissolved PAH exposures in the water column for the four worst-case for shoreline oiling scenarios (by spill volume) for a release offshore of Delaware. (One km^3 is equivalent to 1 billion m^3 and 1.3 billion cubic yards.)

	Low	Medium	High		Blowout
			Unmitigated	Mitigated	
Volume contaminated >1 ppb (km^3)*	0.003	0.2	10	11	40
Volume contaminated >10 ppb (km^3)*	0	0.008	2	3	6
Max Exposure Time >1 ppb (hours)**	4	46	537	507	927

	Low	Medium	High		Blowout
			Unmitigated	Mitigated	
Max Exposure Time >10 ppb (hours)**	0	6	182	274	746

* Volume of water which exceeded 1 ppb and 10 ppb at any given time
** Maximum number of hours with exposure concentrations >1 or 10 ppb

3.3.1.1 Surface Unmitigated Release (Low Volume)

3.3.1.1.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a low-volume surface release of 126 bbl crude oil offshore Delaware started on June 25, 2018. Only a thin layer of oil (0.01-1 g/m^2) was predicted to occur on the water surface until it evaporated, went ashore or degraded (Figure 3-100). The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Just under half of the oil released at the surface evaporated quickly, within in the first 5 days. Emulsification of the crude oil to viscosities between 4,000-8,000 cP during the first few days of the release limited entrainment into the water to occur only during the high wind events, causing oil to oscillate from within the water column to the surface during periods of high and low winds (Figure 3-100 and Figure 3-101). The mass balance (Figure 3-100) shows that the released oil came ashore beginning 14 days after the spill while strong winds (8-12 m/s; 16-24 knots) were blowing from the northeast (Figure 3-101). Approximately 52% of the oil evaporated, 29% of the oil reached shore, 7% of the oil remained in the water column, 1% remained on the surface and approximately 11% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted west, towards shore, and northeast into open waters. The maximum surface oil exposure concentration was between 0.01-1 g/m^2 (which would appear as a scattered colorless sheen or dark brown/metallic sheen; French McCay et al. 2011; French McCay et al. 2012; French McCay 2016) and extended northeastward up to 100 mi (161 km) from the spill site (Figure 3-97). By the end of the 30-day simulation, 141 mi (227 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-98; Table 3-7). Just over half of the oiled shoreline was seaward sandy beach (82 mi; 131 km) along the coasts of Delaware and New Jersey. In total, 0.2 mi^2 (0.4 km^2) of shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-5). Maximum cumulative PAH concentrations for the worst-case run were between 1-10 ppb and remained near the release location (Figure 3-99). As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-7. Shoreline lengths oiled by >1 g/m^2 (1 µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated 126 bbl surface release of crude oil offshore of Delaware starting on June 25, 2018.

Shoreline Type	**Length Oiled (mi)**			**Length Oiled (km)**		
Seaward	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**
Rocky shore	2	0	0	3	0	0
Gravel beach	4	0	0	6	0	0
Sand beach	82	20	0	131	32	0
Mudflat	15	5	0	24	8	0
Wetland	0	0	0	0	0	0
Artificial/manmade shoreline	6	6	0	9	9	0
Total	108	31	0	173	49	0
Landward						
Rocky shore	13	2	0	20	3	0
Gravel beach	6	1	0	10	1	0
Sand beach	3	0	0	5	0	0
Mudflat	0	0	0	0	0	0
Wetland	0	0	0	0	0	0
Artificial/manmade shoreline	11	11	0	18	18	0
Total	33	13	0	54	21	0
All Shorelines						
Total	141	44	0	227	71	0

Table 3-2 shows the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-102 to Figure 3-110 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In both the fall and winter, oil is transported south, with much of the shoreline oiling occurring along the coasts of Maryland and Virginia. In the spring, oil is transported northeast into offshore waters and southwest, where oil makes landfall along Delaware, Maryland, and Virginia coasts.

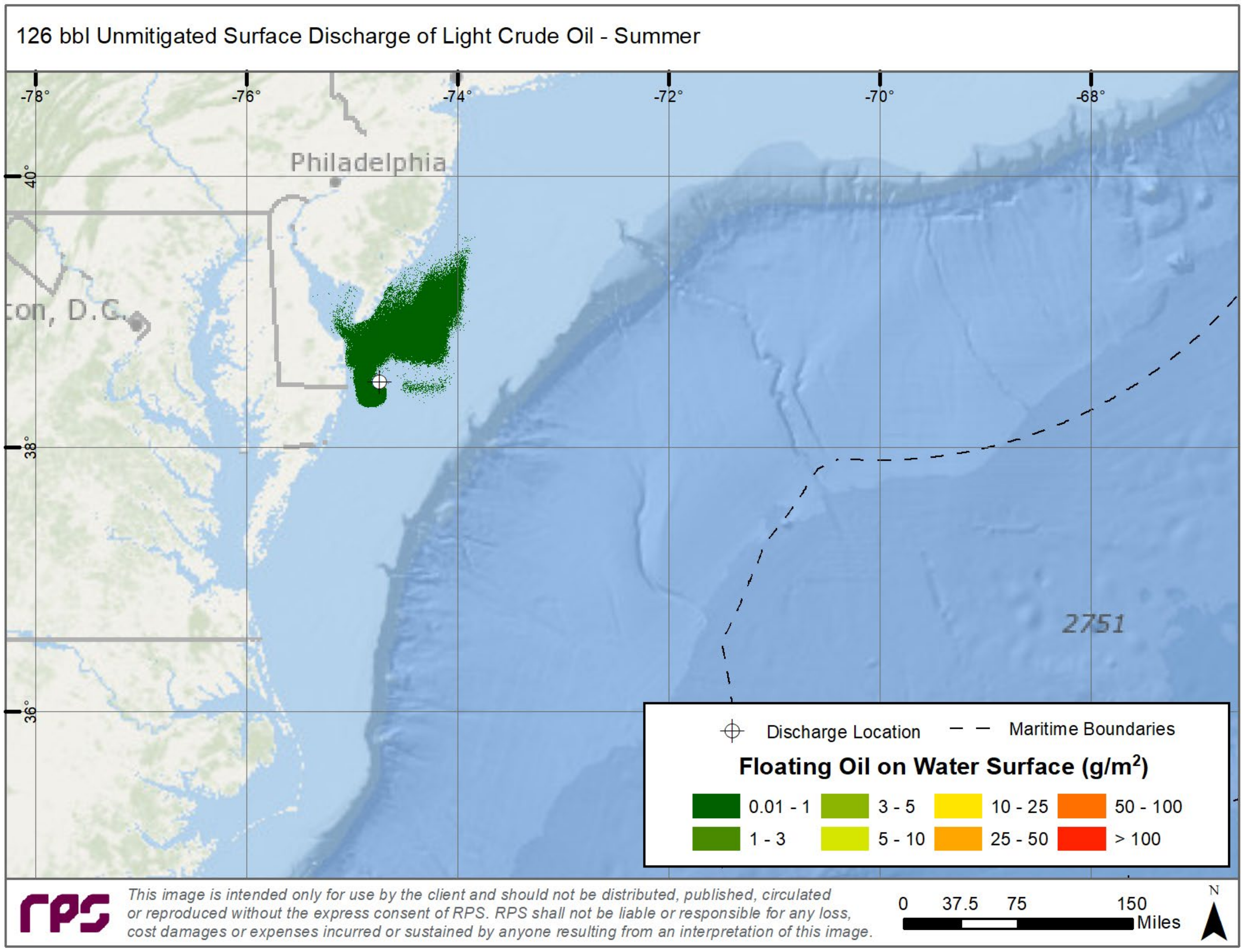


Figure 3-97. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore Delaware starting on June 25, 2018.

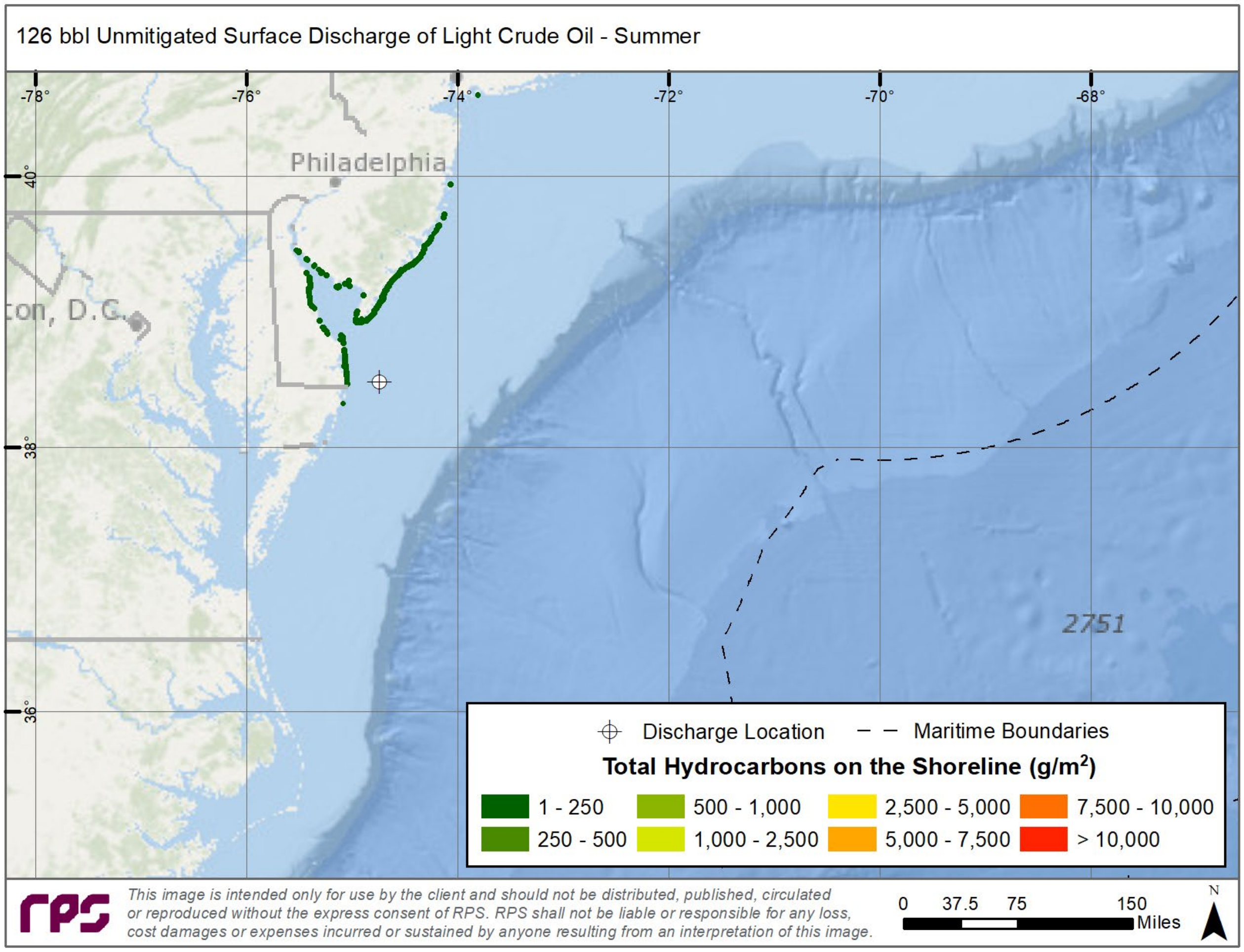


Figure 3-98. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore Delaware starting on June 25, 2018.

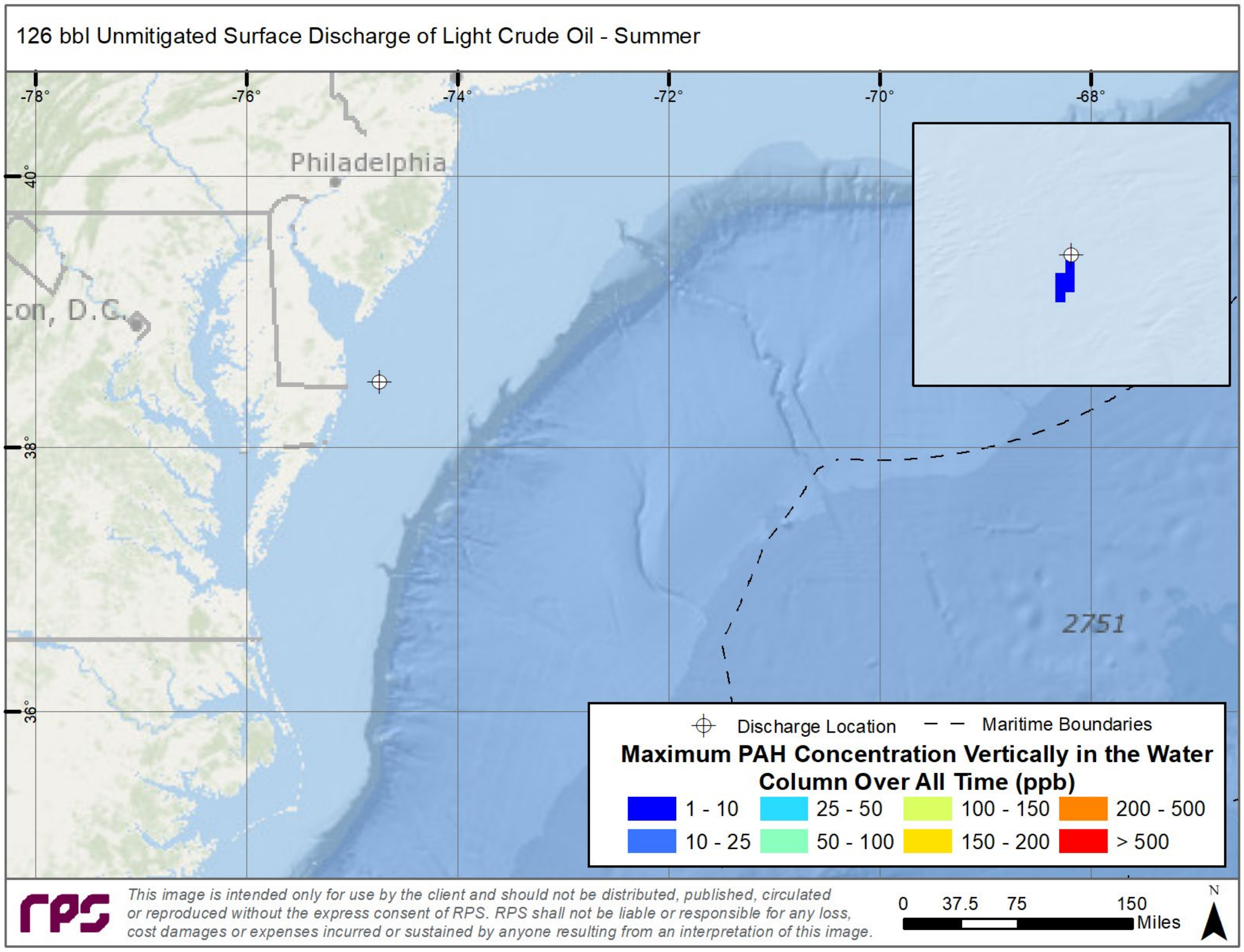


Figure 3-99. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore Delaware starting on June 25, 2018.

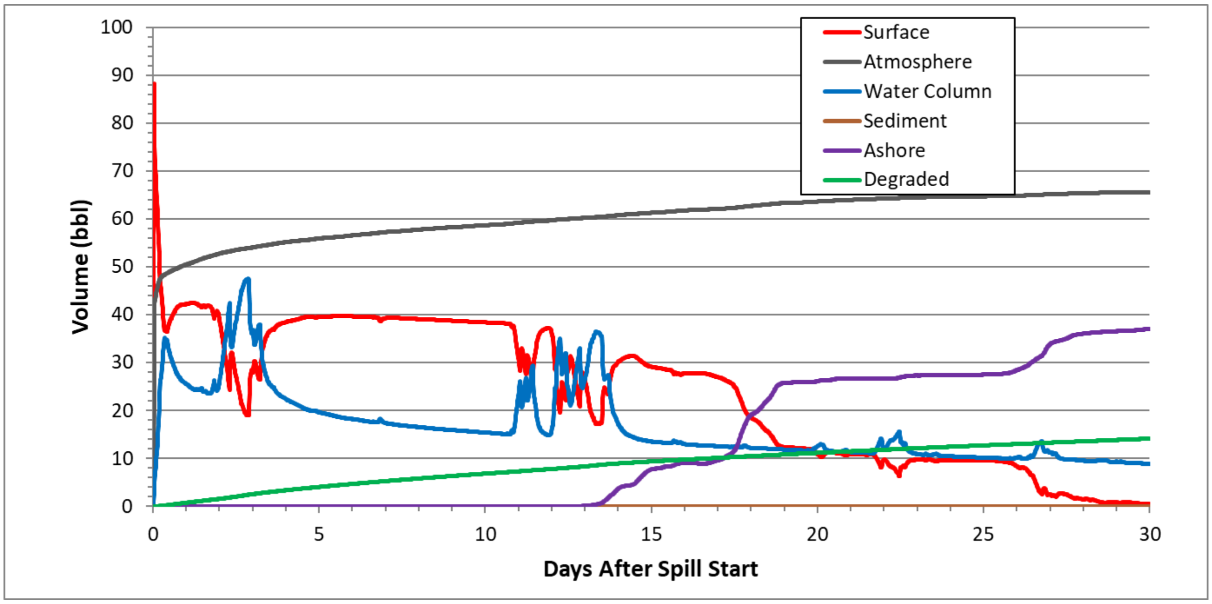


Figure 3-100. Oil volume by environmental compartment over time for a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl surface release of crude oil offshore Delaware starting on June 25, 2018.

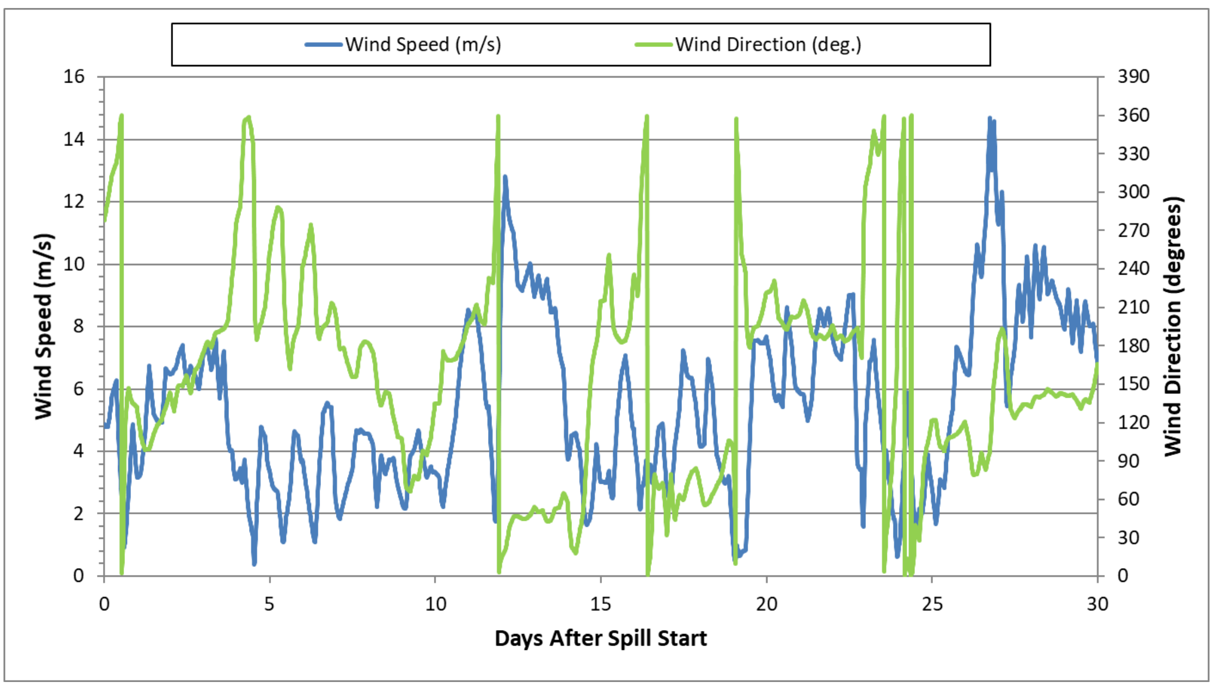


Figure 3-101. Wind speeds (1 m/s = 2 knots) and directions during the30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl surface release of crude oil offshore Delaware starting on June 25, 2018.

3.3.1.1.2 Seasonal Worst-Case Runs

Winter

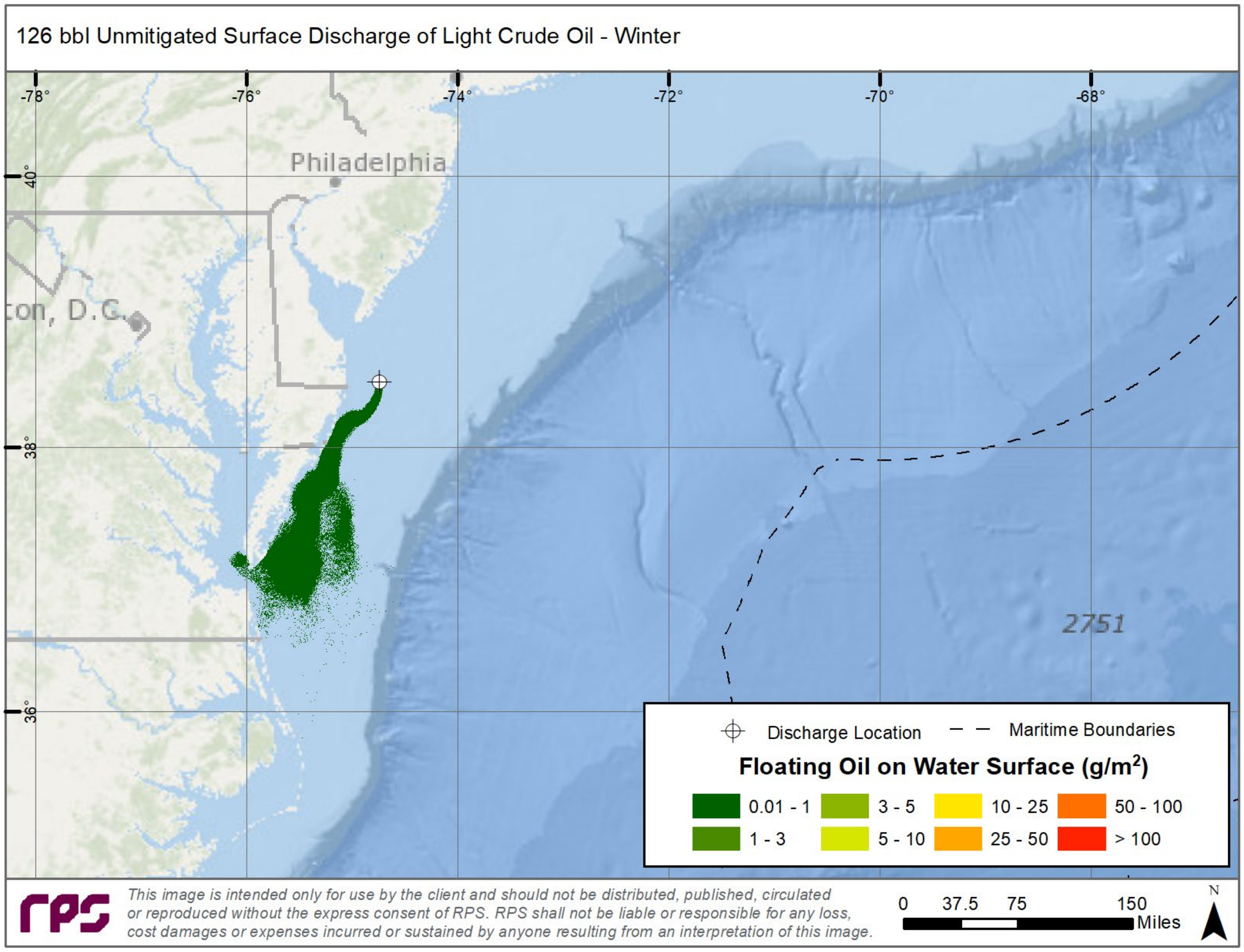


Figure 3-102. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore Delaware starting on February 28, 2019.

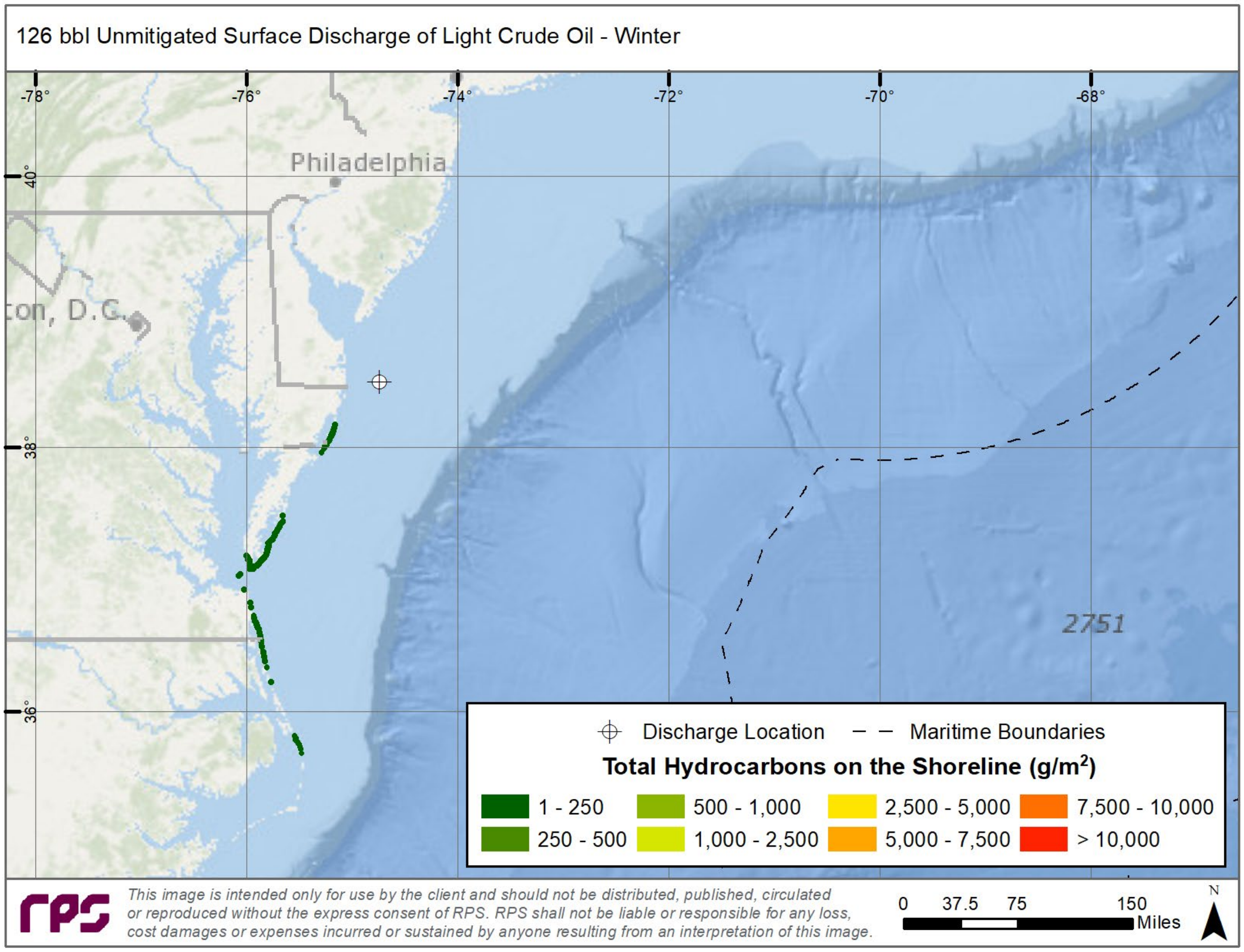


Figure 3-103. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore Delaware starting on February 28, 2019.

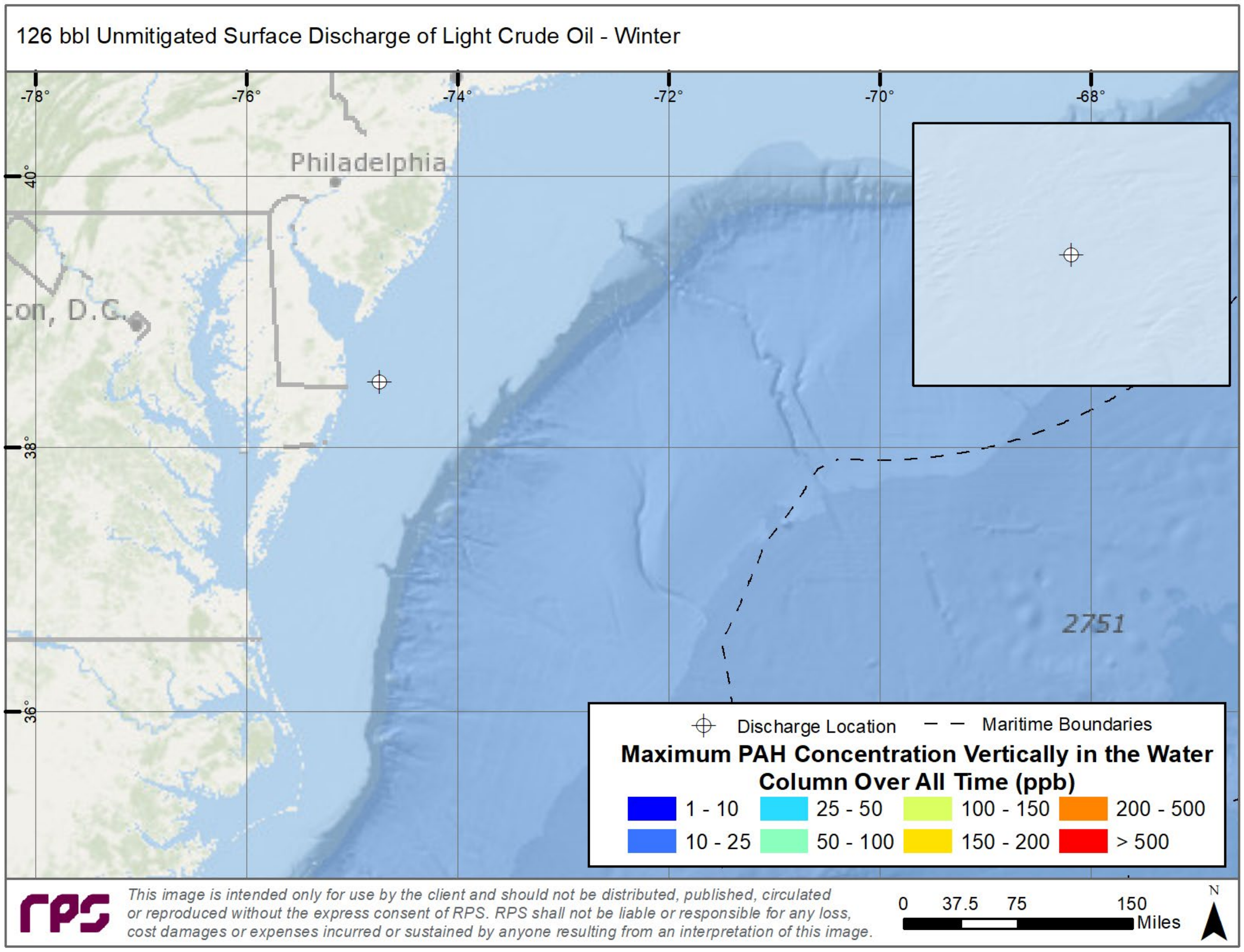


Figure 3-104. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore Delaware starting on February 28, 2019.

Spring

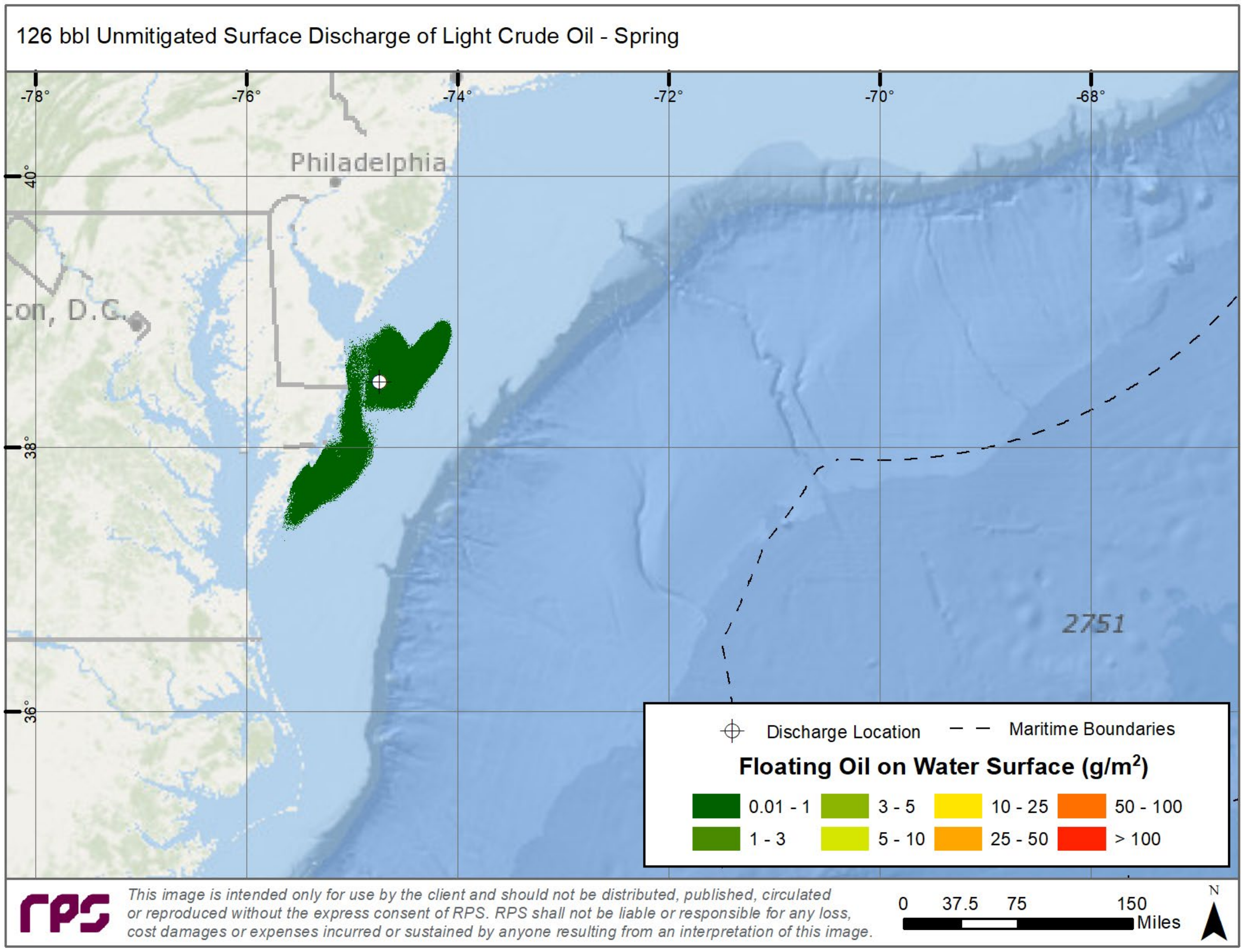


Figure 3-105. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore Delaware starting on May 25, 2018.

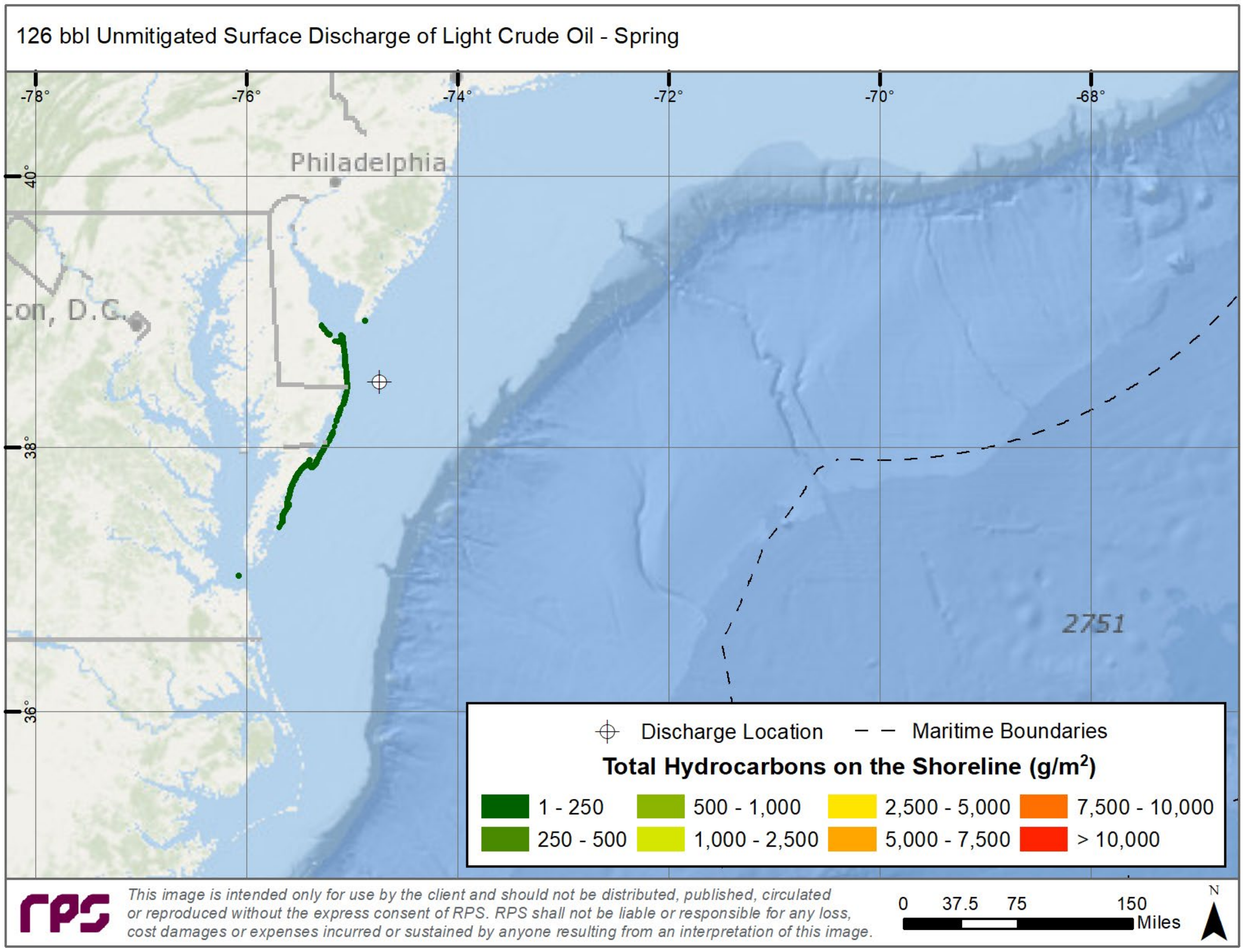


Figure 3-106. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore Delaware starting on May 25, 2018.

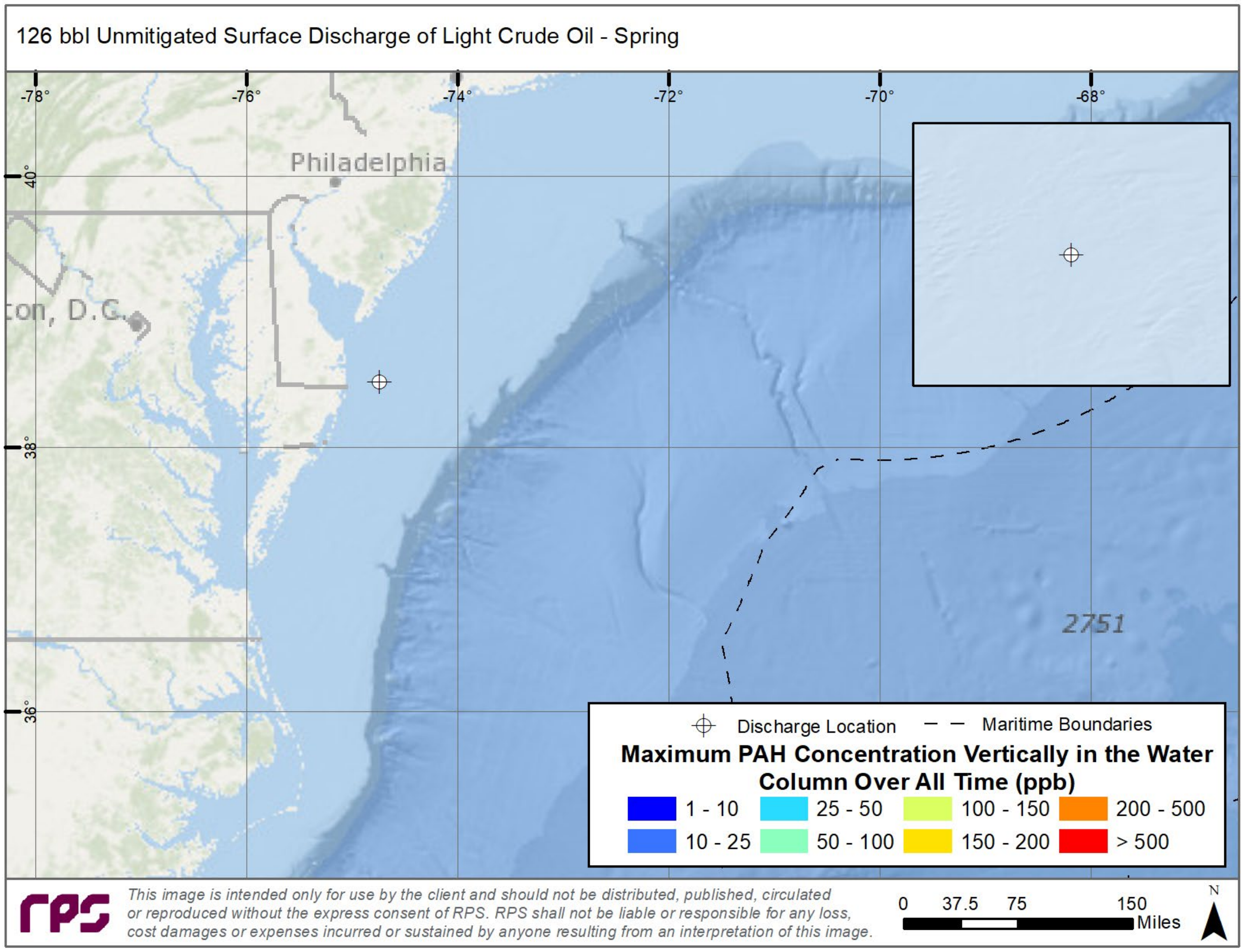


Figure 3-107. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore Delaware starting on May 25, 2018.

Fall

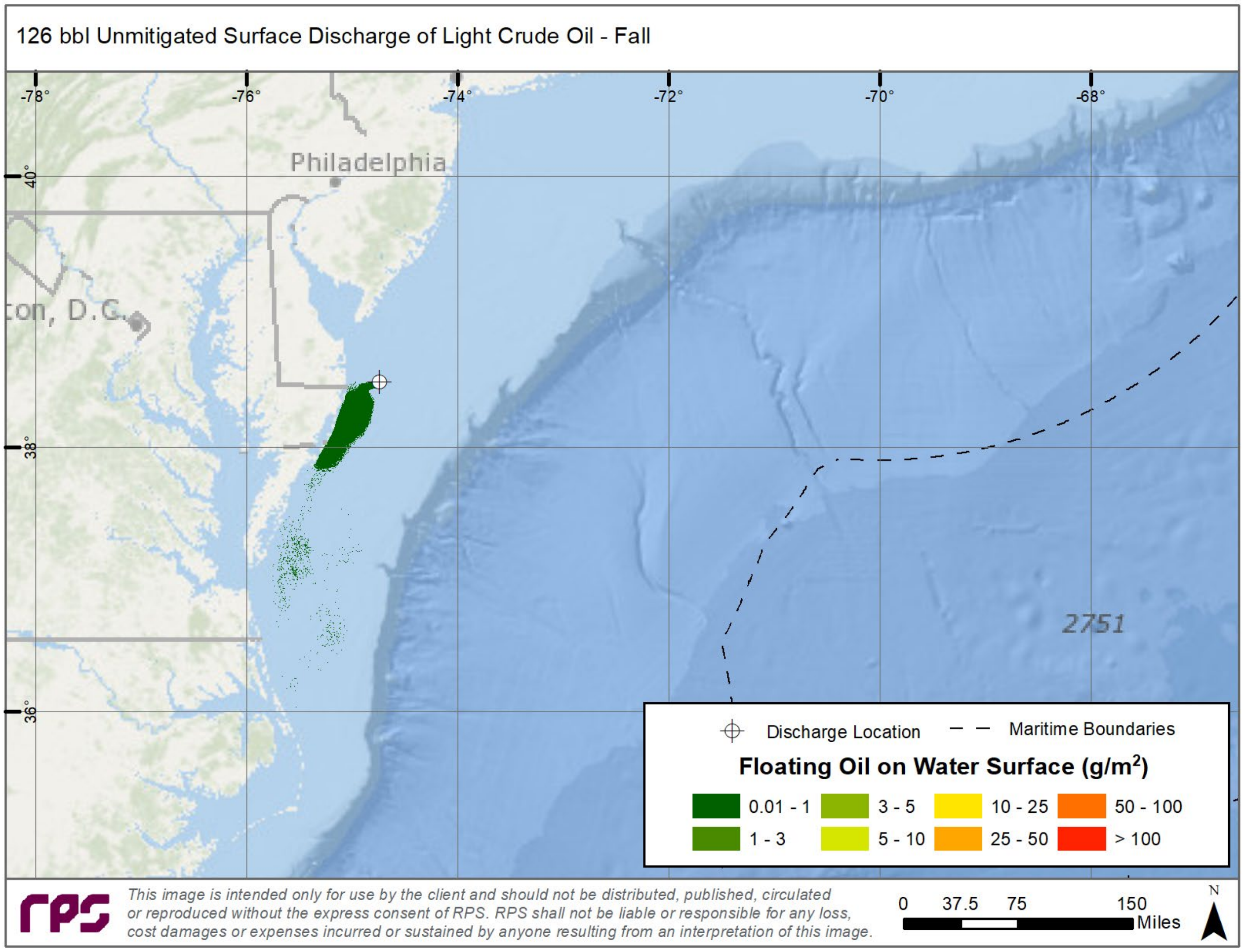


Figure 3-108. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore Delaware starting on October 3, 2019.

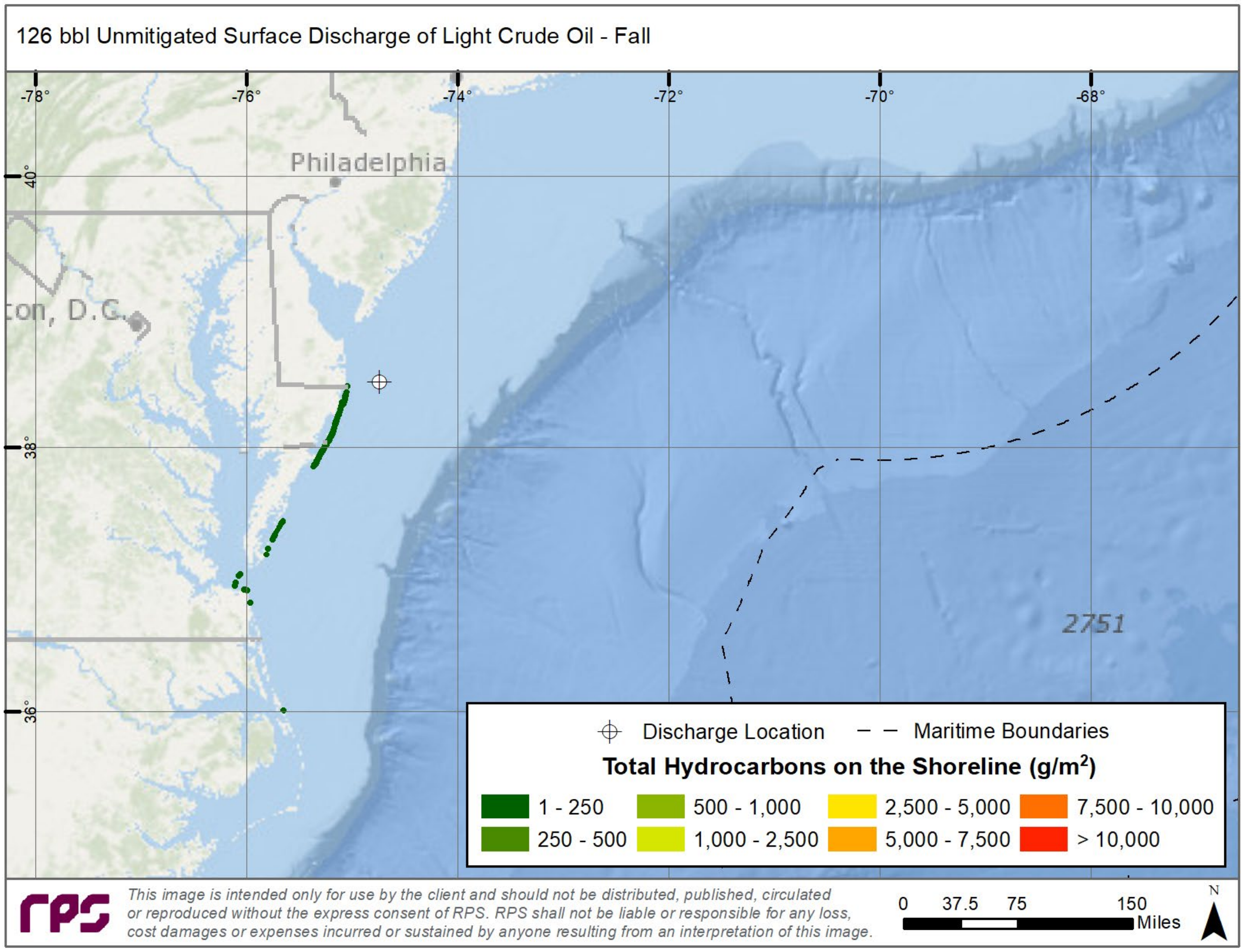


Figure 3-109. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore Delaware starting on October 3, 2019.

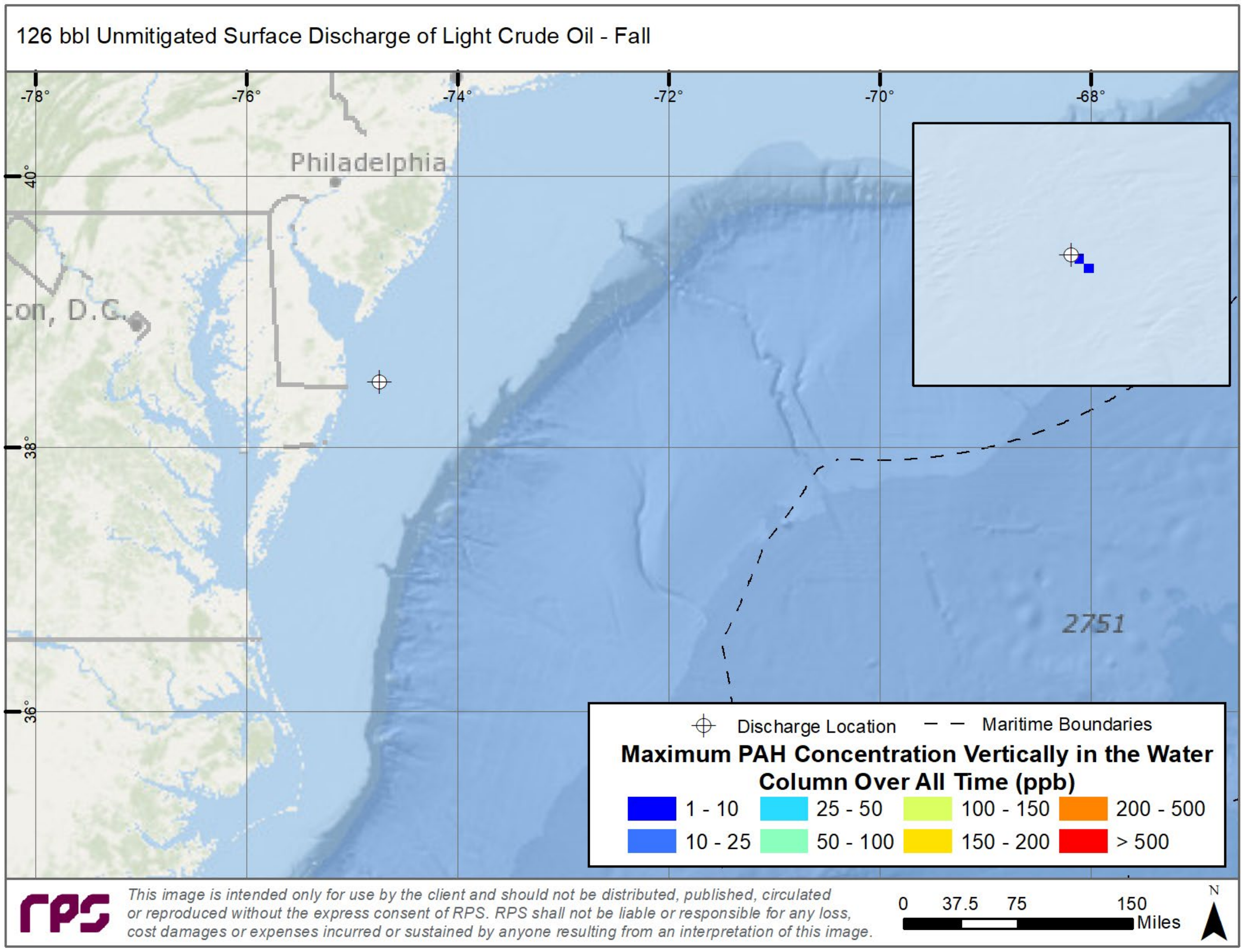


Figure 3-110. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore Delaware starting on October 3, 2019.

3.3.1.2 Surface Unmitigated Release (Medium Volume)

3.3.1.2.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a medium-volume surface release of 2,240 bbl crude oil offshore Delaware started on June 25, 2018. Floating oil on the surface was primarily between 0.01-1 g/m^2 with small patches of higher concentrations near the release location (Figure 3-111). The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Over 40% of the oil released at the surface evaporated quickly, within in the first 5 days. Emulsification of the crude oil to viscosities > 4,000 cP during the first few days of the release limited entrainment into the water to occur only during the high wind events, causing oil to oscillate from within the water column to the surface during periods of high and low winds (Figure 3-114 and Figure 3-115). The mass balance (Figure 3-114) shows that released oil came ashore beginning 14 days after the spill while strong winds (8-12 m/s; 16-24 knots) were blowing from the northeast (Figure 3-115). Approximately 49% of the oil evaporated, 31% of the oil reached shore, 8% of the oil remained in the water column, 1% remained on the surface and approximately 12% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending furthest to the northeast. The highest surface oil exposure concentrations occurred during the release at the release location. Maximum surface oiling concentrations < 50 g/m^2 were reached within four hours upon release (which would appear as patchy oil, emulsions or sheens) and only occurred at the release site. Lower concentrations between 0.01-1 g/m^2 extended northeastward up to 200 mi (322 km) from the spill site (Figure 3-111). By the end of the 30-day simulation, 234 mi (376 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-112; Table 3-8). Just over half of the oiled shoreline was seaward sandy beach (130 mi; 210 km) along the coasts of Delaware, New Jersey, Maryland, Virginia, and New York. In total, 0.4 mi^2 (1.1 km^2) of shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-5). Maximum cumulative PAH concentrations for the worst-case run were between 25-50 ppb and remained near the release location (Figure 3-113). As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-8. Shoreline lengths oiled by >1 g/m^2 (1µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated 2,240 bbl surface release of crude oil offshore of Delaware starting on June 25, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Rocky shore	2	2	1	3	3	2
Gravel beach	6	6	1	10	10	1
Sand beach	130	100	31	210	160	50
Mudflat	22	20	9	35	32	14
Wetland	2	0	0	3	0	0
Artificial/manmade shoreline	5	5	0	9	9	0
Total	167	132	41	269	213	67
Landward						
Rocky shore	14	14	4	23	23	7
Gravel beach	10	10	3	15	15	5
Sand beach	9	5	0	15	9	0
Mudflat	6	0	0	10	0	0
Wetland	12	0	0	19	0	0
Artificial/manmade shoreline	15	15	0	24	24	0
Total	67	45	8	108	72	12
All Shorelines						
Total	234	177	49	376	285	79

Table 3-2 shows the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-116 to Figure 3-124 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In both the spring and fall, oil is transported concentrically and south of the release site, with shoreline oiling occurring along the entire coasts of Delaware, Maryland, and Virginia, as well as along the northern coast of North Carolina (fall only). In the winter, oil is transported directly south and southeast of the release location into nearshore and offshore waters, with oiling occurring along Maryland, Virginia, and North Carolina coasts.

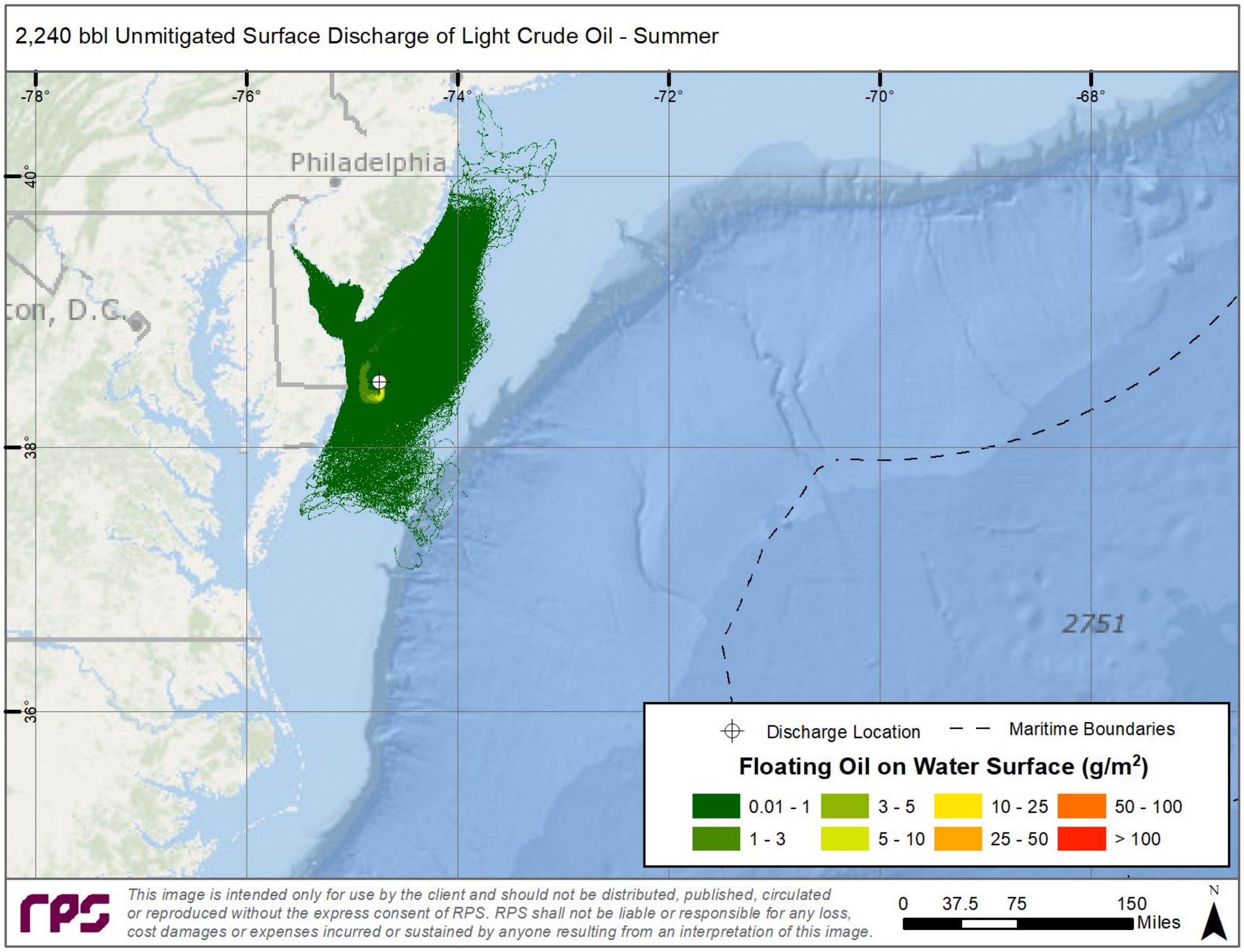


Figure 3-111. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore Delaware starting on June 25, 2018.

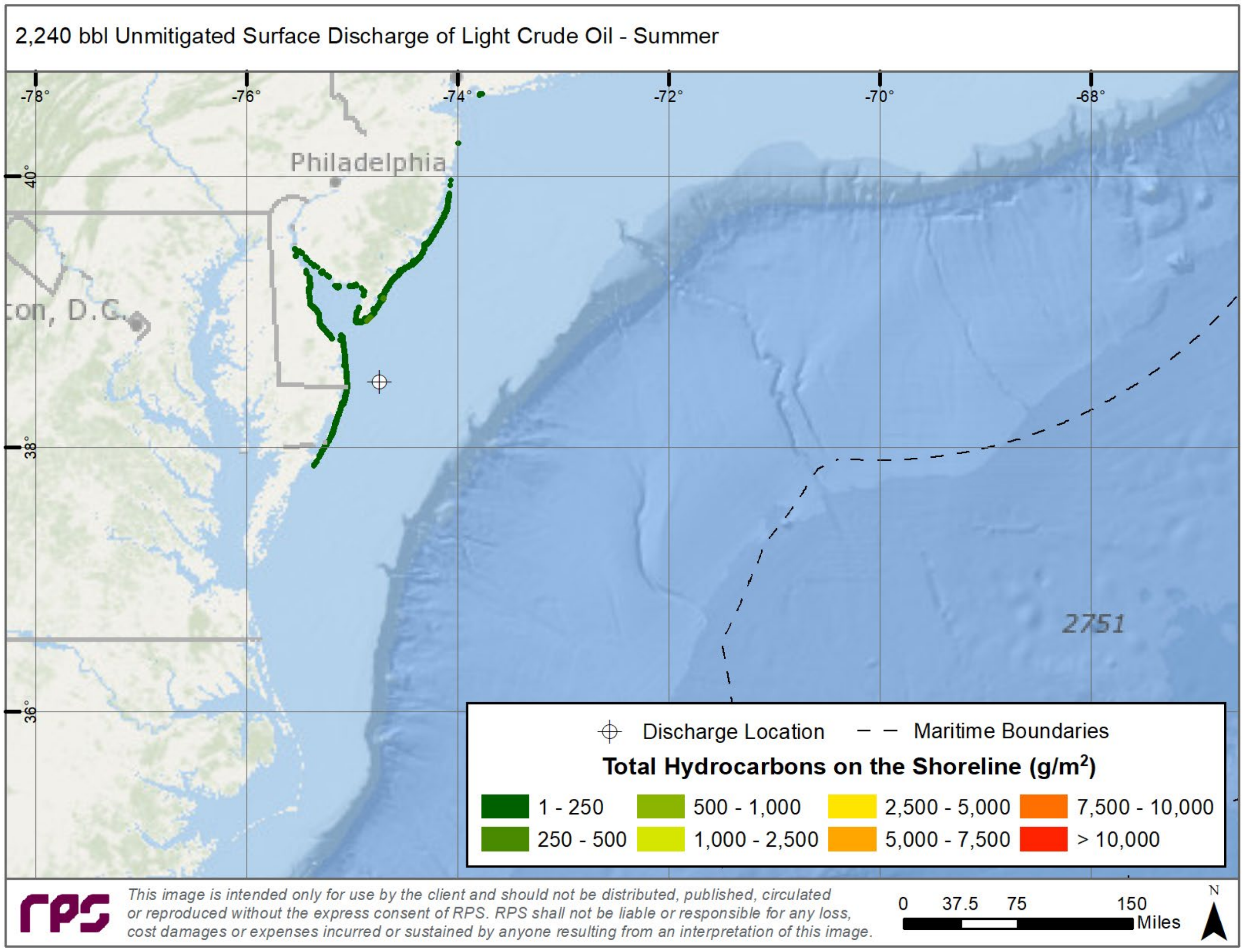


Figure 3-112. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore Delaware starting on June 25, 2018.

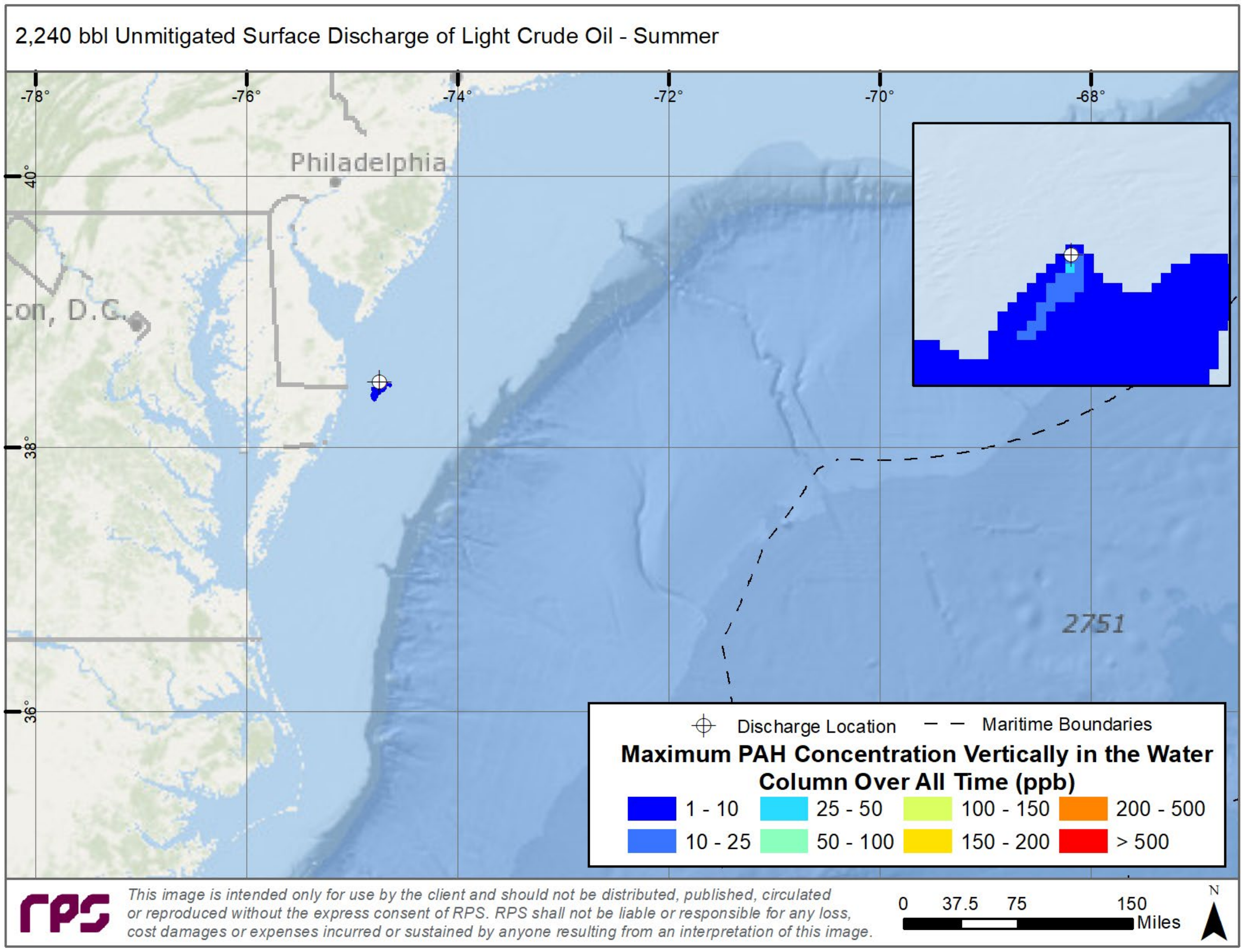


Figure 3-113. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore Delaware starting on June 25, 2018.

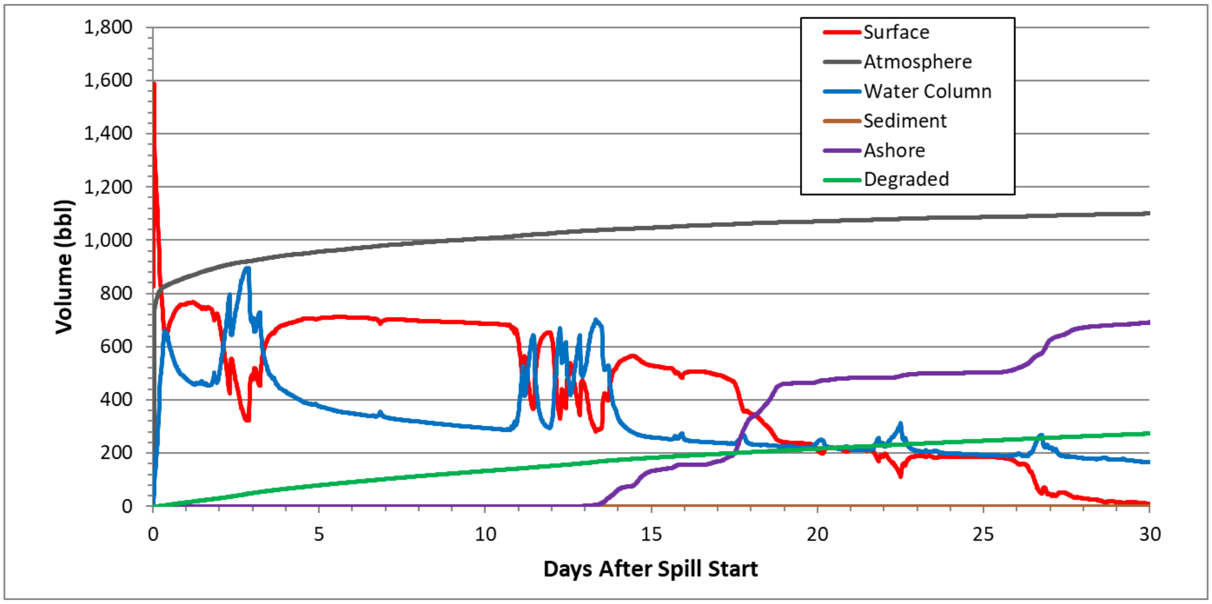


Figure 3-114. Oil volume by environmental compartment over time for a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl surface release of crude oil offshore Delaware starting on June 25, 2018.

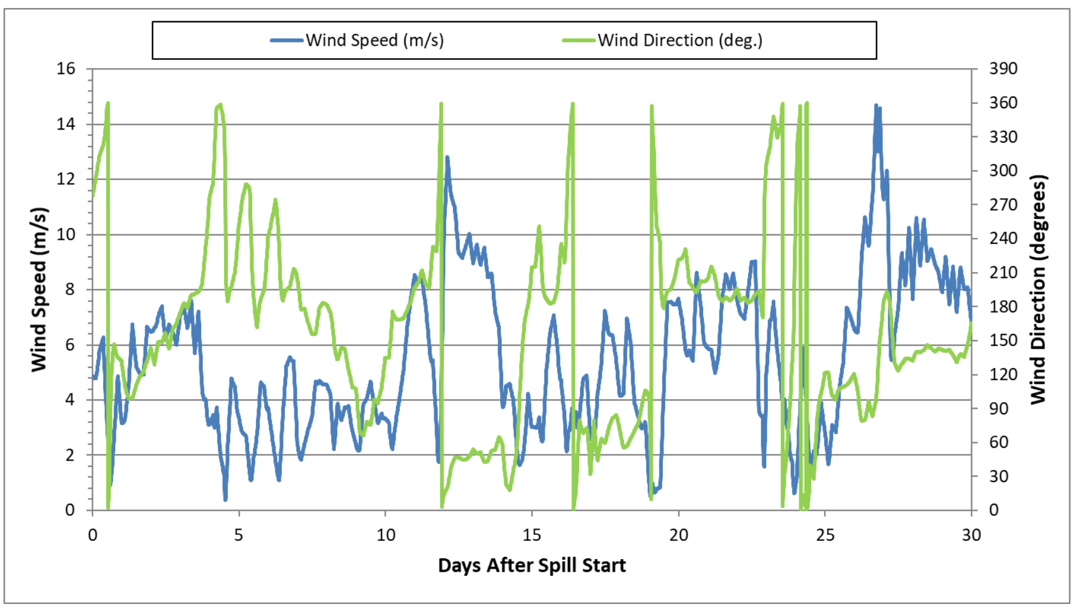


Figure 3-115. Wind speeds (1 m/s = 2 knots) and directions during the 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl surface release of crude oil offshore Delaware starting on June 25, 2018.

3.3.1.2.2 Seasonal Worst-Case Runs

Winter

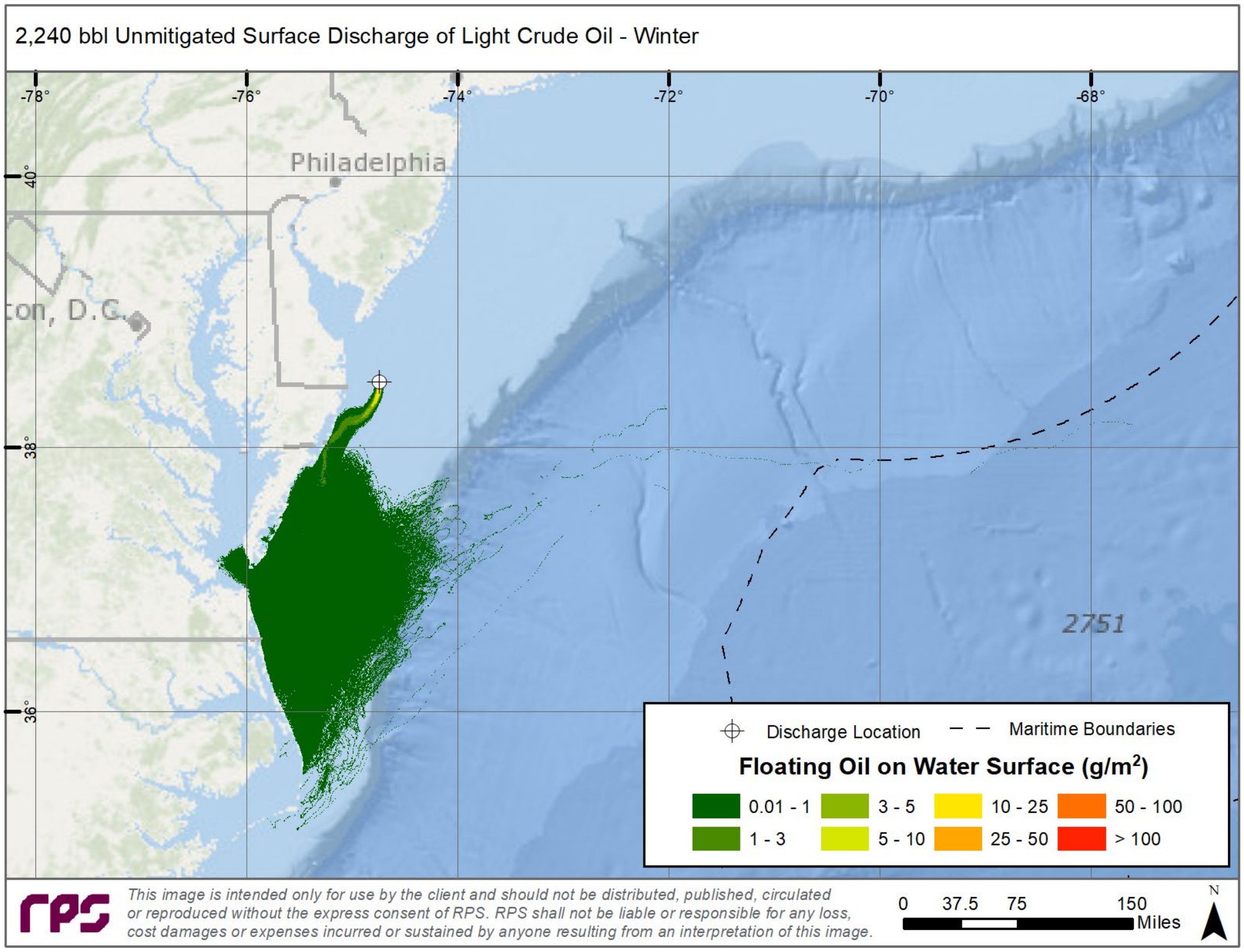


Figure 3-116. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl release of crude oil offshore Delaware starting on February 28, 2019.

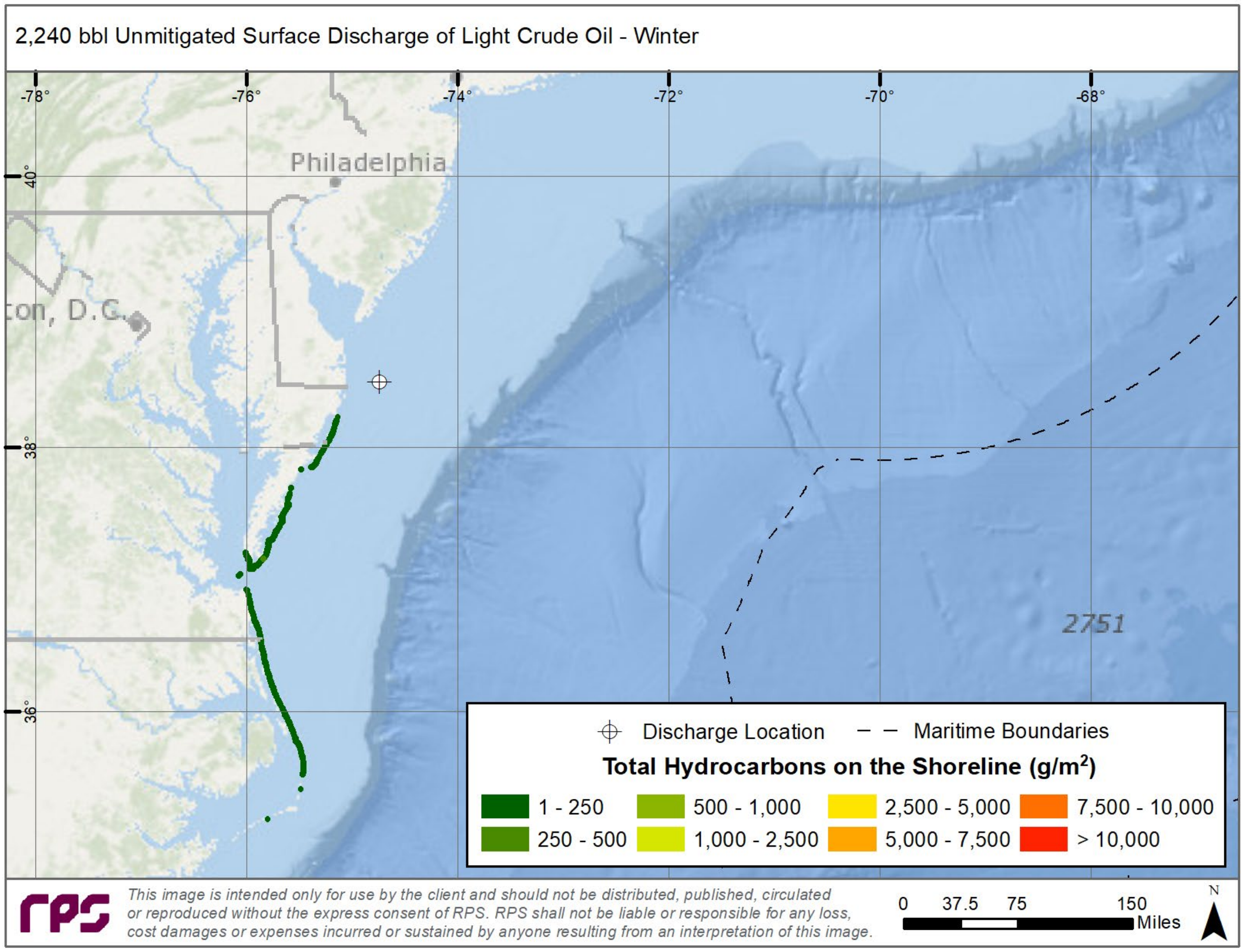


Figure 3-117. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore Delaware starting on February 28, 2019.

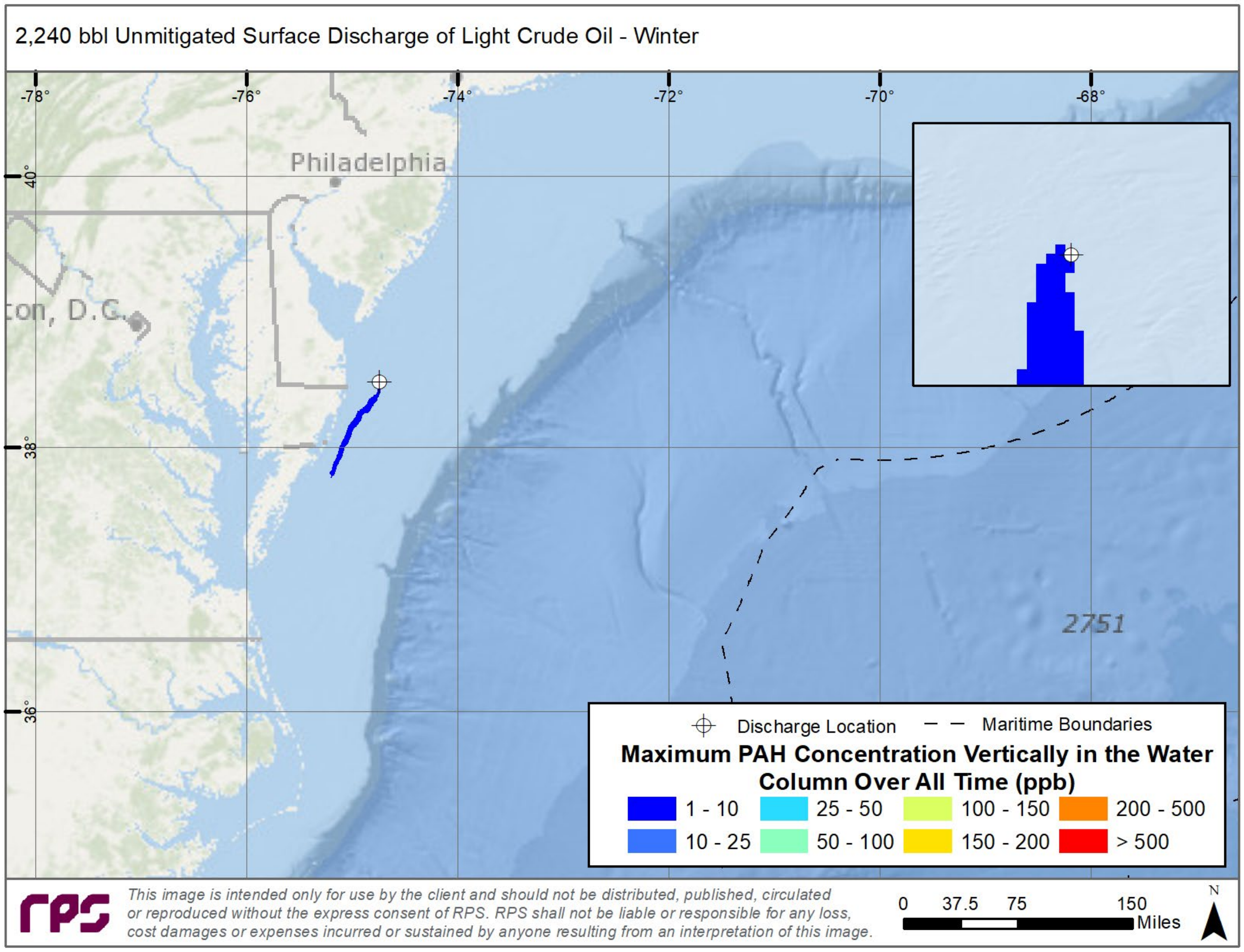


Figure 3-118. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl release of crude oil offshore Delaware starting on February 28, 2019.

Spring

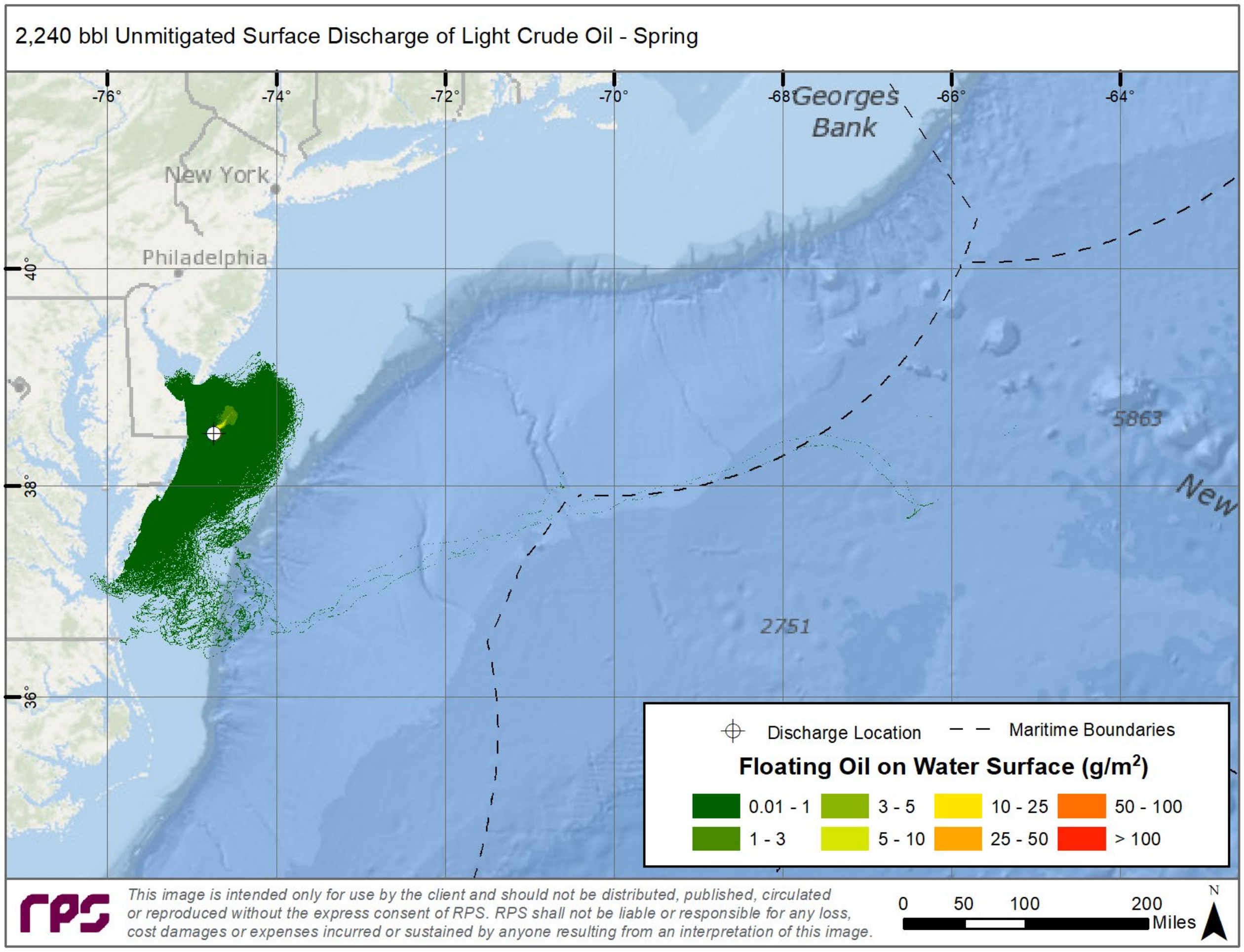


Figure 3-119. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore Delaware starting on May 15, 2018.

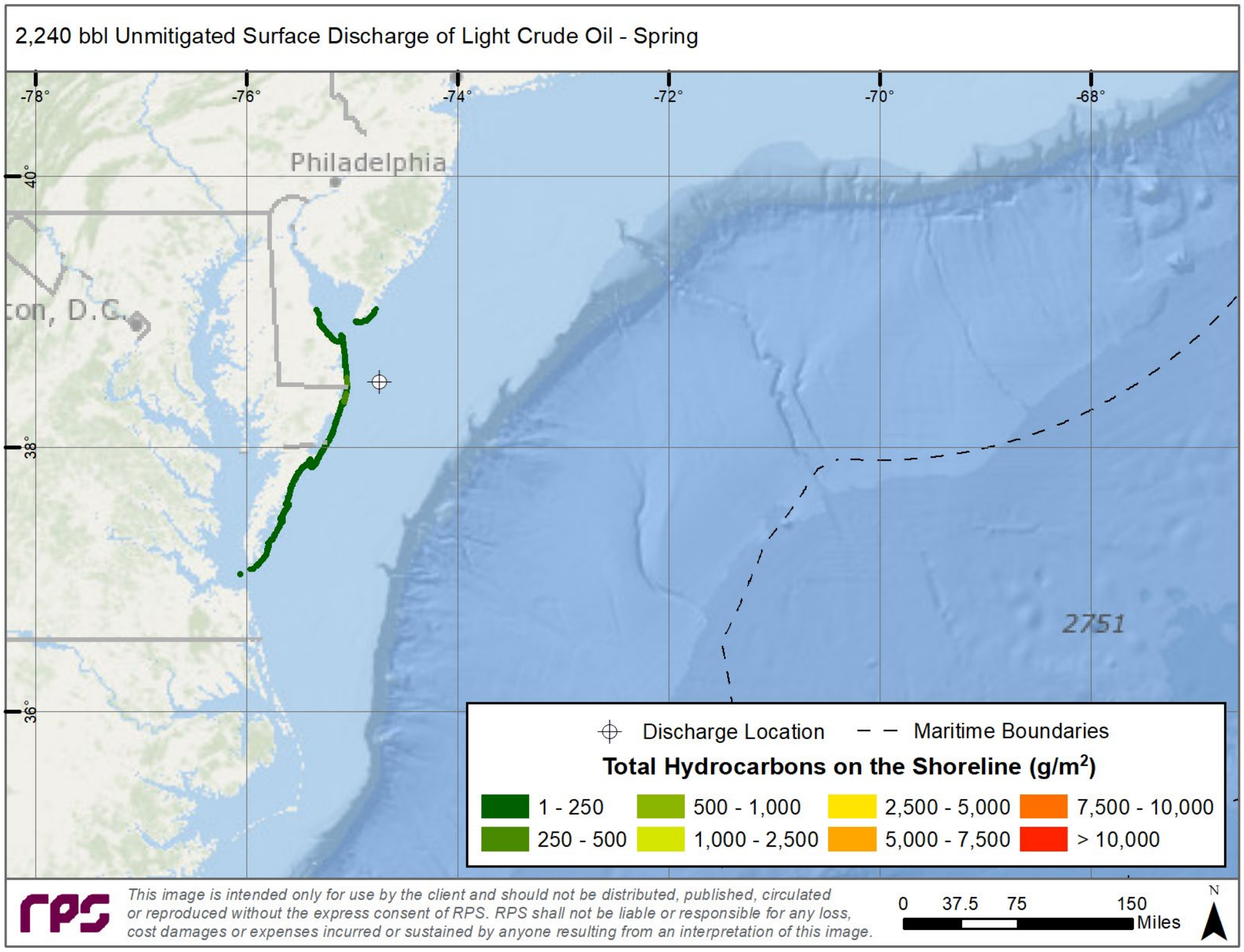


Figure 3-120. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore Delaware starting on May 15, 2018.

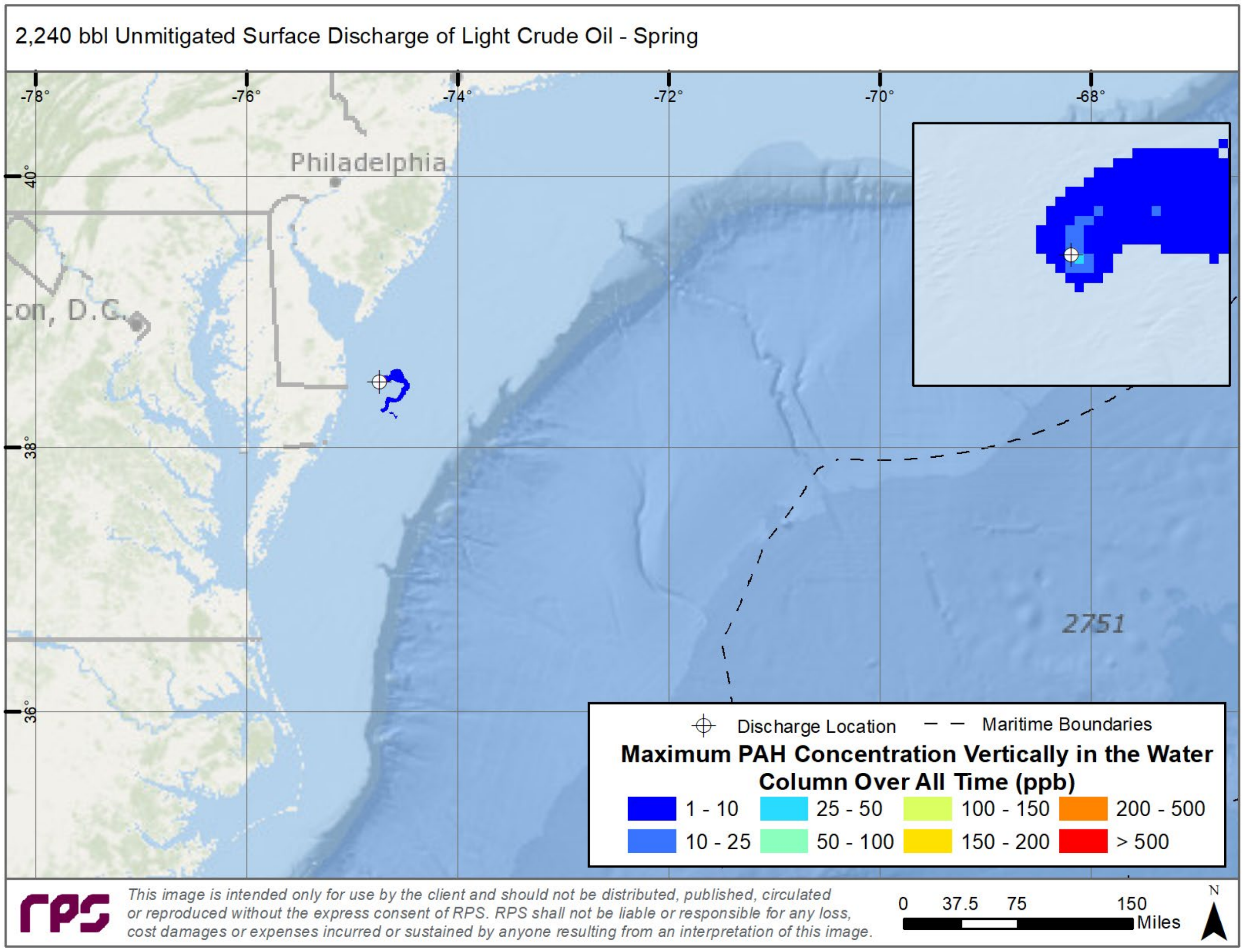


Figure 3-121. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore Delaware starting on May 15, 2018.

Fall

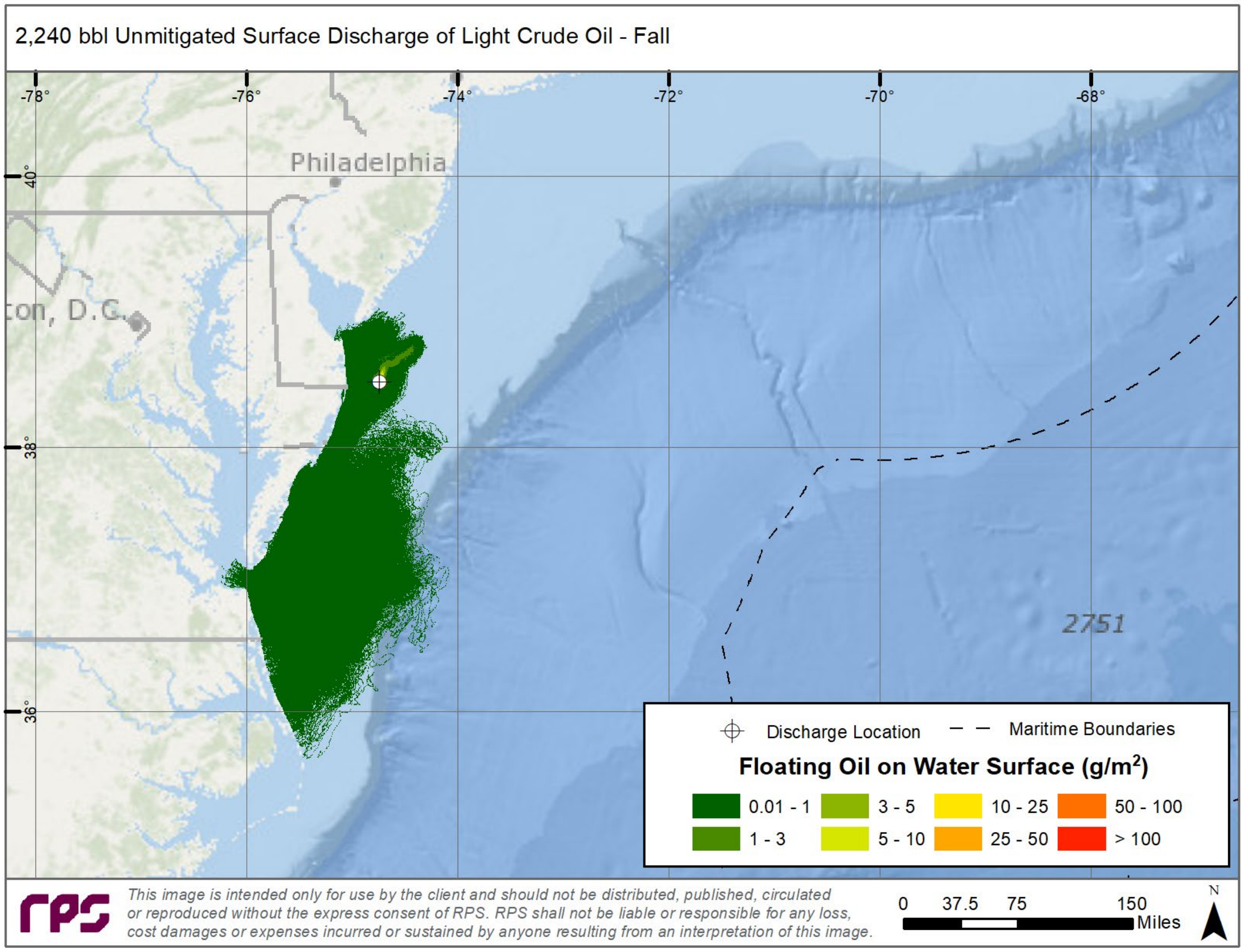


Figure 3-122. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore Delaware starting on October 1, 2019.

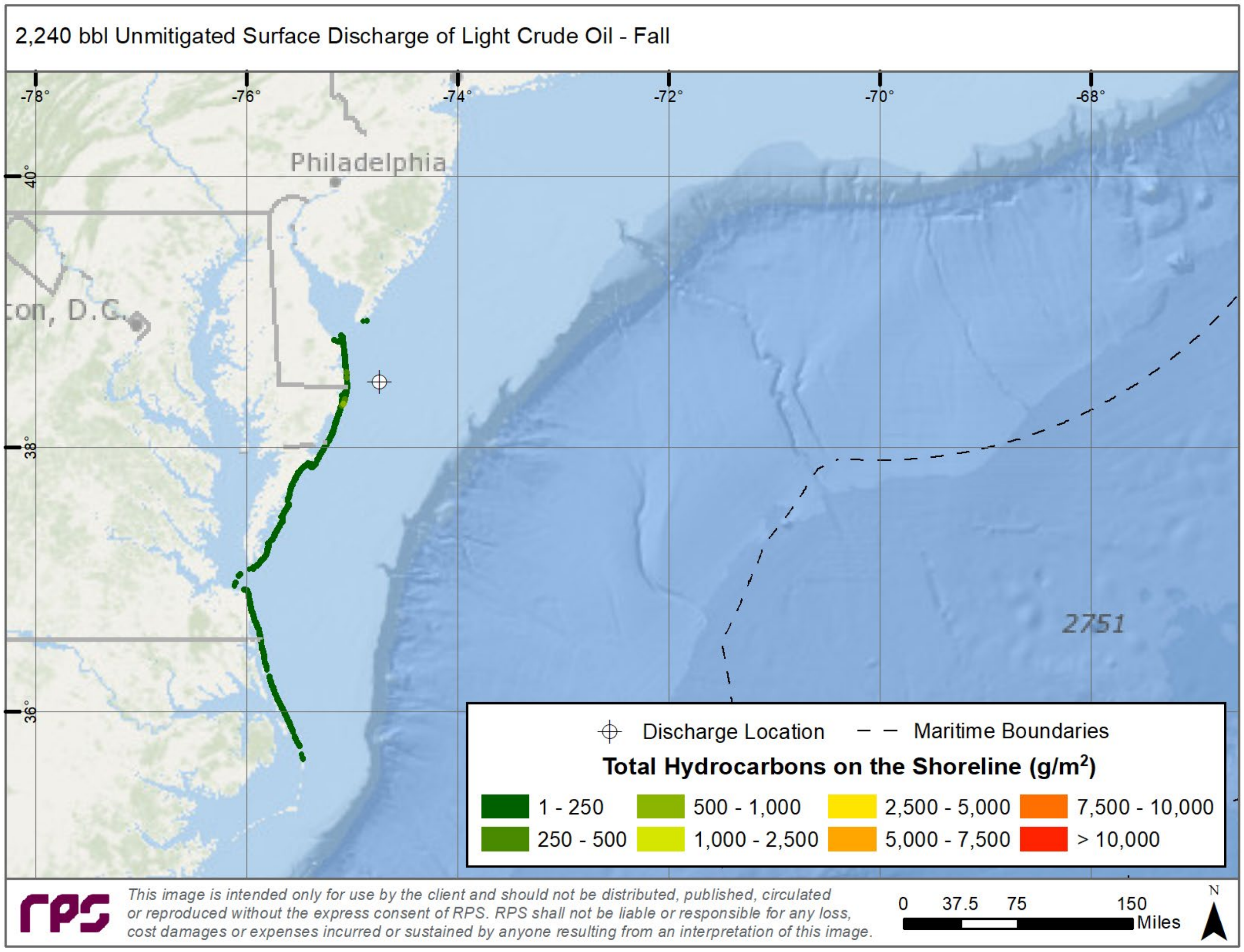


Figure 3-123. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore Delaware starting on October 1, 2019.

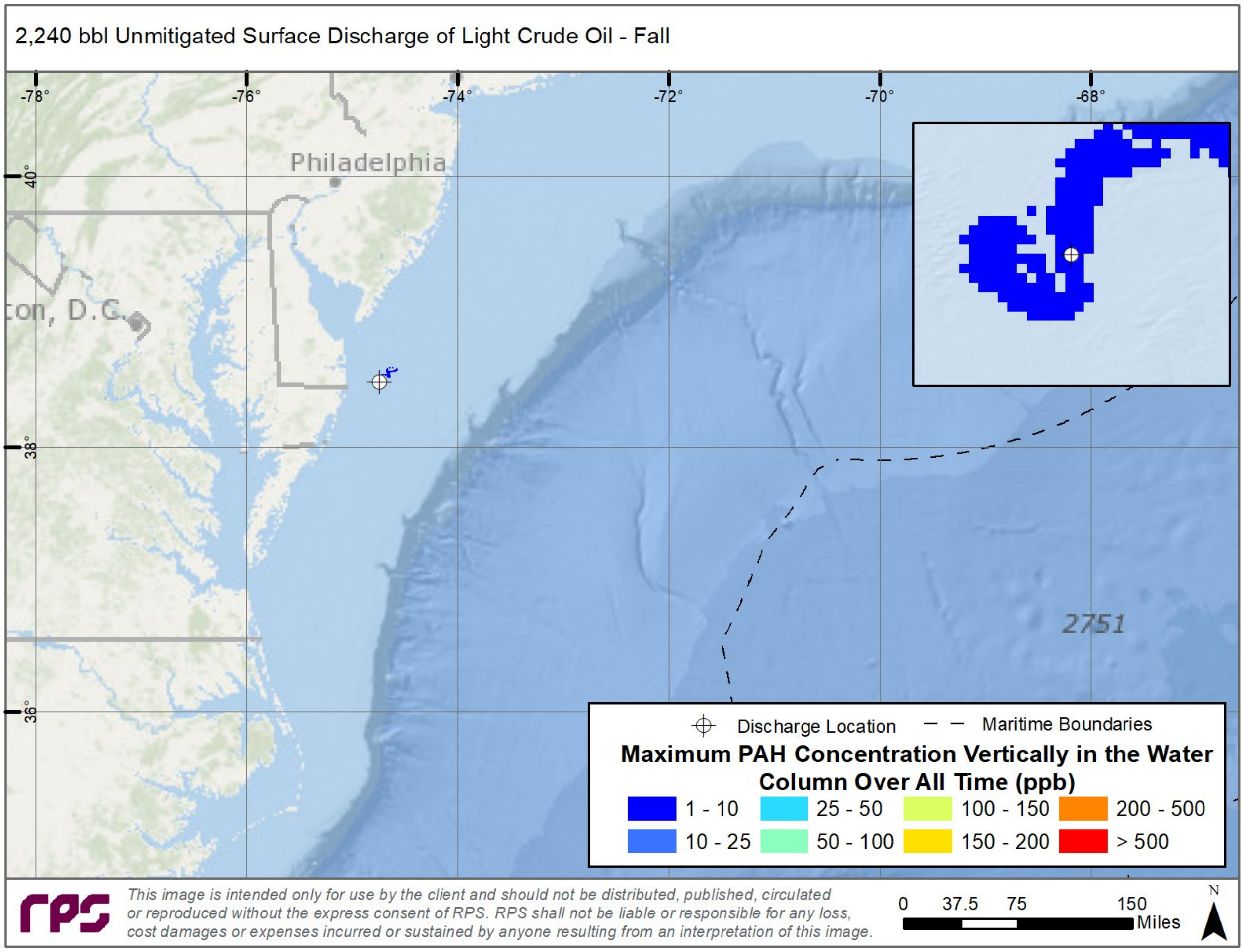


Figure 3-124. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore Delaware starting on October 1, 2019.

3.3.1.3 Surface Unmitigated Release (High Volume)

3.3.1.3.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a high-volume surface release of 200,000 bbl crude oil offshore Delaware started on June 25, 2018. The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Over 40% of the oil released at the surface evaporated quickly, within in the first 5 days. Emulsification of the crude oil to viscosities > 4,000 cP during the first few days of the release limited entrainment into the water to occur only during the high wind events, causing oil to oscillate from within the water column to the surface during periods of high and low winds, as seen in the annual worst-case run for the low and medium-volume spills

(Figure 3-128 and Figure 3-129). The mass balance (Figure 3-128) shows that released the oil came ashore beginning 14 days after the spill while strong winds (8-12 m/s; 16-24 knots) were blowing from the northeast (Figure 3-129). Approximately 44% of the oil evaporated, 29% of the oil reached shore, 10% of the oil remained in the water column, 1% remained on the surface, and approximately 16% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending furthest to the northeast. Maximum floating oil on the surface was >100 g/m^2 (100 µm, on average) and extended from the release site to the south and west (Figure 3-125). Lower (<25 g/m^2, i.e., patchy oil, emulsions or sheens) maximum surface oil exposure concentrations were predicted to extend up to 200 mi (322 km) from the release site, into Delaware Bay to the northwest, offshore of New Jersey to the north, and south in nearshore and offshore waters of Maryland and Virginia. By the end of the 30-day simulation, 354 mi (569 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-126; Table 3-9). Seaward sandy beach was the habitat predicted to have the longest length of shoreline oiled (163 mi; 263 km). Shoreline oiling was predicted along the coasts of Delaware, New Jersey, New York, Maryland, and Virginia, with the highest concentrations of oil (7,500-10,000 g/m^2) occurring along the southern seaward coast of New Jersey. In total, 1.4 mi^2 (3.6 km^2) of shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-5). Maximum cumulative PAH concentrations for the worst-case run were >500 ppb and remained near the release location and extending to the south (Figure 3-127). Lower concentrations, between 1-10 ppb, extended southeast into the deeper, offshore waters off the continental shelf. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-9. Shoreline lengths oiled by >1 g/m^2 (1 µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated 200,000 bbl surface release of crude oil offshore of Delaware starting on June 25, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Rocky shore	2	2	2	3	3	3
Gravel beach	8	8	8	13	13	13
Sand beach	163	163	154	263	263	248
Mudflat	27	27	26	43	43	42
Wetland	3	3	2	5	5	3
Artificial/manmade shoreline	8	8	0	13	13	0
Total	212	211	192	340	340	310
Landward						

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Rocky shore	18	18	16	29	29	26
Gravel beach	12	12	12	20	20	19
Sand beach	16	16	14	26	26	23
Mudflat	25	24	11	41	39	18
Wetland	48	46	17	77	74	28
Artificial/manmade shoreline	22	22	0	36	36	0
Total	142	139	71	229	224	114
All Shorelines						
Total	354	350	263	569	564	424

Table 3-2 shows the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-130 to Figure 3-138 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In both the spring and fall, oil is transported concentrically and south of the release site, with shoreline oiling occurring along the coasts of Delaware, New Jersey, Maryland, and Virginia, as well as along the northern coast of North Carolina (fall only). In the winter, oil is transported directly south and southeast into nearshore and offshore waters of states south of Delaware, with oiling occurring along Maryland, Virginia, and North Carolina coasts.

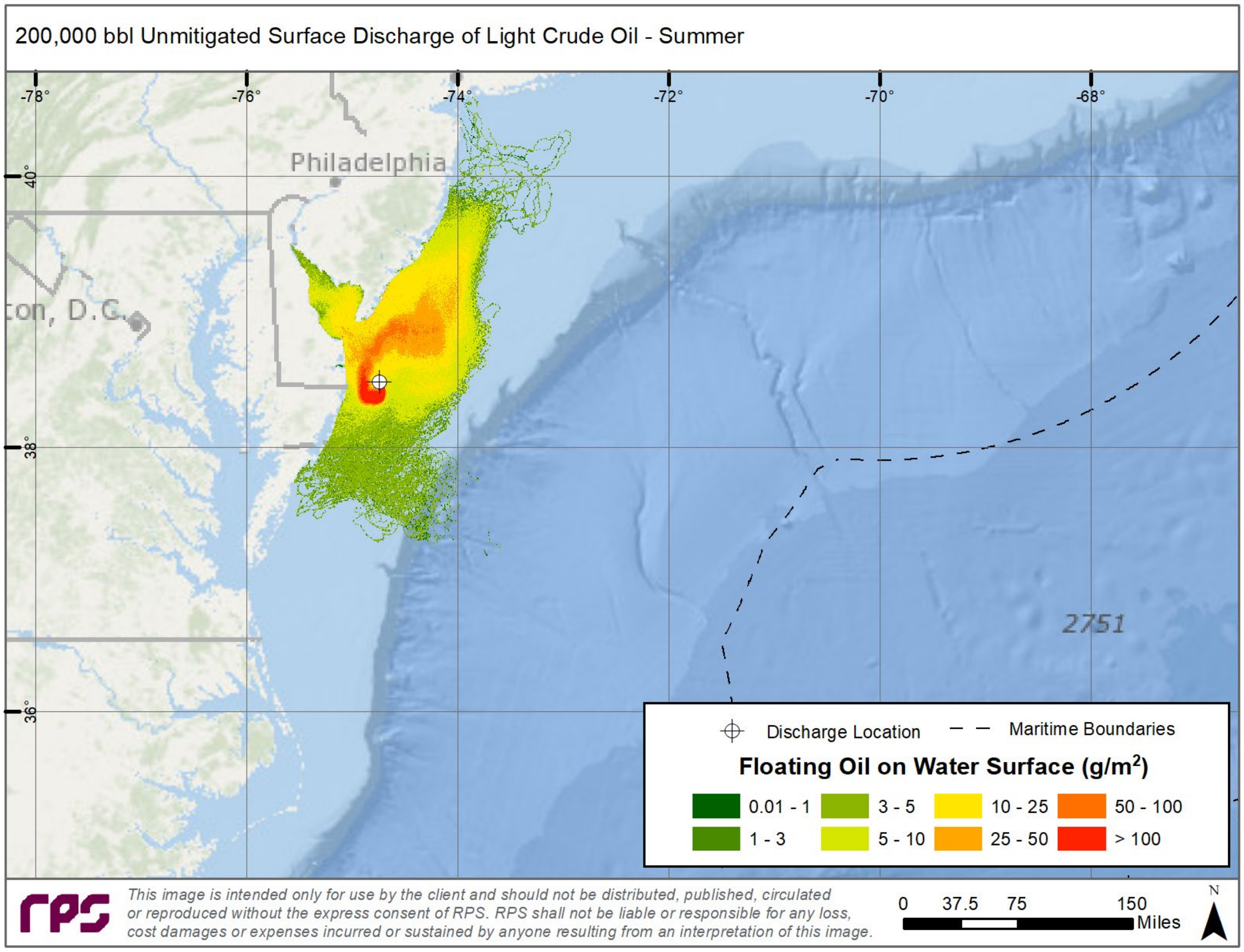


Figure 3-125. Maximum water surface oil exposure concentration at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Delaware starting on June 25, 2018.

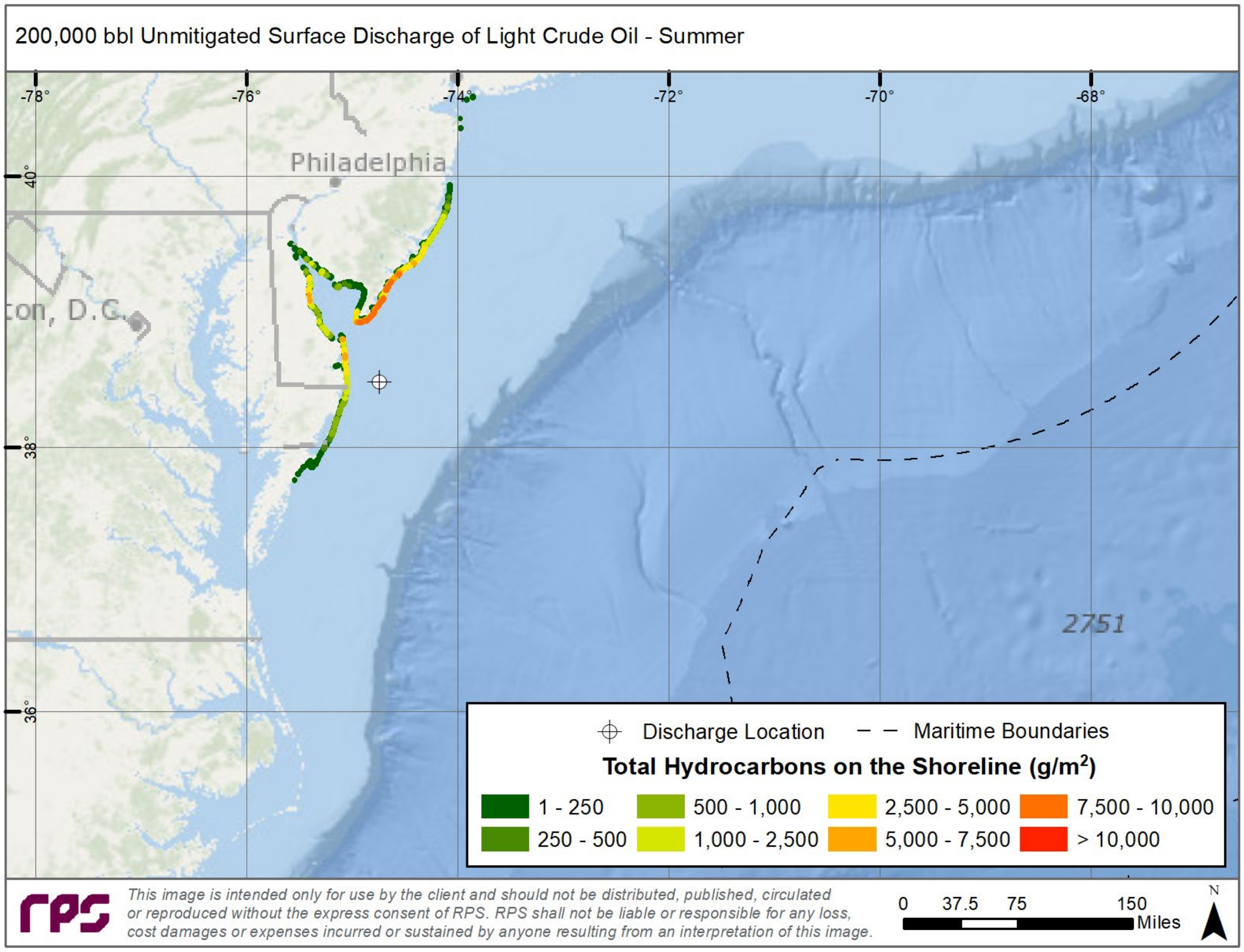


Figure 3-126. Maximum shoreline oil concentration at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Delaware starting on June 25, 2018.

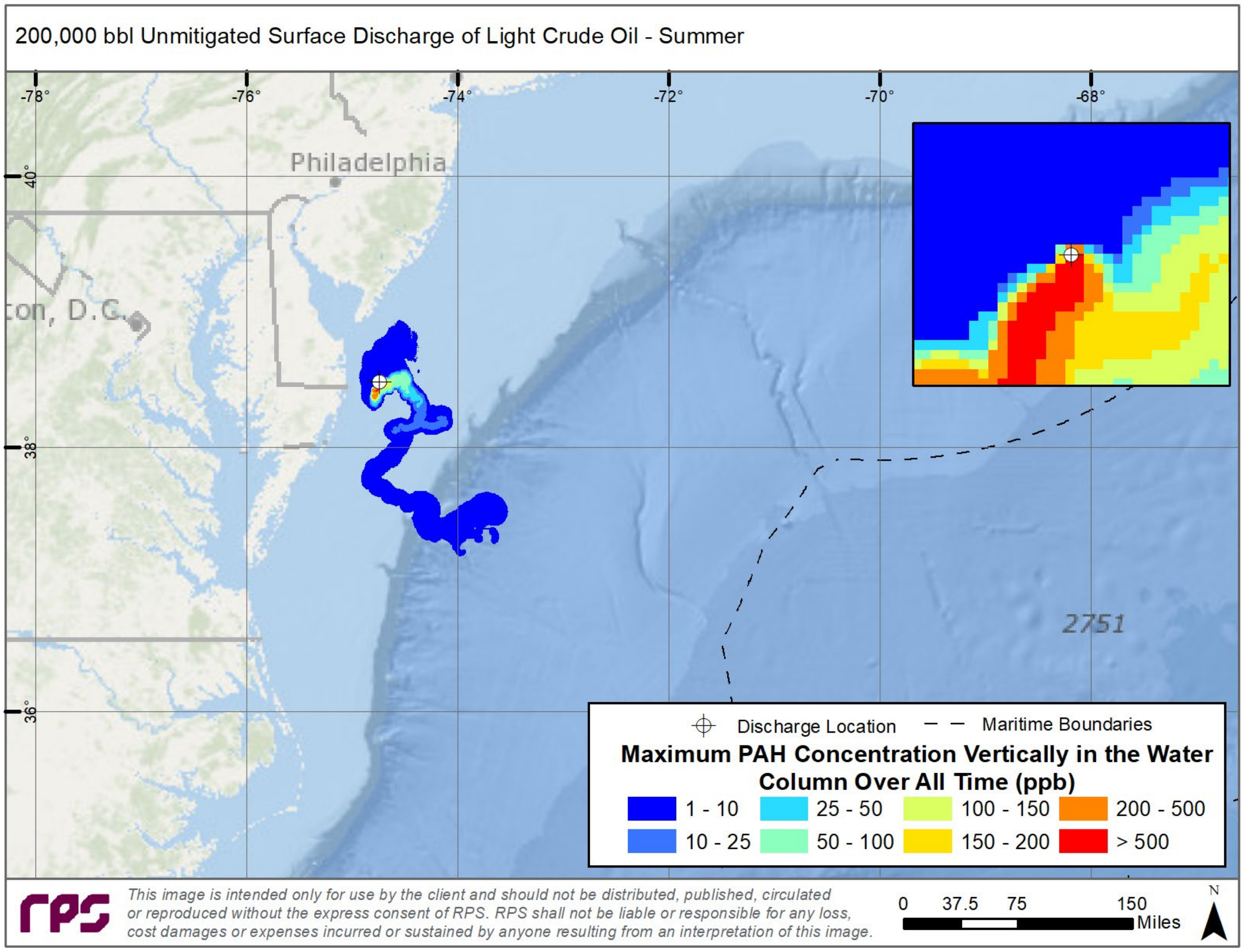


Figure 3-127. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Delaware starting on June 25, 2018.

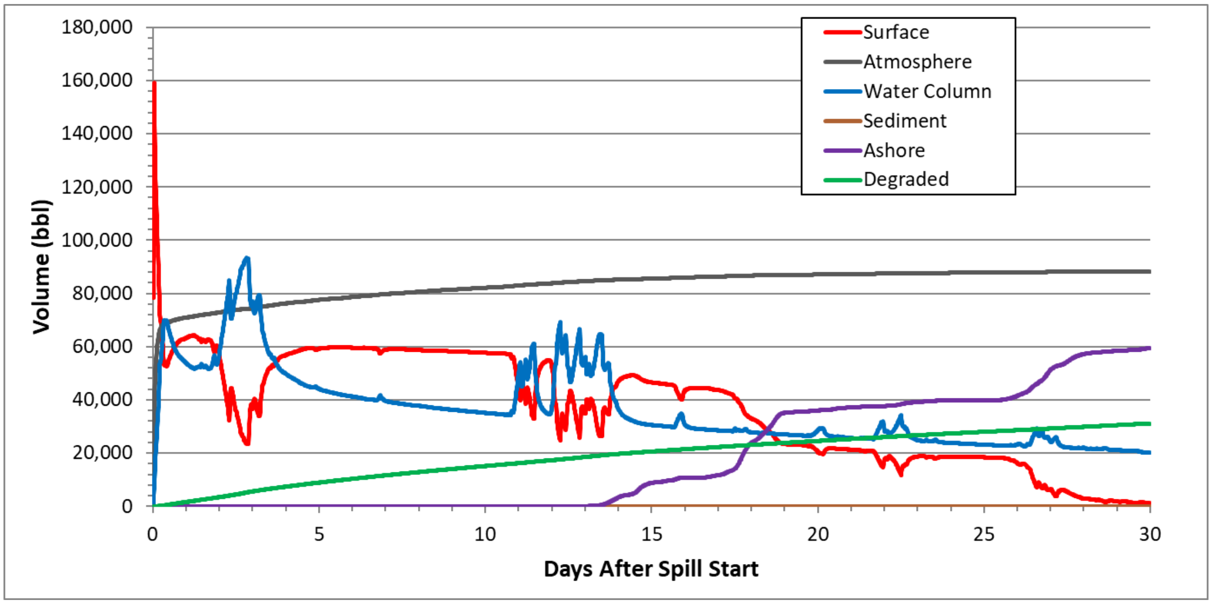


Figure 3-128. Oil volume by environmental compartment over time for an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl surface release of crude oil offshore of Delaware starting on June 25, 2018.

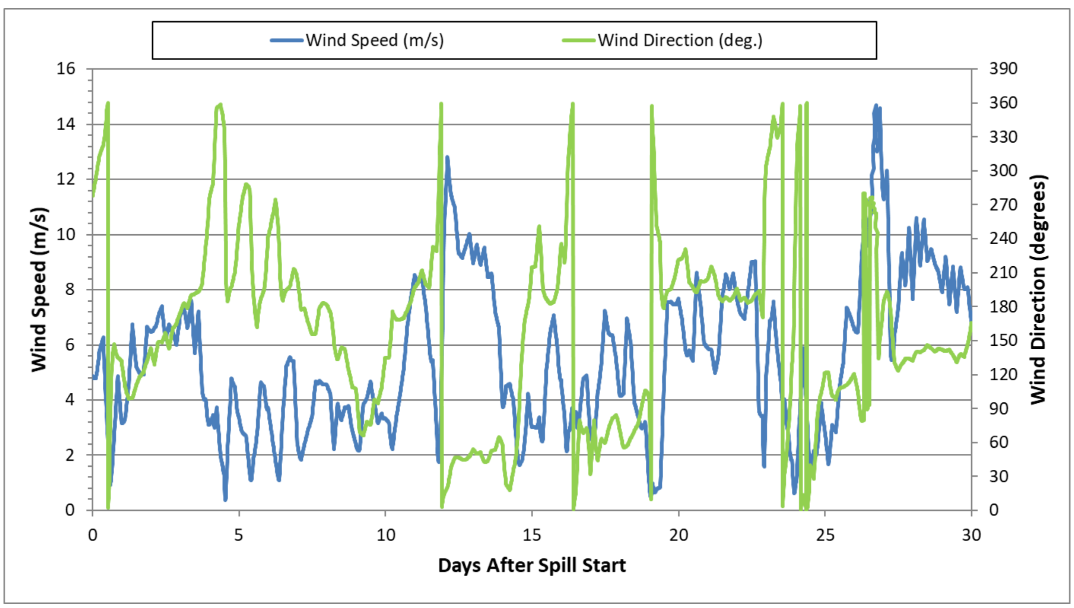


Figure 3-129. Wind speeds (1 m/s = 2 knots) and directions during the unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl surface release of crude oil offshore of Delaware starting on June 25, 2018.

3.3.1.3.2 Seasonal Worst-Case Runs

Winter

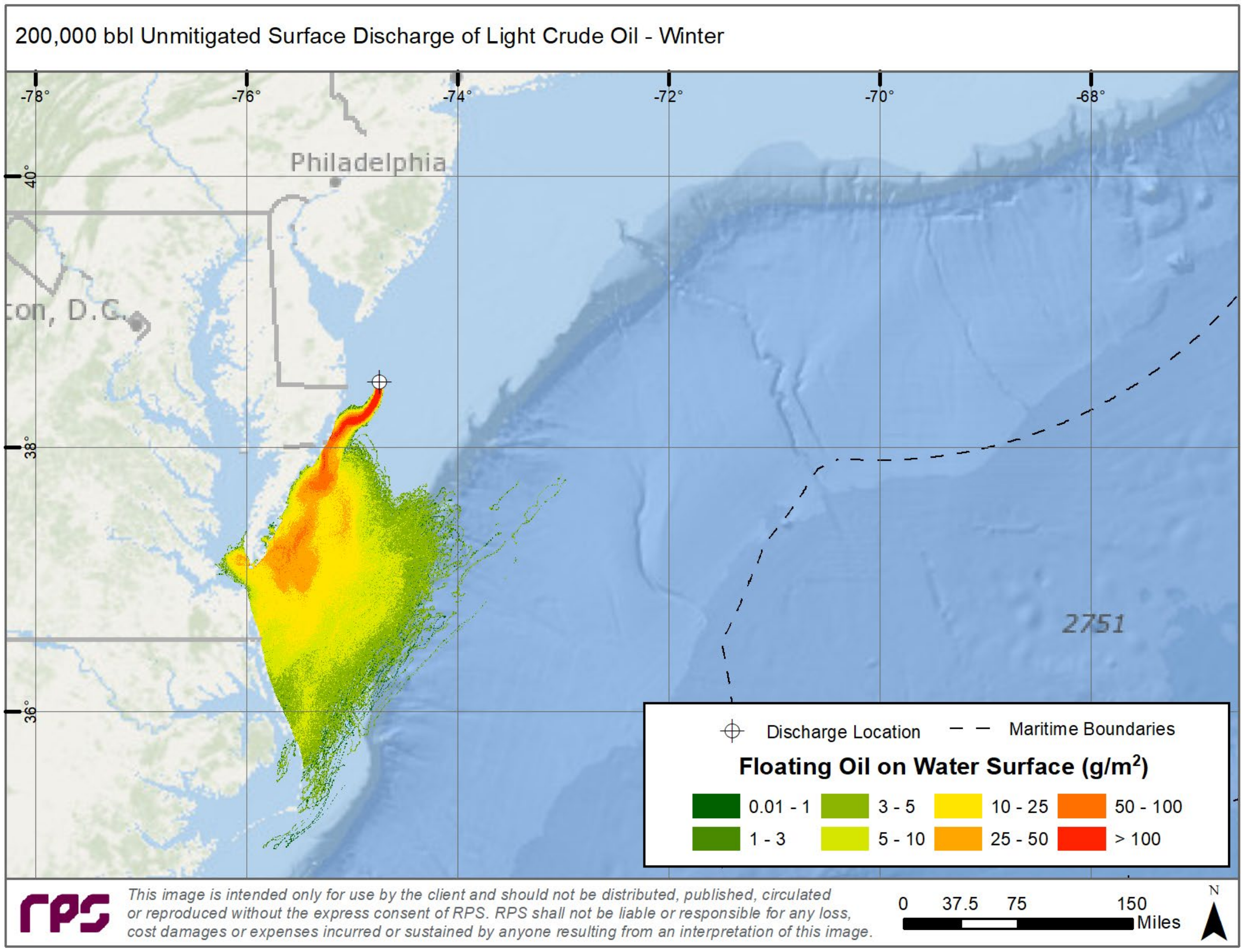


Figure 3-130. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Delaware starting on February 28, 2019.

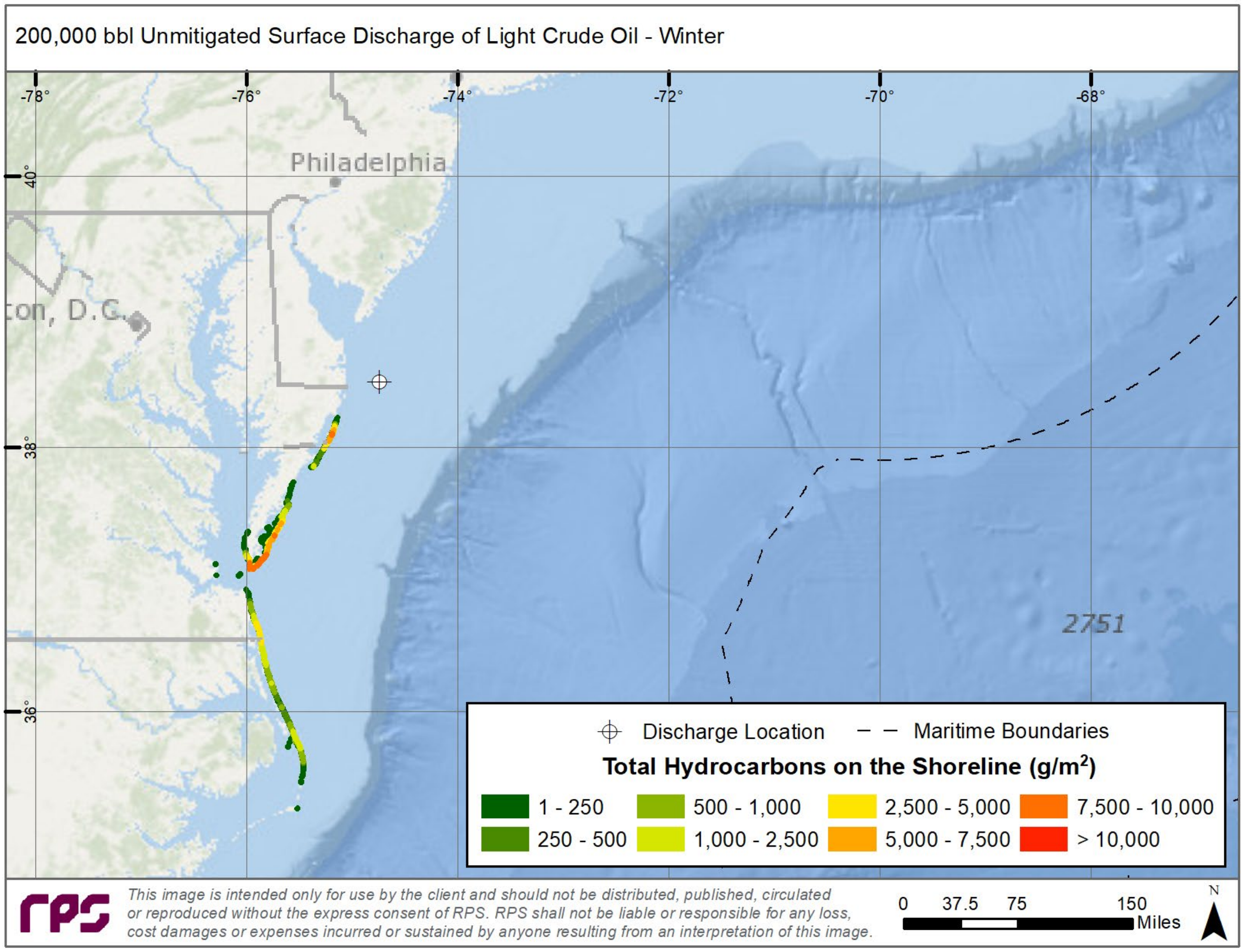


Figure 3-131. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Delaware starting on February 28, 2019.

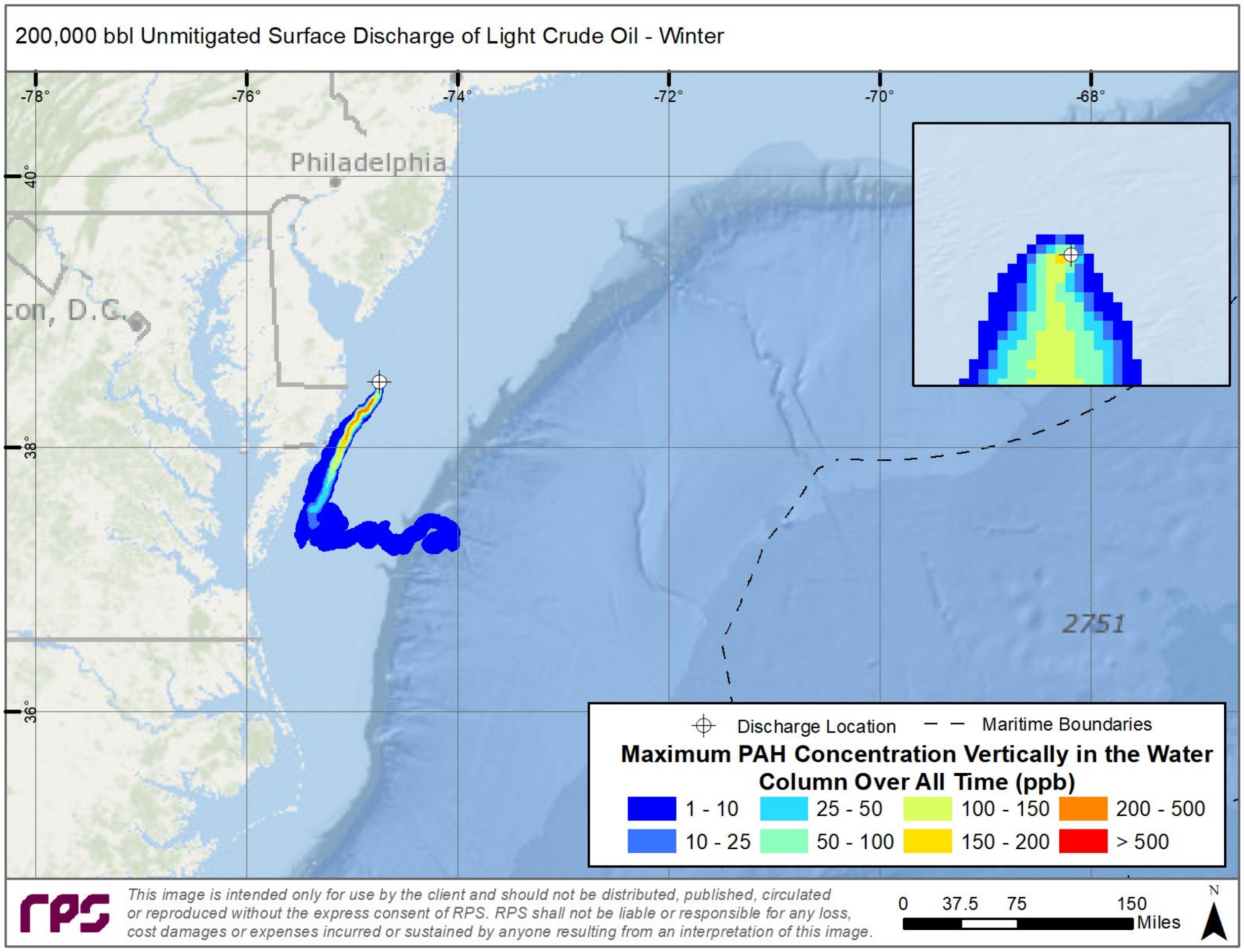


Figure 3-132. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Delaware starting on February 28, 2019.

Spring

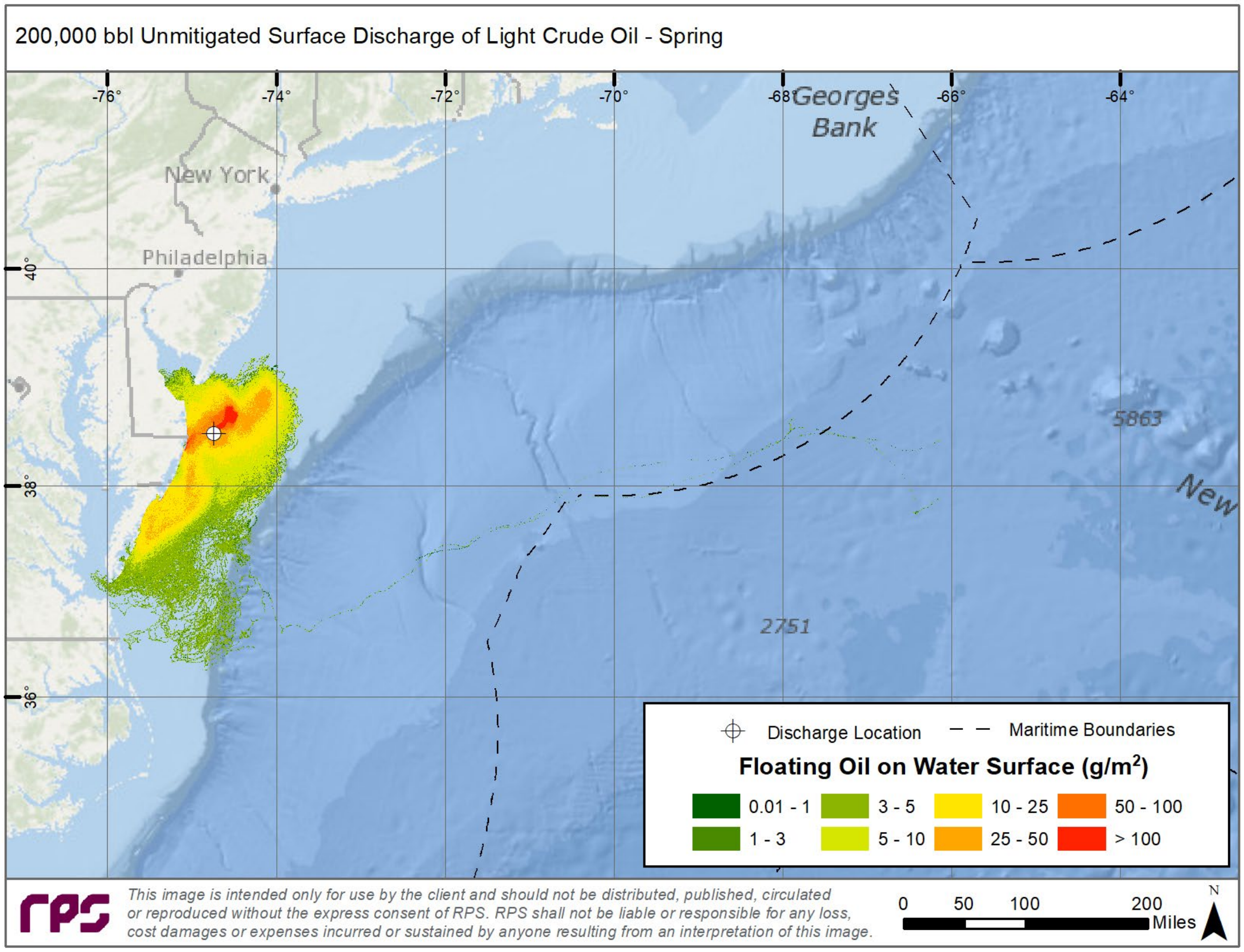


Figure 3-133. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Delaware starting on May 15, 2018.

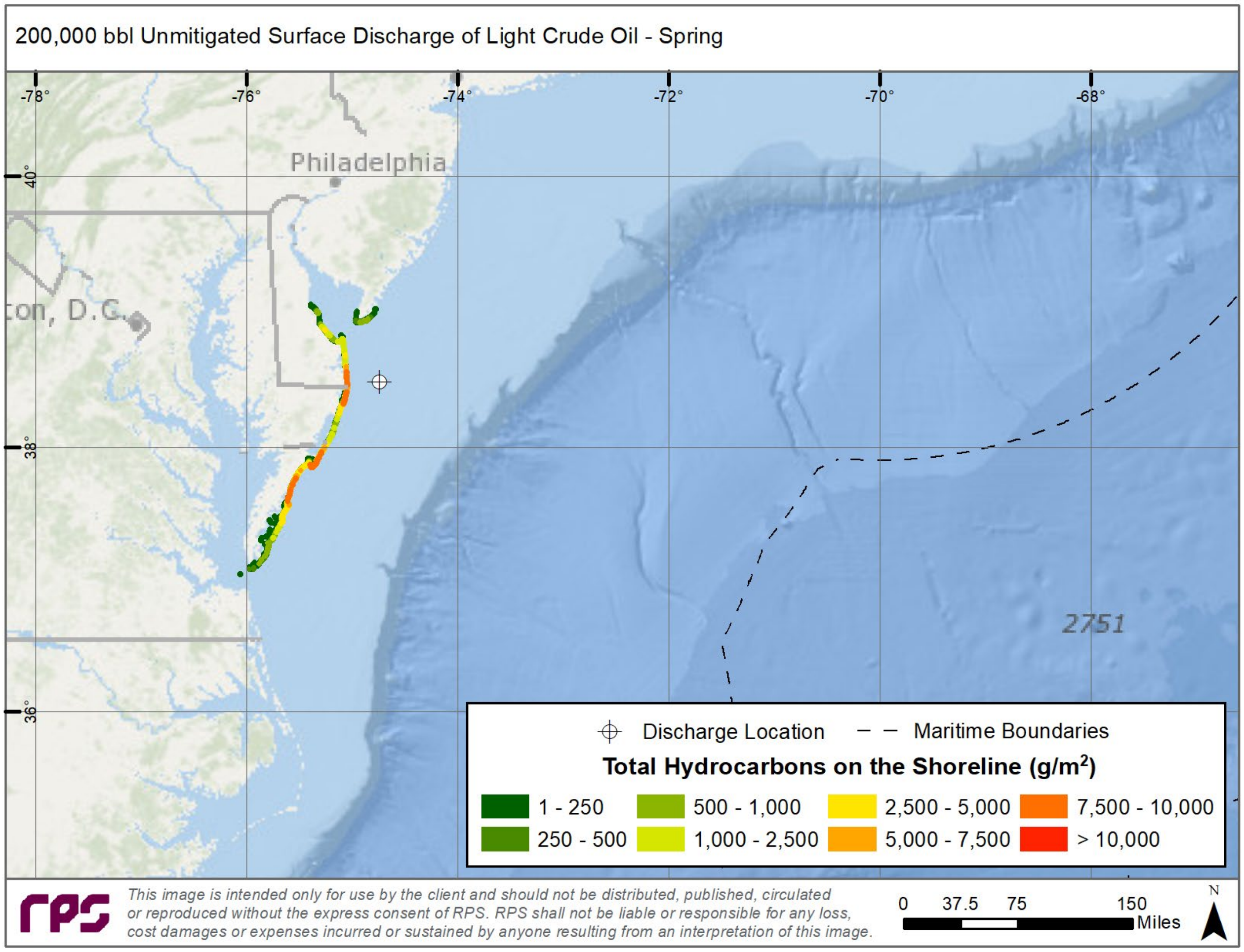


Figure 3-134. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Delaware starting on May 15, 2018.

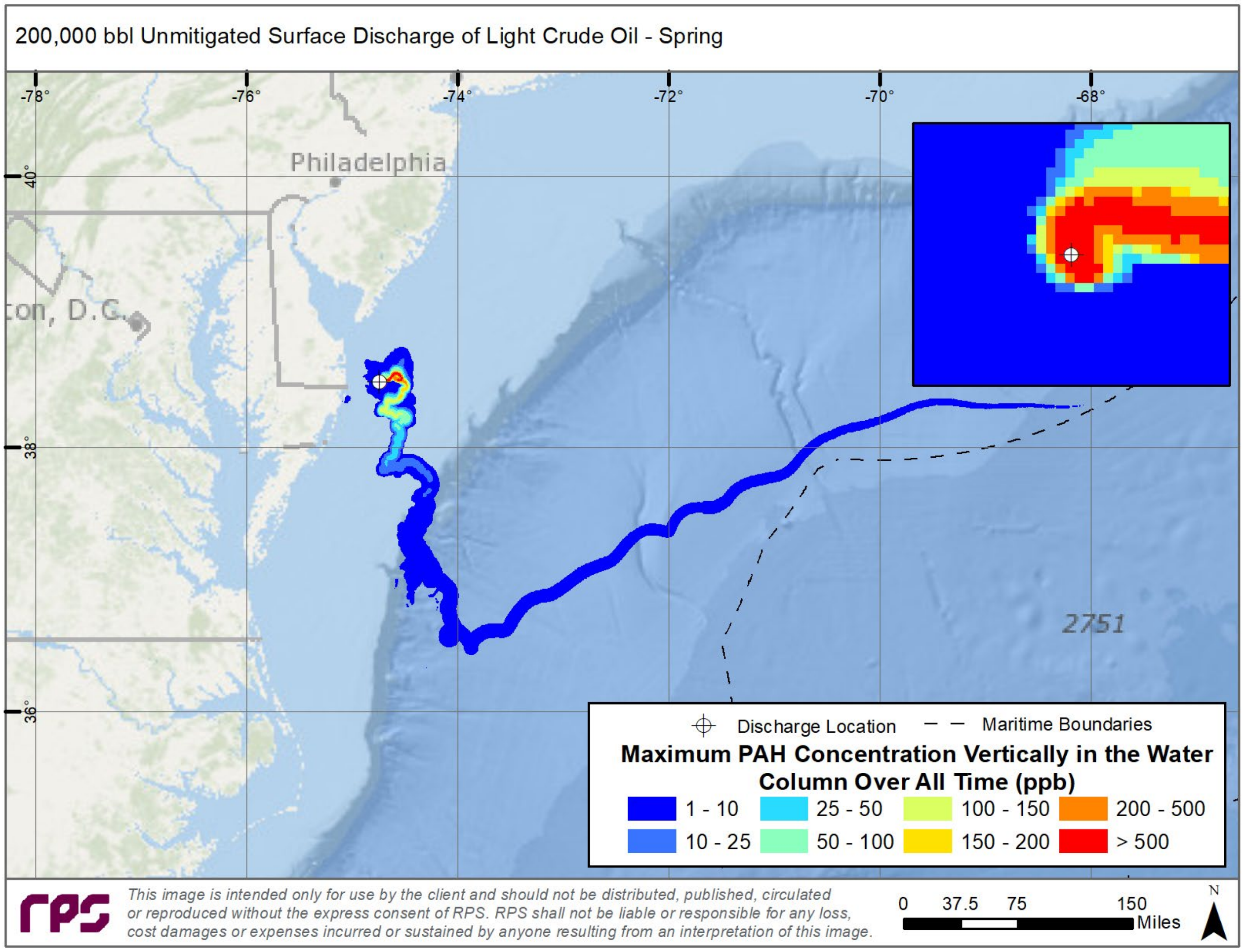


Figure 3-135. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Delaware starting on May 15, 2018.

Fall

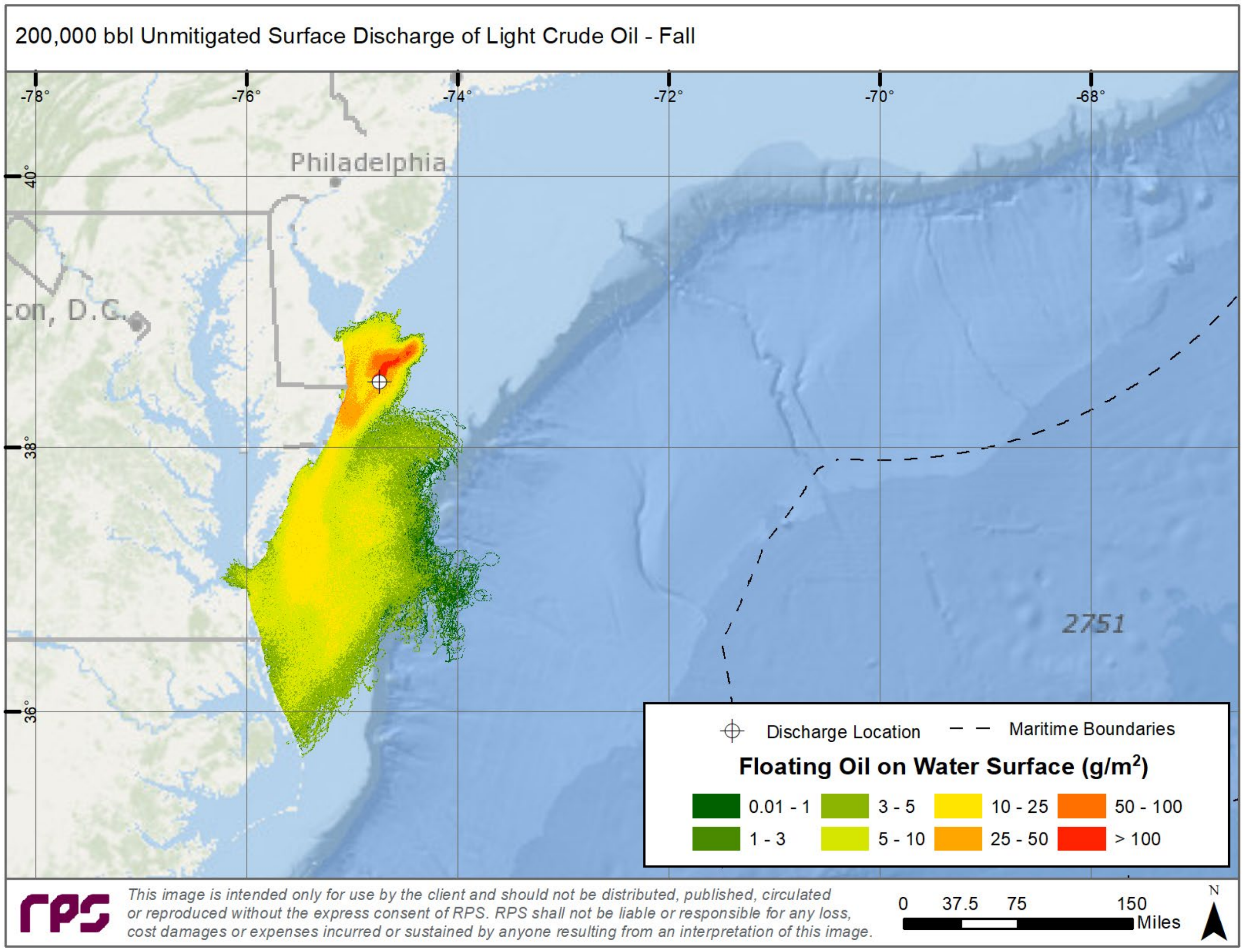


Figure 3-136. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Delaware starting on October 1, 2019.

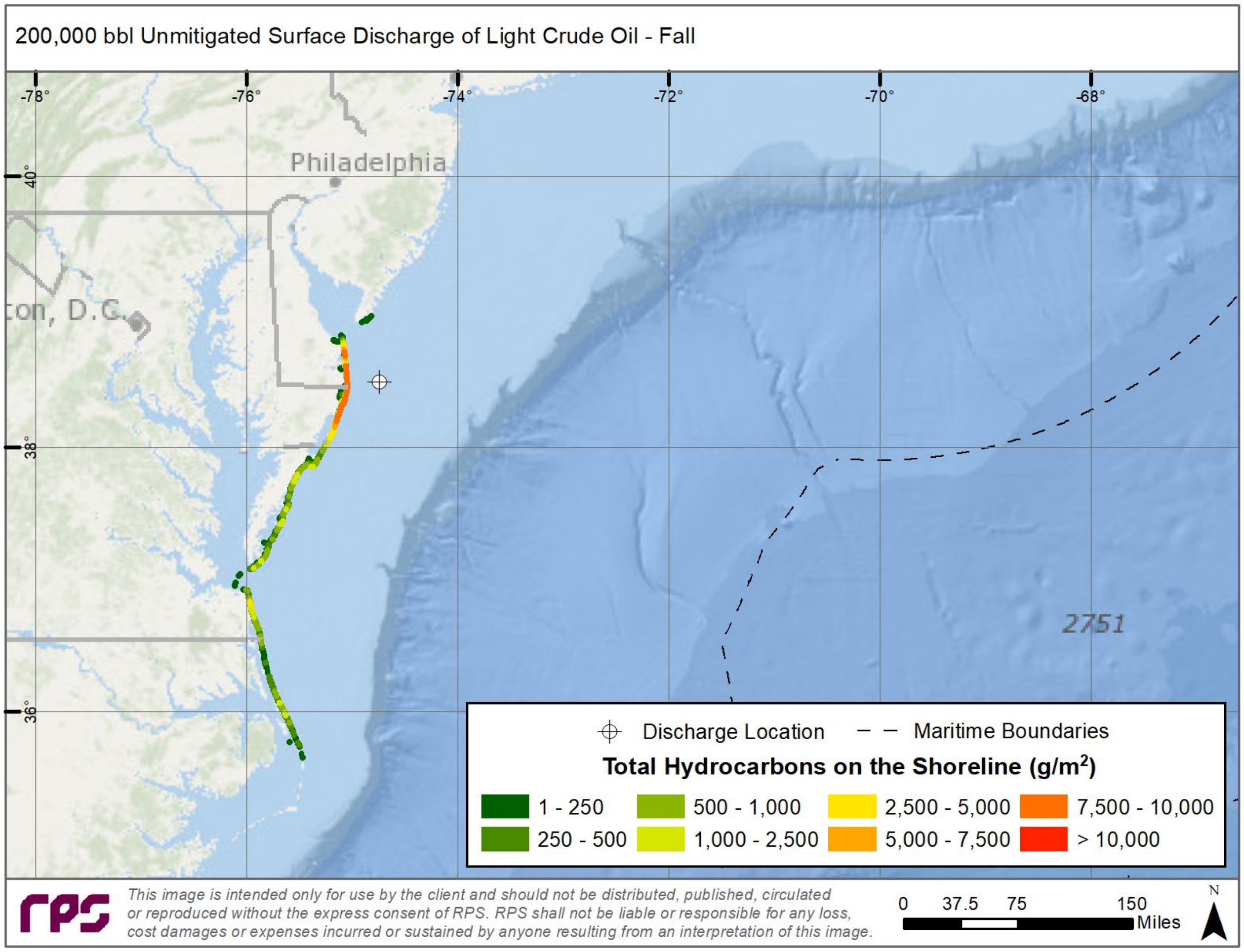


Figure 3-137. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Delaware starting on October 1, 2019.

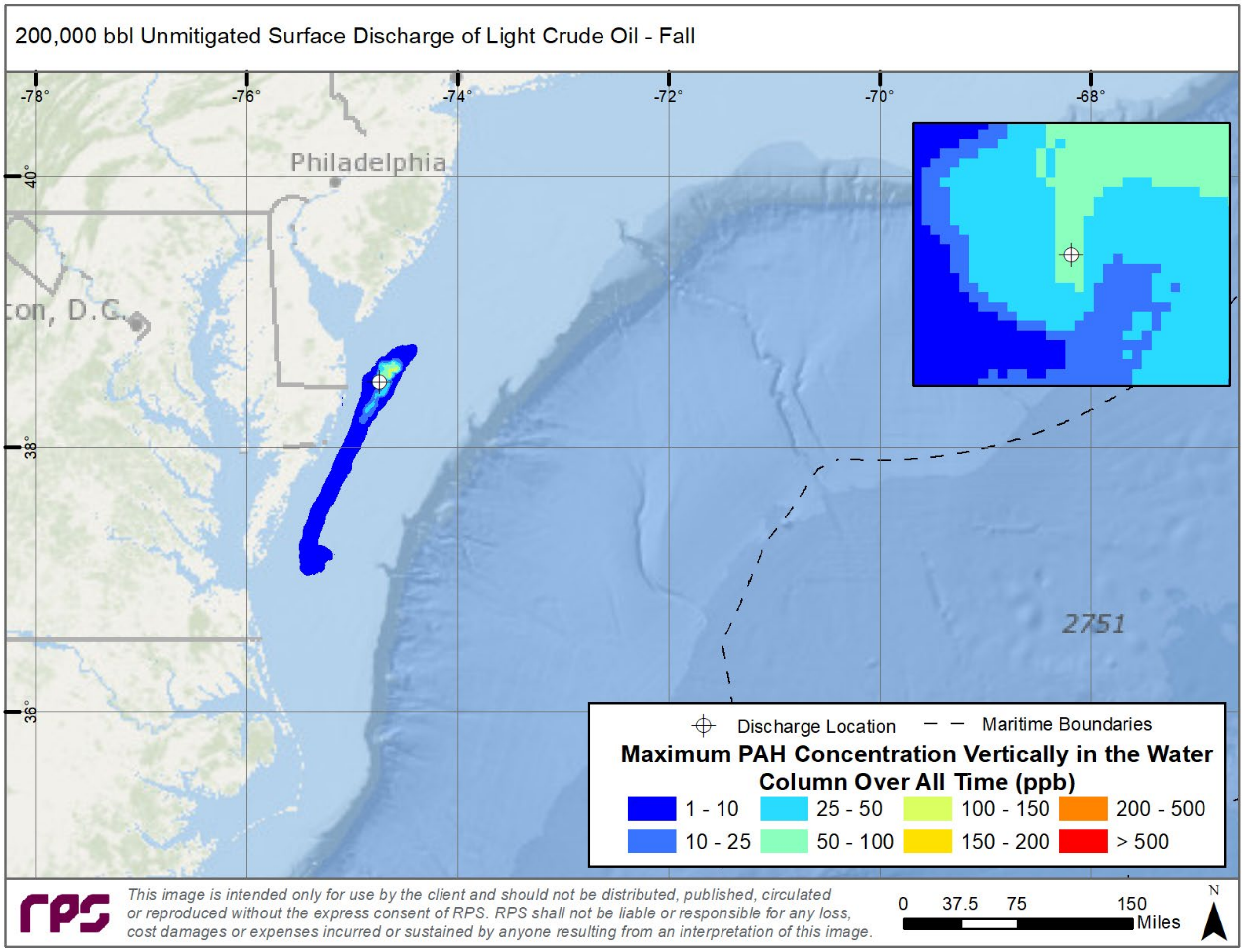


Figure 3-138. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Delaware starting on October 1, 2019.

3.3.1.4 Surface Mitigated Release (High Volume)

3.3.1.4.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a high-volume mitigated surface release of 200,000 bbl crude oil offshore Delaware started on June 25, 2018. Response measures simulated for this case included deployment of surface dispersant, mechanical removal, and ISB. Removal began 24 hours upon release with oil removed steadily increasing over the 30-day simulation (Figure 3-142). Evaporation of just under 40% of the released oil occurred within the first couple days after the crude oil release. As with the unmitigated high-volume crude oil release, high wind events cause an oscillation of oil within the water column and on the surface; however, due to response methods, more oil entrains into the water column as dispersant breaks down oil into small droplets (Figure 3-142 and Figure 3-143). The mass balance (Figure 3-142) shows that no oil remained on the surface while approximately 40% of the oil evaporated, <1% of the oil reached shore, 16% of the oil remained in the water column, 23% was removed via response, and 20% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending furthest to the northeast. Maximum floating oil on the surface was >100 g/m^2 (100 µm, on average) and extended from the release site to the south and west (Figure 3-139). Lower (<25 g/m^2, i.e., patchy oil, emulsions or sheens) maximum surface oil exposure concentrations were predicted to extend up to 125 mi (201 km) from the release site, into Delaware Bay to the northwest, offshore of New Jersey to the north, and south in nearshore and offshore waters of Maryland. Response measures considerably decreased the maximum surface floating oil exposure in the worst-case run when compared to the unmitigated case (Figure 3-125; Figure 3-139). By the end of the 30-day simulation, 76 mi (123 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-140; Table 3-10). Seaward sandy beach was the habitat predicted to have the longest length of shoreline oiled (50 mi; 80 km). Shoreline oiling was predicted along the coasts of Delaware, New Jersey, and Maryland, with the highest concentrations of oil (500-1,000 g/m^2) occurring along the southern seaward coast of New Jersey. In total, 0.1 mi^2 (0.3 km^2) of shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-5). Maximum cumulative PAH concentrations for the worst-case run were >500 ppb and remained near the release location, primarily extending south (Figure 3-141). Lower concentrations, between 1-10 ppb, extended concentrically around the spill site and southeast into the deeper, offshore waters off the continental shelf. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-10. Shoreline lengths oiled by >1 g/m^2 for the run with maximum shoreline length oiled (on an annual basis, in summer), for a mitigated 200,000 bbl surface release of crude oil offshore of Delaware starting on June 25, 2018.

Shoreline Type	**Length Oiled (mi)**			**Length Oiled (km)**		
Seaward	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**
Rocky shore	1	1	0	1	1	0
Gravel beach	2	2	2	4	4	3
Sand beach	50	49	36	80	79	58
Mudflat	11	11	9	18	18	14
Wetland	1	1	0	1	1	0
Artificial/manmade shoreline	2	2	0	4	4	0
Total	67	67	46	108	108	74

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	2	2	1	3	3	2
Mudflat	1	1	0	2	2	0
Wetland	3	3	0	5	5	0
Artificial/manmade shoreline	3	3	0	4	4	0
Total	9	9	1	15	14	2
All Shorelines						
Total	76	76	48	123	122	77

Table 3-2 shows the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-144 to Figure 3-152 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In the winter, oil is transported directly southwest into nearshore and offshore waters of states south of Delaware, with shoreline oiling occurring along Maryland, Virginia, and North Carolina coasts. In the spring, oil is transported concentrically around the release site, primarily in waters offshore of Delaware and Maryland, with shoreline oiling occurring along the coasts of Delaware, New Jersey, and Maryland. During the worst-case run to occur in the fall, the highest concentrations of surface oil occur to the northeast of the release site, with lower concentrations extending south, up to 150 mi (241 km) from the release site. Shoreline oiling >1 g/m^2 occurred along the Delaware, New Jersey, and Virginia coasts.

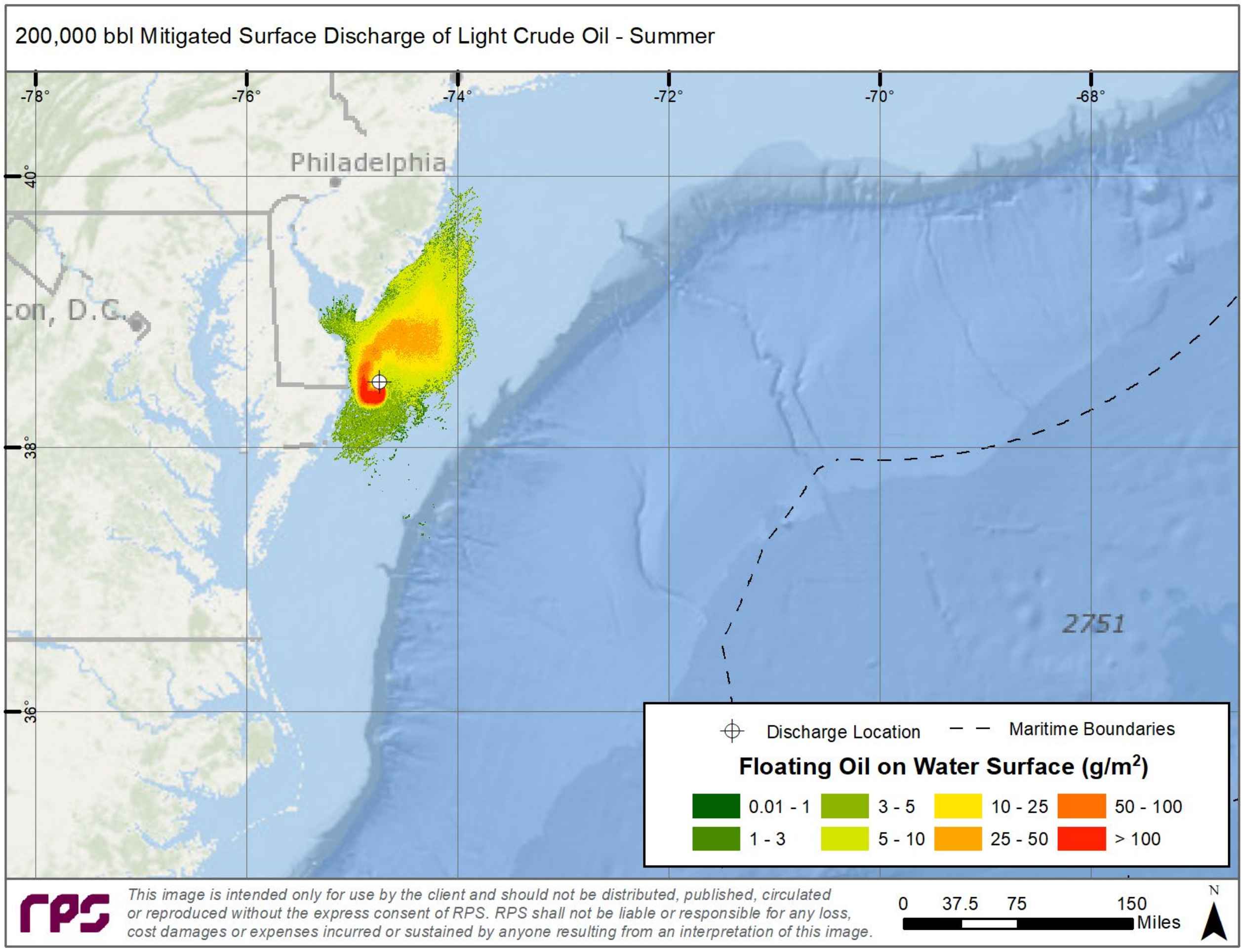


Figure 3-139. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Delaware starting on June 25, 2018.

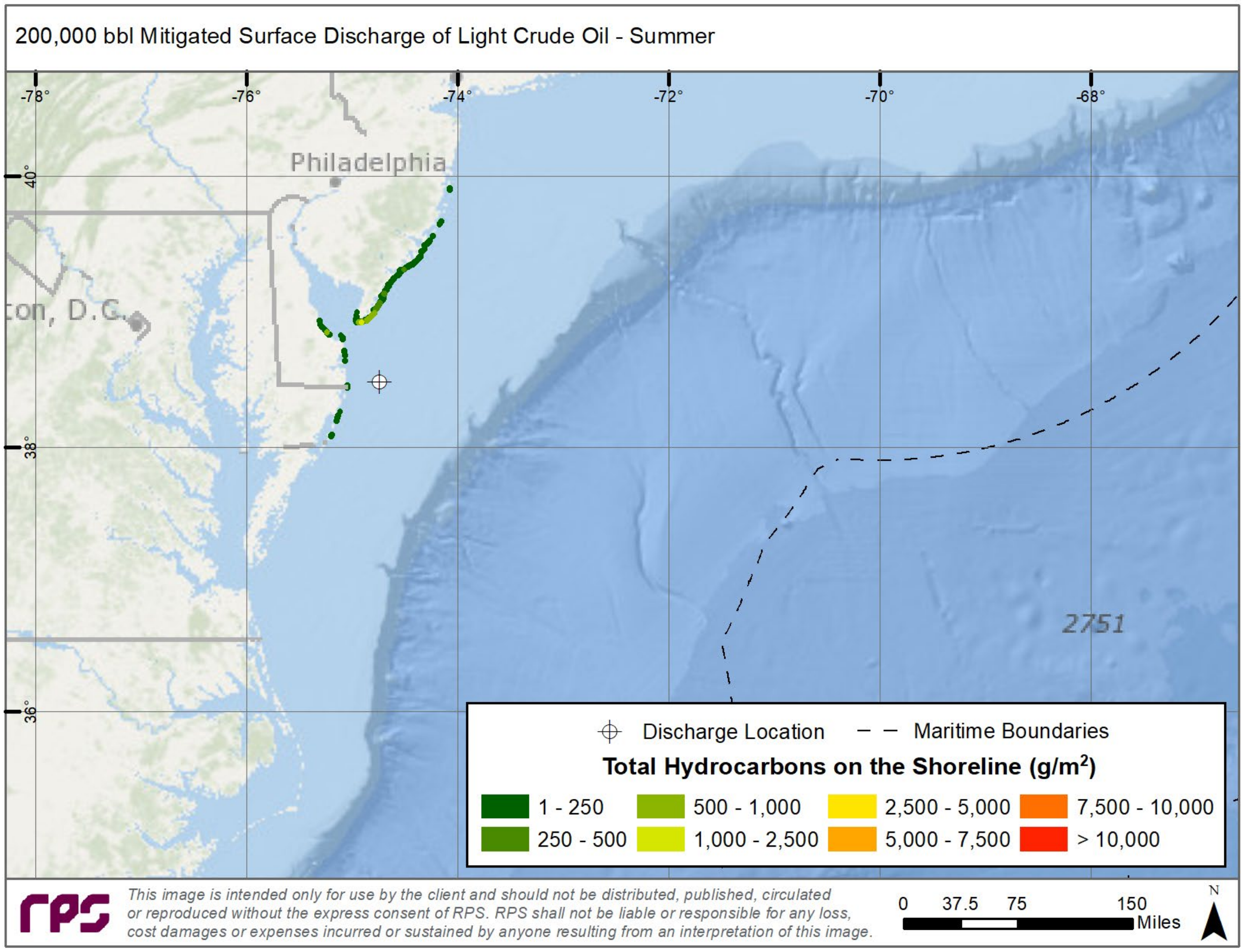


Figure 3-140. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Delaware starting on June 25, 2018.

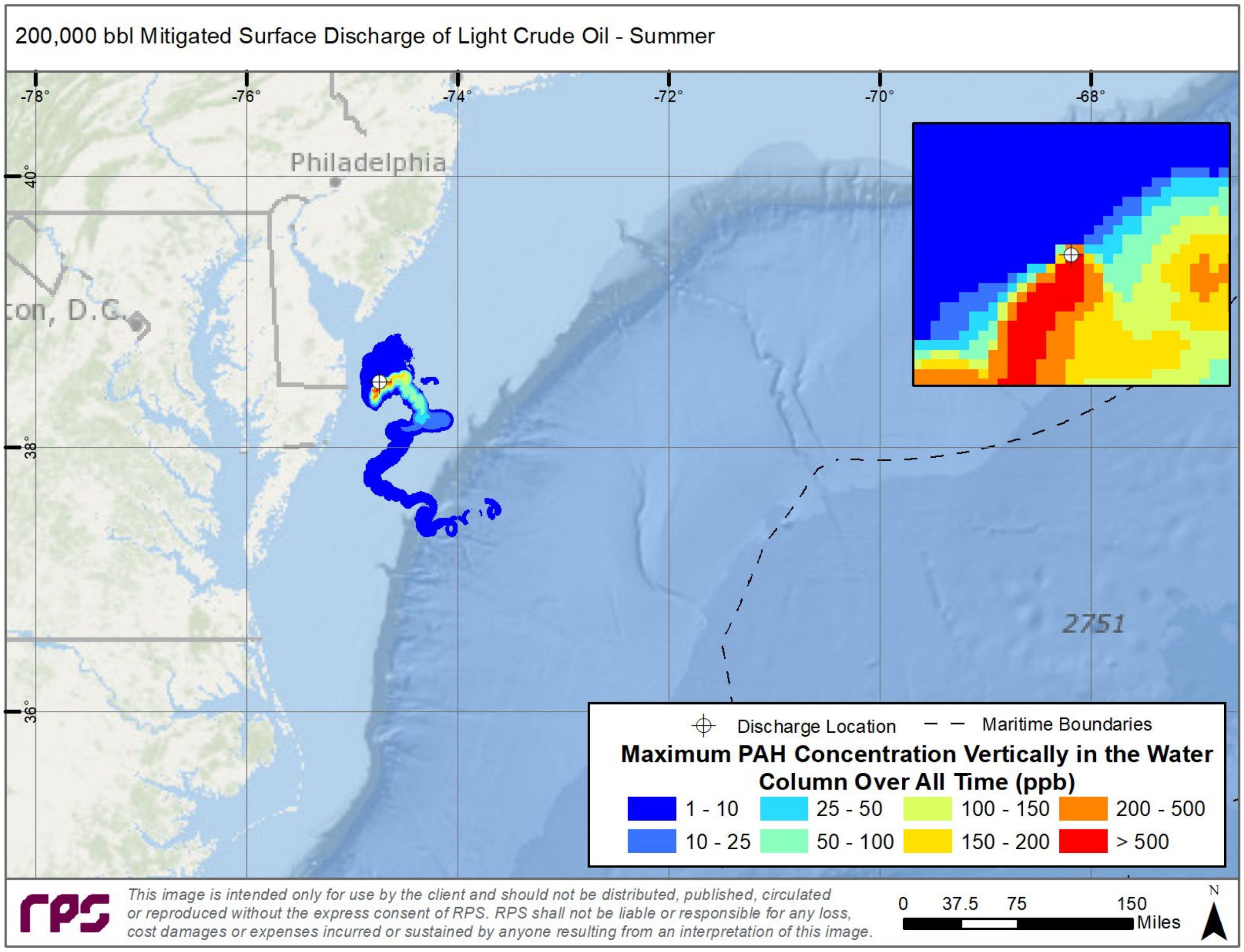


Figure 3-141. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Delaware starting on June 25, 2018.

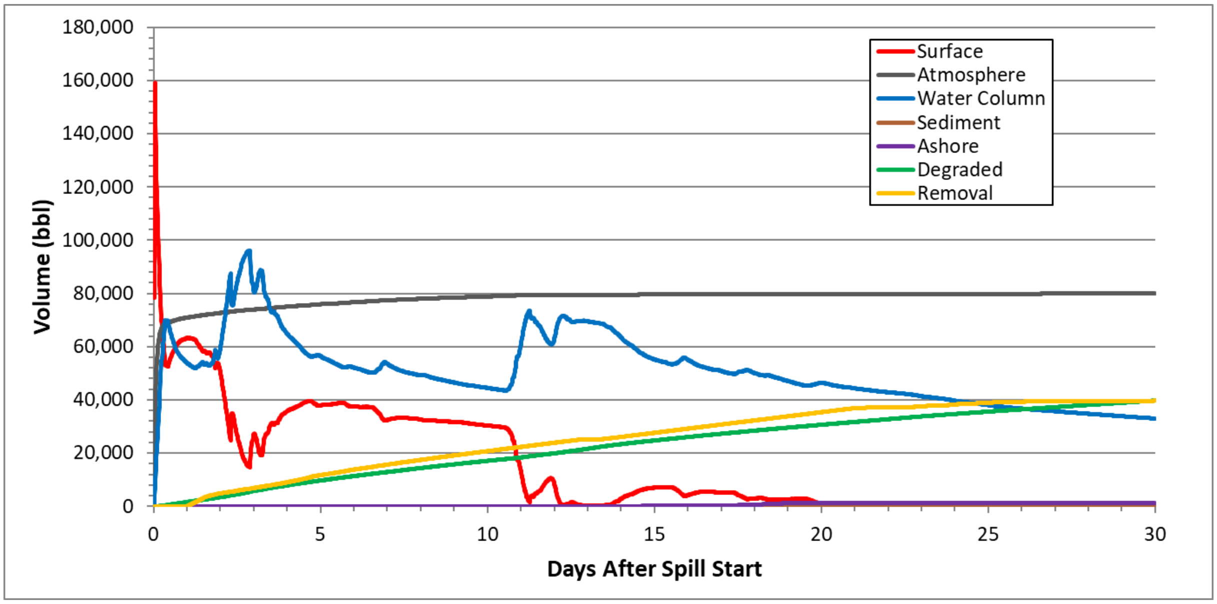


Figure 3-142. Oil volume by environmental compartment over time for a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl surface release of crude oil offshore of Delaware starting on June 25, 2018.

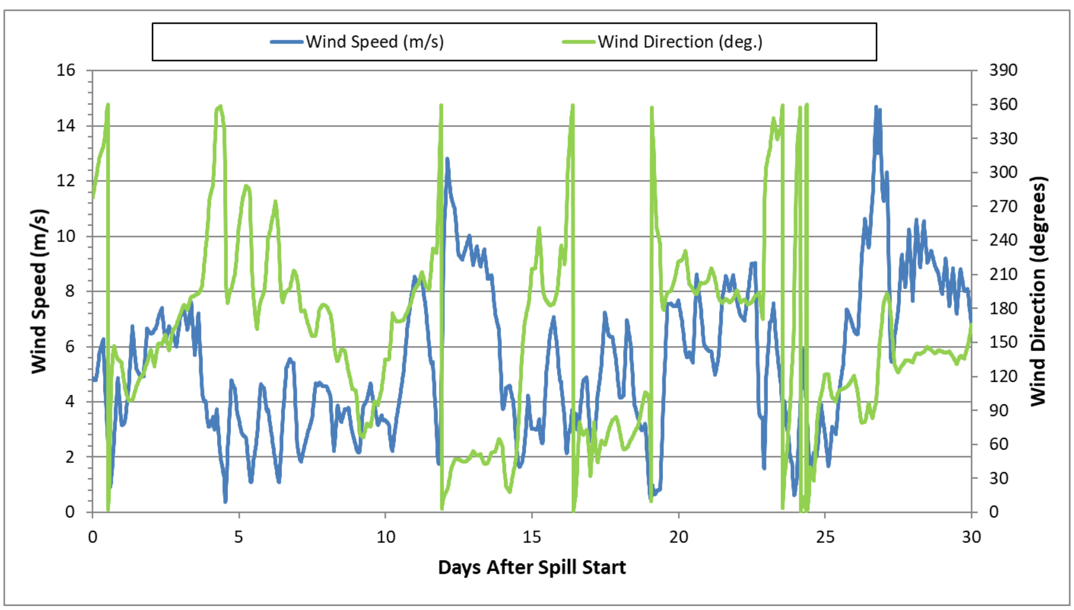


Figure 3-143. Wind speeds (1 m/s = 2 knots) and directions during the mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl surface release of crude oil offshore of Delaware starting on June 25, 2018.

3.3.1.4.2 Seasonal Worst-Case Runs

Winter

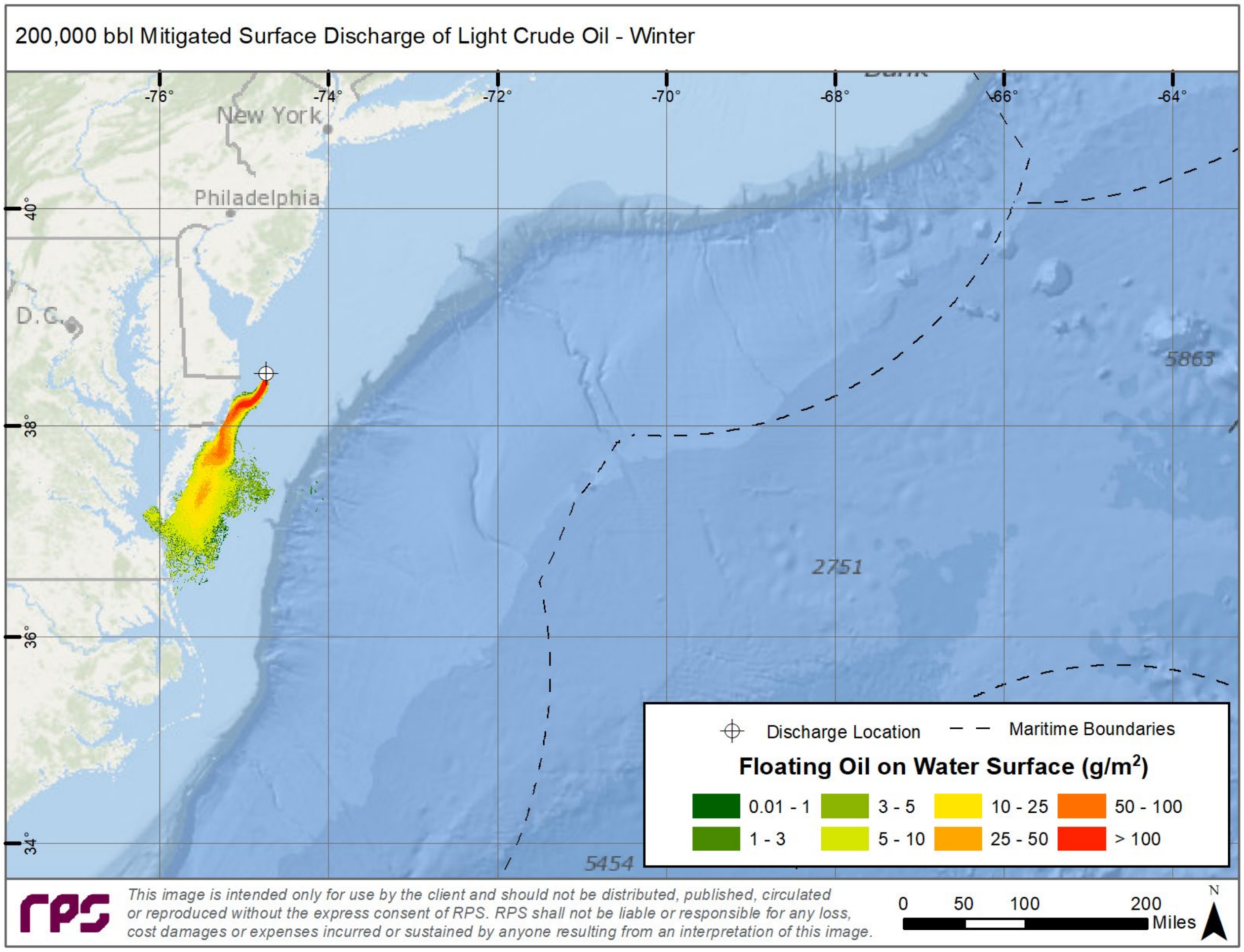


Figure 3-144. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Delaware starting on February 28, 2019.

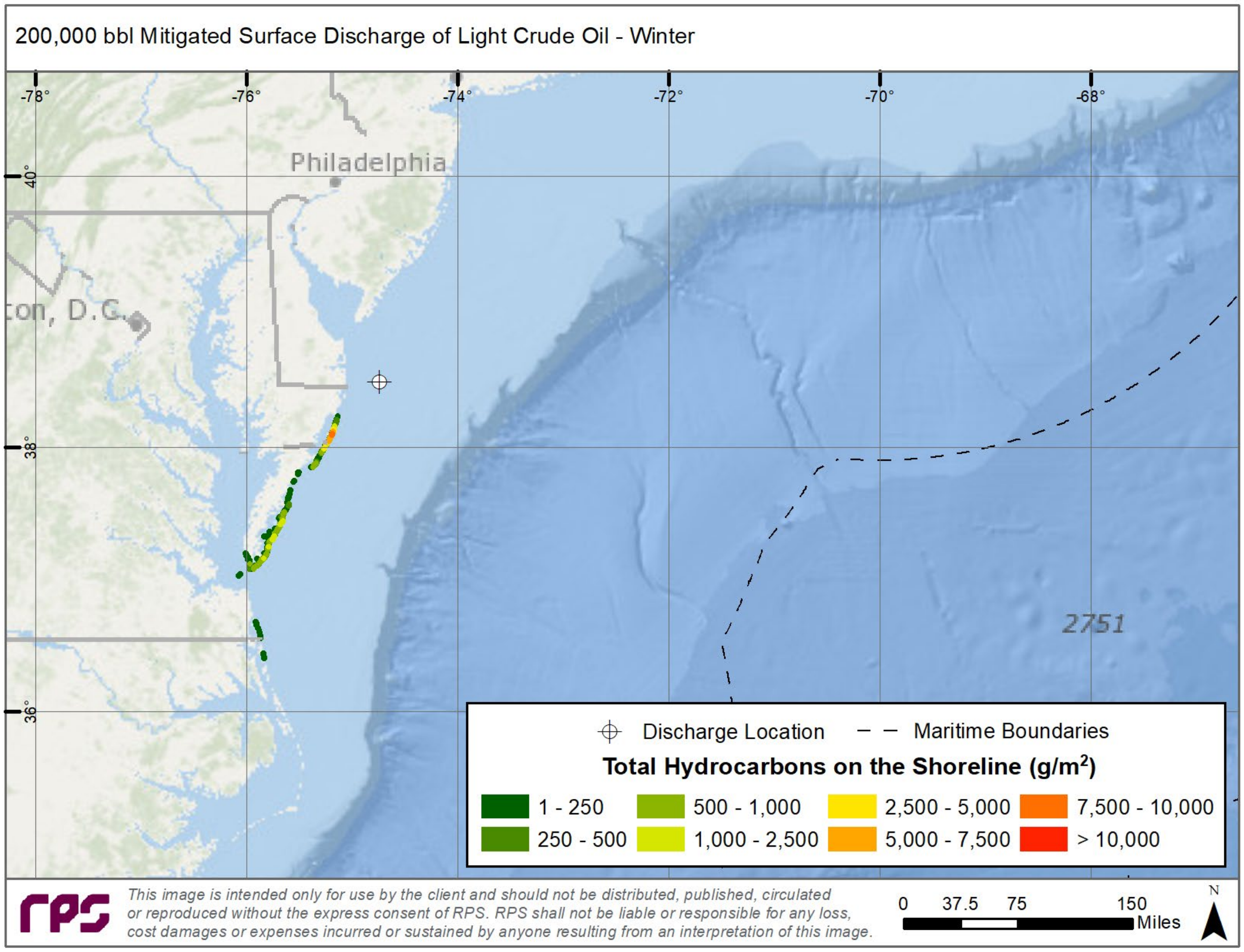


Figure 3-145. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Delaware starting on February 28, 2019.

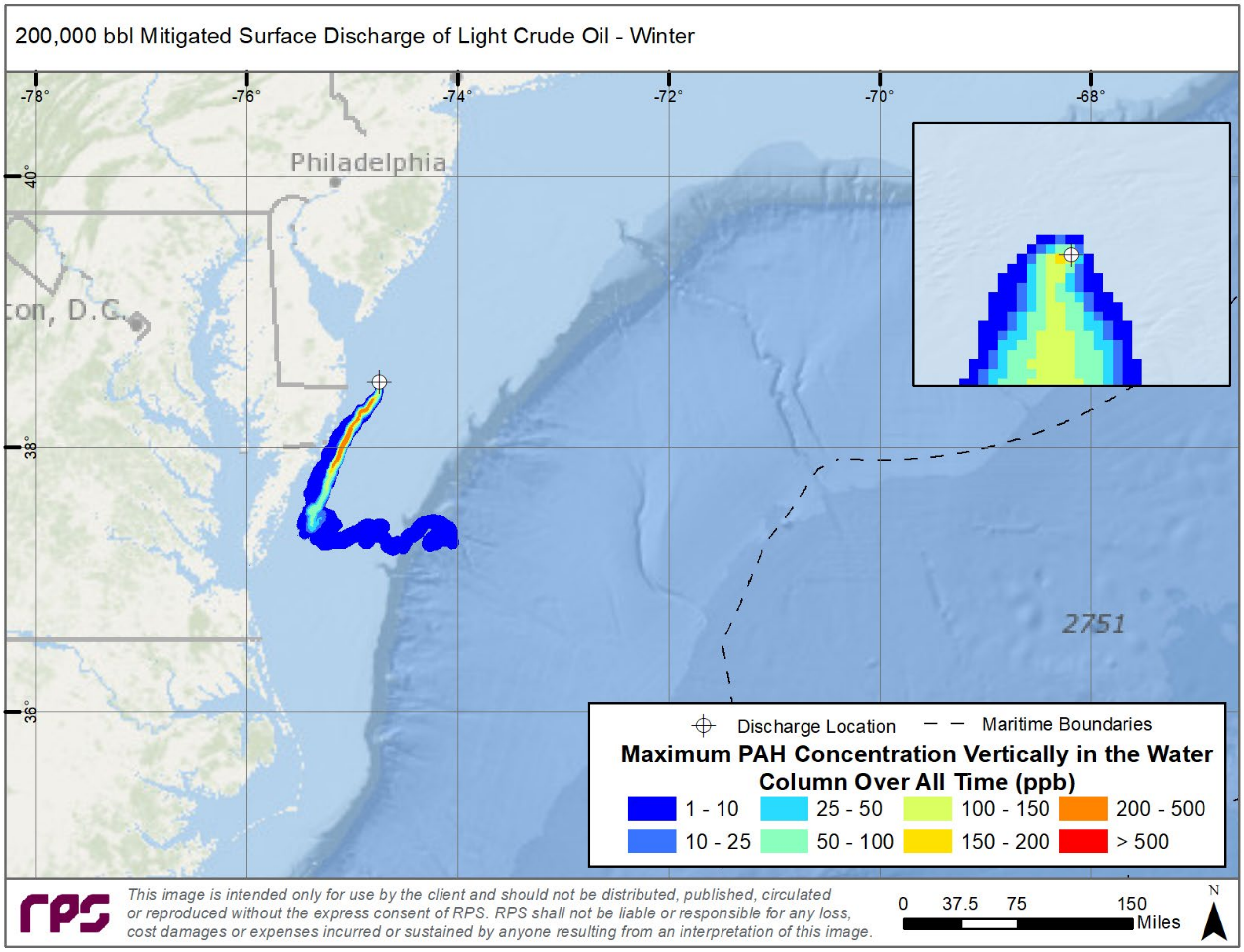


Figure 3-146. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Delaware starting on February 28, 2019.

Spring

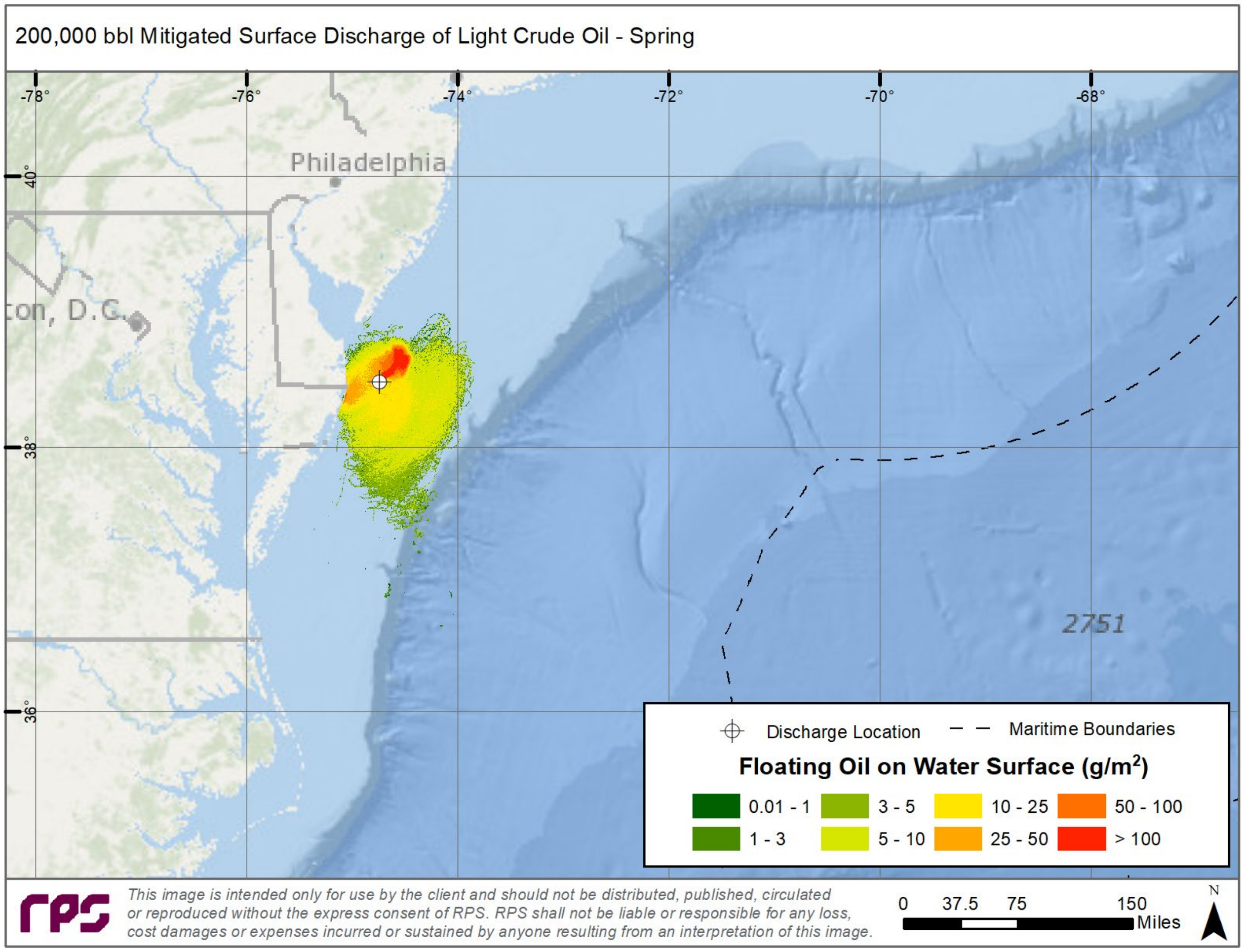


Figure 3-147. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Delaware starting on May 15, 2018.

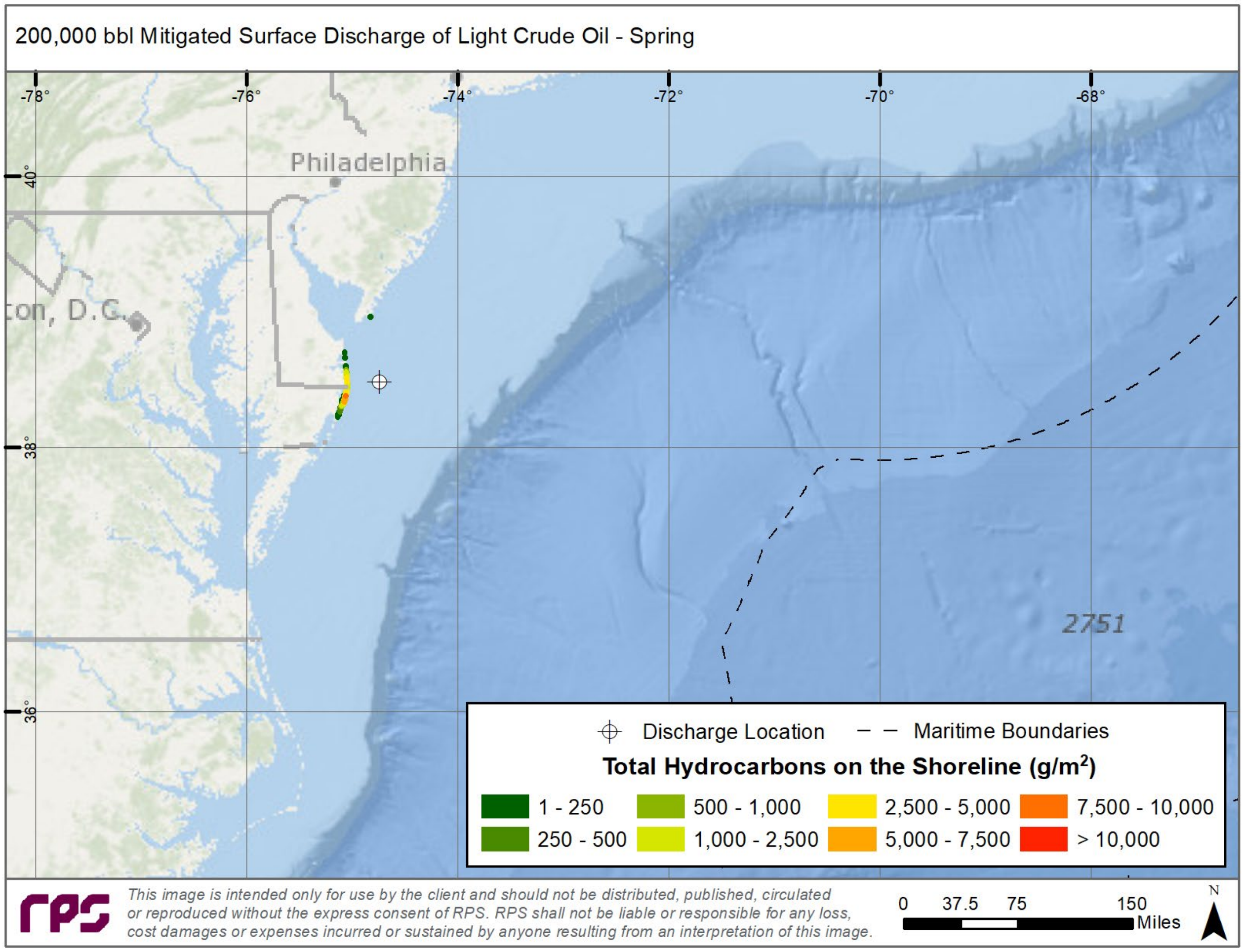


Figure 3-148. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore Delaware starting on May 25, 2018.

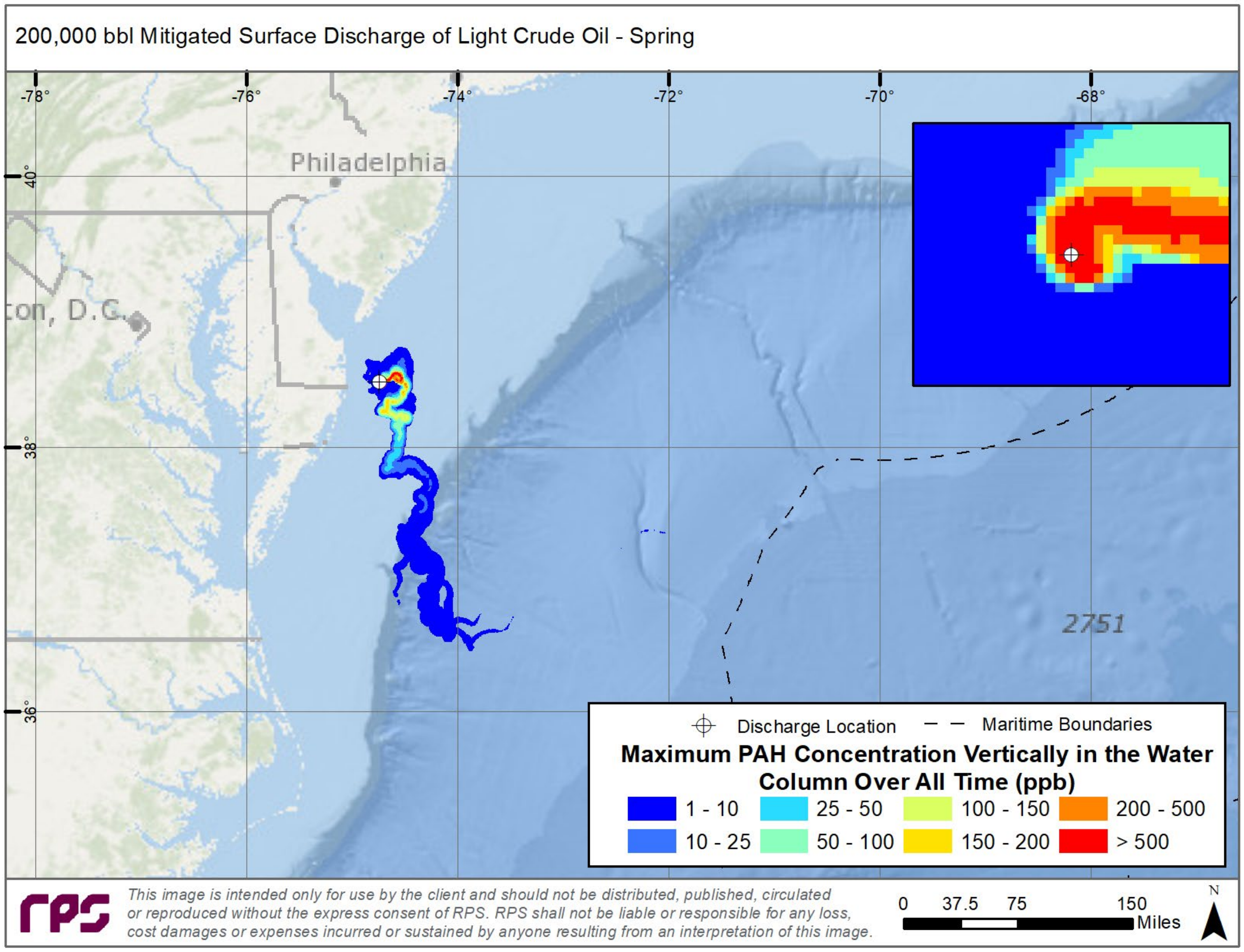


Figure 3-149. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Delaware starting on May 15, 2018.

Fall

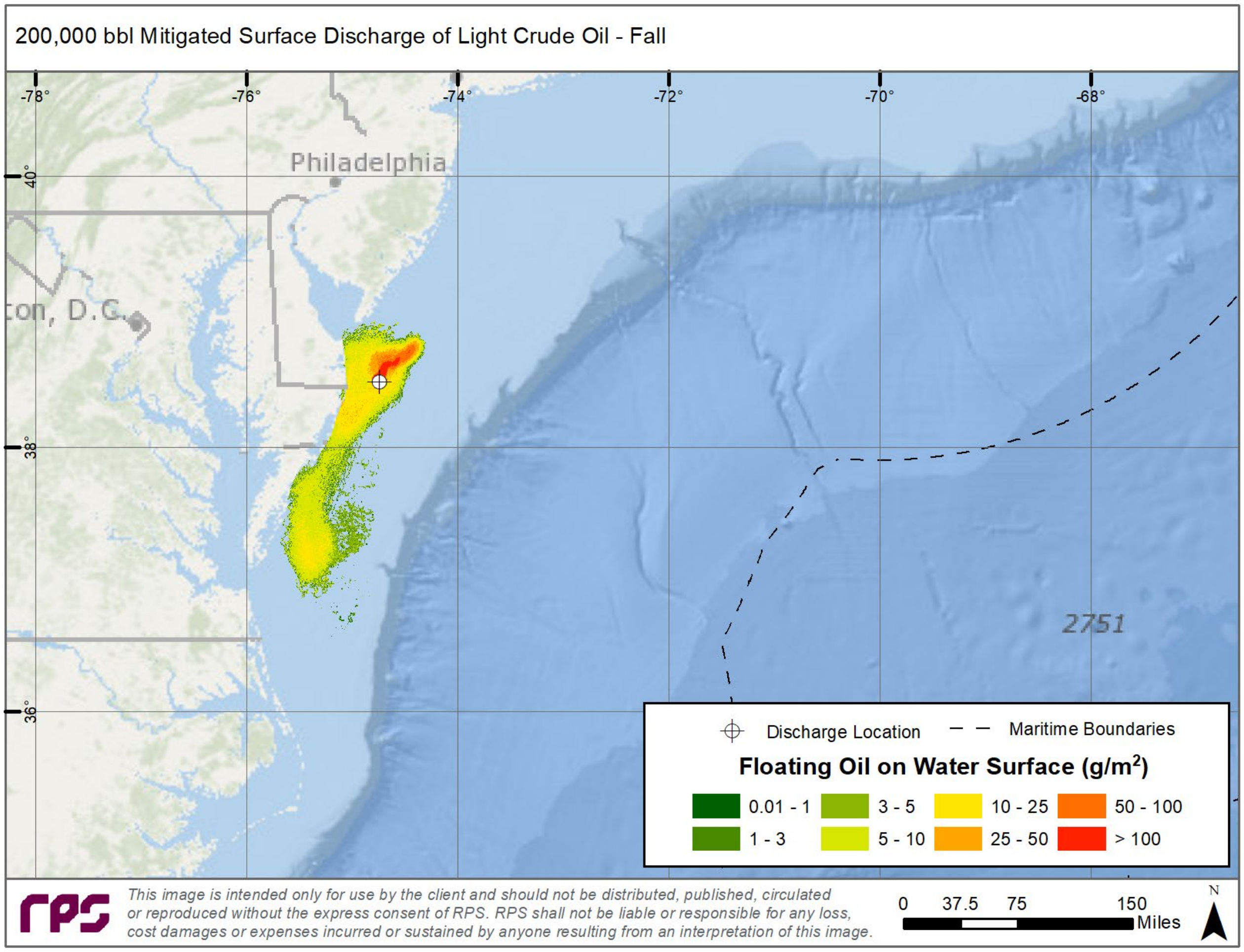


Figure 3-150. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Delaware starting on October 1, 2019.

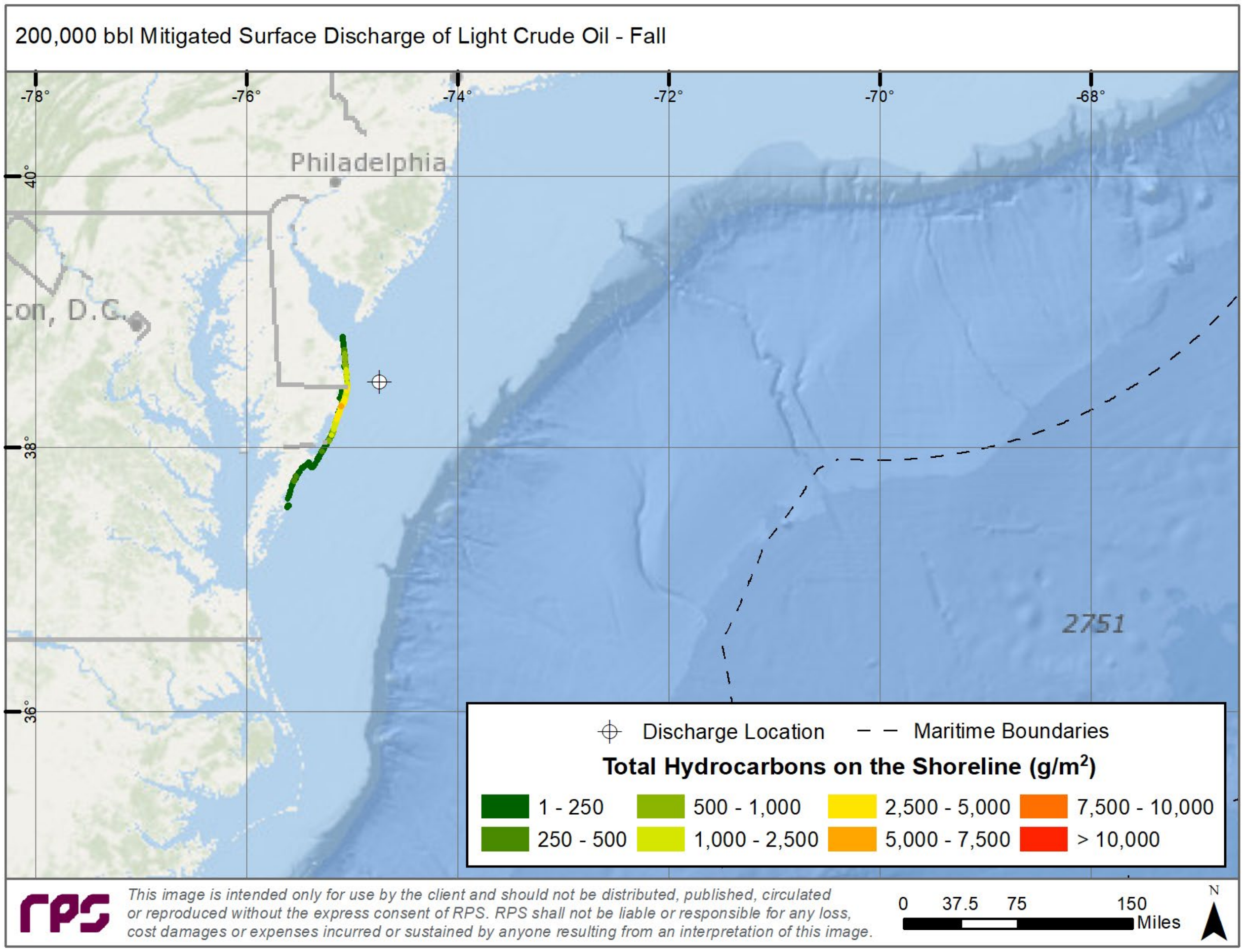


Figure 3-151. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Delaware starting on October 1, 2019.

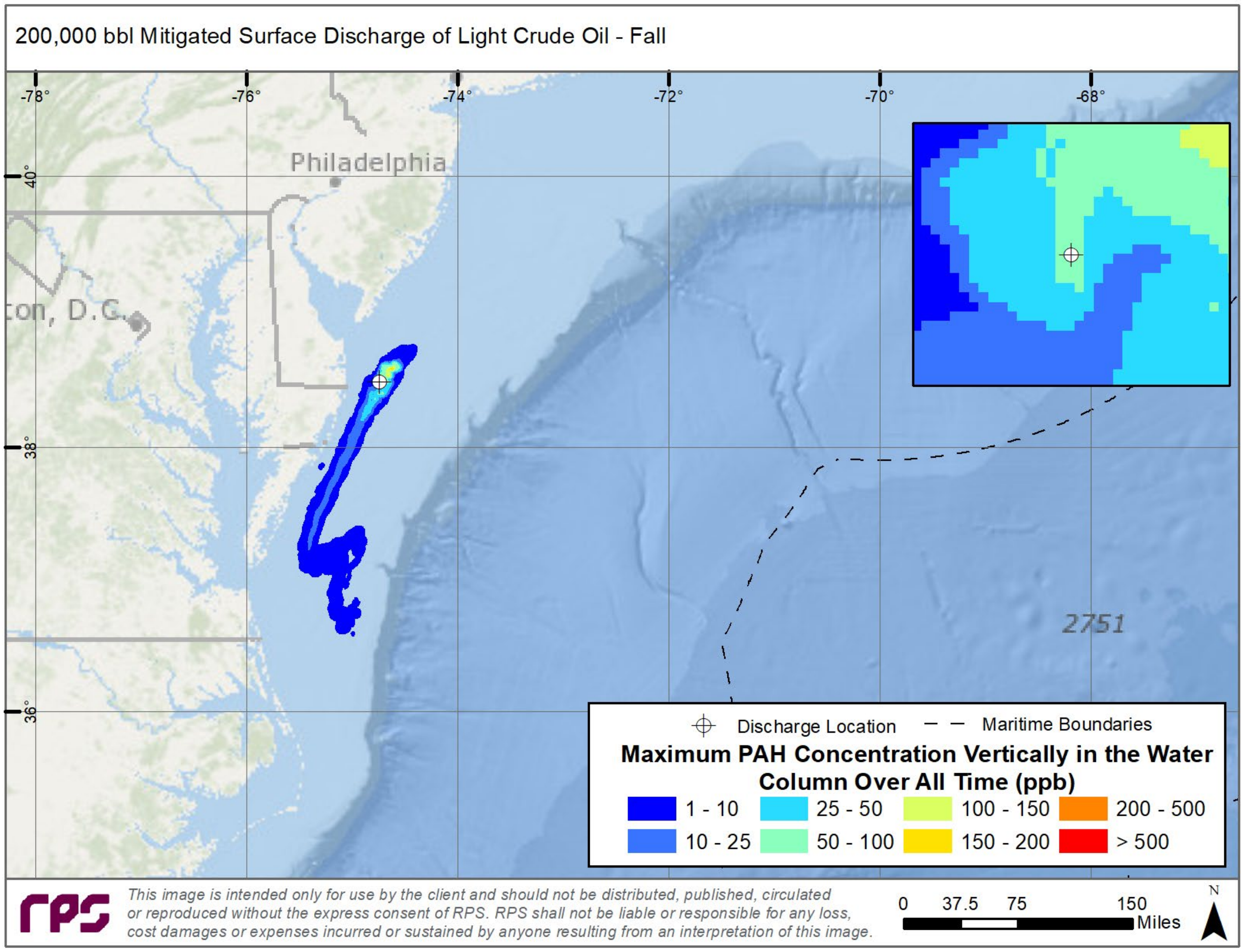


Figure 3-152. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Delaware starting on October 1, 2019.

3.3.1.5 Subsurface Unmitigated Release (Well Blowout)

3.3.1.5.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for shallow water blowout of 30,000 bbl/day crude oil over 30 days (900,000 bbl in total) offshore Delaware started on May 26, 2018. The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Oil evaporated quickly and consistently as it was released over the 30 days. Emulsification of the crude oil to viscosities > 4,000 cP during the first few days upon release limited entrainment into the water to occur only during the high wind events, causing oil to oscillate from within the water column to the surface during periods of high and low winds, as seen in the annual worst-case run for the low and medium-volume spills (Figure 3-156; Figure 3-157). The mass balance (Figure 3-156) shows that released the oil came ashore beginning 19 days after the spill while strong winds (12 m/s; 24 knots) were blowing from the northeast (Figure 3-157). Approximately 47% of the oil evaporated, 19% of the oil reached shore, 4% of the oil remained in the water column, 8% remained on the surface, and approximately 20% of the oil was biodegraded by the end of the 75-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending furthest to the southeast, up to 650 mi (1,046 km) where it reaches the boundary of the model domain. Maximum floating oil on the surface was >100 g/m^2 (100 µm, on average) and extended from the release site to the south and southwest (Figure 3-153). Lower (<25 g/m^2, i.e., patchy oil, emulsions or sheens) maximum surface oil exposure concentrations were predicted to extend into coastal waters to the northwest and southwest, offshore of New Jersey, Maryland, and Virginia. By the end of the 75-day simulation, 638 mi (1,027 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-154; Table 3-11). Seaward sandy beach was the habitat predicted to have the longest length of shoreline oiled (363 mi; 584 km). Shoreline oiling was predicted along the coasts of Delaware, New Jersey, New York, Maryland, Virginia, North Carolina, and Martha's Vineyard, Massachusetts, with the highest concentrations of oil (7,500-10,000 g/m^2) occurring along the southern seaward coast of New Jersey and across Maryland. In total, 1.2 mi^2 (3.1 km^2) of shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-5). Maximum cumulative PAH concentrations for the worst-case run were >500 ppb and remained near the release location and extending to the west and southeast (Figure 3-155). Lower concentrations, between 1-10 ppb, extended approximately 100 mi (161 km) southwest of the release site. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 75-day simulation.

Table 3-11. Shoreline lengths oiled by >1 g/m^2 (1µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on May 26, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**
Rocky shore	2	2	2	3	3	3
Gravel beach	8	8	8	13	13	13
Sand beach	363	363	344	584	584	553
Mudflat	37	37	33	59	59	54
Wetland	6	6	5	10	10	8
Artificial/manmade shoreline	21	21	0	34	34	0
Total	437	437	391	704	704	630

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Landward						
Rocky shore	21	21	19	34	34	31
Gravel beach	10	10	8	15	15	13
Sand beach	31	31	28	51	50	45
Mudflat	47	44	22	75	72	35
Wetland	61	60	30	98	96	48
Artificial/manmade shoreline	31	31	0	50	50	0
Total	201	197	106	323	317	171
All Shorelines						
Total	638	634	497	1,027	1,021	800

Table 3-2 shows the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-158 to Figure 3-166 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In the winter, oil is primarily transported east into waters further offshore, with relatively low concentrations of shoreline oiling predicted along Delaware, New Jersey, and Maryland coasts. In the spring, oil is transported concentrically around the release site, with highest concentrations predicted primarily northwest in waters offshore of Delaware, New Jersey, and New York. Shoreline oiling was predicted along mainland coastlines of Delaware, New Jersey, New York, Maryland, and Virginia, as well as islands offshore of Rhode Island and Massachusetts. During the worst-case run to occur in the fall, the highest concentrations of surface oil occur to the west of the release site, with lower concentrations extending south and east, over to 650 mi (1,046 km) from the release site. Shoreline oiling >1 g/m^2 occurred along the Delaware, New Jersey, Virginia, and North Carolina coasts.

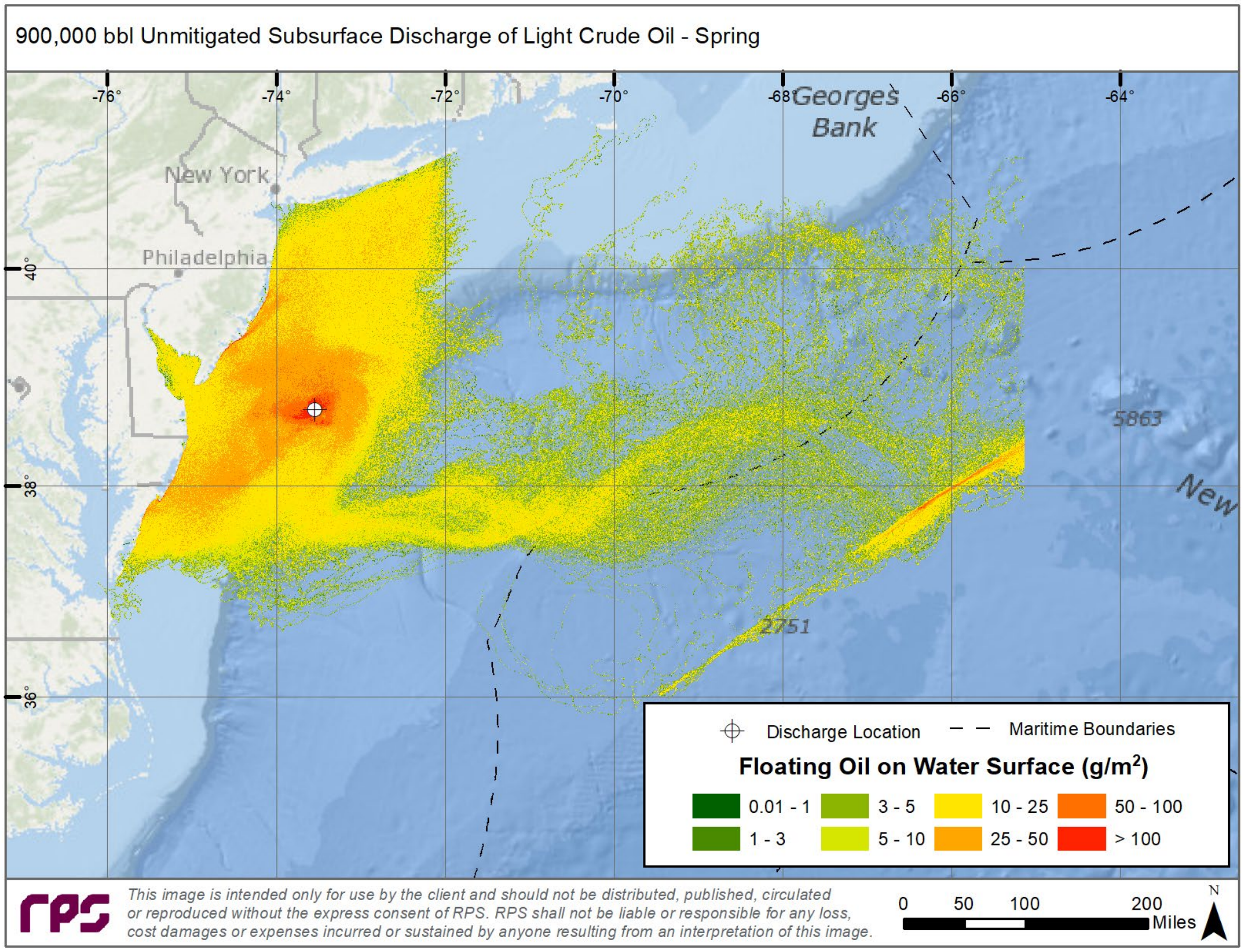


Figure 3-153. Maximum water surface oil exposure concentration at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on May 26, 2018.

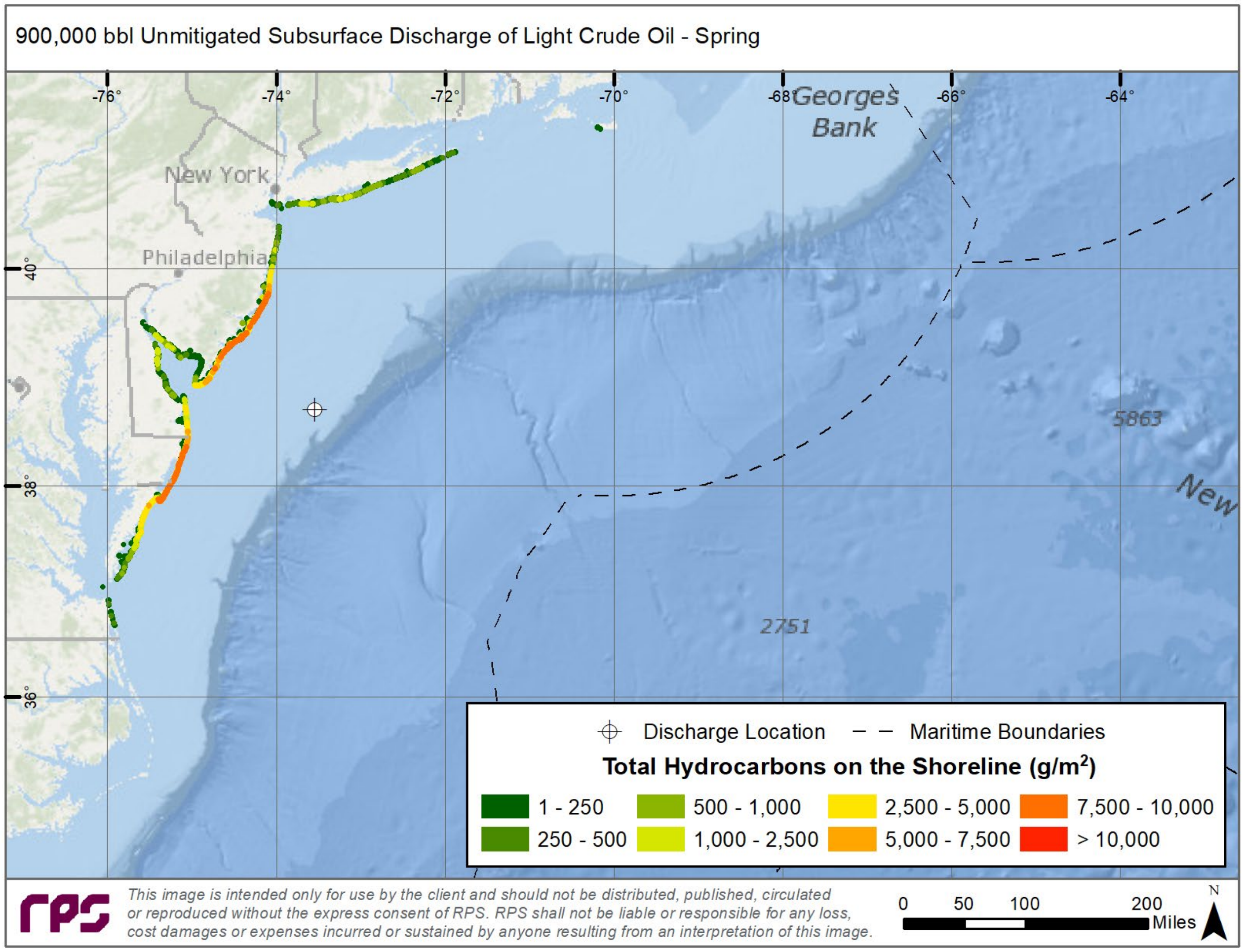


Figure 3-154. Maximum shoreline oil concentration at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled(on an annual basis, in spring), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on May 26, 2018.

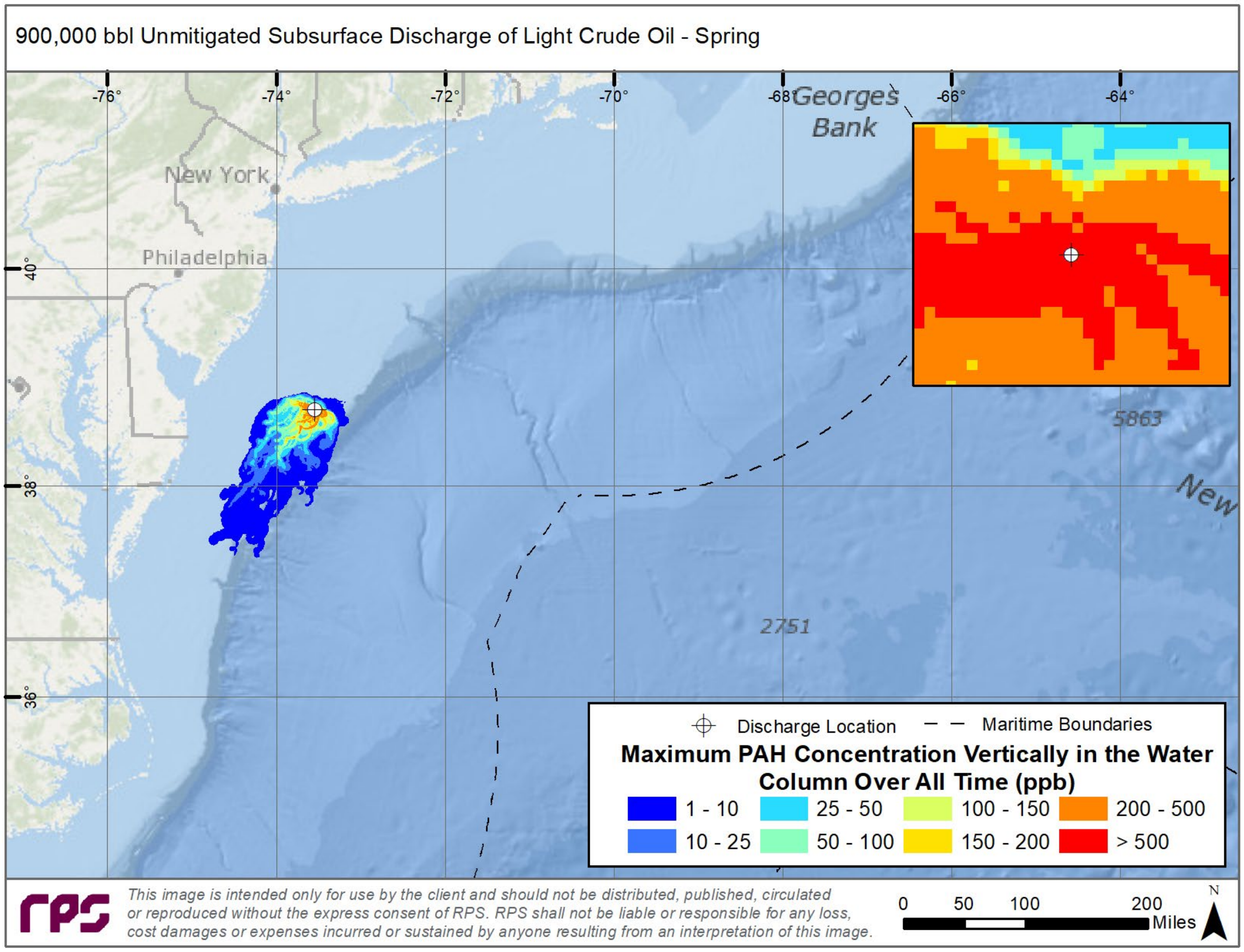


Figure 3-155. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on May 26, 2018.

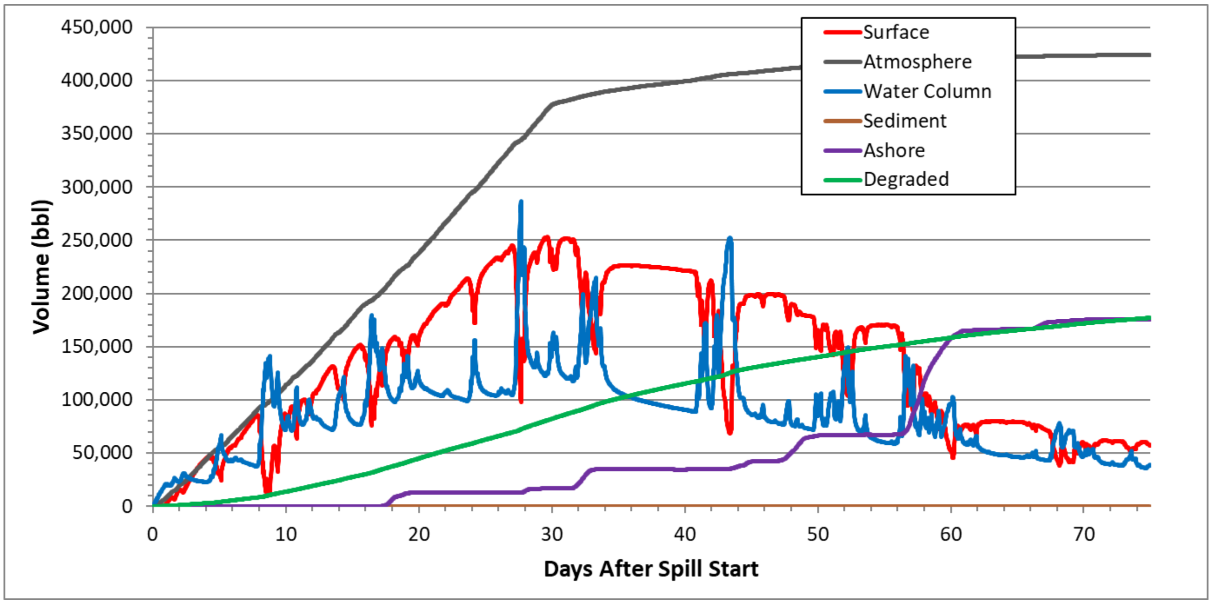


Figure 3-156. Oil volume by environmental compartment over time for an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on May 26, 2018.

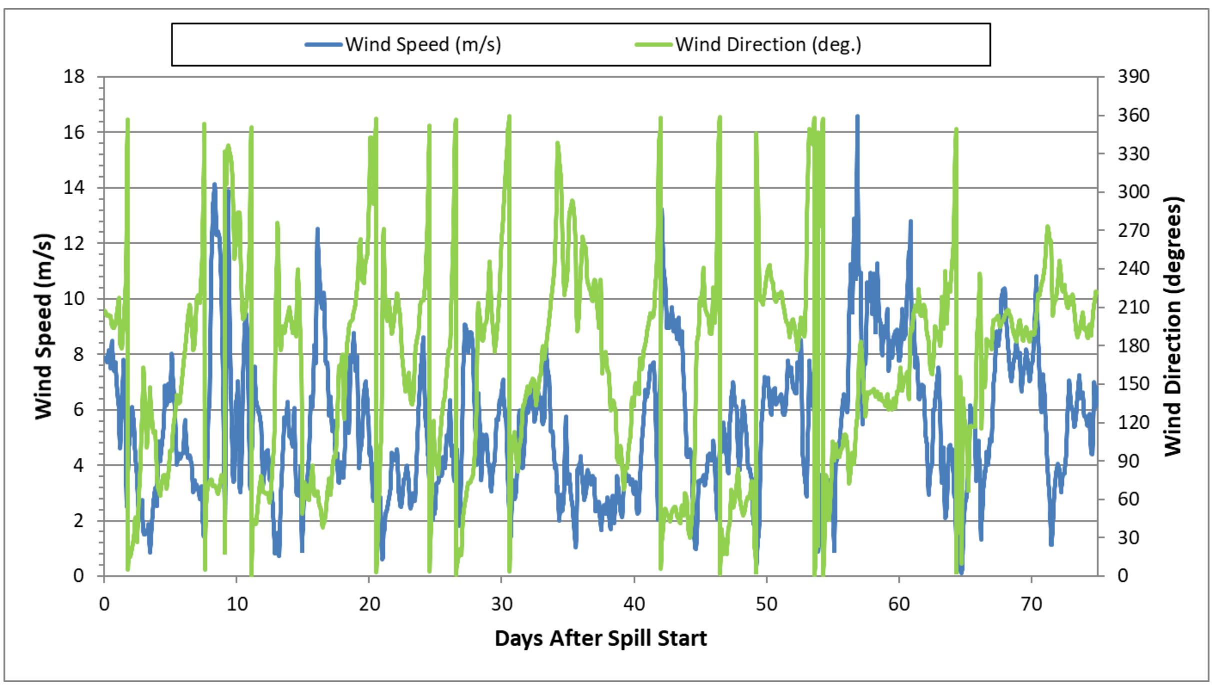


Figure 3-157. Wind speeds (1 m/s = 2 knots) and directions during the unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on May 26, 2018.

3.3.1.5.2 Seasonal Worst-Case Runs

Winter

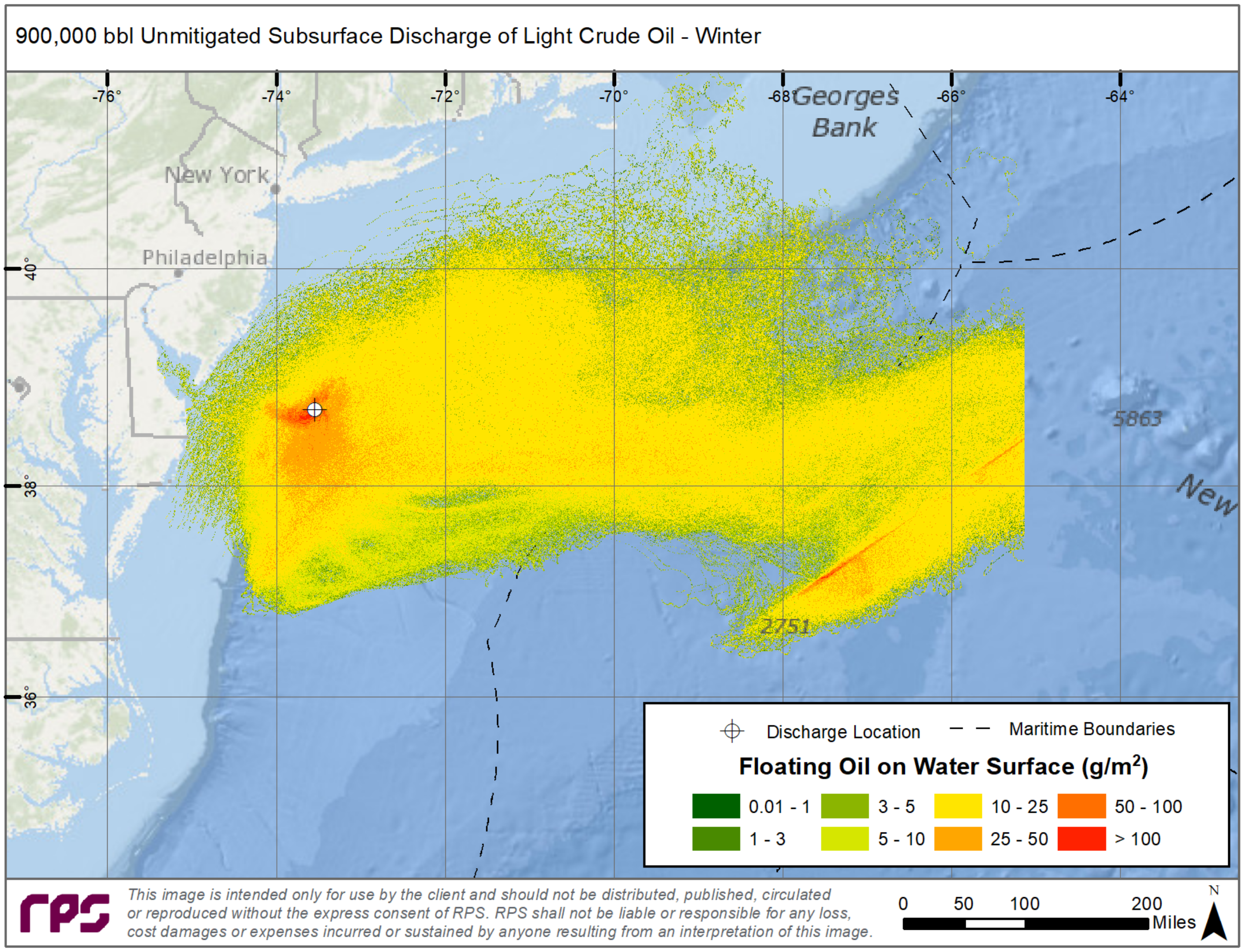


Figure 3-158. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on February 28, 2019.

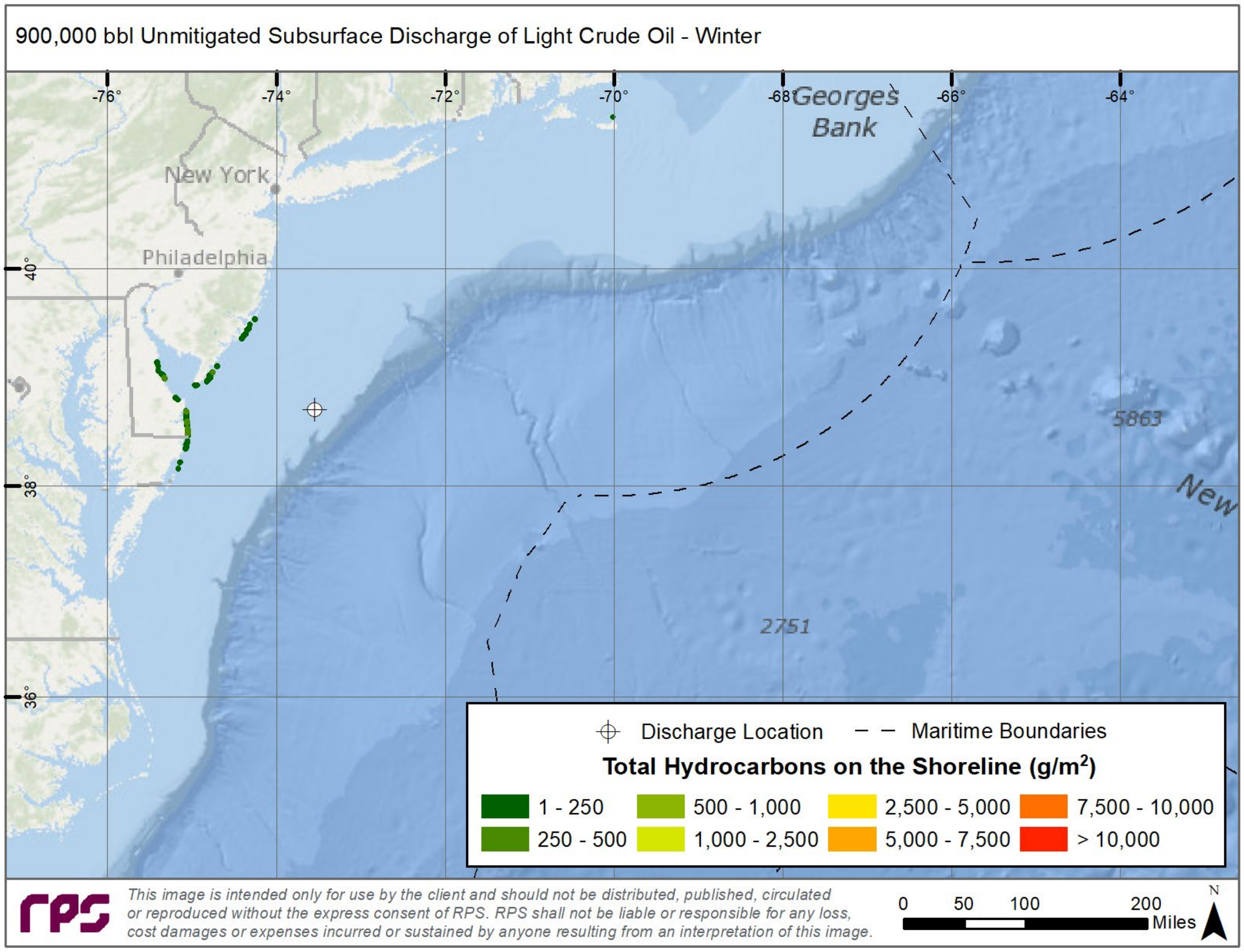


Figure 3-159. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on February 28, 2019.

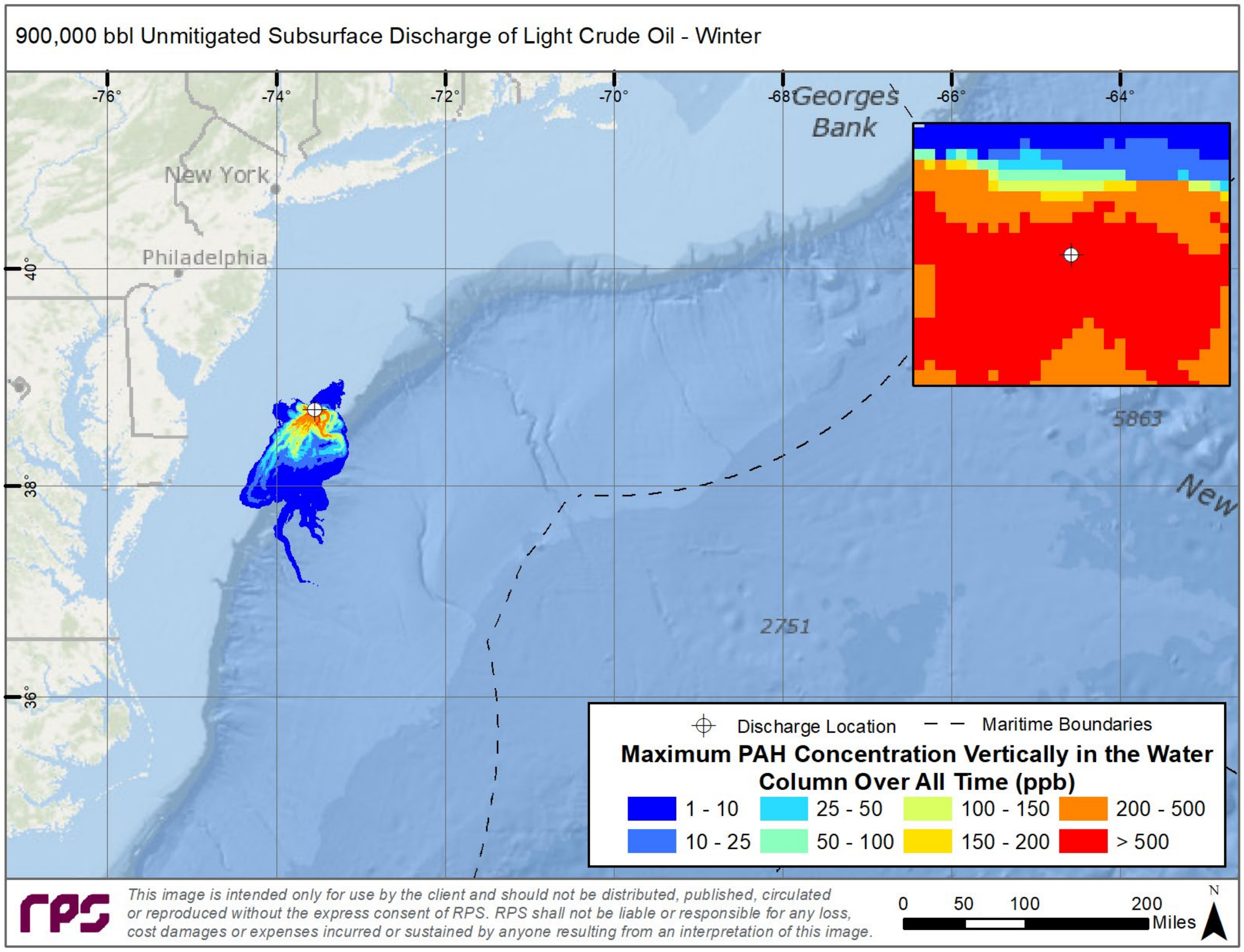


Figure 3-160. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on February 28, 2019.

Summer

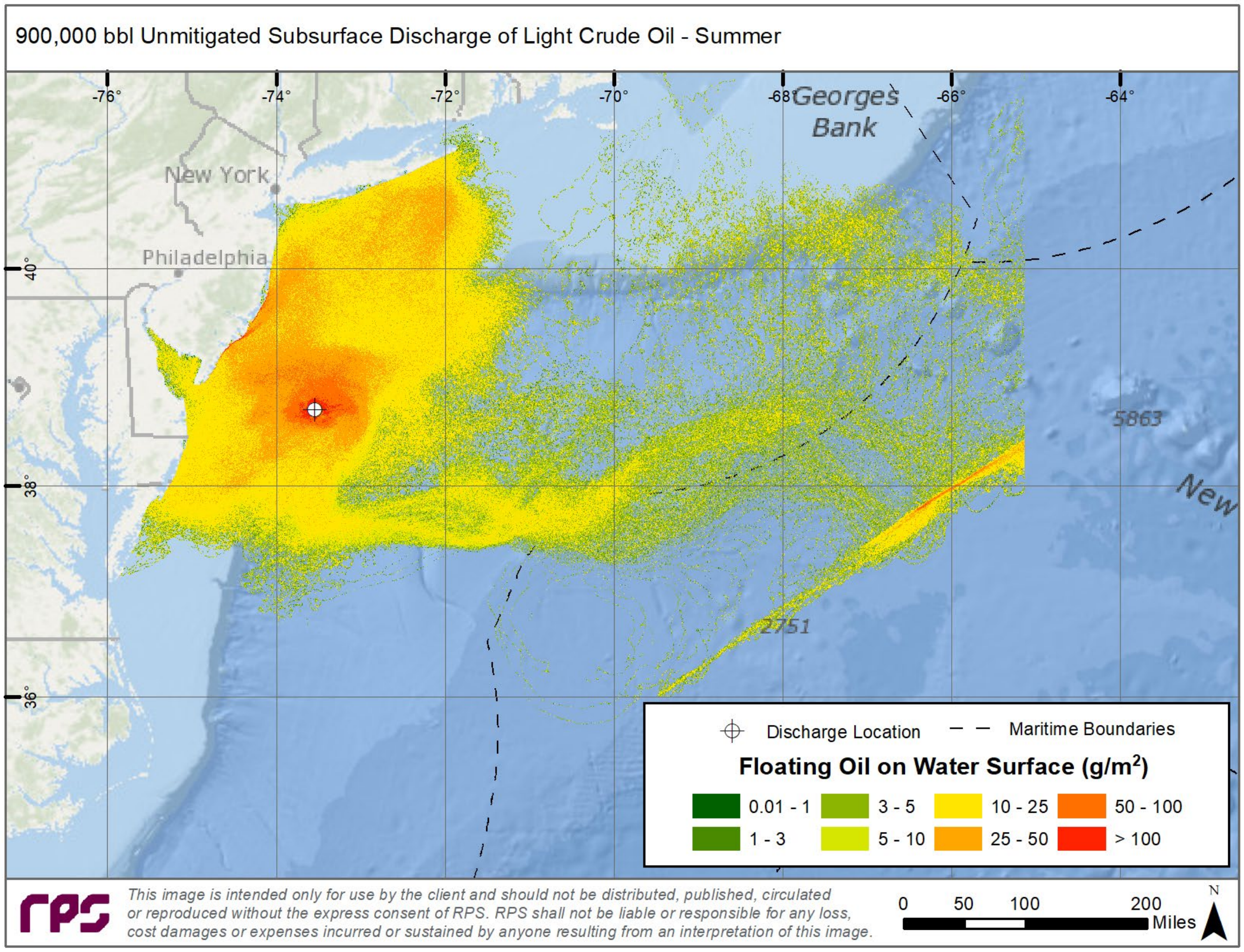


Figure 3-161. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on June 2, 2018.

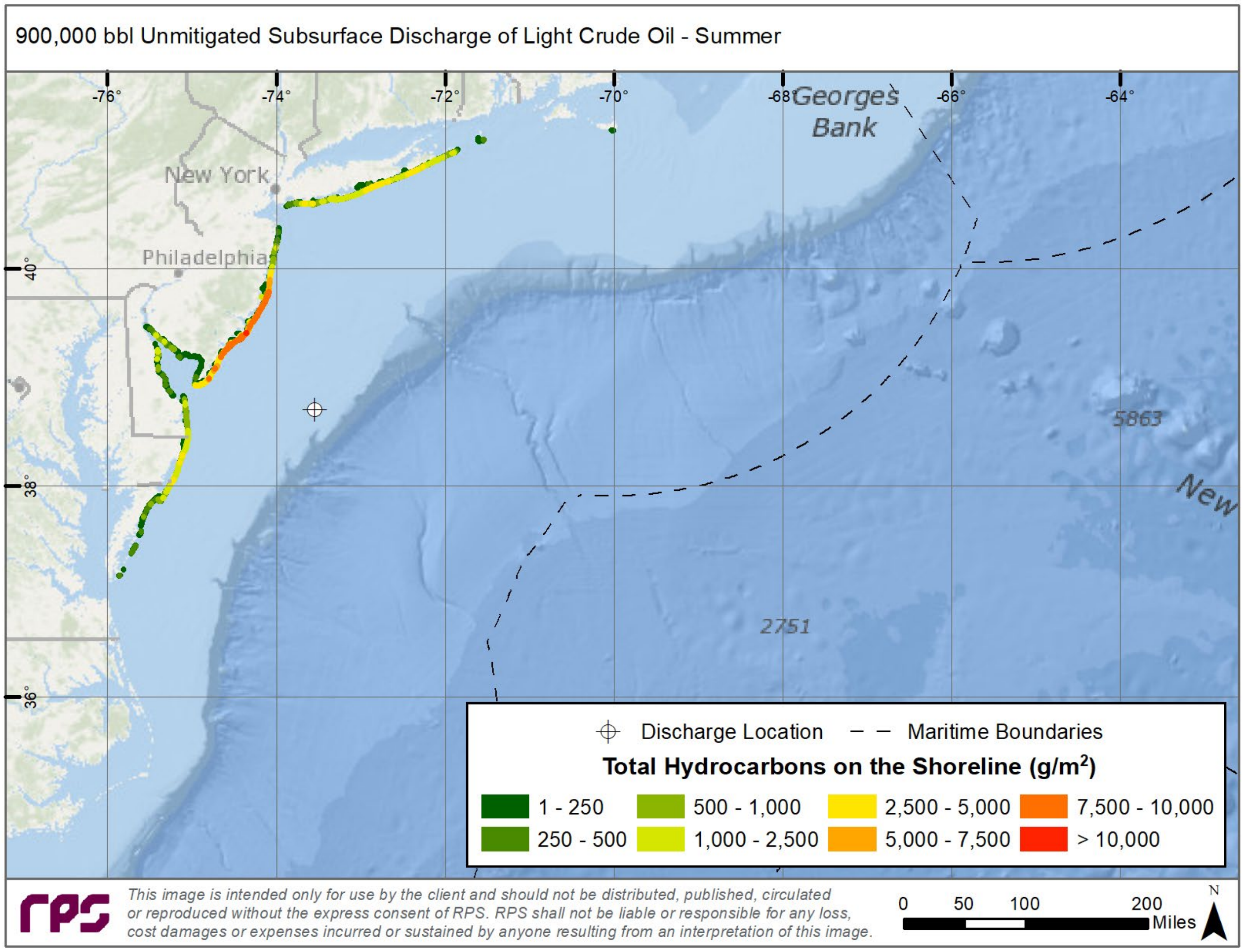


Figure 3-162. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on June 2, 2018.

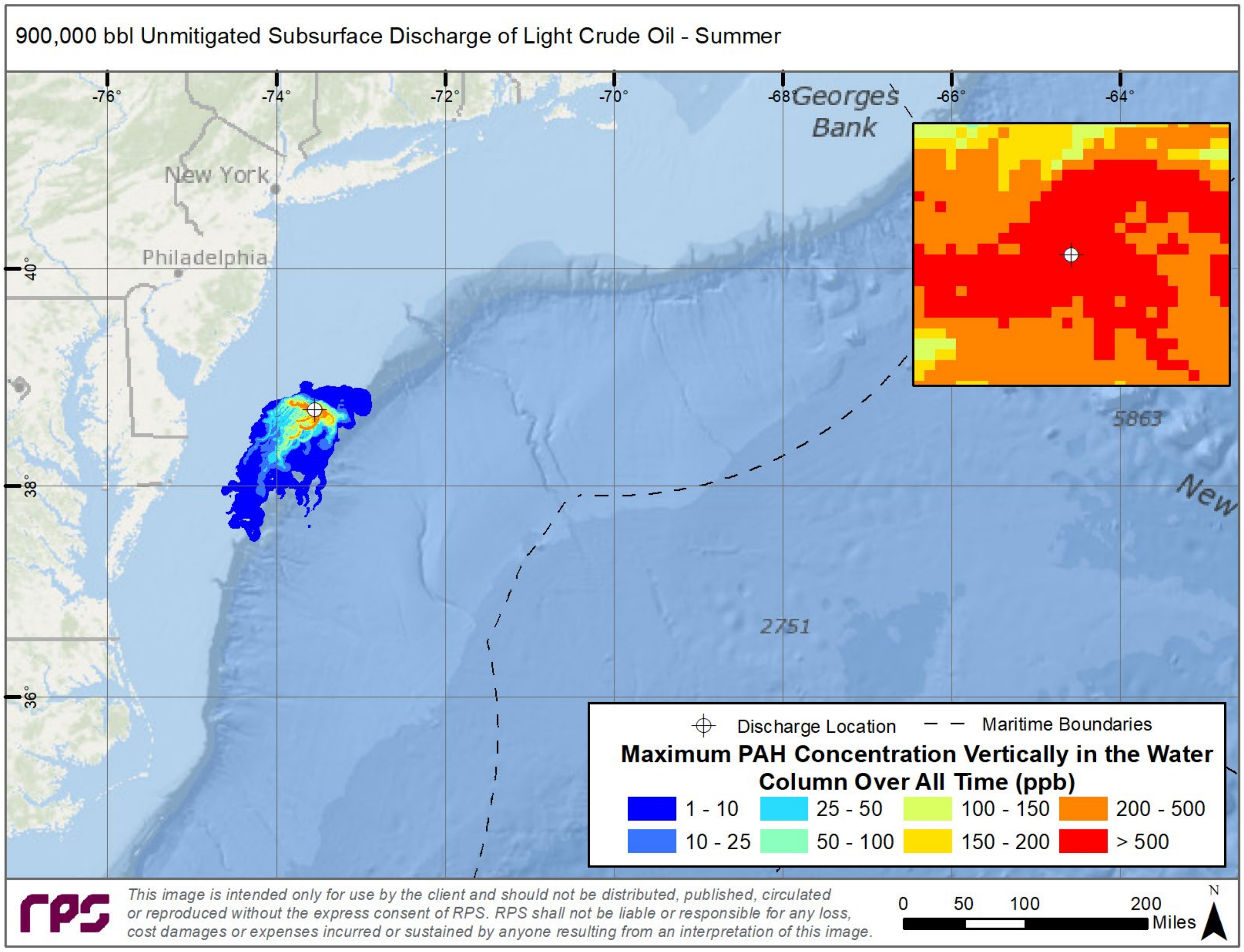


Figure 3-163. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on June 2, 2018.

Fall

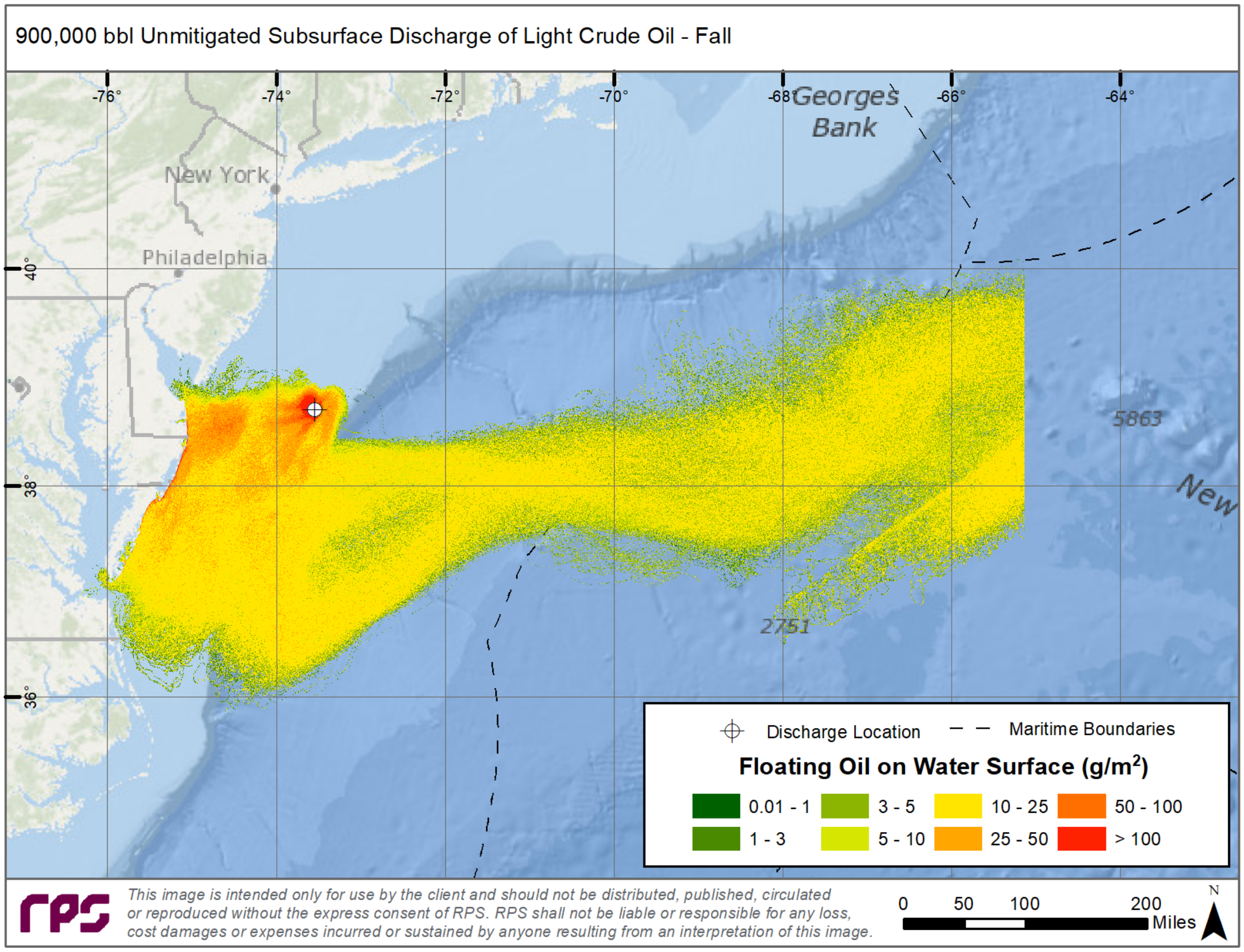


Figure 3-164. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on September 1, 2018.

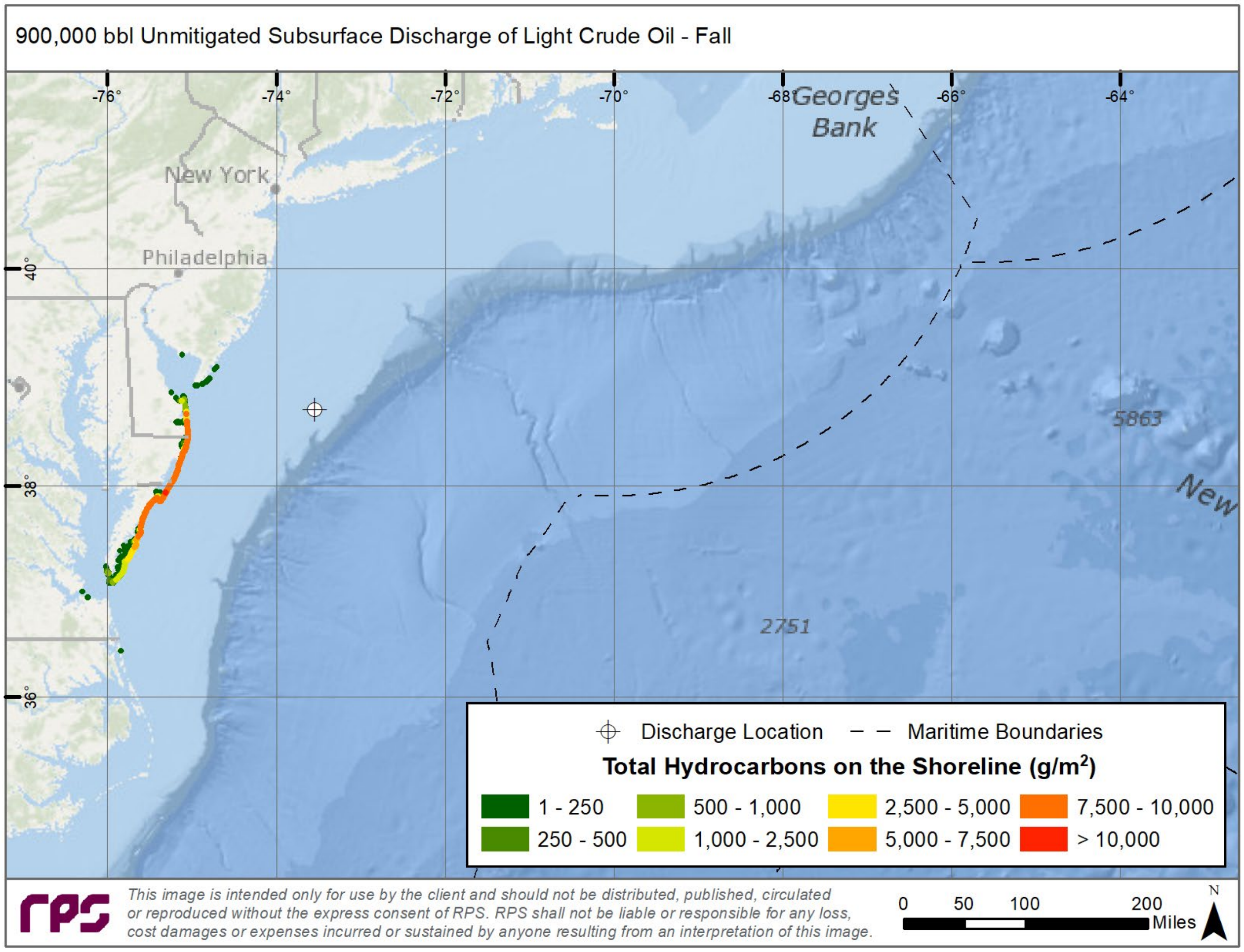


Figure 3-165. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on September 1, 2018.

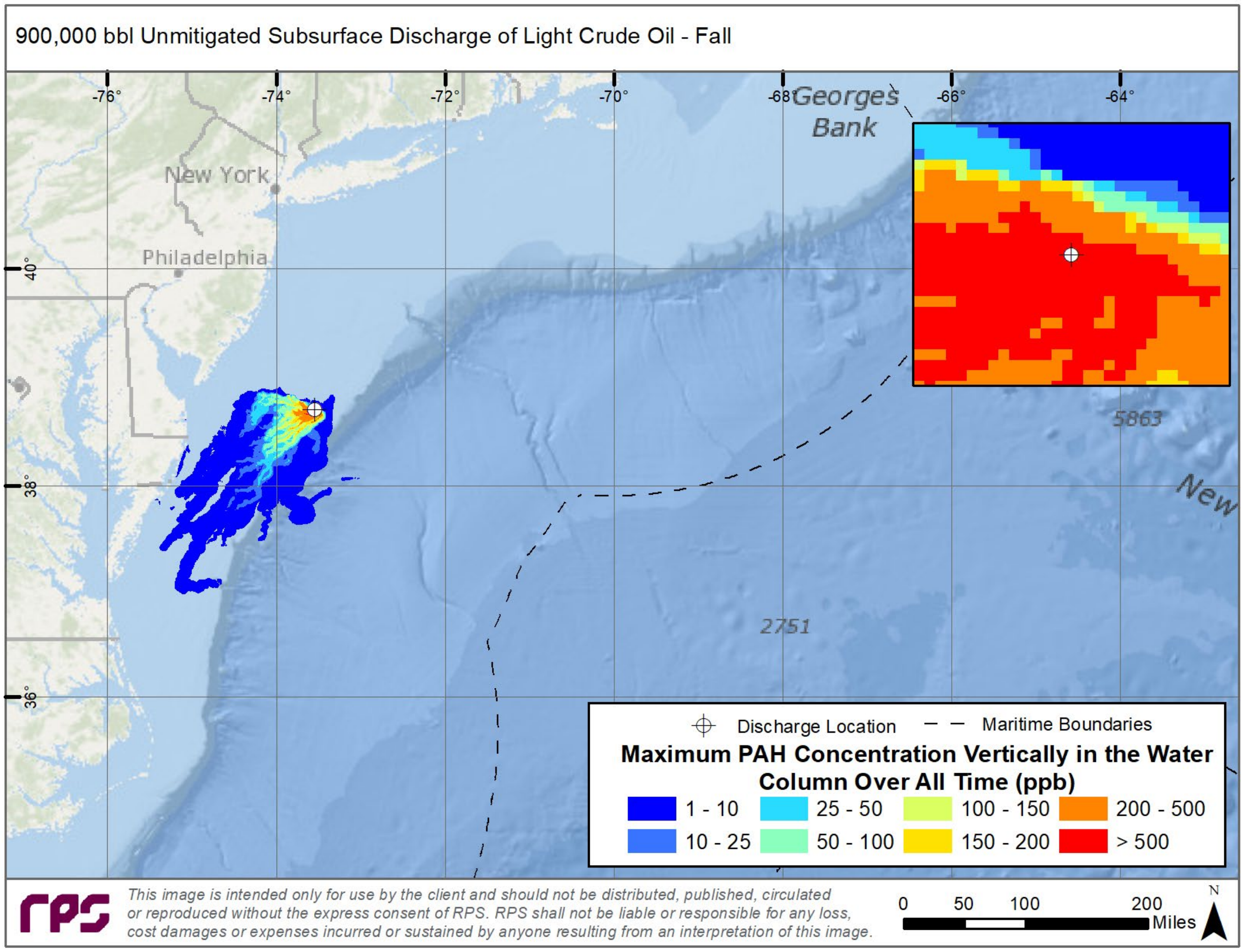


Figure 3-166. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Delaware starting on September 1, 2018.

3.3.2 Offshore New Jersey

The spill locations used for modeling in New Jersey waters were a high vessel traffic area offshore New Jersey at 40.1113°N, 73.8329°W (vessel releases) and Hudson Canyon at 39.2658°N, 73.1658°W (blowout) (Figure 2-2). The annual and seasonal worst-case runs were selected based on the longest length of shoreline oiling (>1.0 g/m^2) and model start dates are presented in Table 3-12.

Table 3-12. Modeled start dates for the runs offshore New Jersey with worst case shoreline oiling on an annual basis and for each of four seasons. The annual worst case for each scenario is presented with an "*" and bolded.

Scenario ID	Spill Site	Spill Event	Spill Volume	Start Date of Worst Case
1	Offshore New Jersey	Surface Unmitigated 126 bbl Release During Winter	Low	12/7/2018
2		Surface Unmitigated 126 bbl Release During Spring	Low	**5/1/2018***
3		Surface Unmitigated 126 bbl Release During Summer	Low	8/28/2019
4		Surface Unmitigated 126 bbl Release During Fall	Low	9/28/2019
5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	12/7/2018
6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	**5/1/2018***
7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	8/28/2019
8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	9/28/2019
9		Surface Unmitigated 200k bbl Release During Winter	High	12/7/2018
10		Surface Unmitigated 200k bbl Release During Spring	High	**5/1/2018***
11		Surface Unmitigated 200k bbl Release During Summer	High	7/21/2018
12		Surface Unmitigated 200k bbl Release During Fall	High	9/13/2018
13		Surface Mitigated 200k bbl Release During Winter	High	12/7/2018
14		Surface Mitigated 200k bbl Release During Spring	High	**5/1/2018***
15		Surface Mitigated 200k bbl Release During Summer	High	7/21/2018
16		Surface Mitigated 200k bbl Release During Fall	High	9/13/2018
17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/28/2019
18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	**5/21/2018***
19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	8/9/2019
20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2018

Table 3-13 summarizes the final mass balance of the spilled oil at the end of the 30- or 75-day simulations for the Delaware location surface and blowout modeling scenarios, respectively. In all surface release cases, almost half of the released oil evaporated within the first five days of the release.

Table 3-13. Mass balance at the end of the simulation for the worst-case run for shoreline oiling (on an annual basis) for each of the five scenarios at the New Jersey release locations.

Spill Scenario	Season	Percent of Oil by End of Simulation				
		Surface	Atmos-phere	Shore-line	Water	Degraded
Low Volume	Spring	2	53	30	6	9
Medium Volume	Spring	2	51	31	6	10
High Volume (unmitigated)	Spring	4	46	28	9	13
High Volume (mitigated)[a]	Spring	<1%	44	11	9	12.8
Blowout[b]	Spring	10	49	17	4	18

[a]23% of released oil removed via response methods.
[b]2% of released oil left model domain in which it was no longer tracked.

The length of shoreline oiled by habitat type and area of shoreline oiled inside and outside of Delaware for each of the New Jersey location annual worst-case scenarios, including an unmitigated and mitigated trajectory for the high-volume surface release, is presented in Table 3-14 and Table 3-15. Shoreline oiling was consistently at a maximum for cases that began in the spring, with the worst-case run for the three vessel releases occurring in May of 2018. Table 3-16 summarizes the water column exposure results for all four worst-case scenarios and the mitigated high-volume release. Note that the PAH concentrations in the water column are highly variable in space and over time. Thus, durations of exposure are summarized to give some sense of the ephemeral nature of the exposures above thresholds of concern. PAH exposure in the water column and max exposure time increase with spill volume in the unmitigated cases, with exposures at the most conservative threshold dissipating within 2 hours during the low volume release and 31 hours during the medium volume release. The degree of exposure to PAH within the water column is similar in the unmitigated and mitigated high-volume case, however, exposure time to higher concentrations >10 ppb was longer with the use of response.

Table 3-14. Shoreline lengths oiled by >1 g/m^2 for the run with maximum shoreline length oiled (on an annual basis), for each New Jersey spill scenario.

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Summer	140	51	0	226	82	0
Medium Volume	Summer	218	161	43	351	259	70
High Volume (unmitigated)	Summer	307	305	215	494	491	347
High Volume (mitigated)	Summer	191	190	135	307	305	217

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m²	>10g/m²	>100g/m²	>1g/m²	>10g/m²	>100g/m²
Blowout	Spring	530	527	400	854	848	643

Table 3-15. Shoreline area oiled by >1 g/m² inside and outside of the Delaware state territory for the run with maximum shoreline length oiled (on an annual basis), for each New Jersey spill scenario.

Spill Scenario	Location	Length Oiled (mi²)			Length Oiled (km²)		
		>1g/m²	>10g/m²	>100g/m²	>1g/m²	>10g/m²	>100g/m²
Low Volume	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	0.0	0.2	0.7	1.9	0.4	0.0
Medium Volume	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	0.3	0.9	1.2	3.1	2.2	0.7
High Volume (unmitigated)	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	2.0	3.9	4.0	10.4	10.1	5.2
High Volume (mitigated)	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	1.1	1.8	1.9	5.0	4.7	2.8
Blowout	Delaware	1.1	1.5	1.5	4.0	4.0	2.9
	Outside	7.3	11.1	11.4	29.5	28.7	19.0

Table 3-16. Modeling results of dissolved PAH exposures in the water column for the four worst-case for shoreline oiling scenarios (by spill volume) for a release offshore of New Jersey. (One km³ is equivalent to 1 billion m³ and 1.3 billion cubic yards.)

	Low	Medium	High		Blowout
			Unmitigated	Mitigated	
Volume contaminated >1 ppb (km³)*	0.0001	0.1	10	10	33
Volume contaminated >10 ppb (km³)*	0	0.0005	2	2	6
Max Exposure Time >1 ppb (hours)**	2	31	662	538	977
Max Exposure Time >10 ppb (hours)**	0	2	177	263	770

* Volume of water which exceeded 1 ppb and 10 ppb at any given time
** Maximum number of hours with exposure concentrations >1 or 10 ppb

3.3.2.1 Surface Unmitigated Release (Low Volume)

3.3.2.1.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a low-volume surface release of 126 bbl crude oil offshore Delaware started on May 1, 2018. Only a thin layer of oil (0.01-1 g/m^2) was predicted to occur on the water surface until it evaporated, went ashore or degraded (Figure 3-167). The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Just under half of the oil released at the surface evaporated quickly, within in the first 5 days. Emulsification of the crude oil to viscosities >4,000 cP during the first few days of the release limited entrainment into the water to occur only during the high wind events (Figure 3-170 and Figure 3-171). The mass balance (Figure 3-170) shows that much of the released oil came ashore 14 days after the spill while strong winds (>11 m/s; 22 knots) were blowing from the northeast (Figure 3-171). Approximately 53% of the oil evaporated, 30% of the oil reached shore, 6% of the oil remained in the water column, 2% remained on the surface and approximately 9% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted northeast, towards Long Island, New York, and east into open waters. The maximum surface oil exposure concentration was between 0.01-1 g/m^2 (which would appear as a scattered colorless sheen or dark brown/metallic sheen; French McCay et al. 2011; French McCay et al. 2012; French McCay 2016) (Figure 3-167). By the end of the 30-day simulation, 140 mi (225 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-168; Table 3-17). Most of the oiled shoreline was seaward sandy beach (102 mi; 171 km) along the coasts of New Jersey and New York. No shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-15). Maximum cumulative PAH concentrations for the worst-case run did not exceed the threshold of 1 ppb (Figure 3-169). As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-17. Shoreline lengths oiled by >1 g/m^2 (1 µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated 126 bbl surface release of crude oil offshore of New Jersey starting on May 1, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	107	24	0	171	39	0
Mudflat	4	1	0	7	1	0
Wetland	0	0	0	0	0	0

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Artificial/manmade shoreline	16	16	0	26	26	0
Total	127	41	0	205	66	0
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	4	1	0	6	2	0
Mudflat	0	0	0	0	0	0
Wetland	0	0	0	0	0	0
Artificial/manmade shoreline	9	9	0	14	14	0
Total	13	10	0	21	16	0
All Shorelines						
Total	140	51	0	226	82	0

Table 3-12 shows the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-172 to Figure 3-180 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In winter and summer oil is transported south, with much of the shoreline oiling occurring along the coasts of New Jersey in the winter and New Jersey, Delaware, and Maryland in the summer. In the fall, oil is transported north into nearshore waters and along the coastlines of mid-New Jersey and Long Island Sound.

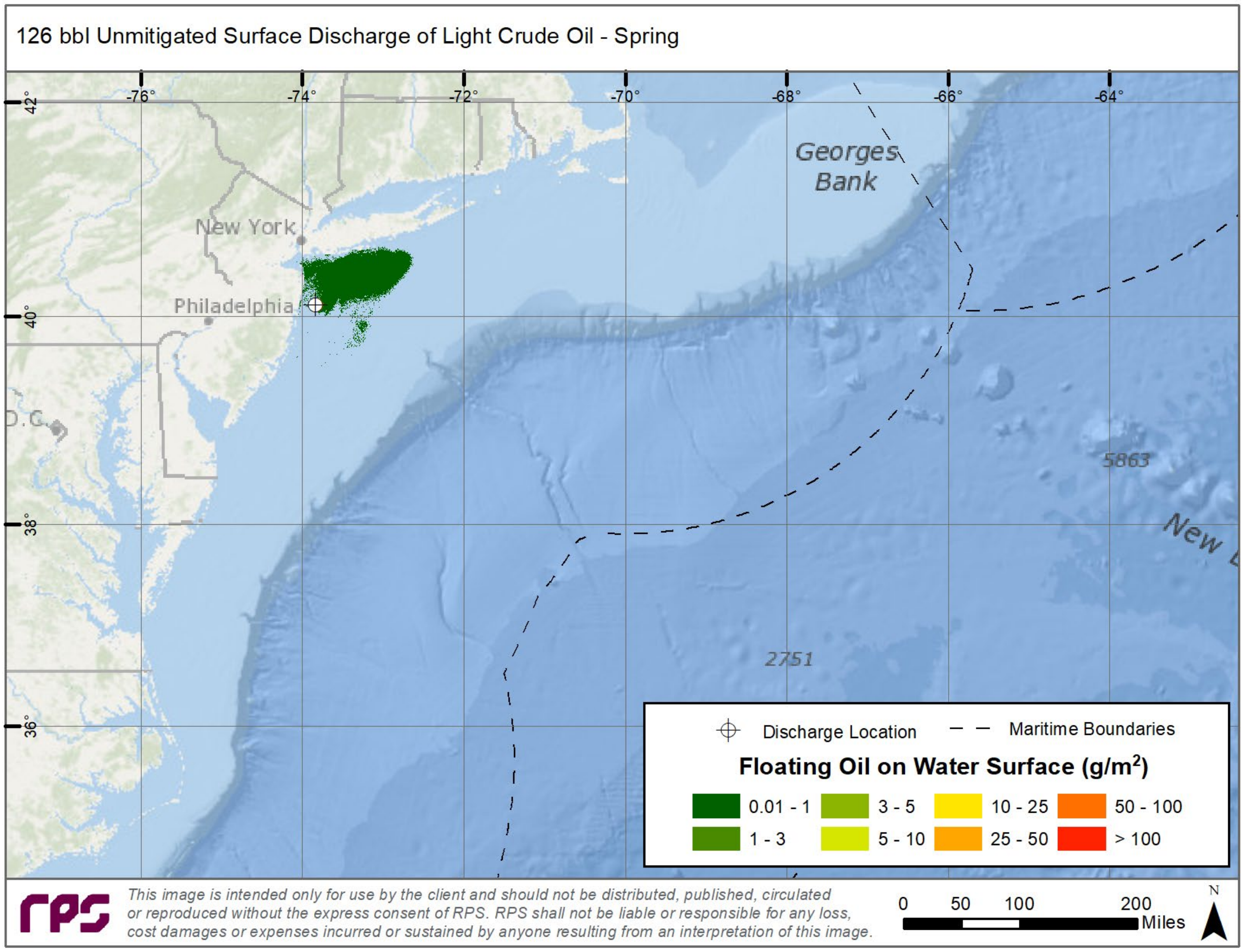


Figure 3-167. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore New Jersey starting on May 1, 2018.

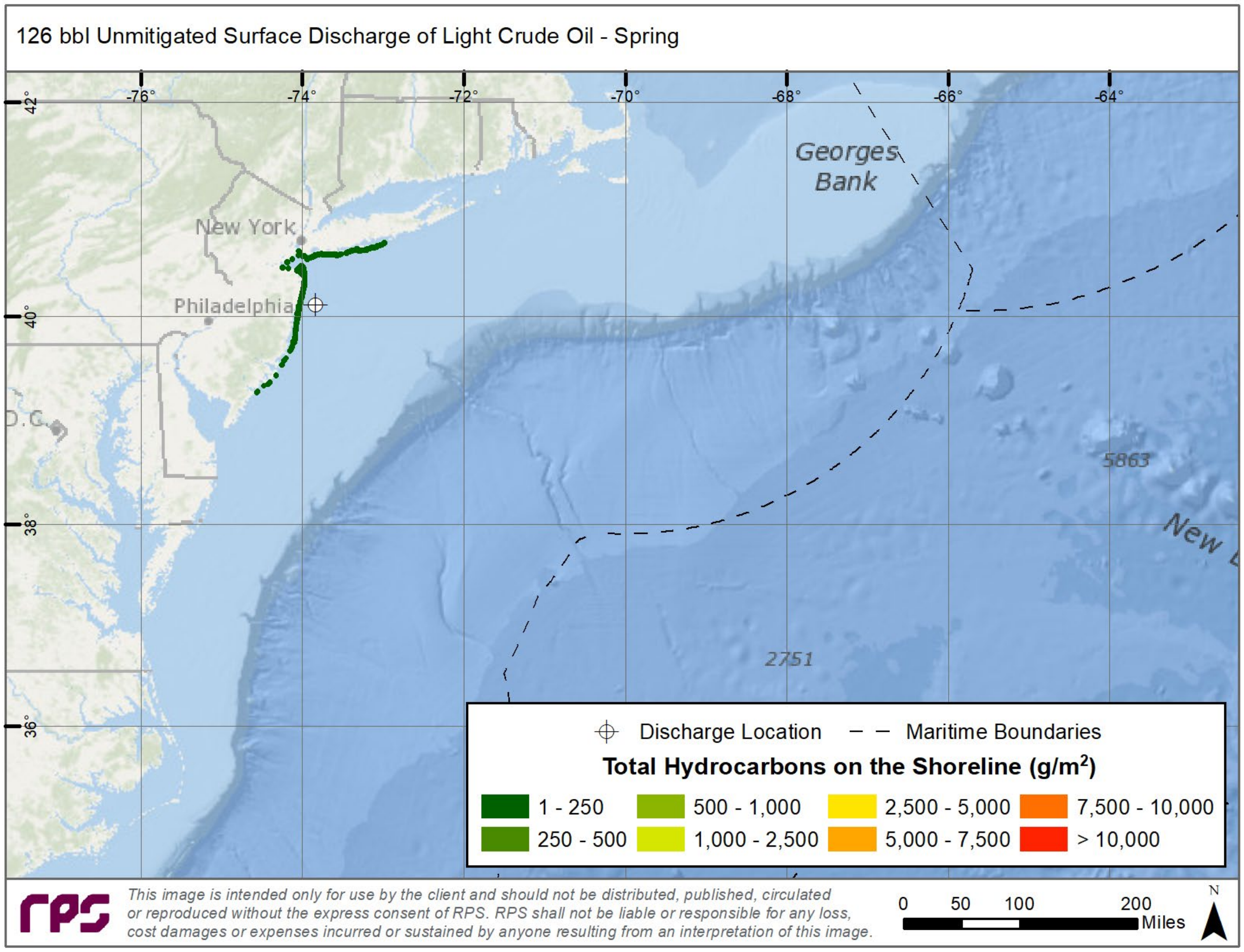


Figure 3-168. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore New Jersey starting on May 1, 2018.

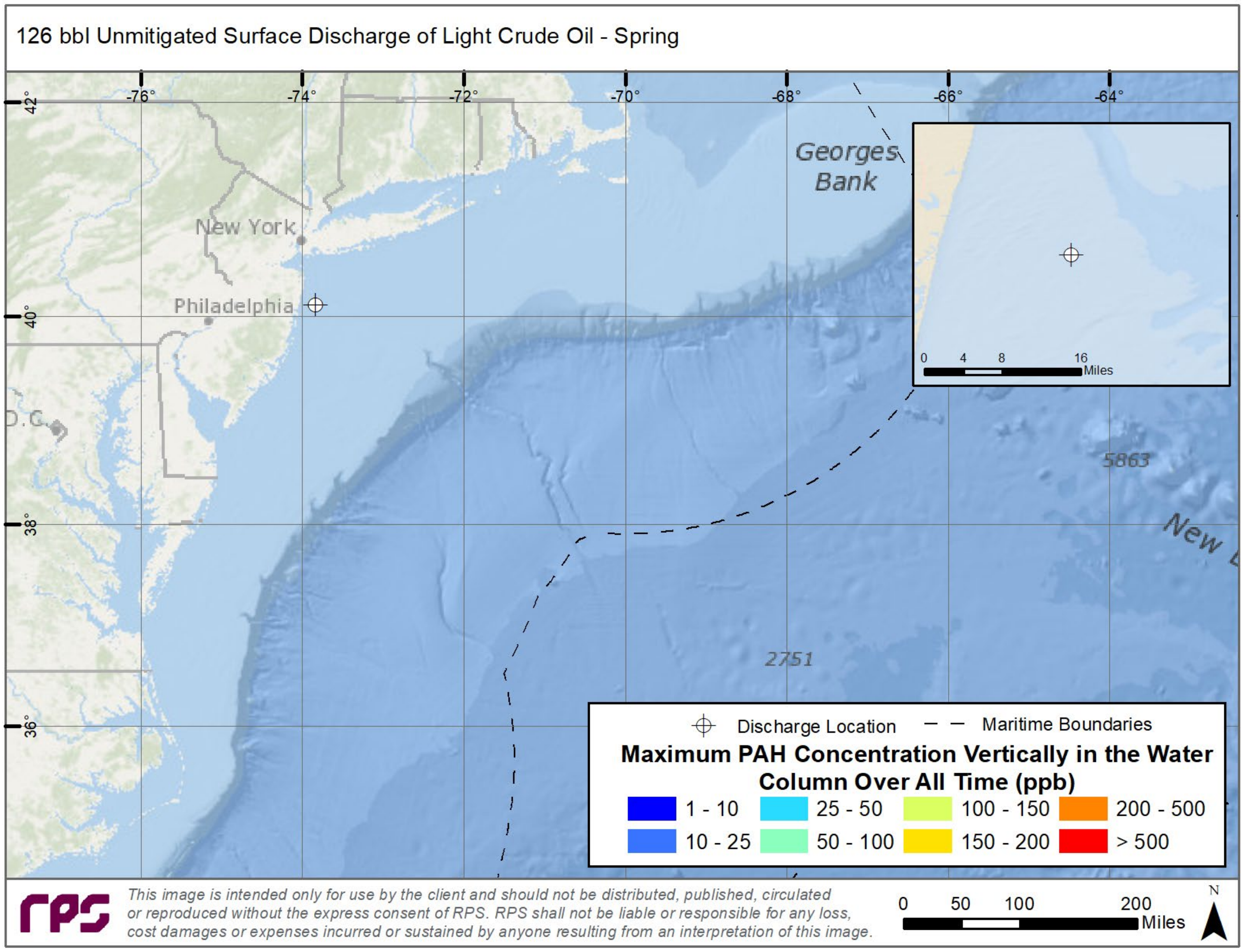


Figure 3-169. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore New Jersey starting on May 1, 2018.

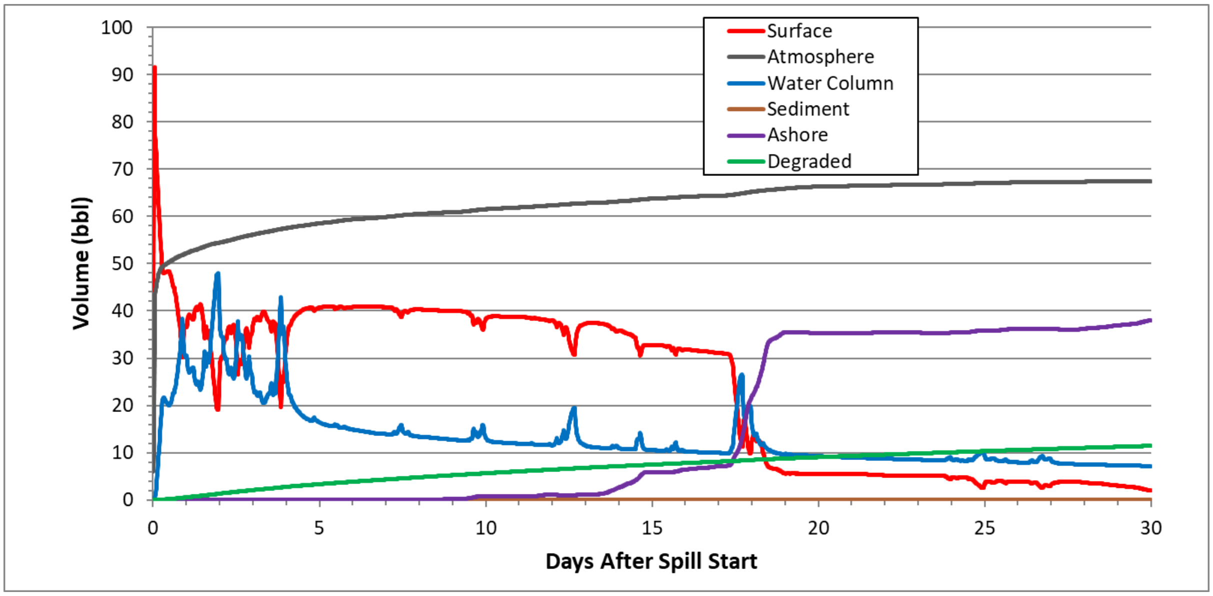


Figure 3-170. Oil volume by environmental compartment over time for a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl surface release of crude oil offshore New Jersey starting on May 1, 2018.

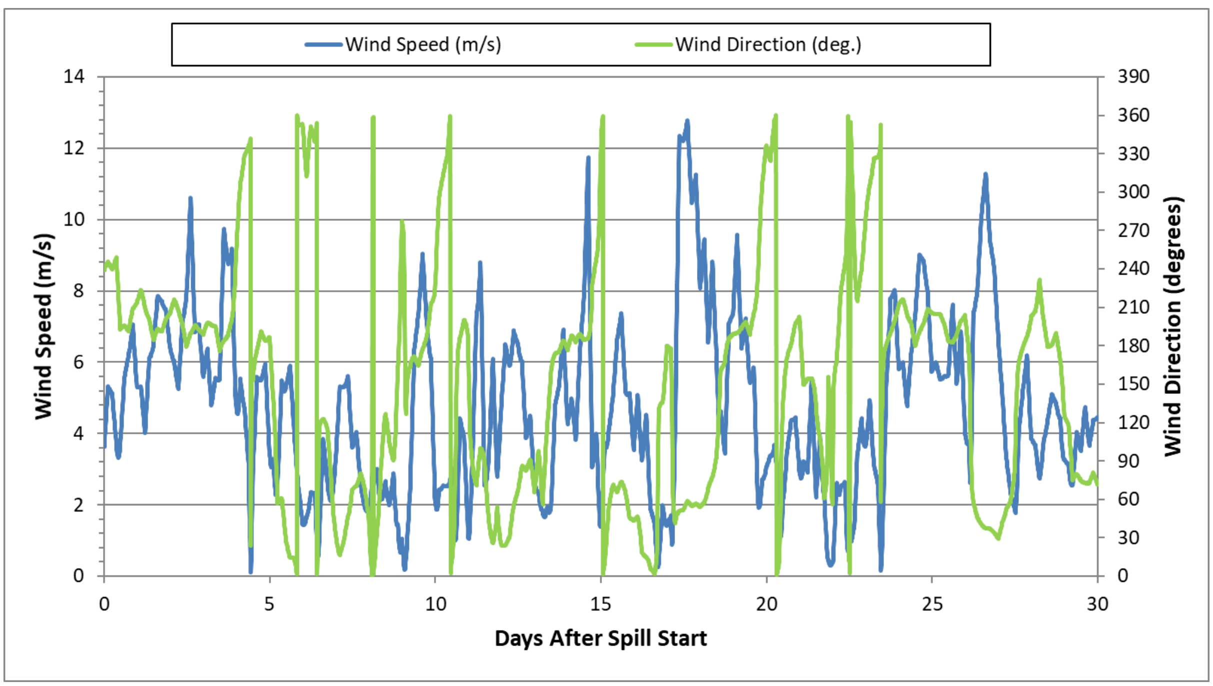


Figure 3-171. Wind speeds (1 m/s = 2 knots) and directions during the30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl surface release of crude oil offshore New Jersey starting on May 1, 2018.

3.3.2.1.2 Seasonal Worst-Case Runs

Winter

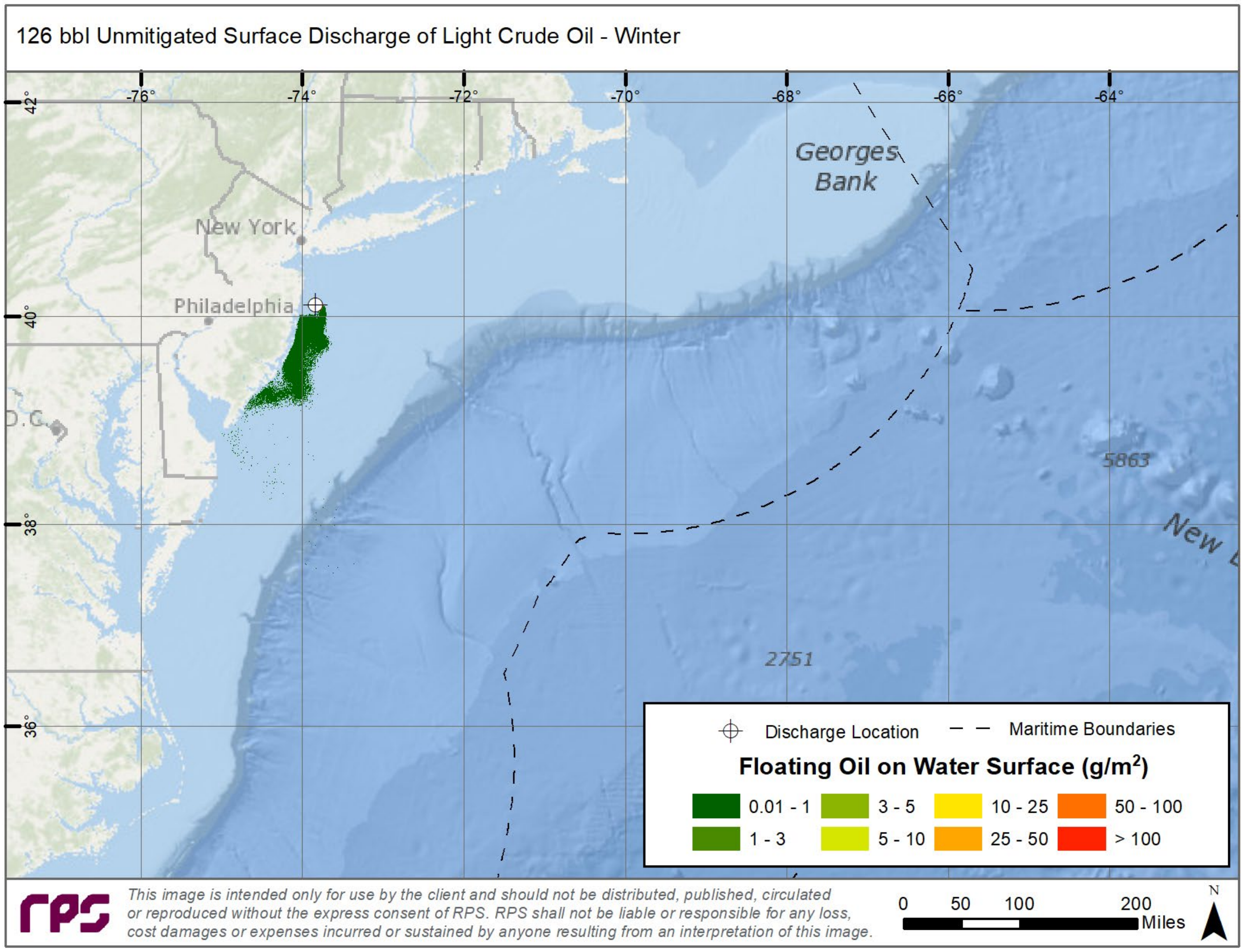


Figure 3-172. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

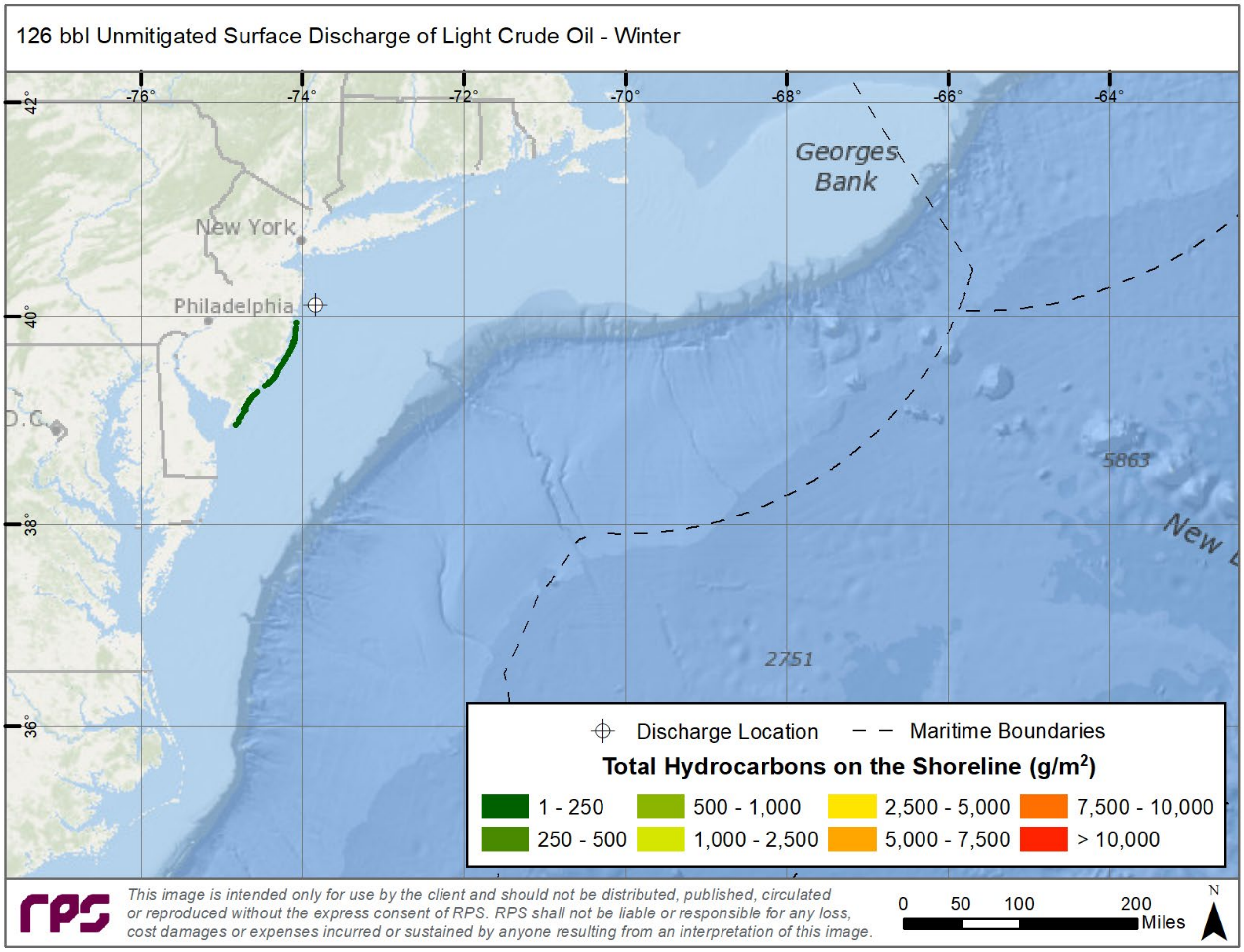


Figure 3-173. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

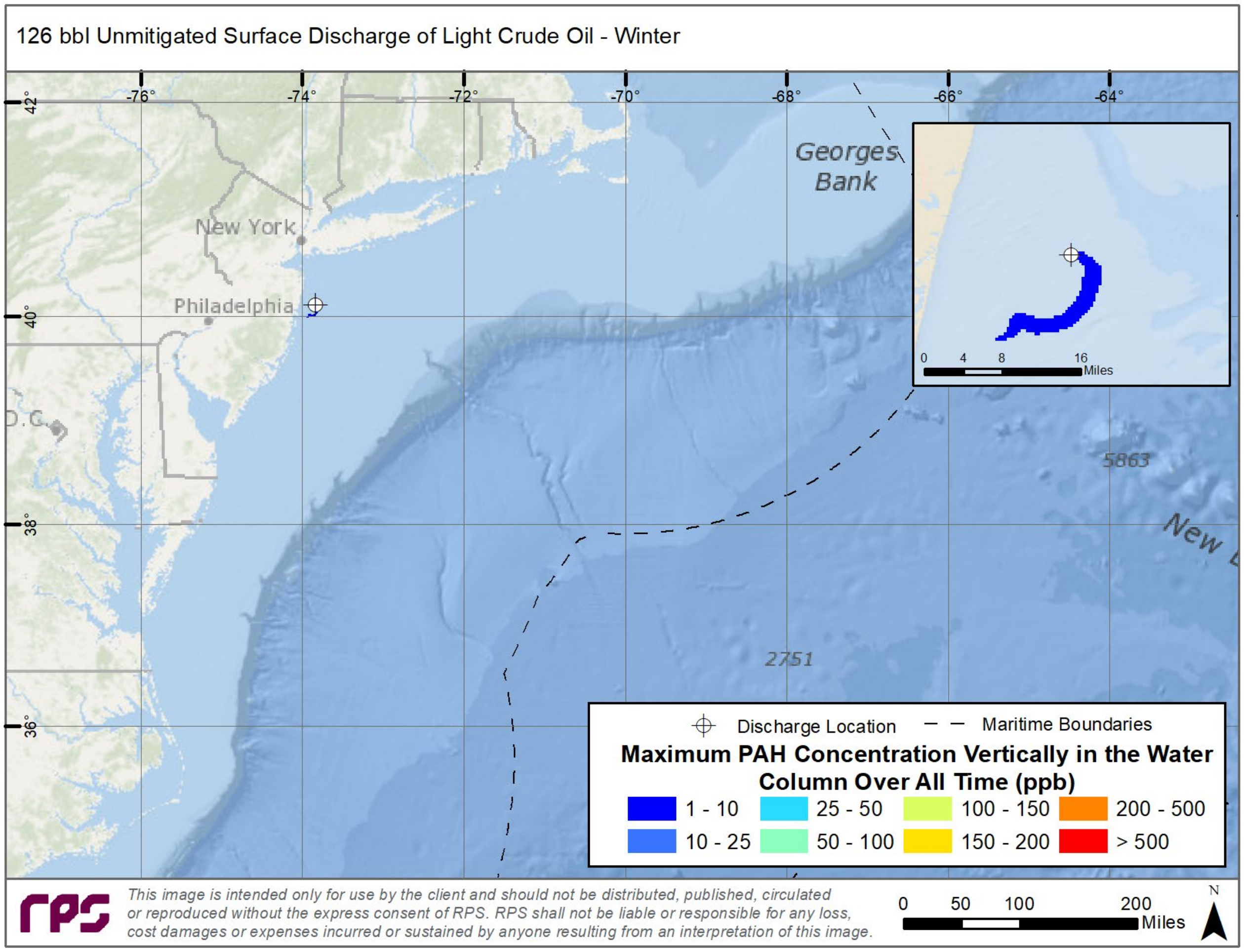


Figure 3-174. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

Summer

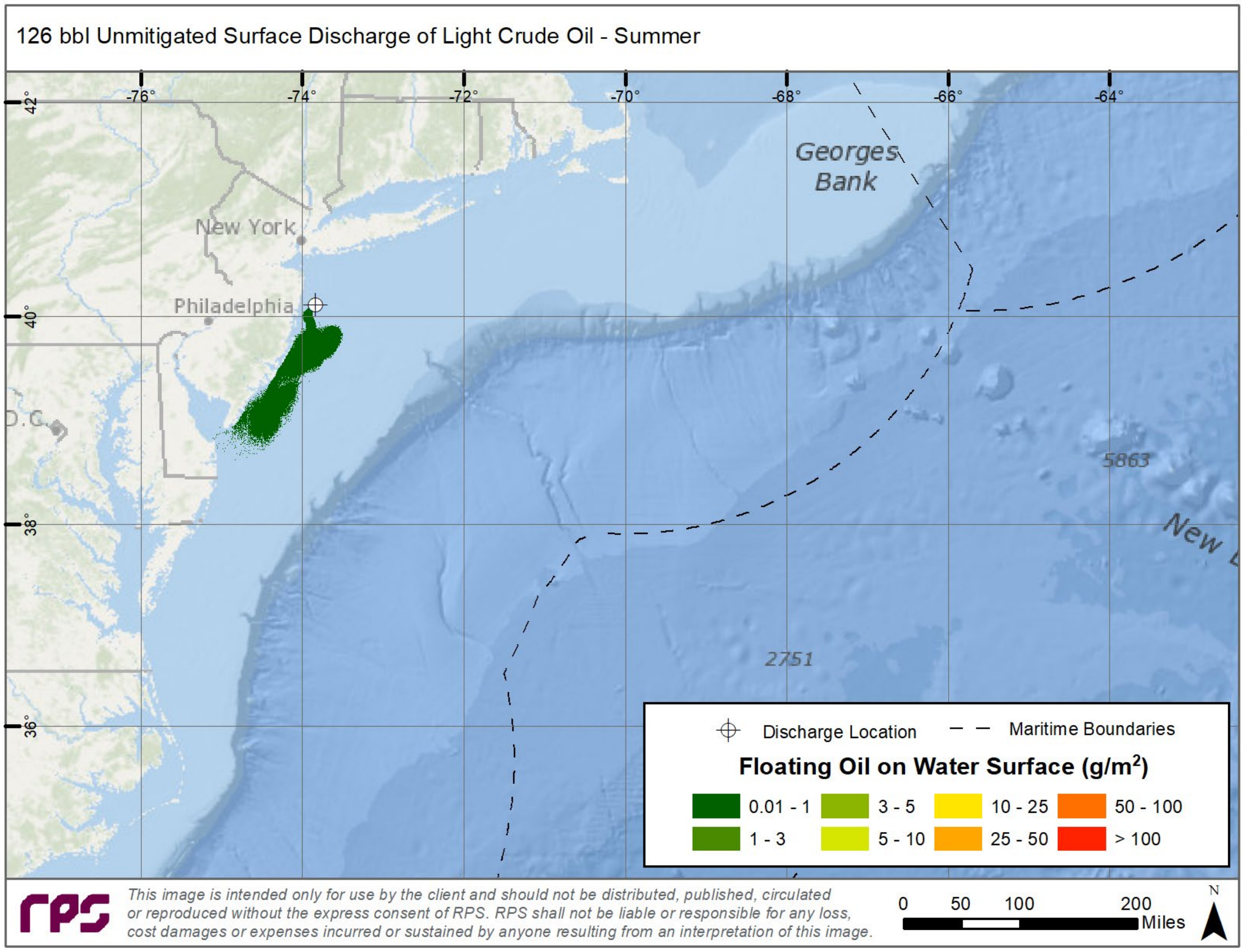


Figure 3-175. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore New Jersey starting August 28, 2019.

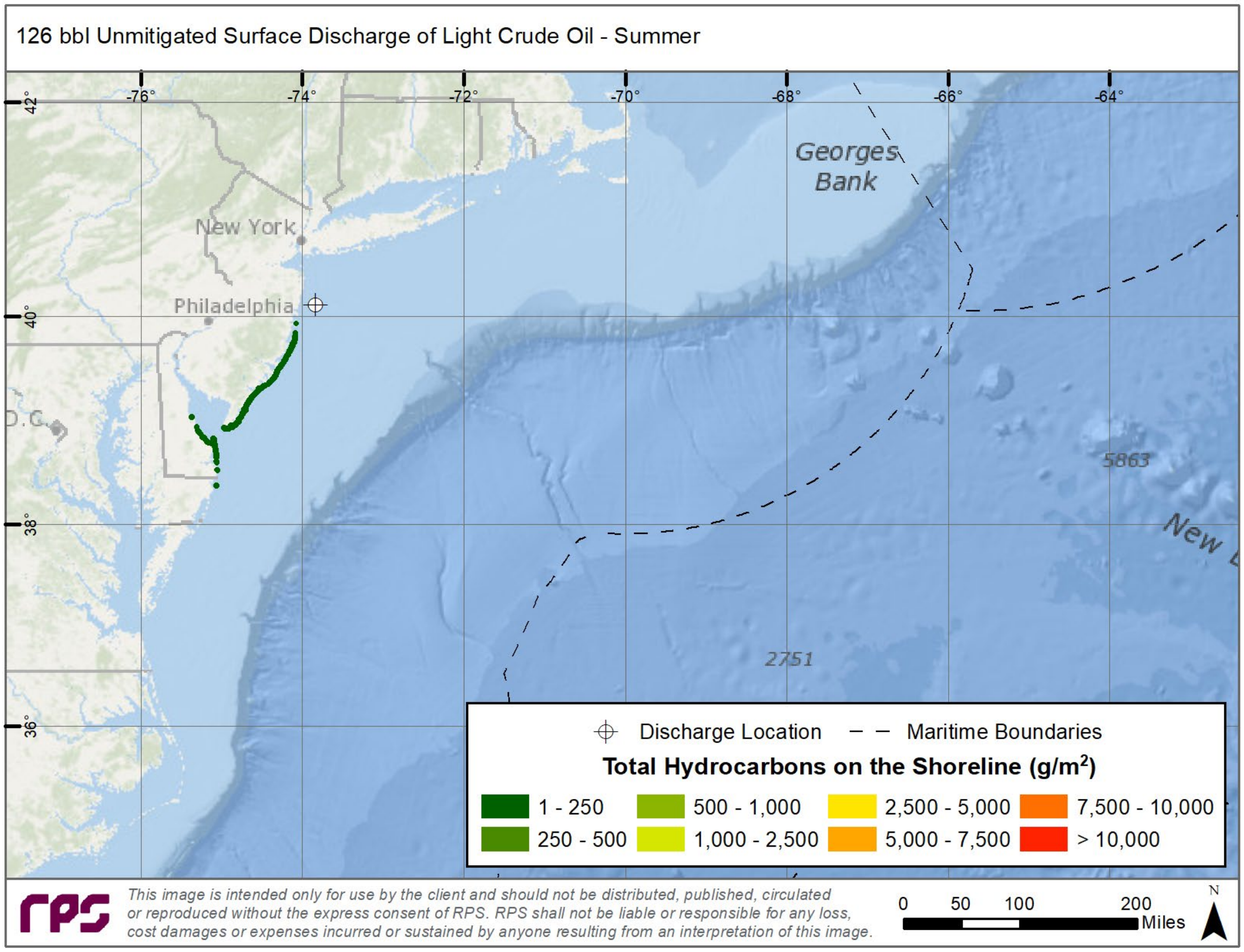


Figure 3-176. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore New Jersey starting August 28, 2019.

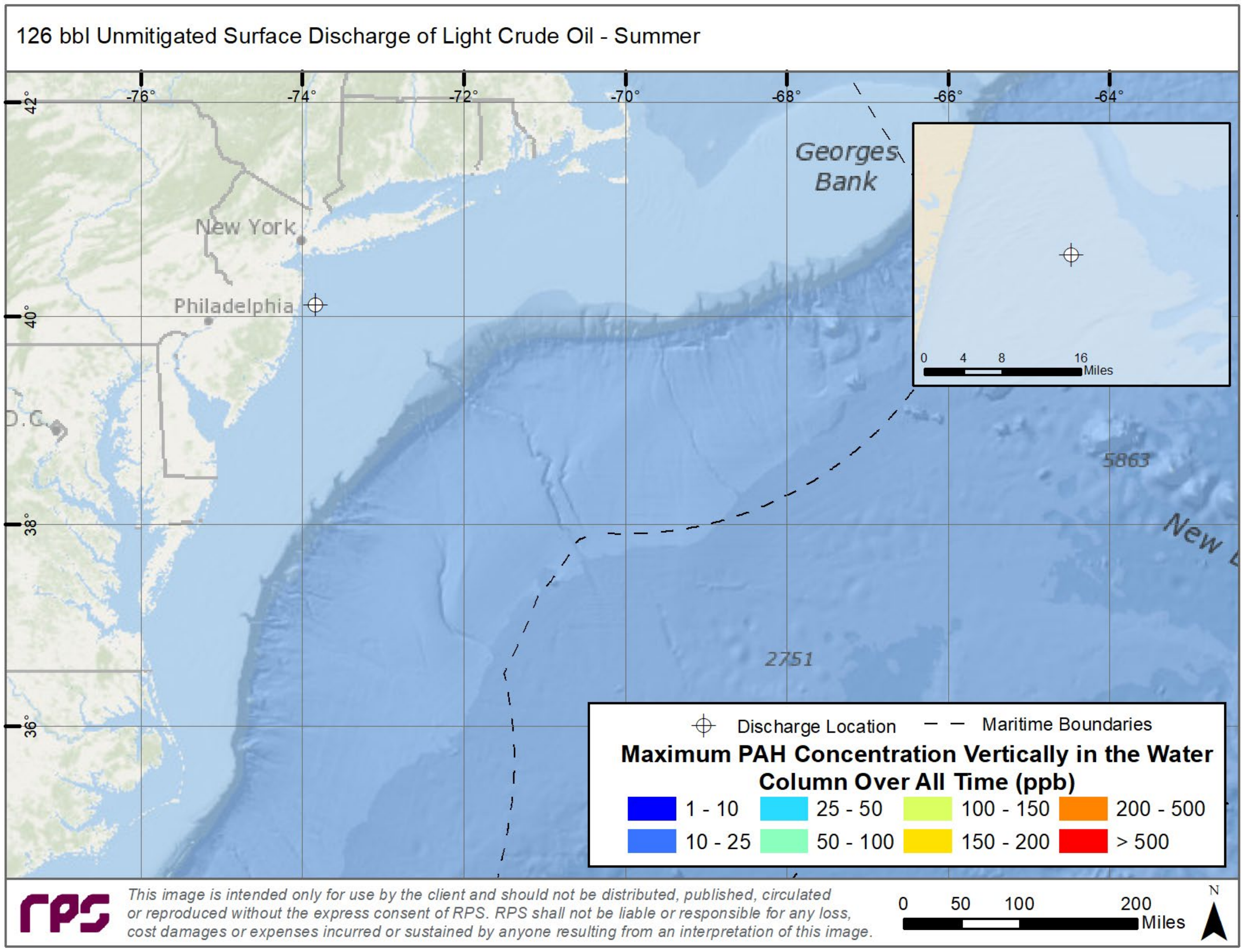


Figure 3-177. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore New Jersey starting August 28, 2019.

Fall

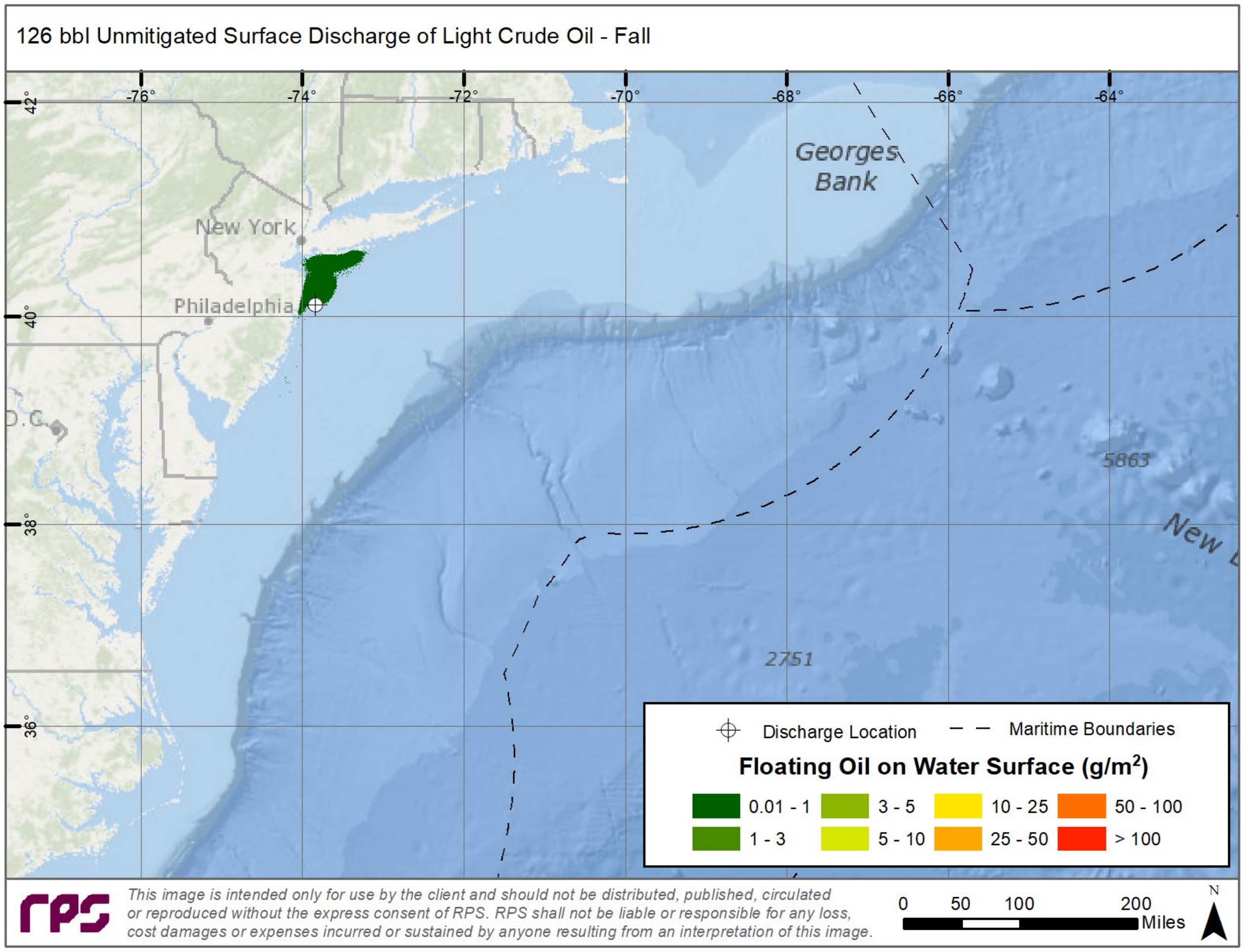


Figure 3-178. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore New Jersey starting on September 28, 2019.

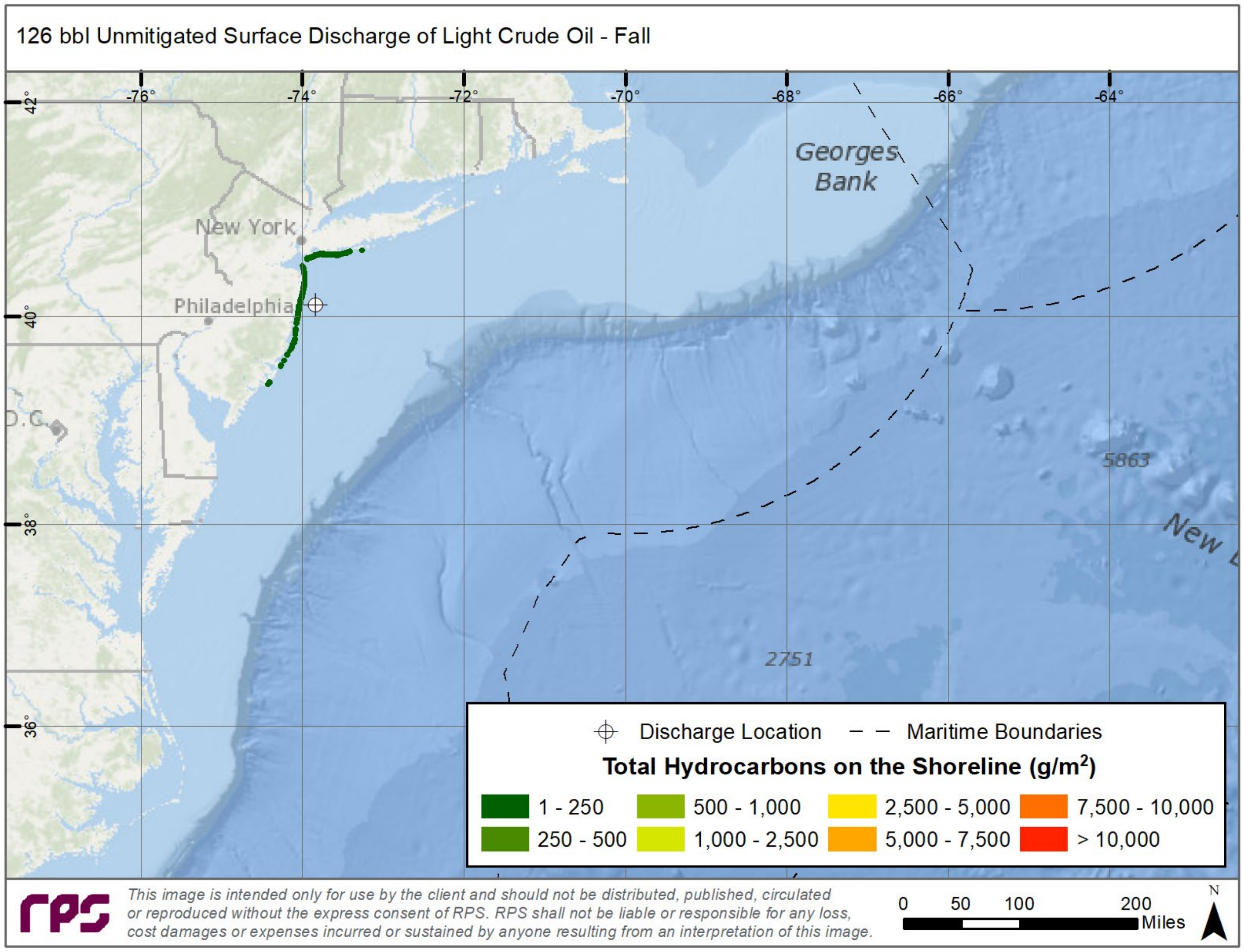


Figure 3-179. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore New Jersey starting on September 28, 2019.

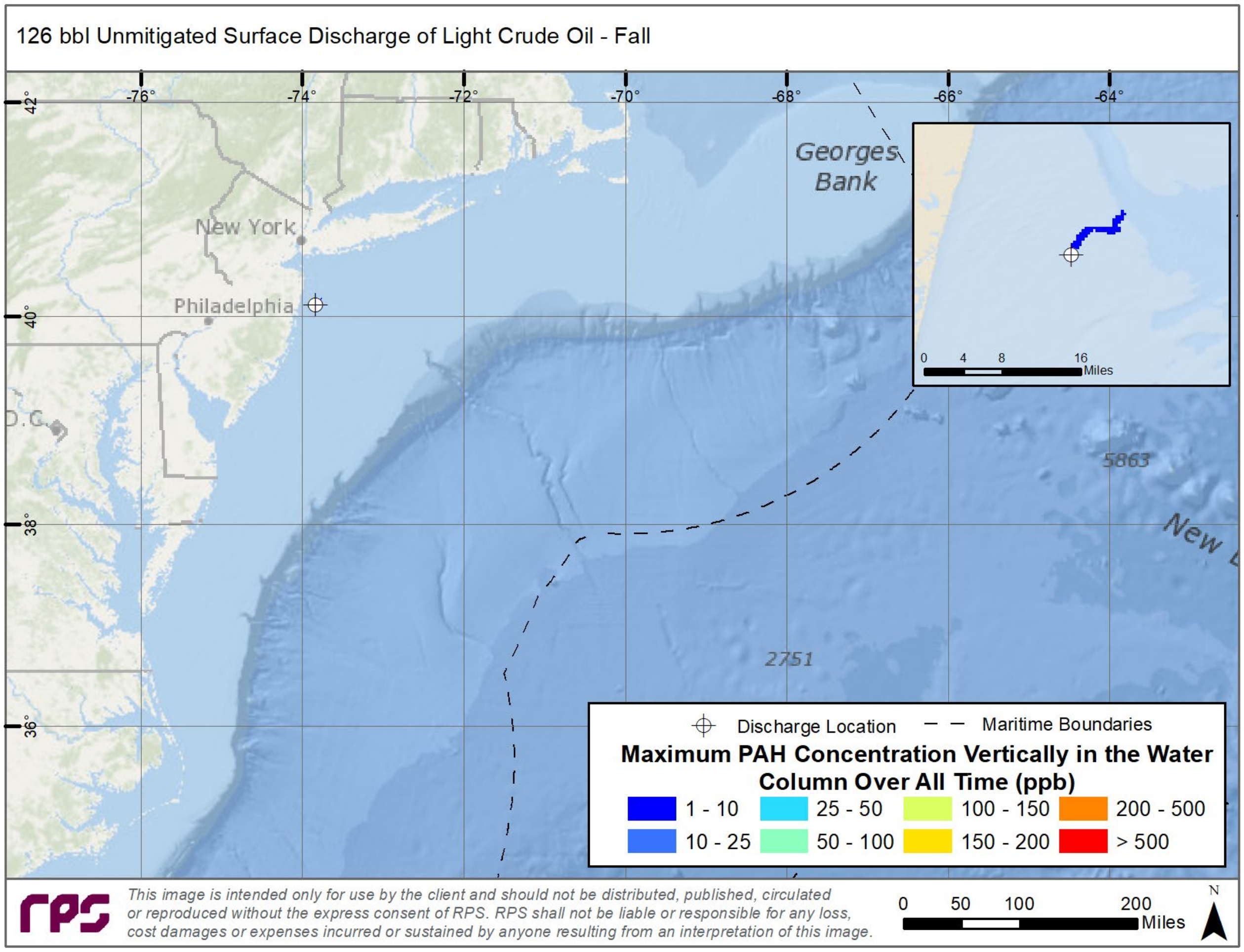


Figure 3-180. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore New Jersey starting on September 28, 2019.

3.3.2.2 Surface Unmitigated Release (Medium Volume)

3.3.2.2.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a medium-volume surface release of 2,240 bbl crude oil offshore Delaware started on May 1, 2018. Floating oil on the surface was primarily between 0.01-1 g/m^2 with small patches of higher concentrations to the northeast of the release location (Figure 3-181). Over 40% of the oil released at the surface evaporated quickly, within in the first 5 days. Emulsification of the crude oil to viscosities > 4,000 cP during the first few days of the release limited entrainment into the water to occur only during the high wind events (Figure 3-184 and Figure 3-185). The mass balance (Figure 3-184) shows that released the oil came ashore beginning 14 days after the spill while strong winds (11 m/s; 22 knots) were blowing from the northeast (Figure 3-185). Approximately 51% of the oil evaporated, 31% of the oil reached shore, 6% of the oil remained in the water column, 2% remained on the surface and approximately 10% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending northeast and south. The highest surface oil exposure concentrations occurred during the release at the release location. Maximum surface oiling concentrations > 50 g/m^2 (which would appear as patchy oil, emulsions or sheens) only occurred at the release site. Lower concentrations between 0.01-1 g/m^2 extended northeastward up 65 mi (105 km) from the spill site (Figure 3-181). By the end of the 30-day simulation, 218 mi (351 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-182; Table 3-19). Over half of the oiled shoreline was seaward sandy beach (130 mi; 210 km) along the coasts of New Jersey and New York. No shoreline habitat in Delaware was oiled >1 g/m^2 during the worst-case run of a medium-volume surface release (Table 3-15). Maximum cumulative PAH concentrations for the worst-case run were between 1-15 ppb and remained near the release location (Figure 3-183). As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-18. Shoreline lengths oiled by >1 g/m^2 (1µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated 2,240 bbl surface release of crude oil offshore of New Jersey starting on May 1, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Rocky shore	0	0	0	0	0	0
Gravel beach	6	6	1	10	10	1

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Sand beach	130	100	31	210	160	50
Mudflat	22	20	9	35	32	14
Wetland	2	0	0	3	0	0
Artificial/manmade shoreline	5	5	0	9	9	0
Total	165	131	40	266	210	65
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	10	10	3	15	15	5
Sand beach	9	5	0	15	9	0
Mudflat	6	0	0	10	0	0
Wetland	12	0	0	19	0	0
Artificial/manmade shoreline	15	15	0	24	24	0
Total	53	30	3	84	49	5
All Shorelines						
Total	218	161	43	351	259	70

Table 3-12 shows the model results for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-186 to Figure 3-194 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In both the winter and summer, oil is transported south of the release site, with shoreline oiling occurring along the New Jersey coastline in the winter and along the New Jersey, Delaware, Maryland, and Virginia coastlines in the summer. In the fall, oil is transported to the north and south of the release location, with oiling occurring along New Jersey and New York coasts.

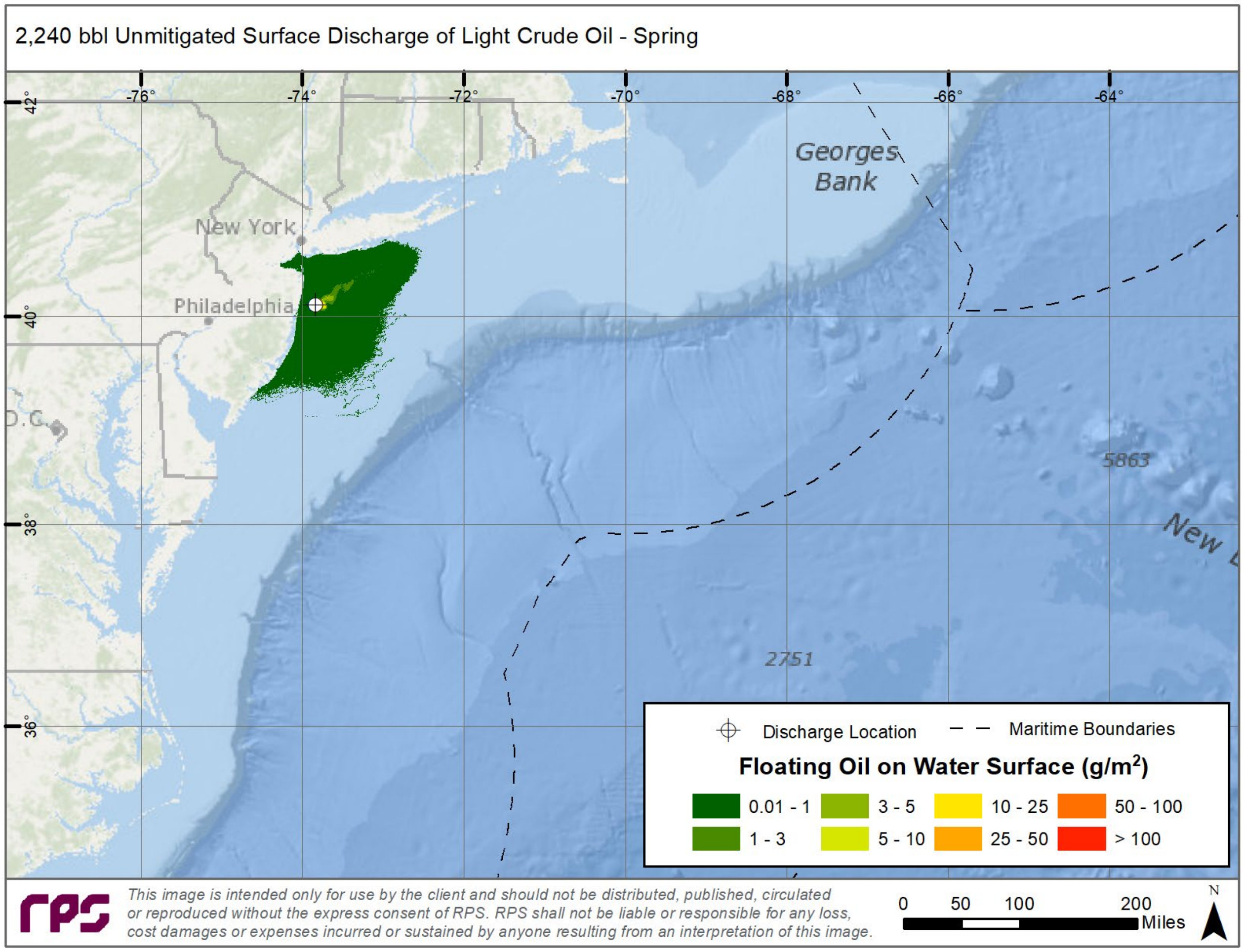


Figure 3-181. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore New Jersey starting May 1, 2018.

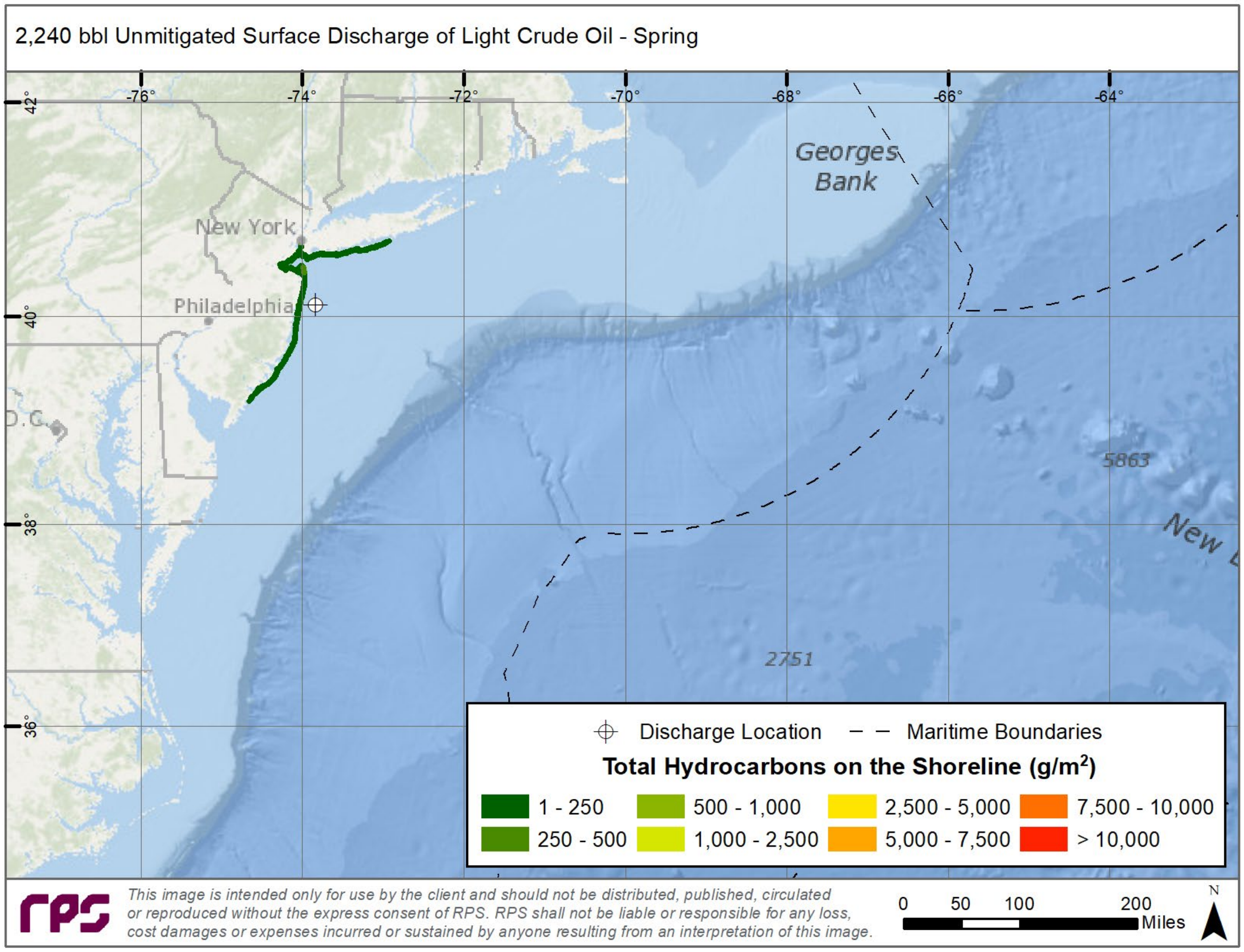


Figure 3-182. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore New Jersey starting May 1, 2018.

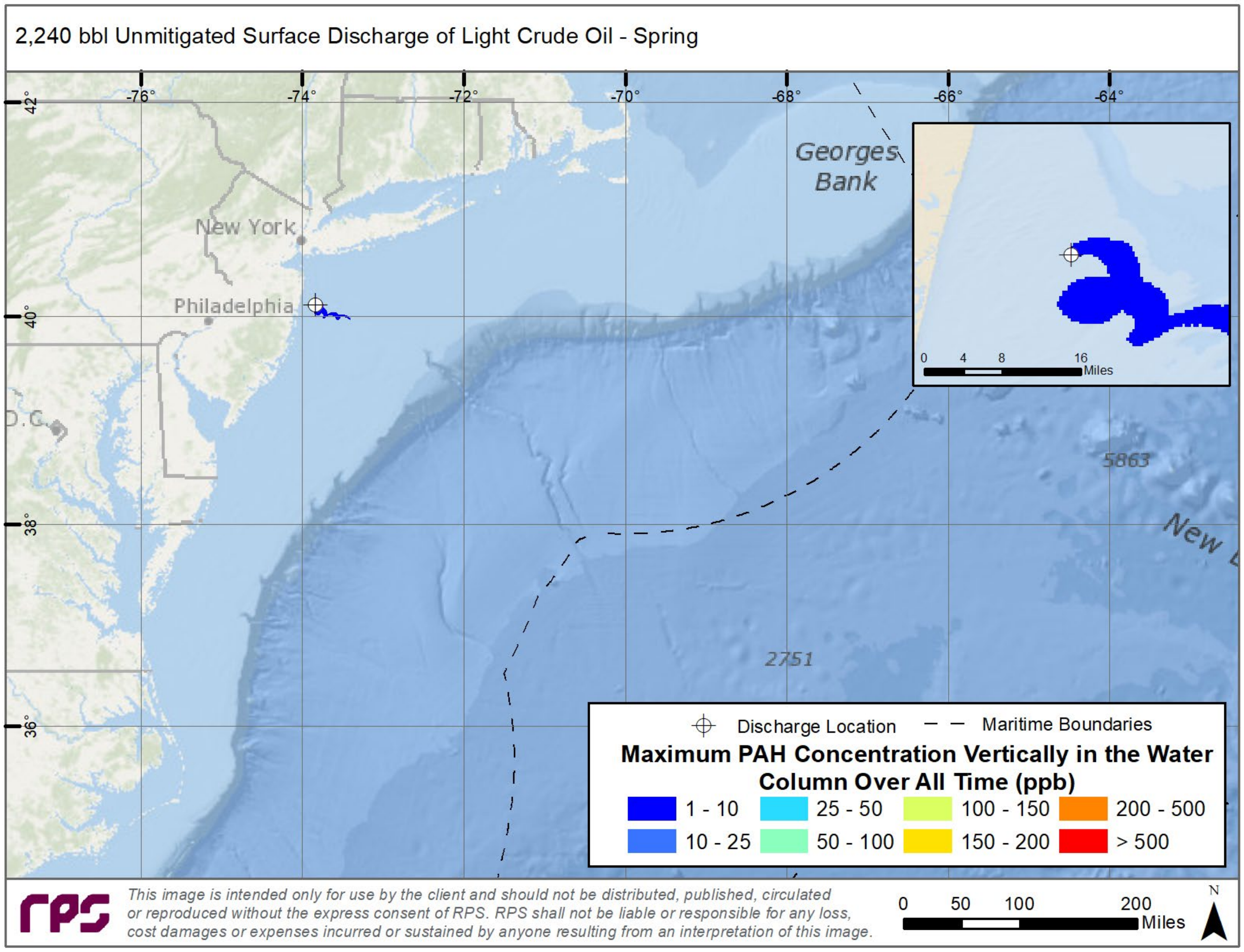


Figure 3-183. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore New Jersey starting May 1, 2018.

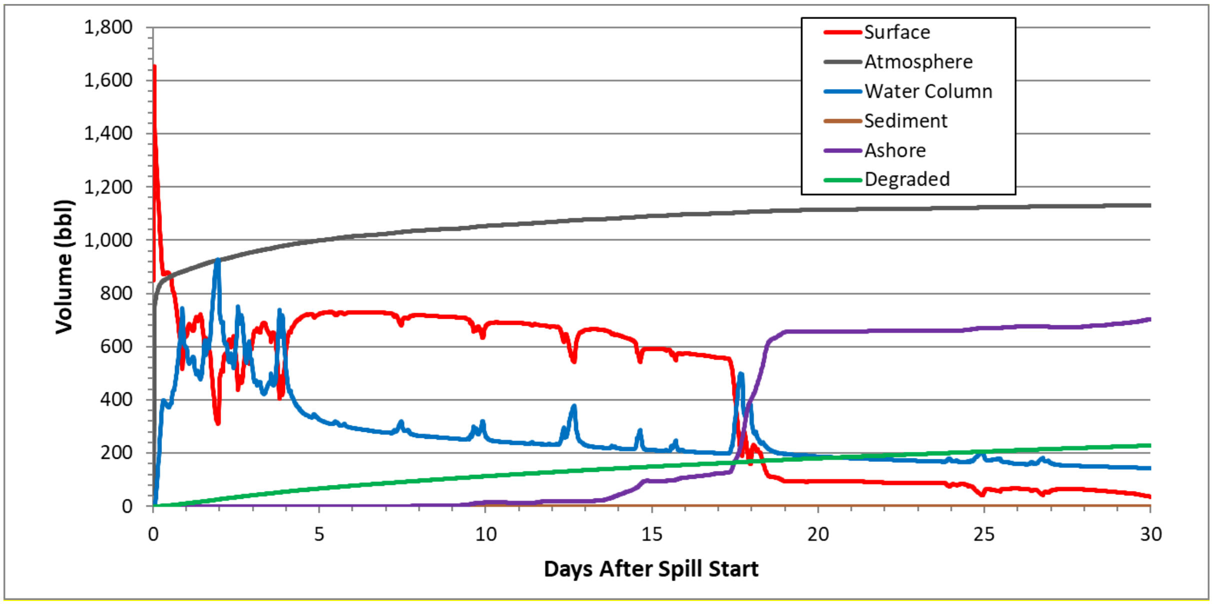


Figure 3-184. Oil volume by environmental compartment over time for a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl surface release of crude oil offshore New Jersey starting May 1, 2018.

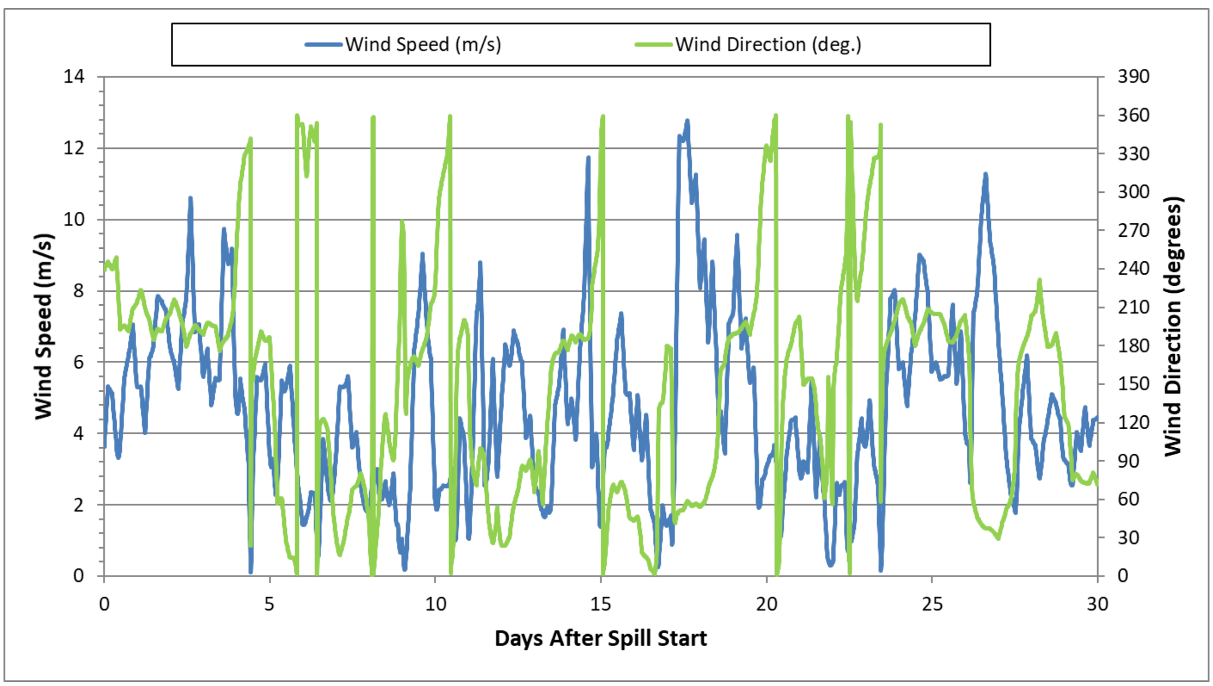


Figure 3-185. Wind speeds (1 m/s = 2 knots) and directions during the30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl surface release of crude oil offshore New Jersey starting May 1, 2018.

3.3.2.2.2 Seasonal Worst-Case Runs

Winter

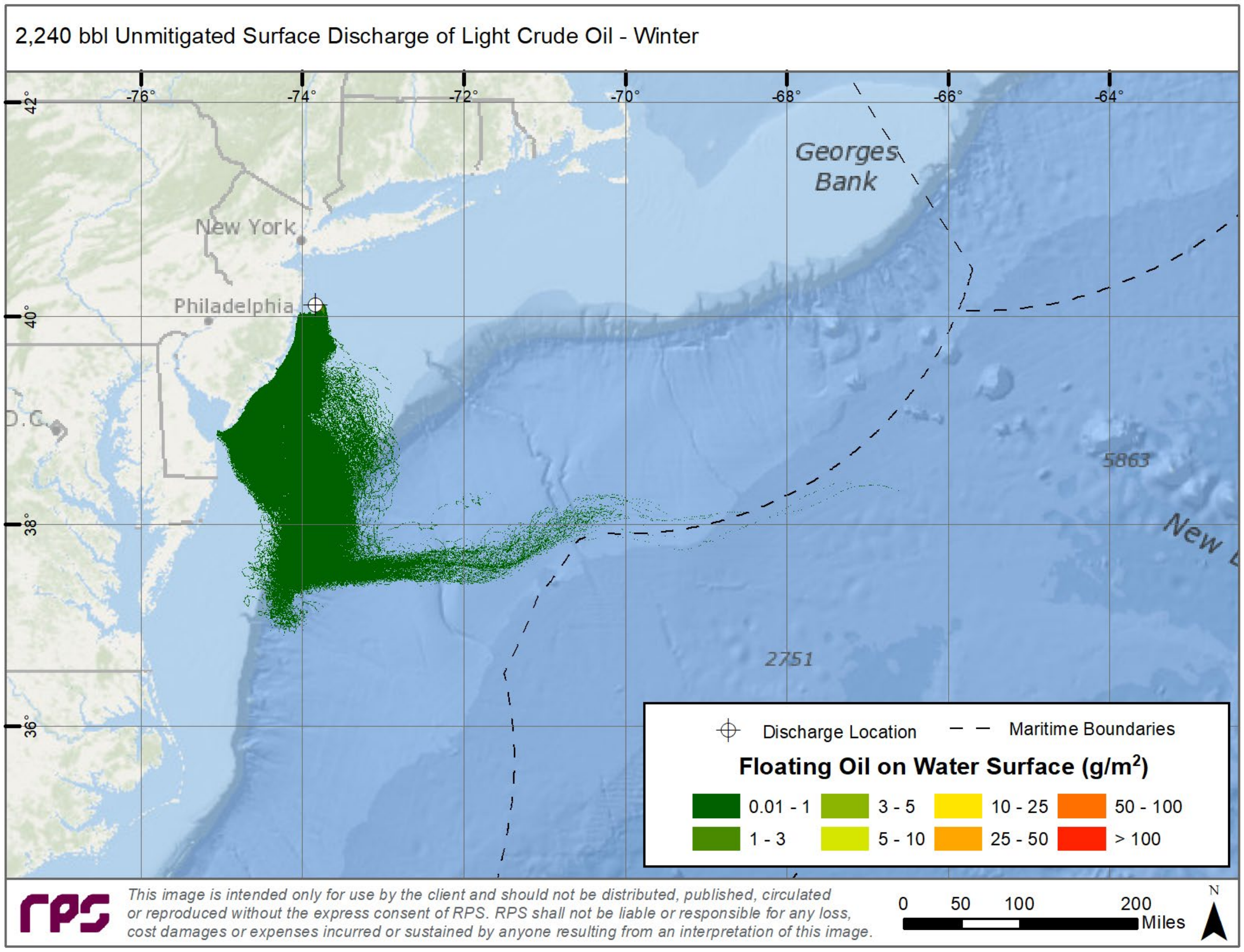


Figure 3-186. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

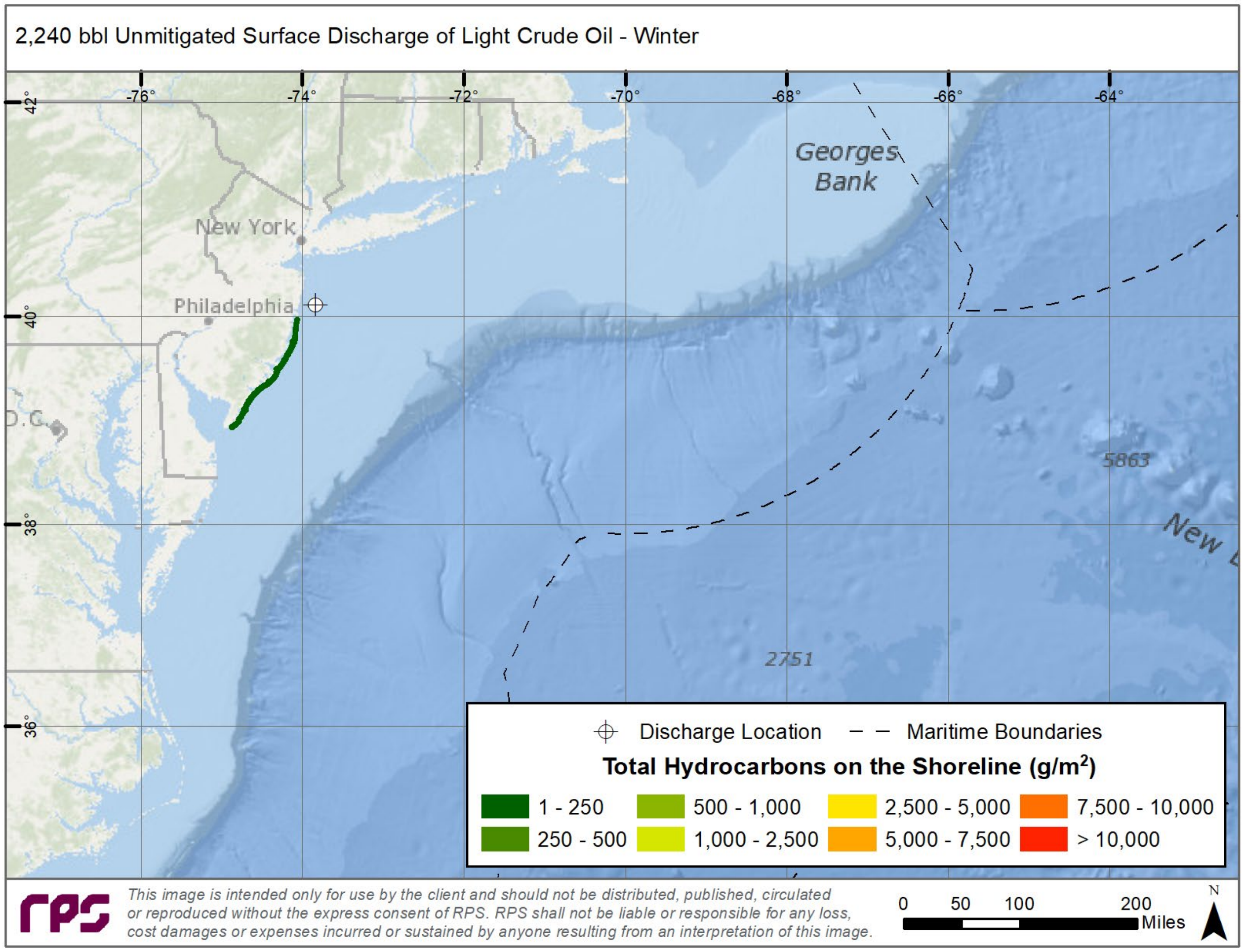


Figure 3-187. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

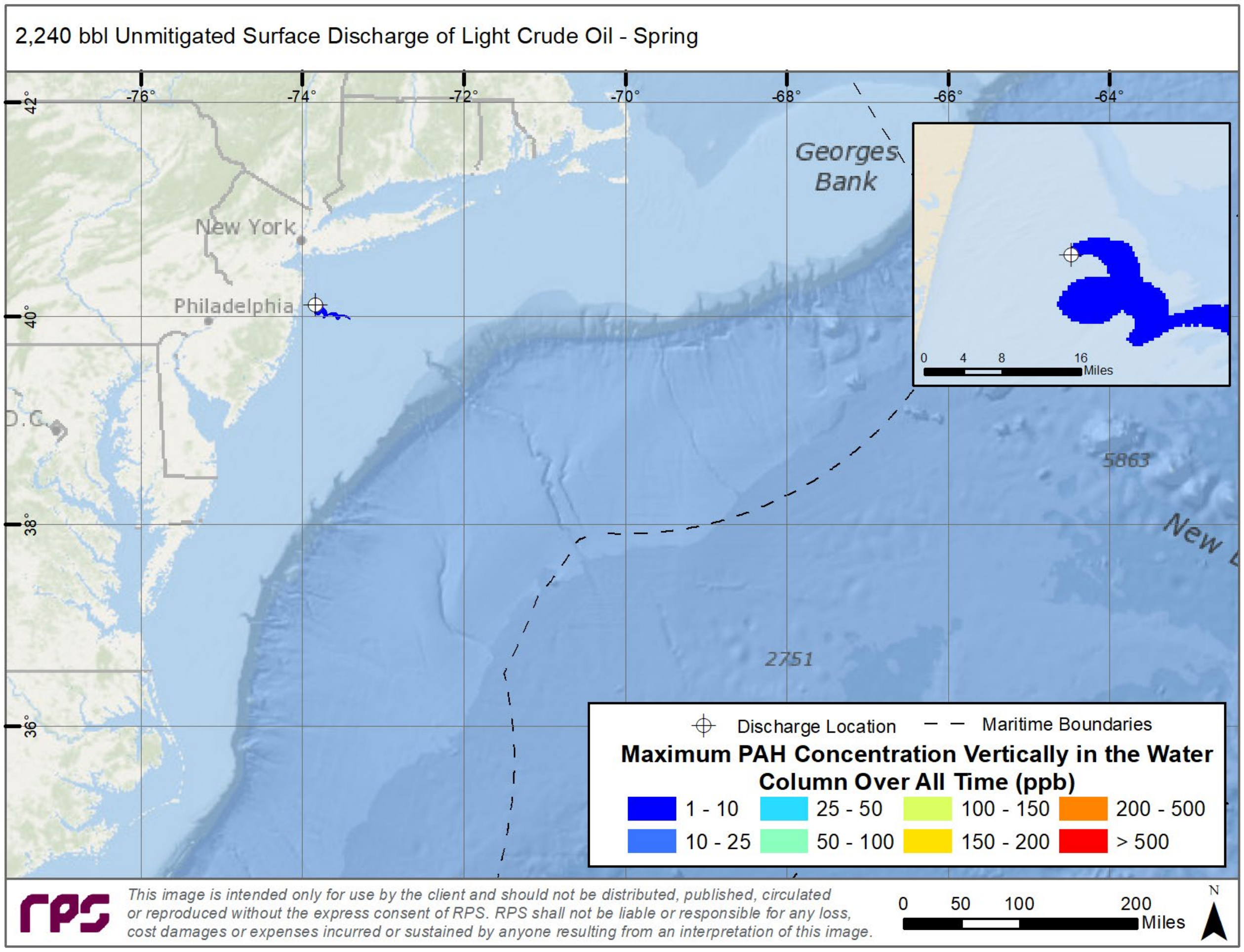


Figure 3-188. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

Summer

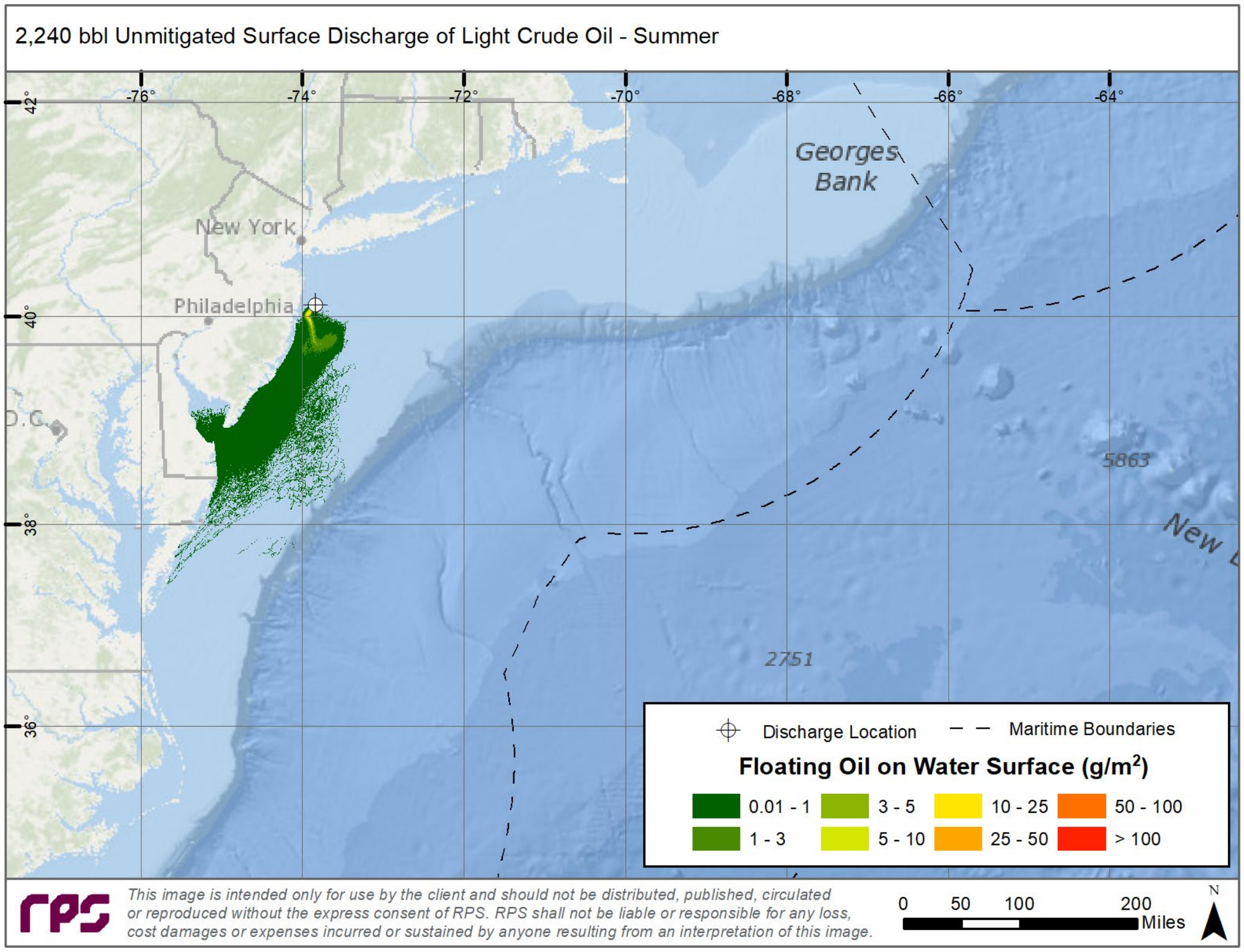


Figure 3-189. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore New Jersey starting on August 28, 2019.

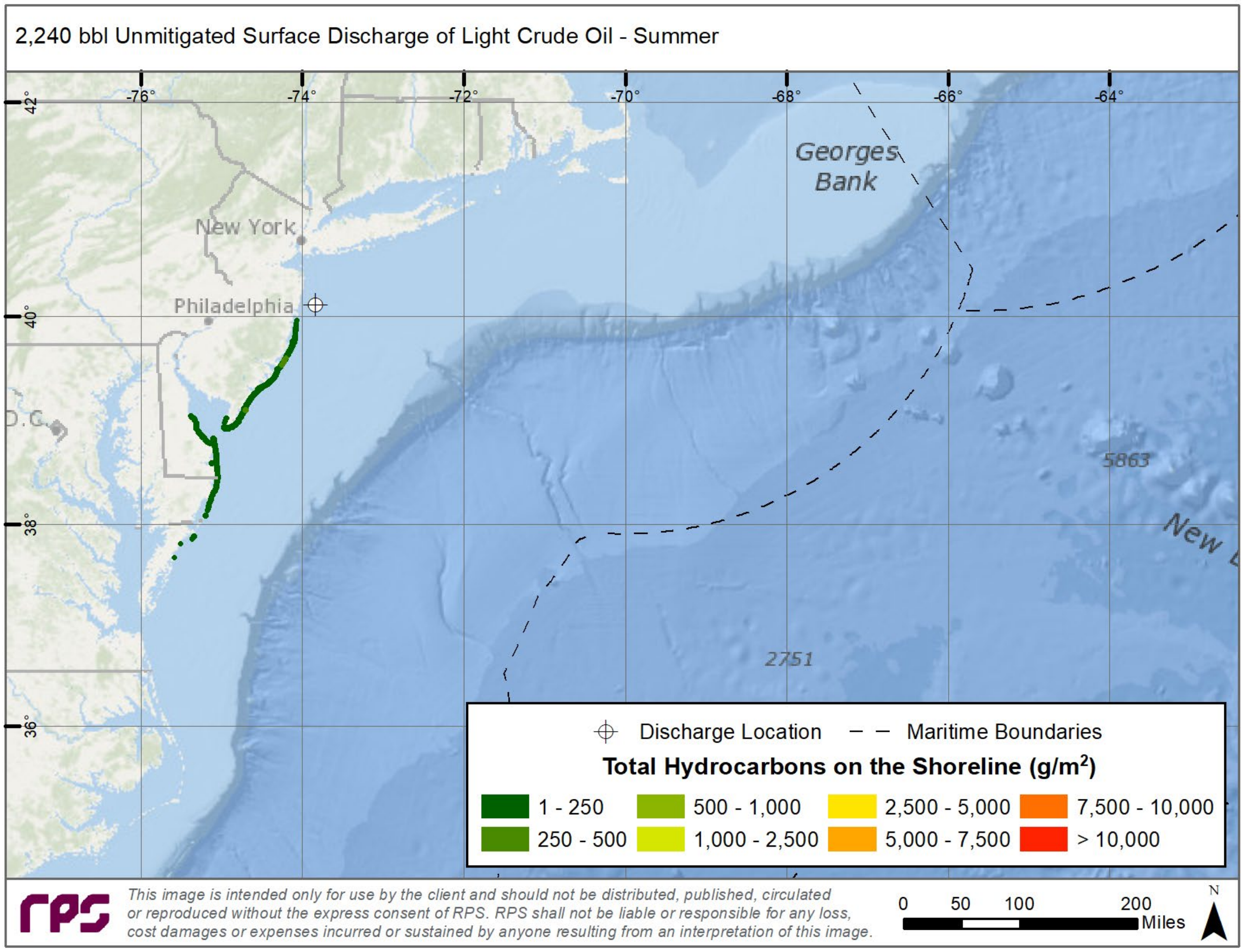


Figure 3-190. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore New Jersey starting on August 28, 2019.

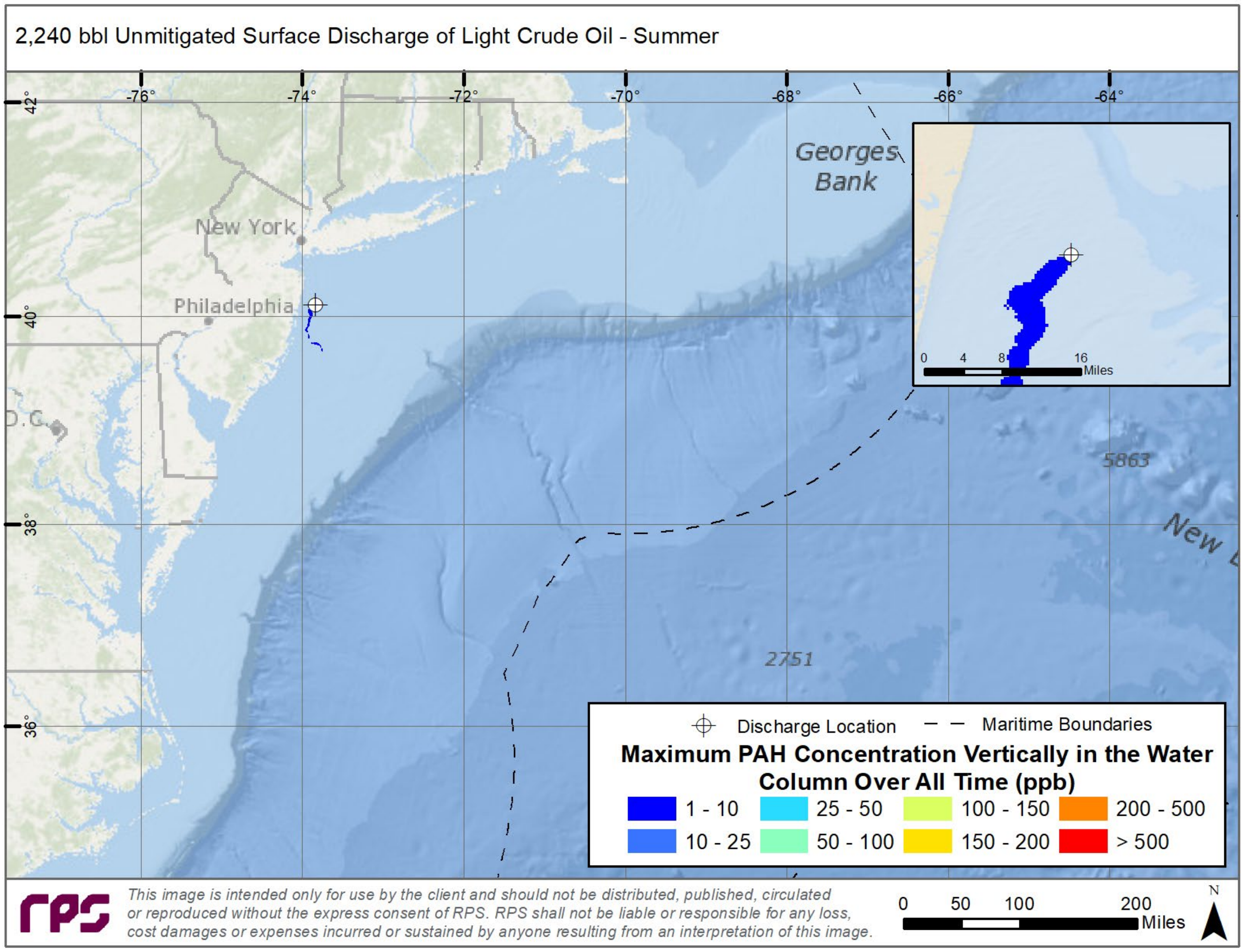


Figure 3-191. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore New Jersey starting on August 28, 2019.

Fall

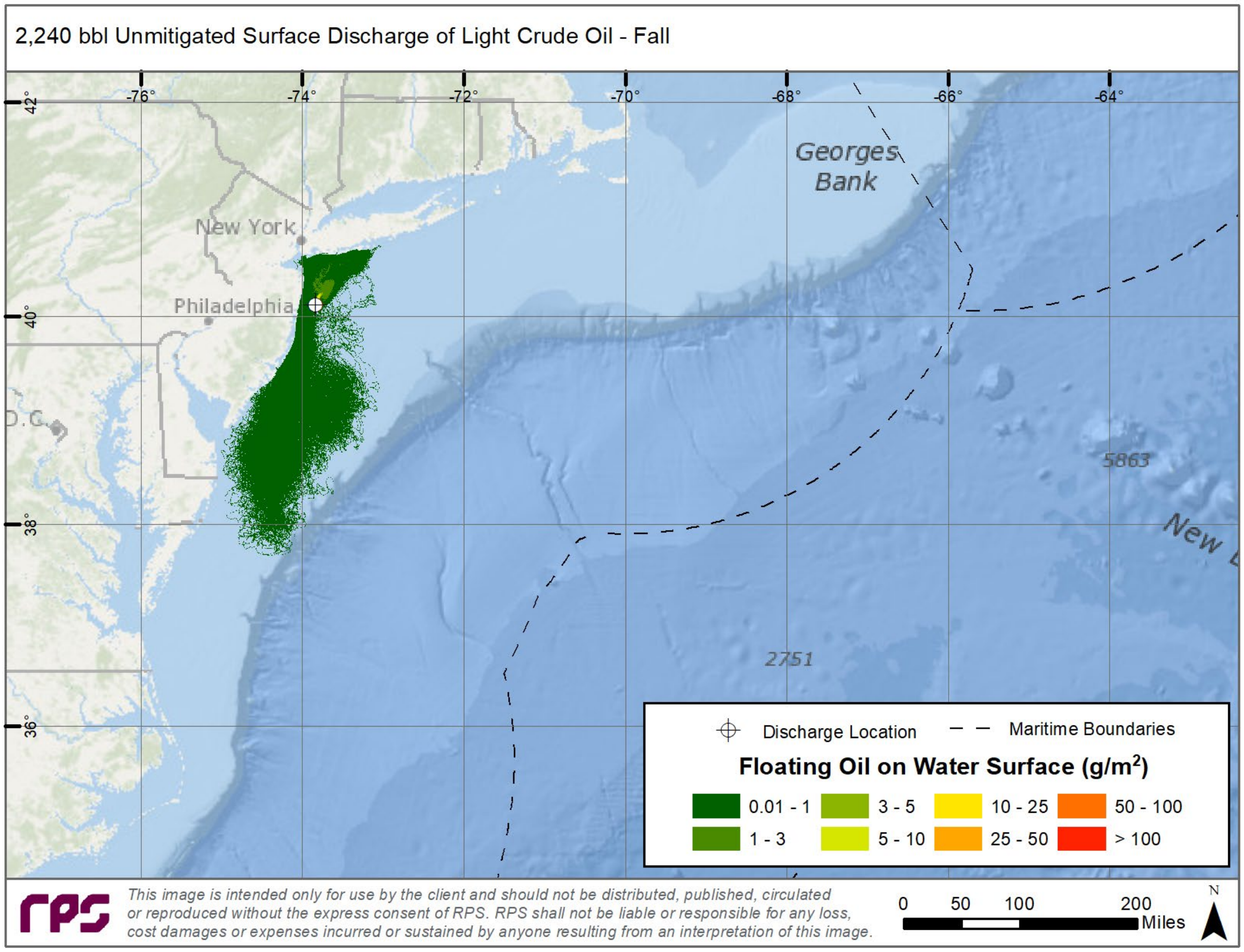


Figure 3-192. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore New Jersey starting on September 28, 2019.

2,240 bbl Unmitigated Surface Discharge of Light Crude Oil - Fall

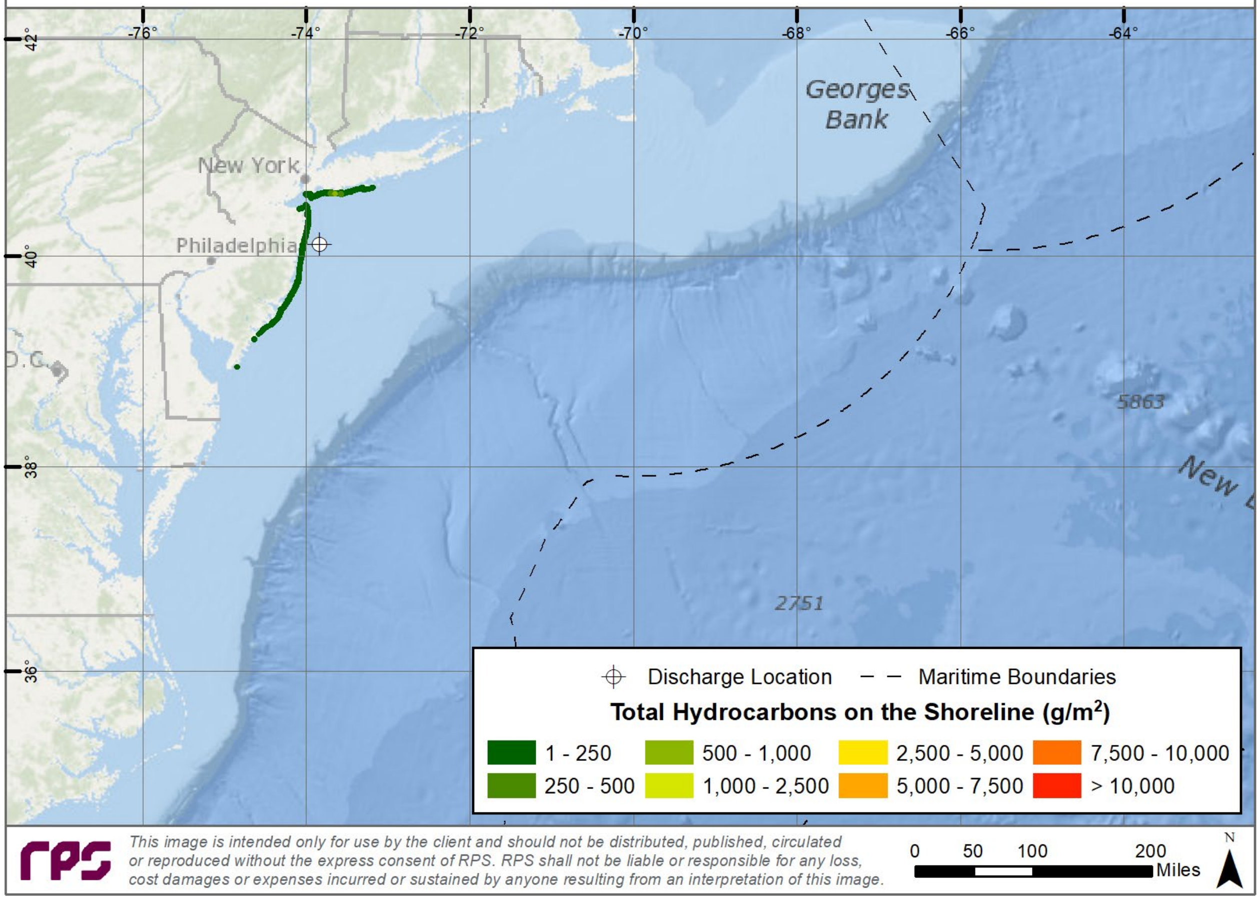


Figure 3-193. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore New Jersey starting on September 28, 2019.

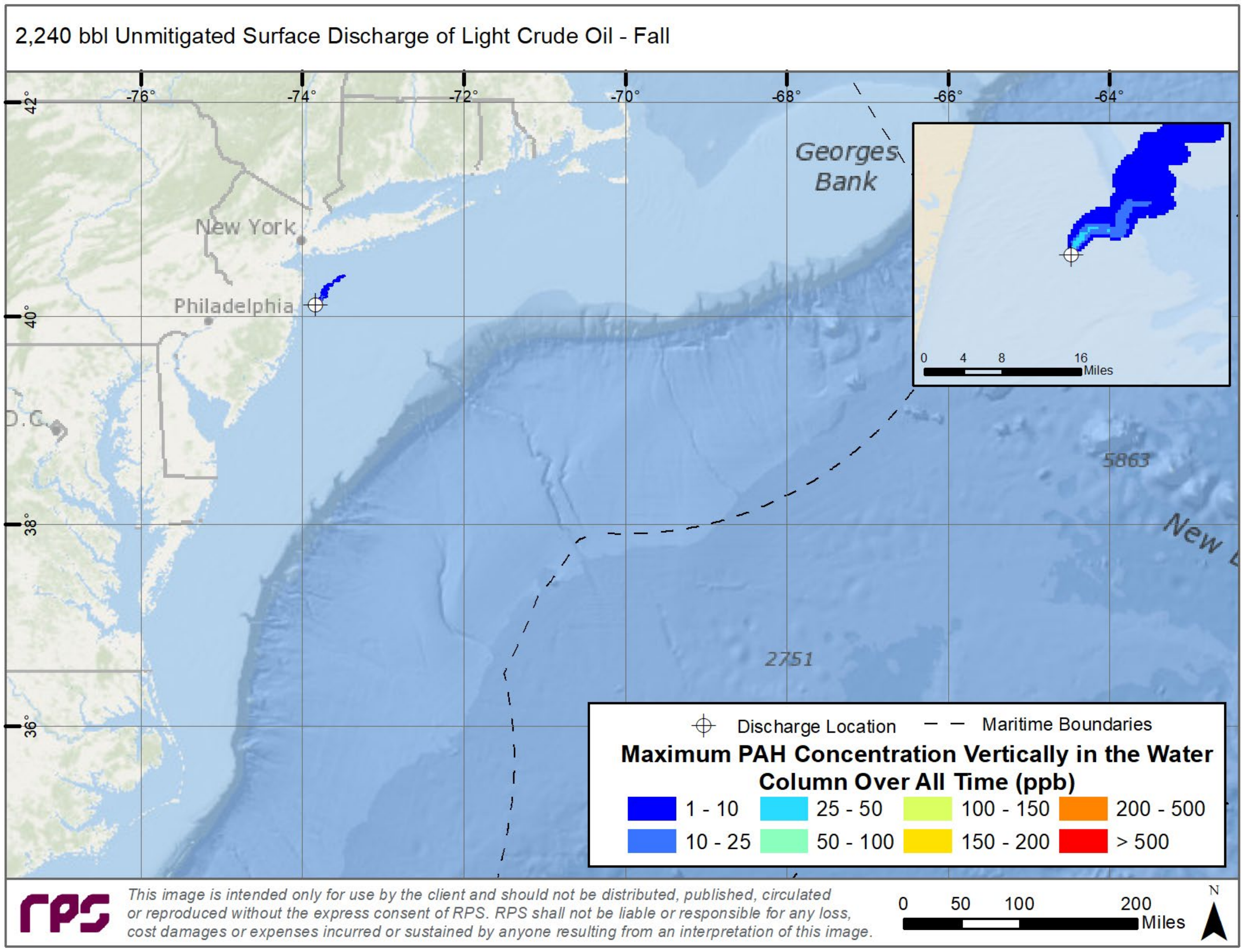


Figure 3-194. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore New Jersey starting on September 28, 2019.

3.3.2.3 Surface Unmitigated Release (High Volume)

3.3.2.3.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a high-volume surface release of 200,000 bbl crude oil offshore New Jersey started on May 1, 2018. The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Over 40% of the oil released at the surface evaporated quickly, within in the first 5 days. Emulsification of the crude oil to viscosities > 4,000 cP during the first few days of the release limited entrainment into the water to occur only during the high wind events, causing oil to oscillate from within the water column to the surface during periods of high and low winds (Figure 3-198 and Figure 3-199). The mass balance (Figure 3-198) shows that released the oil came ashore beginning 14 days after the spill while strong winds (8-12 m/s; 16-24 knots) were blowing from the northeast (Figure 3-199). Approximately 46% of the oil evaporated, 28% of the oil reached shore, 9% of the oil remained in the water column, 4% remained on the surface, and approximately 13% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending furthest to the south. Maximum floating oil on the surface was >100 g/m² (100 µm, on average) and extended from the release site to the east (Figure 3-125). Lower (<25 g/m², i.e., patchy oil, emulsions or sheens) maximum surface oil exposure concentrations were predicted to extend up to 380 mi (611 km) southeast from the release site, nearshore and offshore New Jersey and Delaware into international waters. By the end of the 30-day simulation, 307 mi (494 km) of shoreline was contaminated by >1 g/m² of oil (Figure 3-201; Table 3-19). Seaward sandy beach was the habitat predicted to have the longest length of shoreline oiled (161 mi; 259 km). Shoreline oiling was predicted along the coasts of New Jersey, with the highest concentrations of oil (7,500-10,000 g/m²) occurring along the southern seaward coast of New Jersey.

Maximum cumulative PAH concentrations for the worst-case run were >500 ppb and remained near the release location and extending to the south (Figure 3-202). Lower concentrations, between 1-10 ppb, extended south to waters off the coast of Delaware. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-19. Shoreline lengths oiled by >1 g/m² (1 µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated 200,000 bbl surface release of crude oil offshore of New Jersey starting on May 1, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m²	>10g/m²	>100g/m²	>1g/m²	>10g/m²	>100g/m²
Rocky shore	0	0	0	0	0	0
Gravel beach	1	1	0	1	1	0
Sand beach	161	161	156	259	259	251
Mudflat	16	16	14	26	26	22
Wetland	3	2	1	4	4	2
Artificial/manmade shoreline	20	20	0	33	33	0
Total	201	200	171	323	322	275
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	5	5	4	8	8	7

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Sand beach	39	39	33	63	63	53
Mudflat	14	13	4	22	21	6
Wetland	14	14	4	23	22	6
Artificial/manmade shoreline	34	34	0	55	55	0
Total	106	106	44	171	170	72
All Shorelines						
Total	307	305	215	494	491	347

Table 3-12 shows the model results for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-200 to Figure 3-208 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In both the fall and winter, oil is transported concentrically and south of the release site, with shoreline oiling occurring along the coasts of New Jersey. In the summer, oil is transported northeast into nearshore and offshore waters along the coast of Long Island, New York, extending as far as Block Island, Rhode Island.

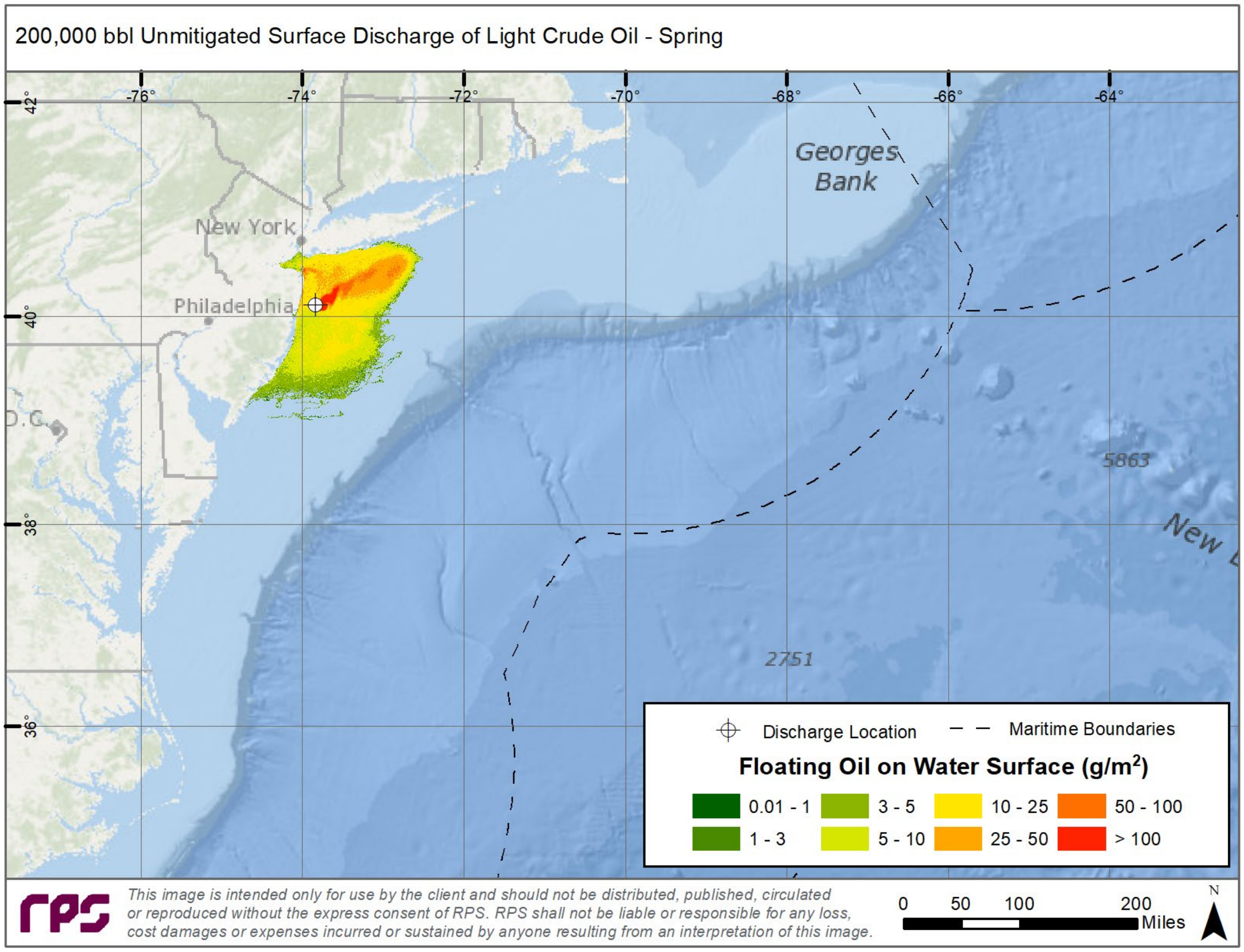


Figure 3-195. Maximum water surface oil exposure concentration at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore of New Jersey starting on May 1, 2018.

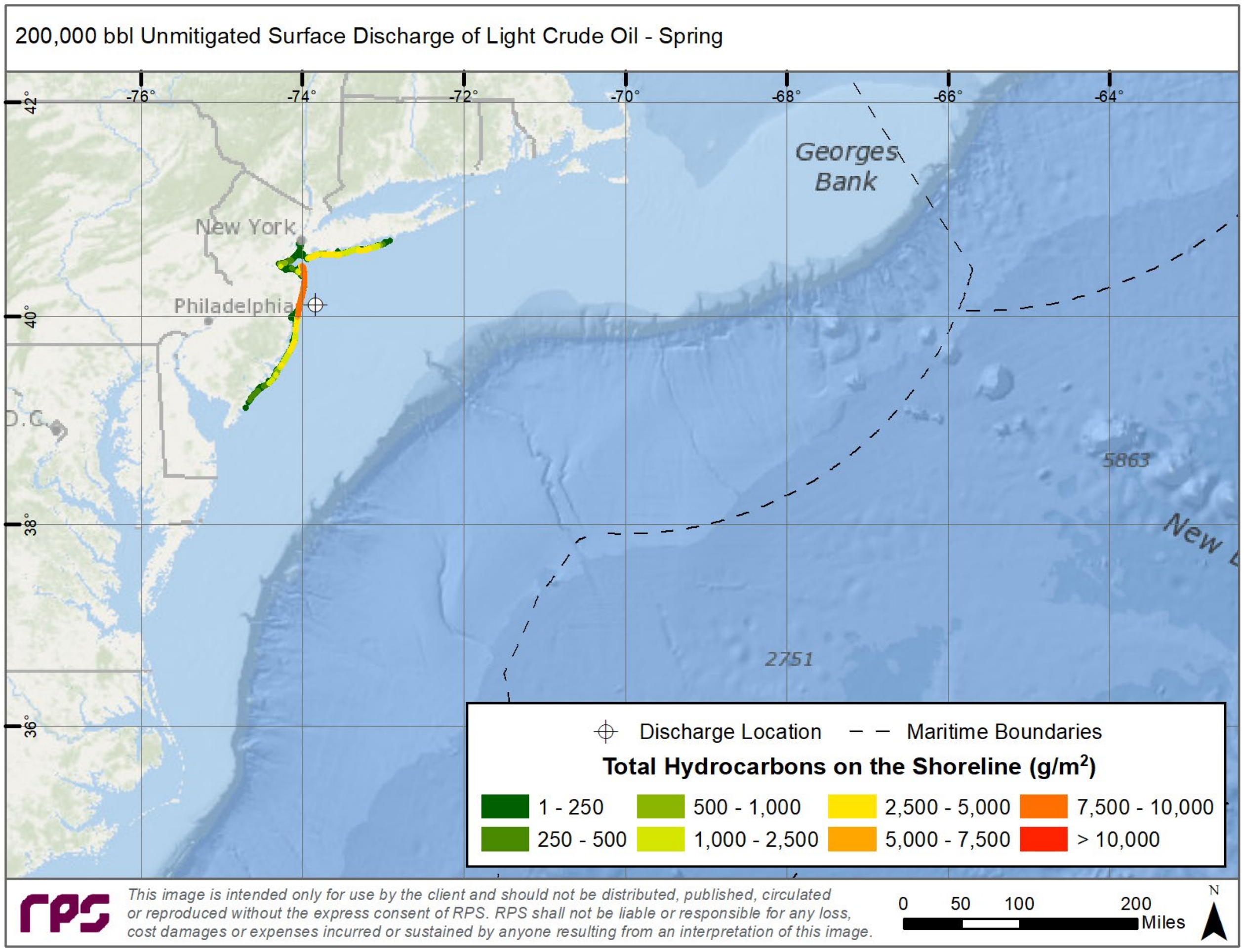


Figure 3-196. Maximum shoreline oil concentration at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore of New Jersey starting on May 1, 2018.

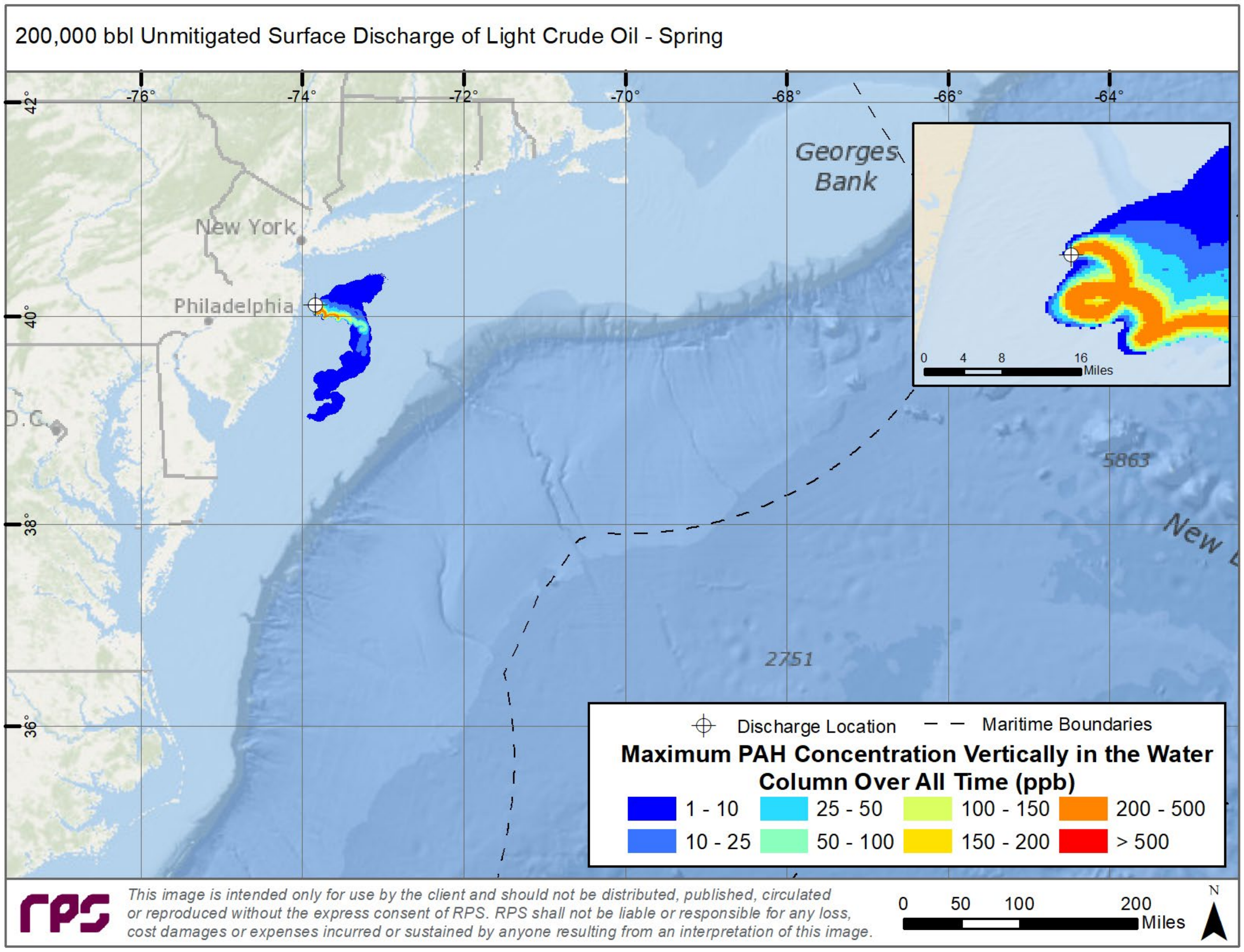


Figure 3-197. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore of New Jersey starting on May 1, 2018.

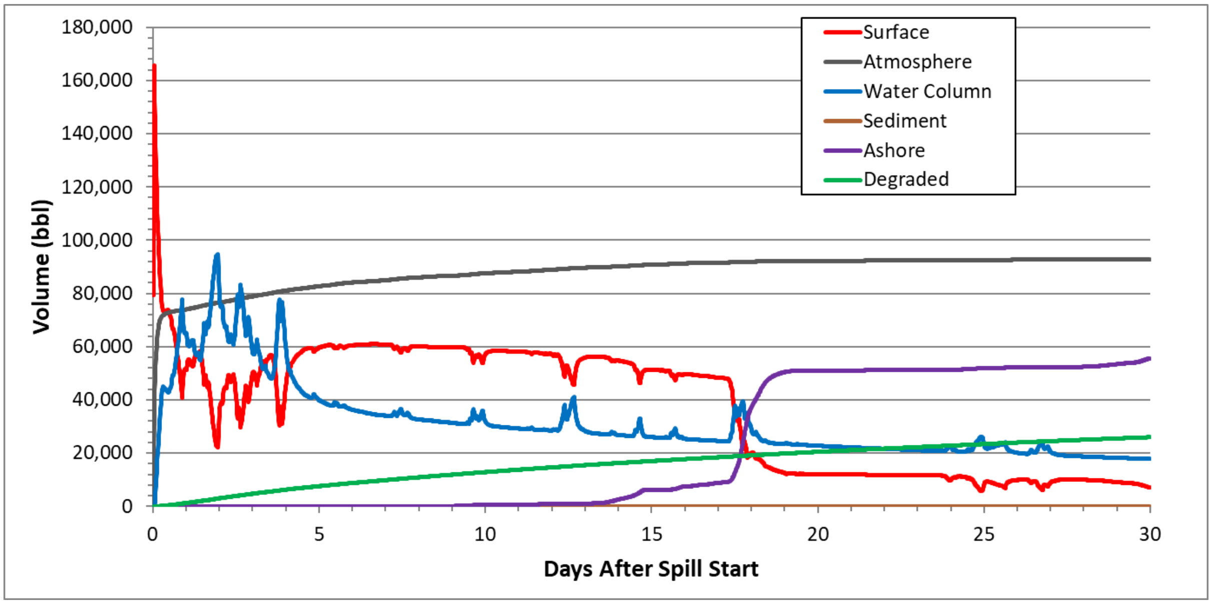


Figure 3-198. Oil volume by environmental compartment over time for an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl surface release of crude oil offshore of New Jersey starting on May 1, 2018.

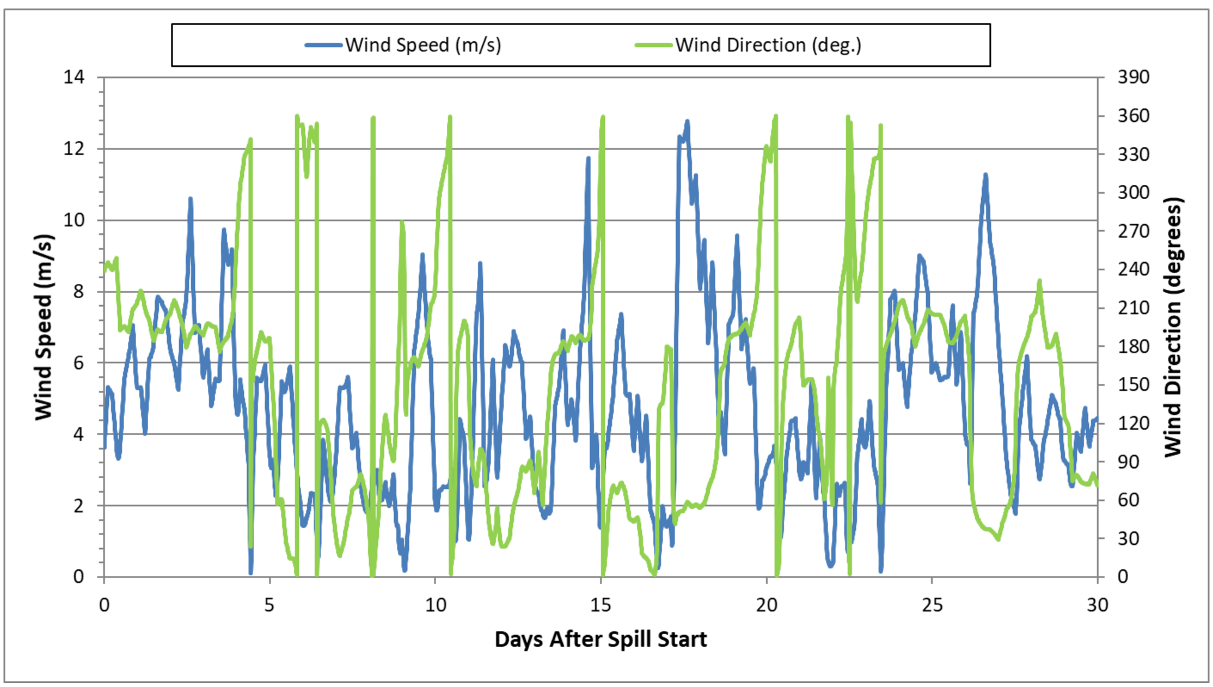


Figure 3-199. Wind speeds (1 m/s = 2 knots) and directions during the unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl surface release of crude oil offshore of New Jersey starting on May 1, 2018.

3.3.2.3.2 Seasonal Worst-Case Runs

Winter

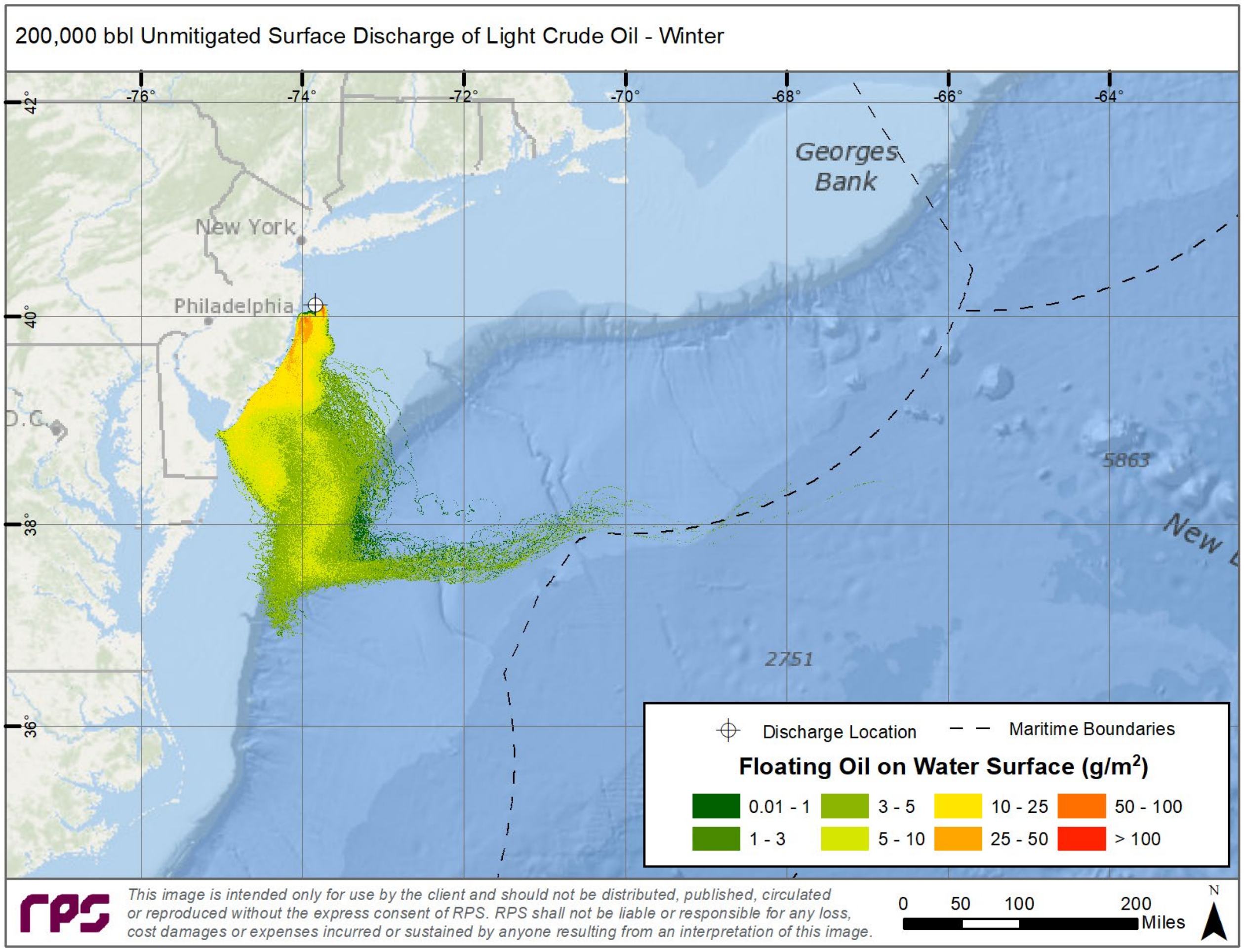


Figure 3-200. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore New Jersey starting on December 21, 2018.

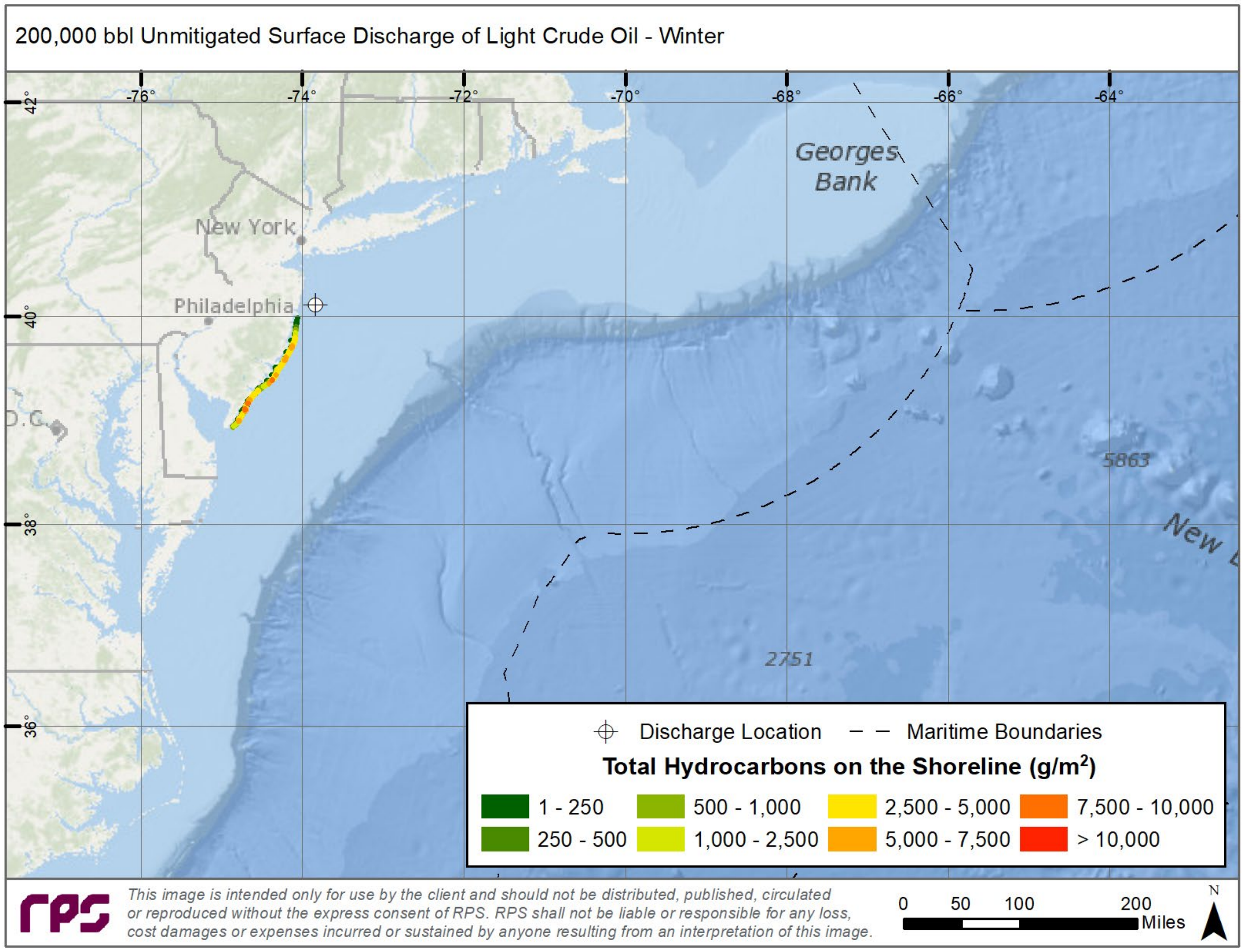


Figure 3-201. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore New Jersey starting on December 21, 2018.

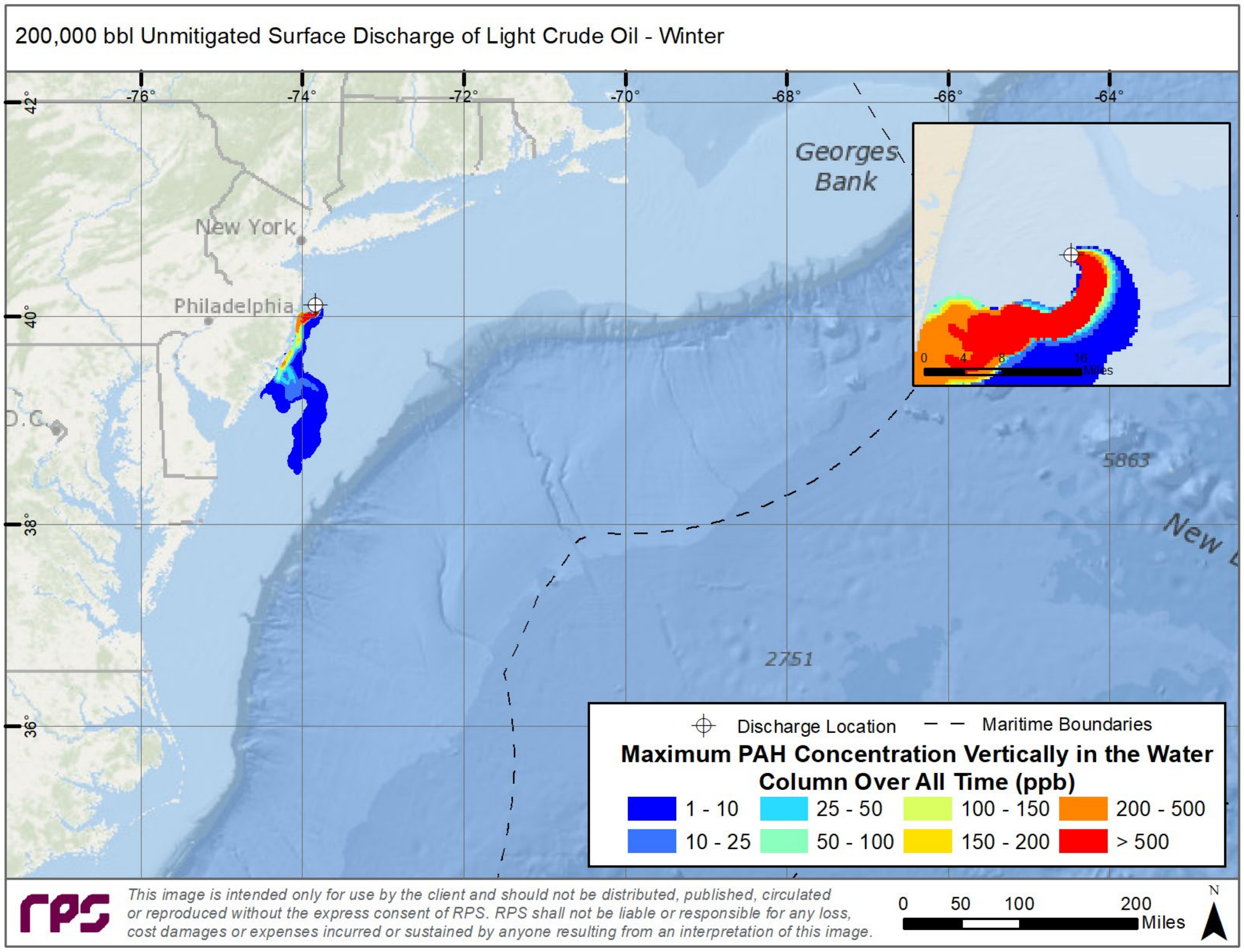


Figure 3-202. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore New Jersey starting on December 21, 2018.

Summer

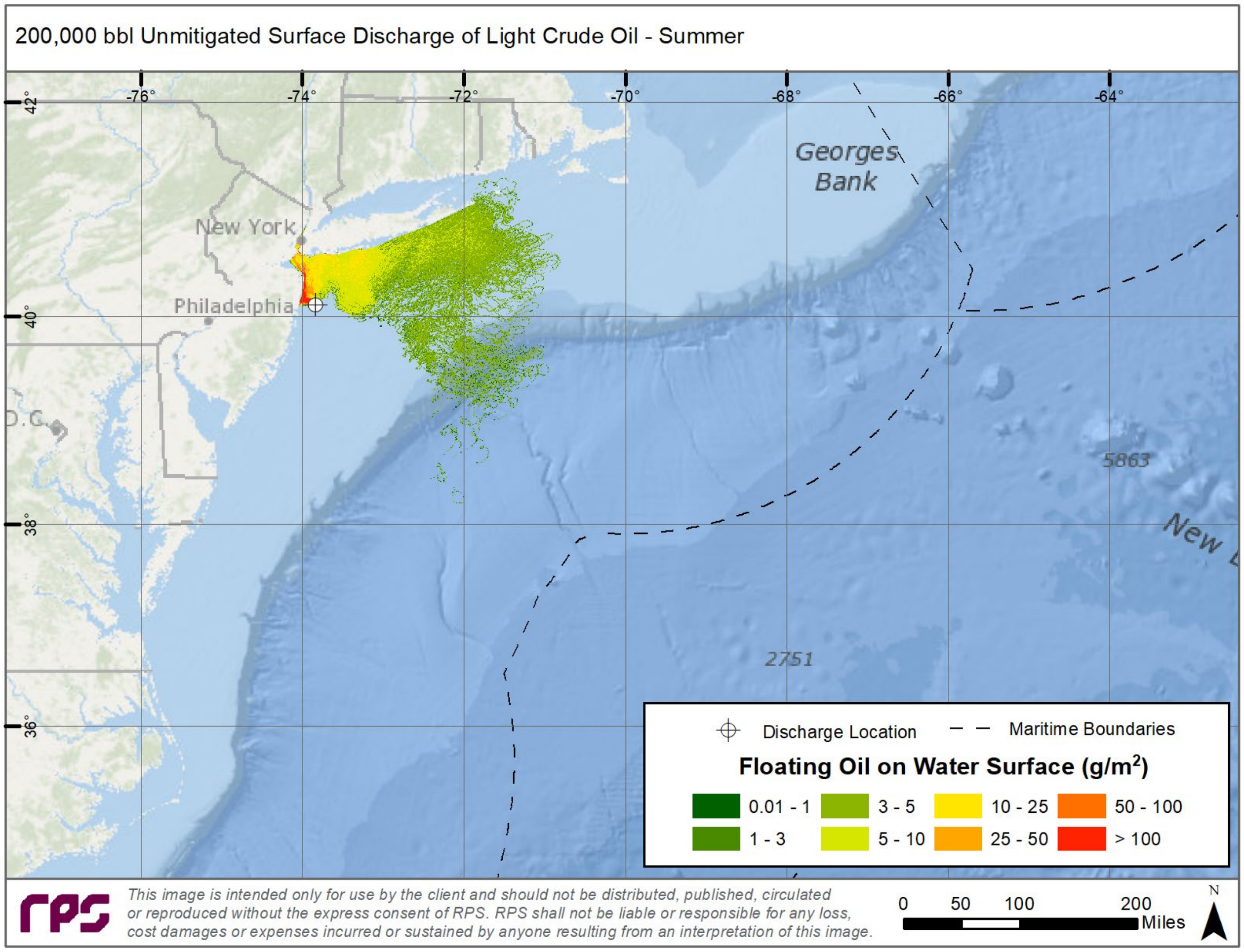


Figure 3-203. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore New Jersey starting on July 21, 2018.

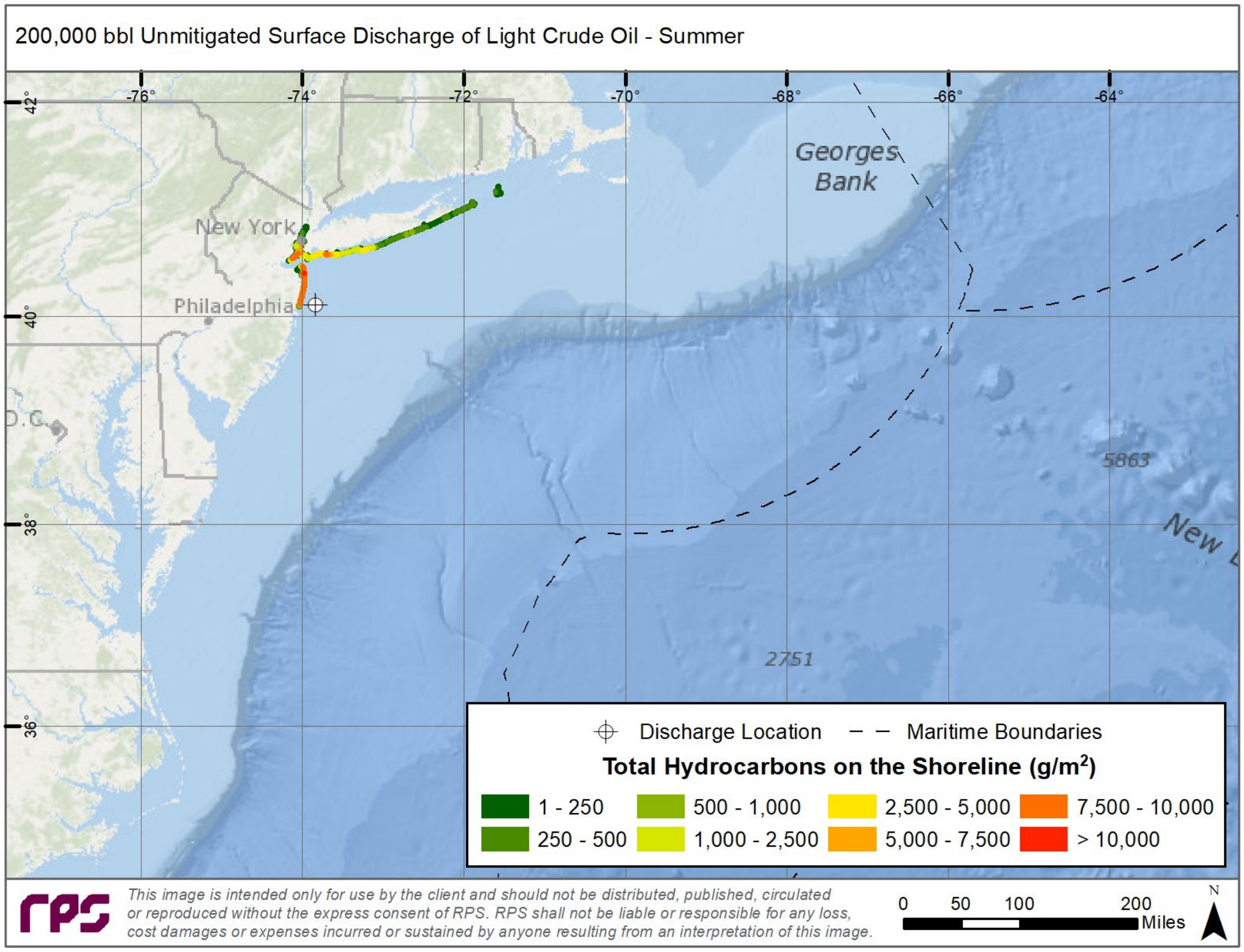


Figure 3-204. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore New Jersey starting on July 21, 2018.

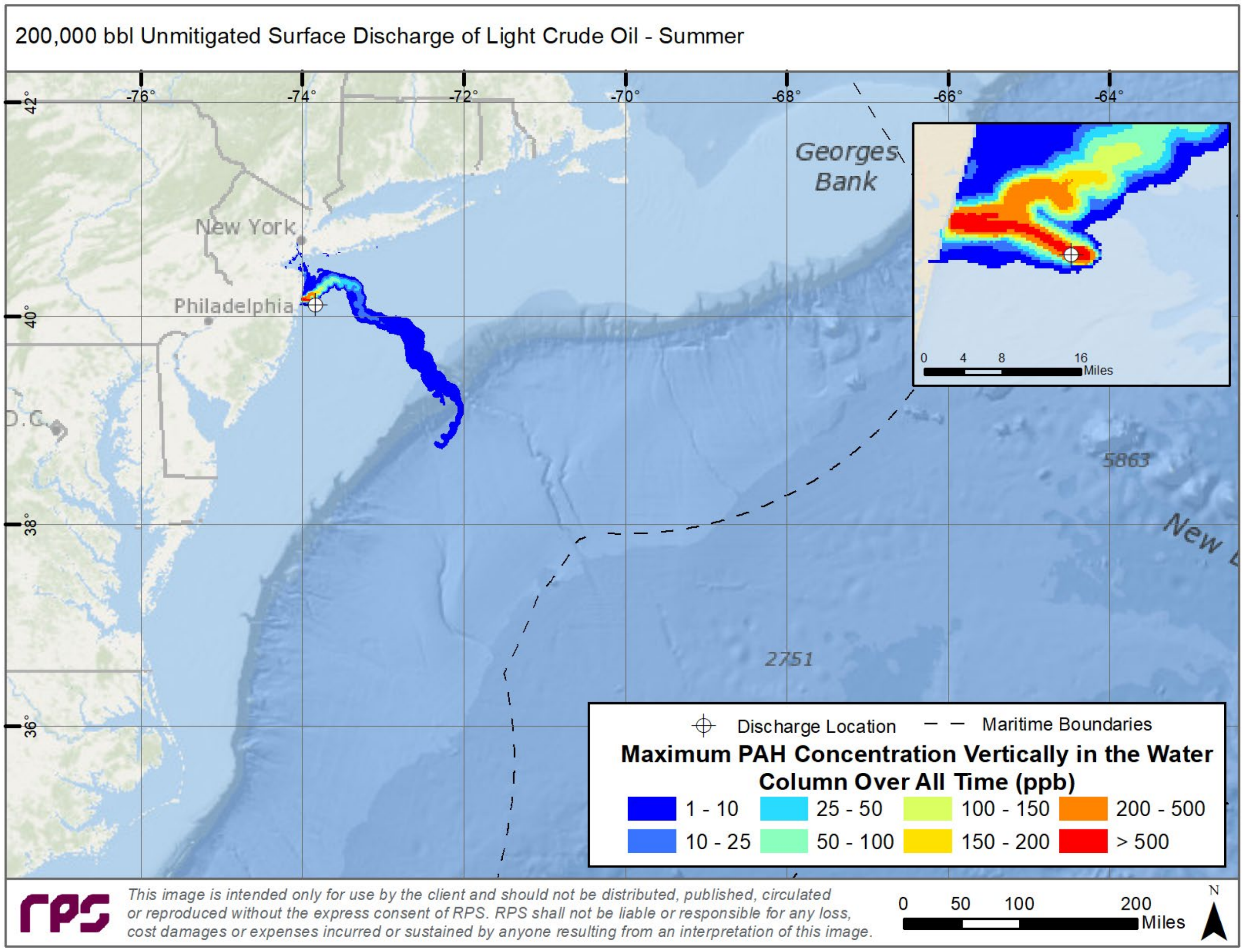


Figure 3-205. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore New Jersey starting on July 21, 2018.

Fall

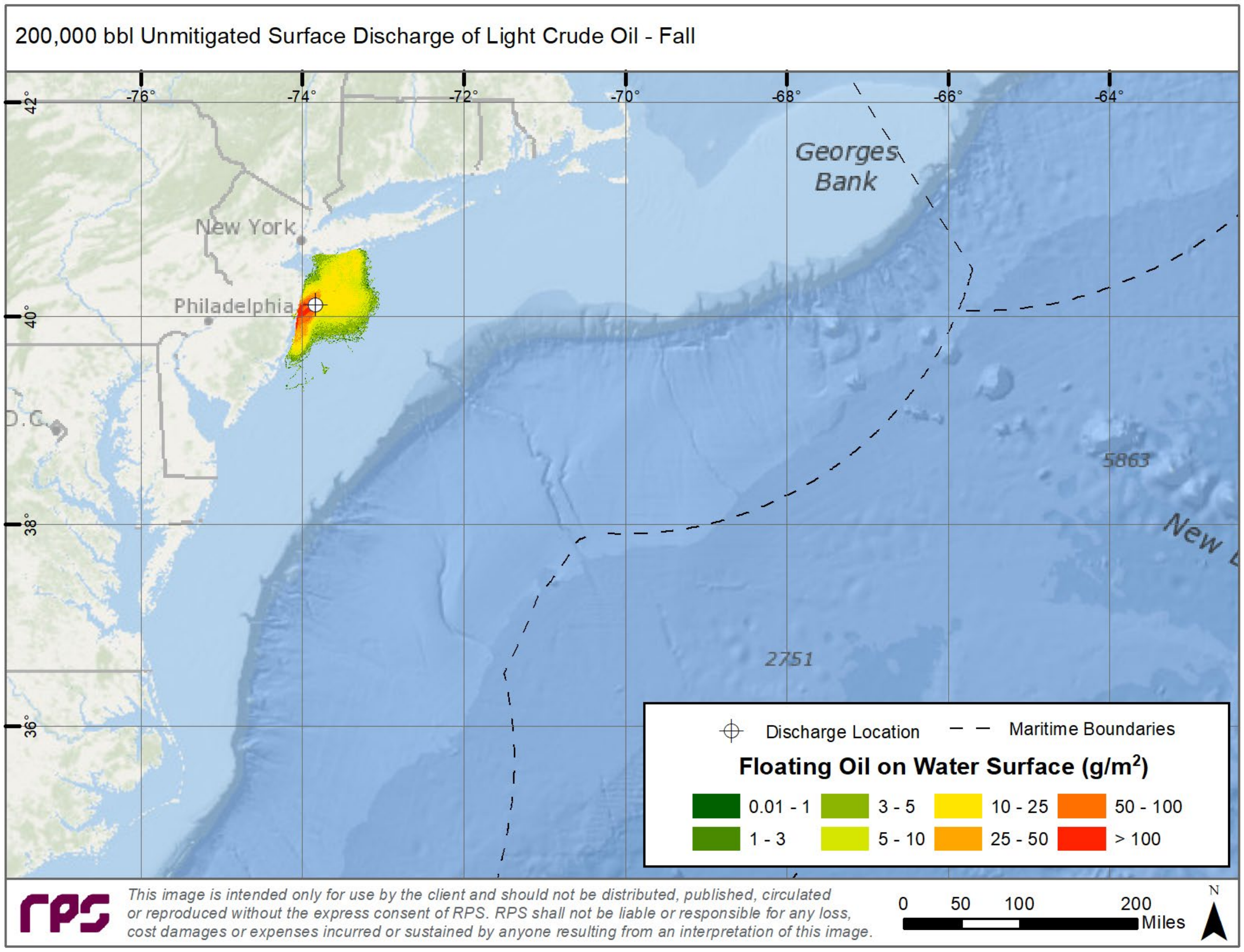


Figure 3-206. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore New Jersey starting on September 13, 2018.

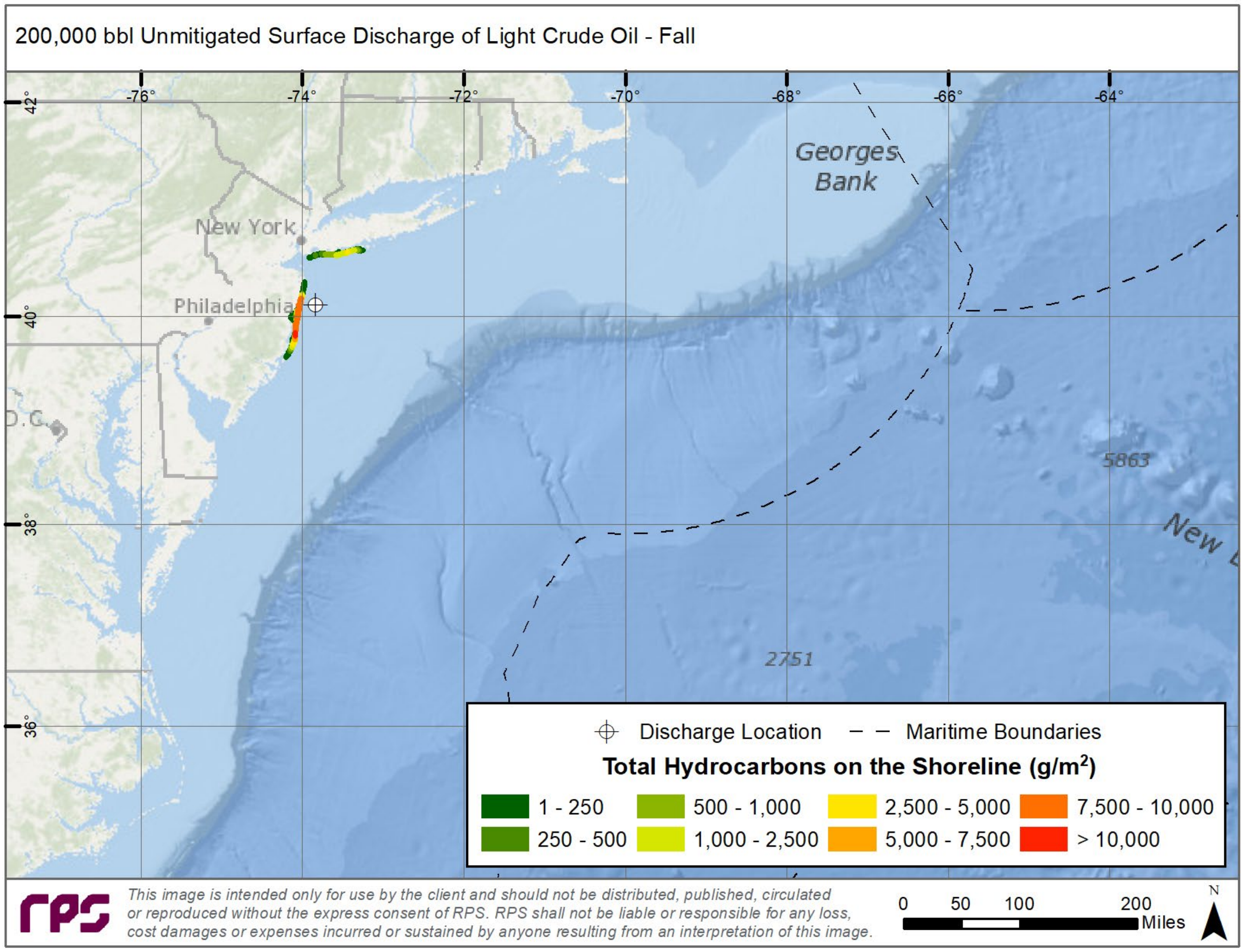


Figure 3-207. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore New Jersey starting on September 13, 2018.

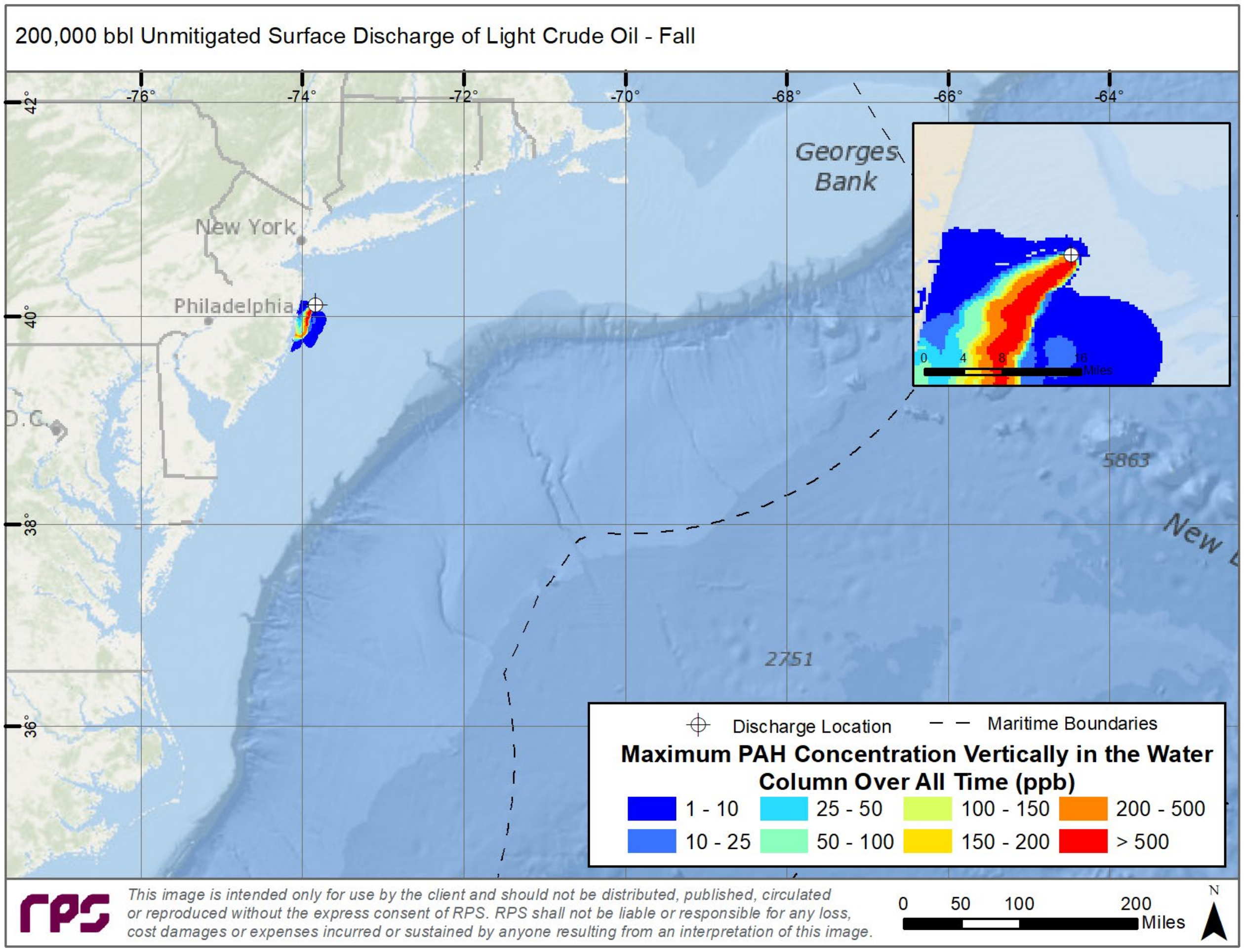


Figure 3-208. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore New Jersey starting on September 13, 2018.

3.3.2.4 Surface Mitigated Release (High Volume)

3.3.2.4.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a mitigated high-volume surface release of 200,000 bbl crude oil offshore New Jersey started on May 1, 2018. Response measures simulated for this case included deployment of surface dispersant, mechanical removal, and ISB. Removal began 24 hours upon release with oil removed steadily increasing over the 30-day simulation (Figure 3-212). Evaporation of just under 40% of the released oil occurred within the first couple days after the crude oil release. Similar to the unmitigated high volume cases, a few high wind events cause the oil to entrain in the water column in the first few days. Ultimately, due to response methods, more water entrains into the water column and surface oil disappears as dispersant breaks down oil into small droplets (Figure 3-212 and Figure 3-213). The mass balance (Figure 3-212) shows that no oil remained on the surface while approximately 44% of the oil evaporated, 11% of the oil reached shore, 9% of the oil remained in the water column, 23% was removed via response, and 12.8% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending furthest to the northeast. Maximum floating oil on the surface was >100 g/m^2 (100 µm, on average) and extended from the release site to the northeast (Figure 3-209). Lower (<25 g/m^2, i.e., patchy oil, emulsions or sheens) maximum surface oil exposure concentrations were predicted to extend up to 70 mi (113 km) from the release site, into the nearshore waters of New Jersey and New York. Response measures decreased the maximum surface floating oil exposure in the worst-case run when compared to the unmitigated case, especially in the waters off the southern coast of New Jersey (Figure 3-195; Figure 3-209). By the end of the 30-day simulation, 191 mi (307 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-210; Table 3-20). Seaward sandy beach was the habitat predicted to have the longest length of shoreline oiled (107 mi; 172 km). Shoreline oiling was predicted along the coasts of New Jersey and New York, with the highest concentrations of oil (7,500-10,000 g/m^2) occurring along the seaward coast of New Jersey near Sandy Hook Bay and Seaside Heights.

Maximum cumulative PAH concentrations for the worst-case run were <400 ppb and remained near the release location, primarily extending east (Figure 3-211). Lower concentrations, between 1-10 ppb, extended from the release location to the northeast and southeast. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-20. Shoreline lengths oiled by >1 g/m^2 for the run with maximum shoreline length oiled (on an annual basis, in summer), for a mitigated 200,000 bbl surface release of crude oil offshore of New Jersey starting on May 1, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	107	107	102	173	173	165
Mudflat	8	8	7	12	12	11
Wetland	1	1	1	1	1	1
Artificial/manmade shoreline	15	15	0	24	24	0
Total	131	131	110	210	210	177

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	3	3	3	5	5	5
Sand beach	24	24	19	38	38	31
Mudflat	5	4	0	8	7	0
Wetland	6	6	3	10	10	4
Artificial/manmade shoreline	21	21	0	34	34	0
Total	60	59	25	97	95	40
All Shorelines						
Total	191	190	135	307	305	217

Table 3-12 shows the model results for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-214 to Figure 3-222 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In the winter and fall, oil is transported south along the coast of New Jersey in the nearshore waters. In the summer, oil is transported concentrically around the release site and to the northeast, in waters offshore of New Jersey and New York. During the worst-case run to occur in the spring, the highest concentrations of surface oil occur to the northeast of the release site, with lower concentrations extending northeast, up to 70 mi (112 km) from the release site. Shoreline oiling >1 g/m^2 occurred along the New Jersey and New York coast.

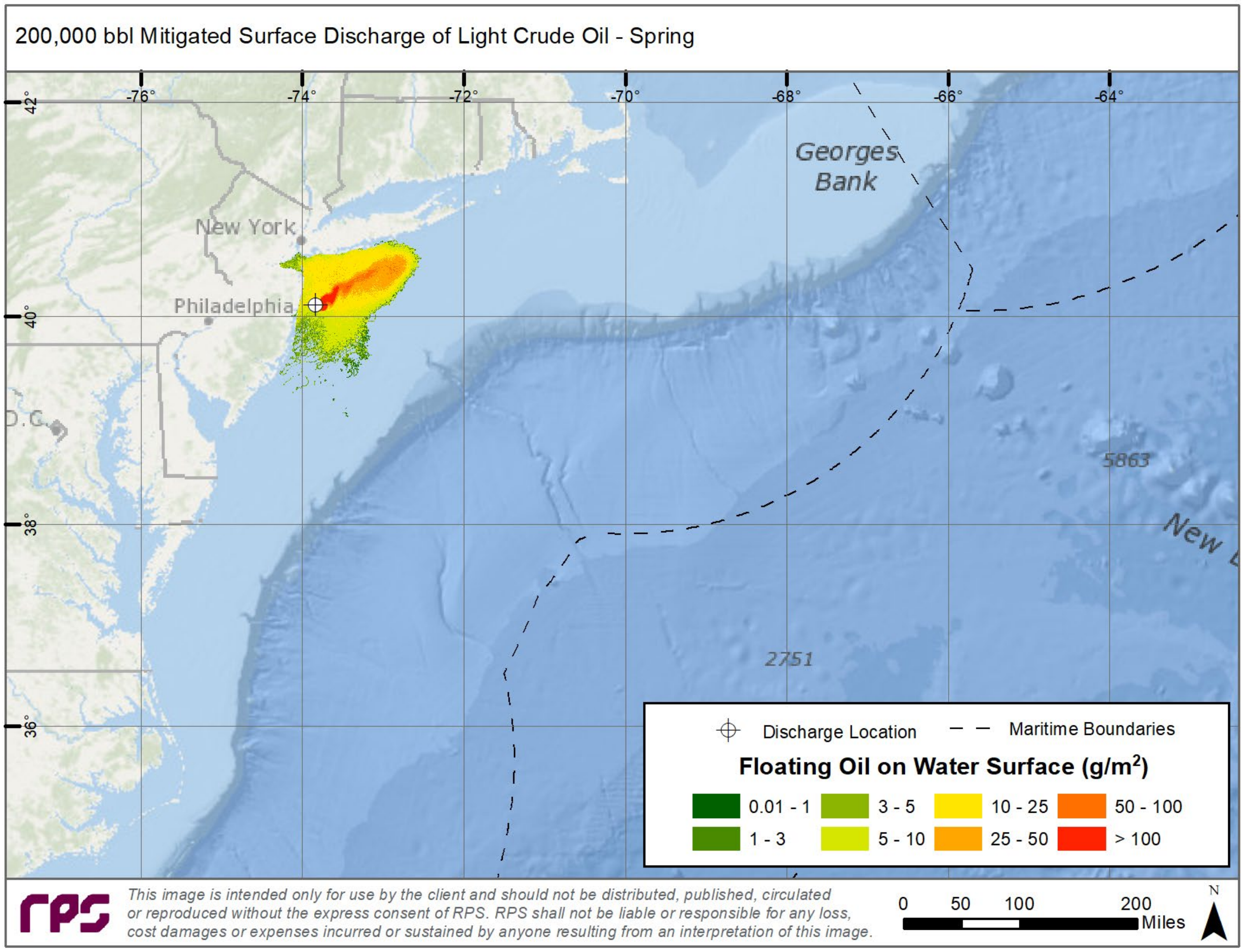


Figure 3-209. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore of New Jersey starting on May 1, 2018.

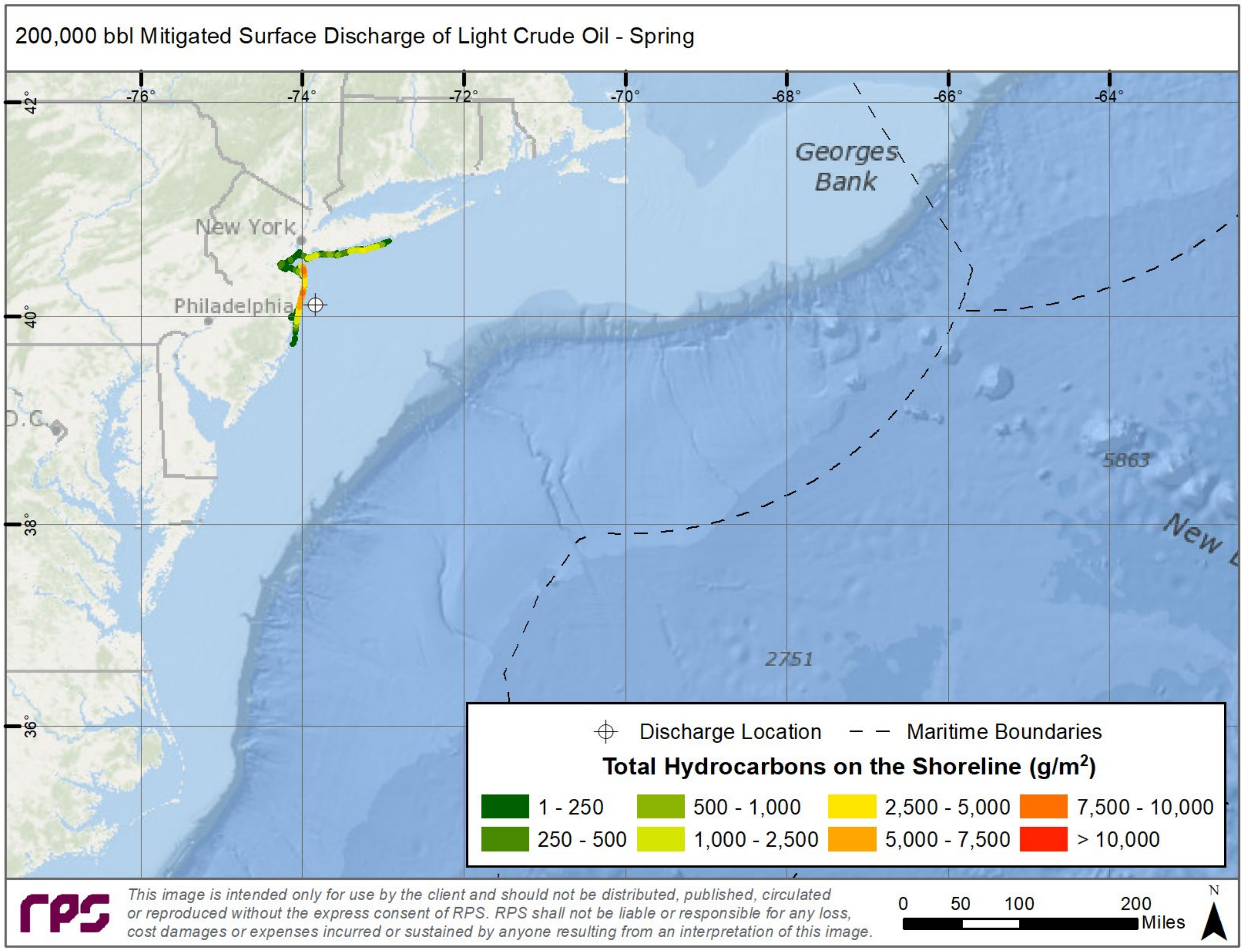


Figure 3-210. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore of New Jersey starting on May 1, 2018.

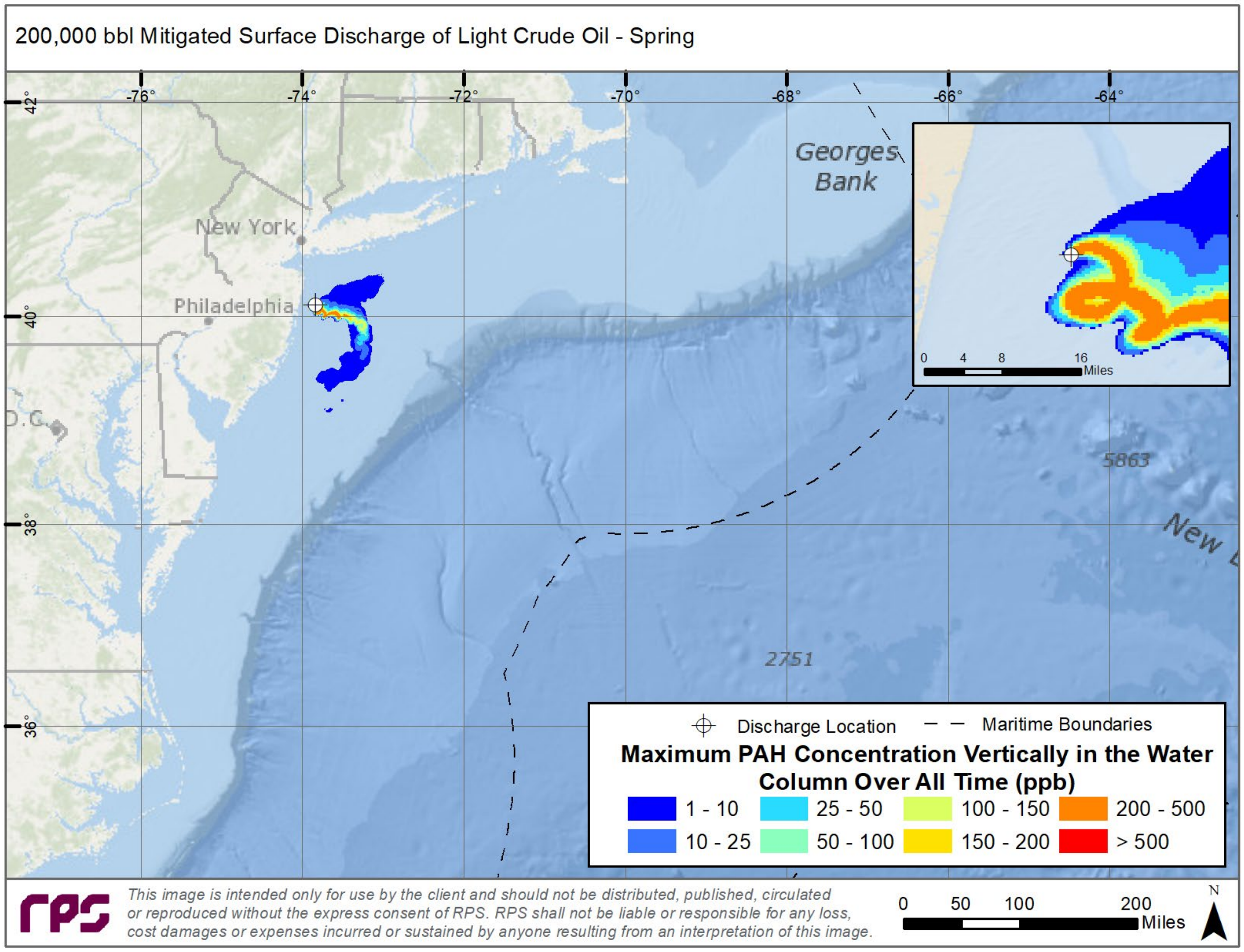


Figure 3-211. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore of New Jersey starting on May 1, 2018.

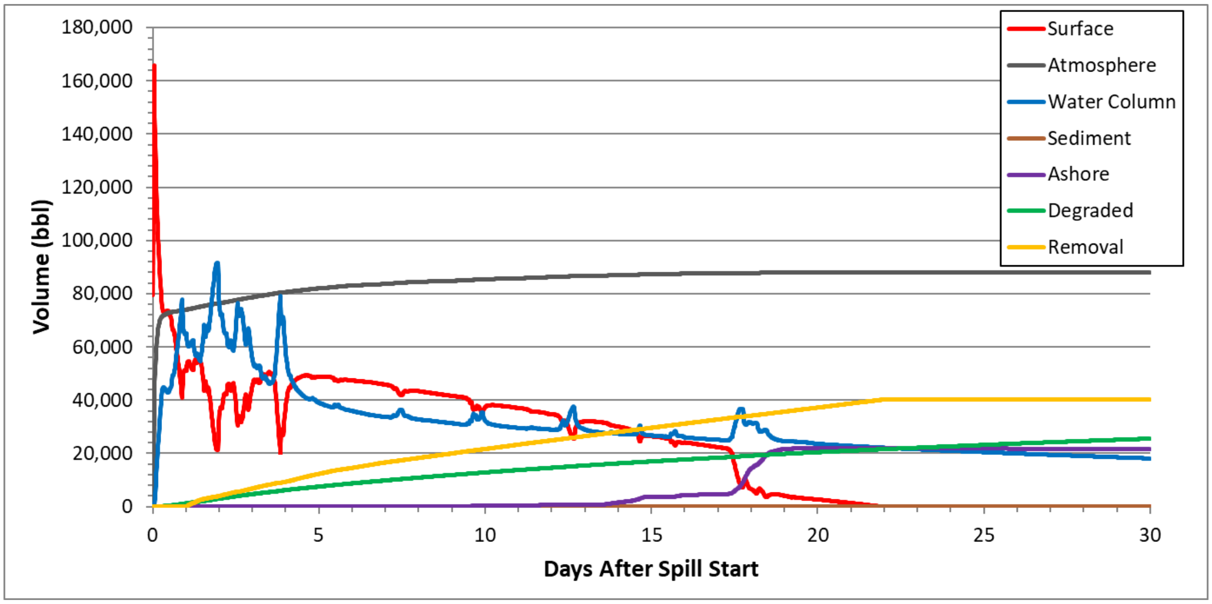


Figure 3-212. Oil volume by environmental compartment over time for a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl surface release of crude oil offshore of New Jersey starting on May 1, 2018.

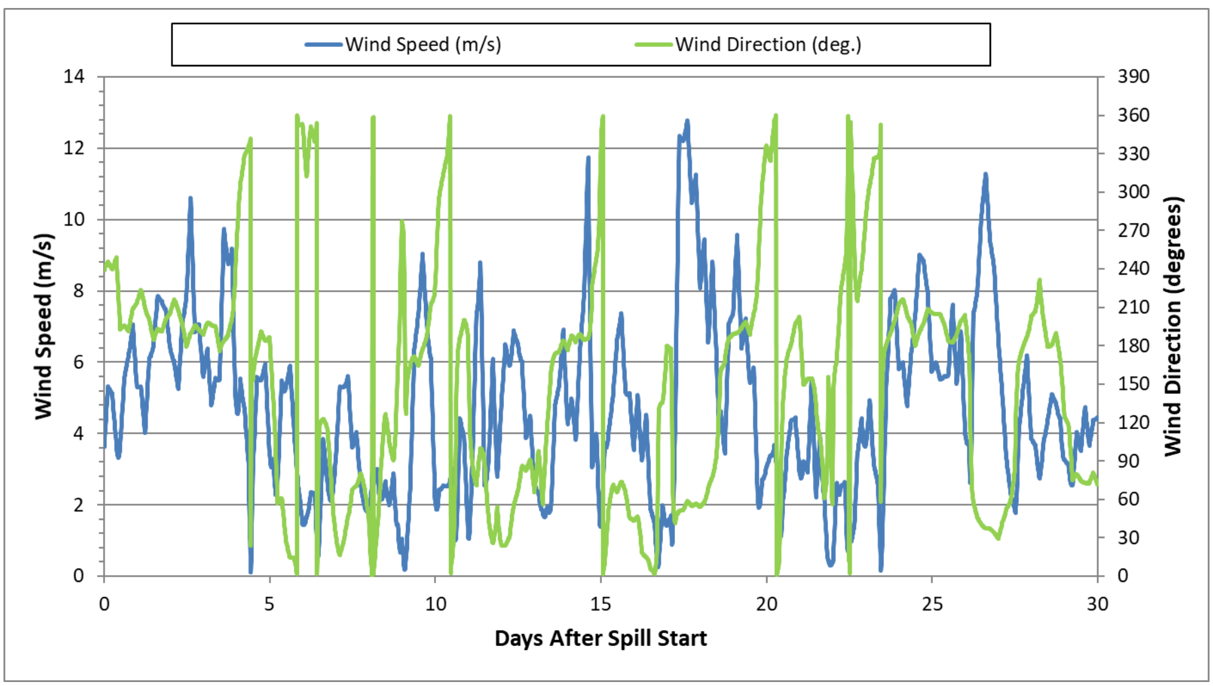


Figure 3-213. Wind speeds (1 m/s = 2 knots) and directions during the mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl surface release of crude oil offshore of New Jersey starting on May 1, 2018.

3.3.2.4.2 Seasonal Worst-Case Runs

Winter

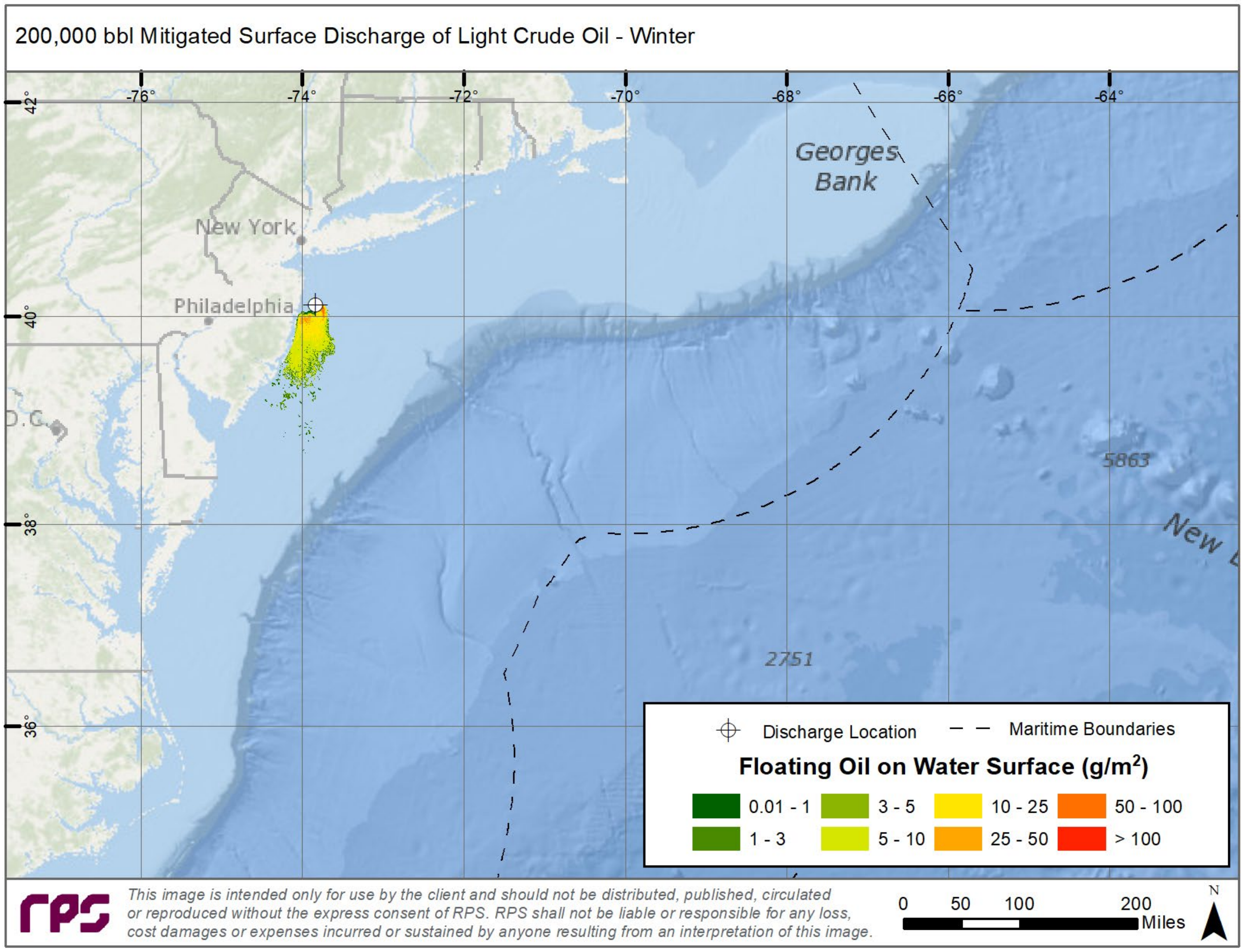


Figure 3-214. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

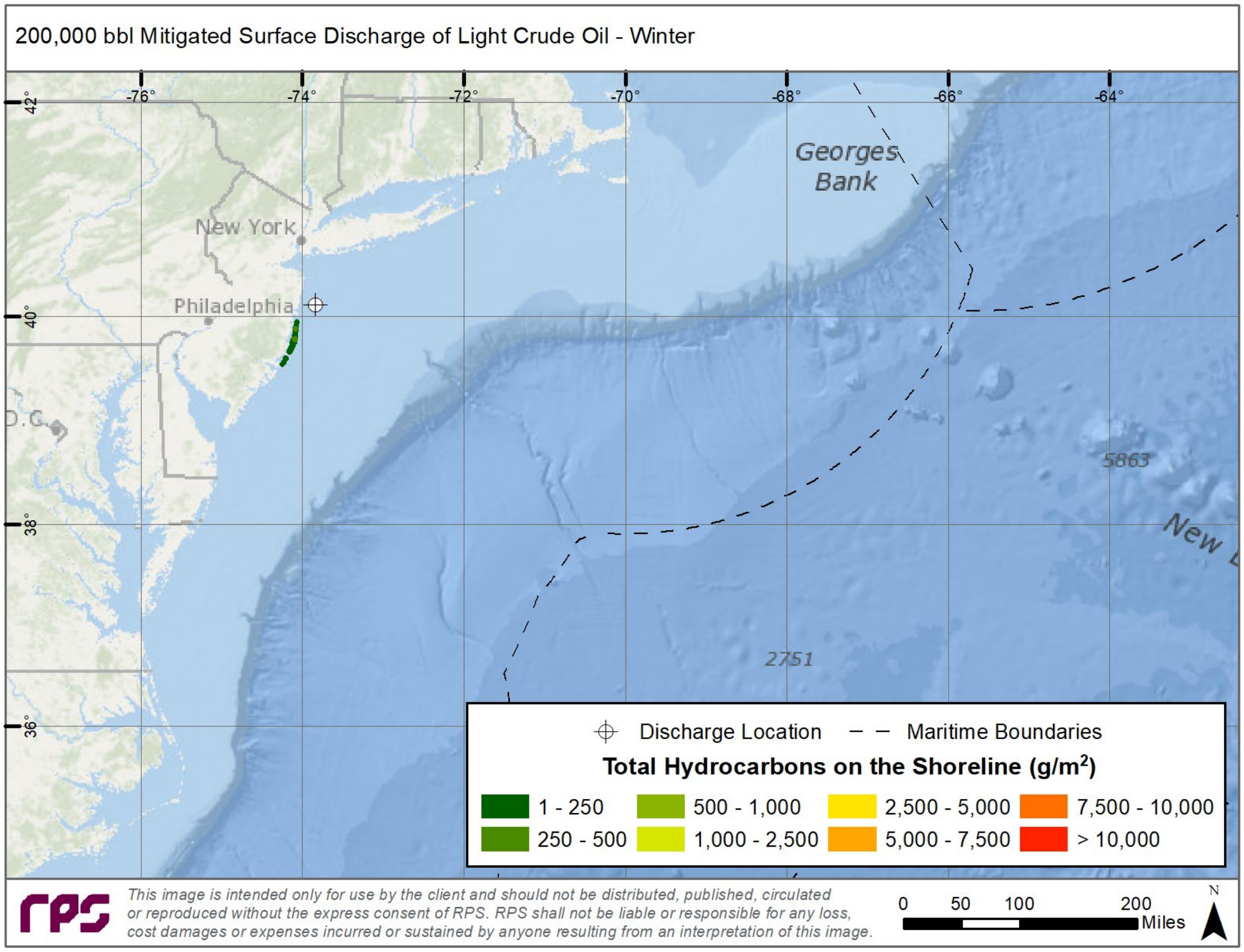


Figure 3-215. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

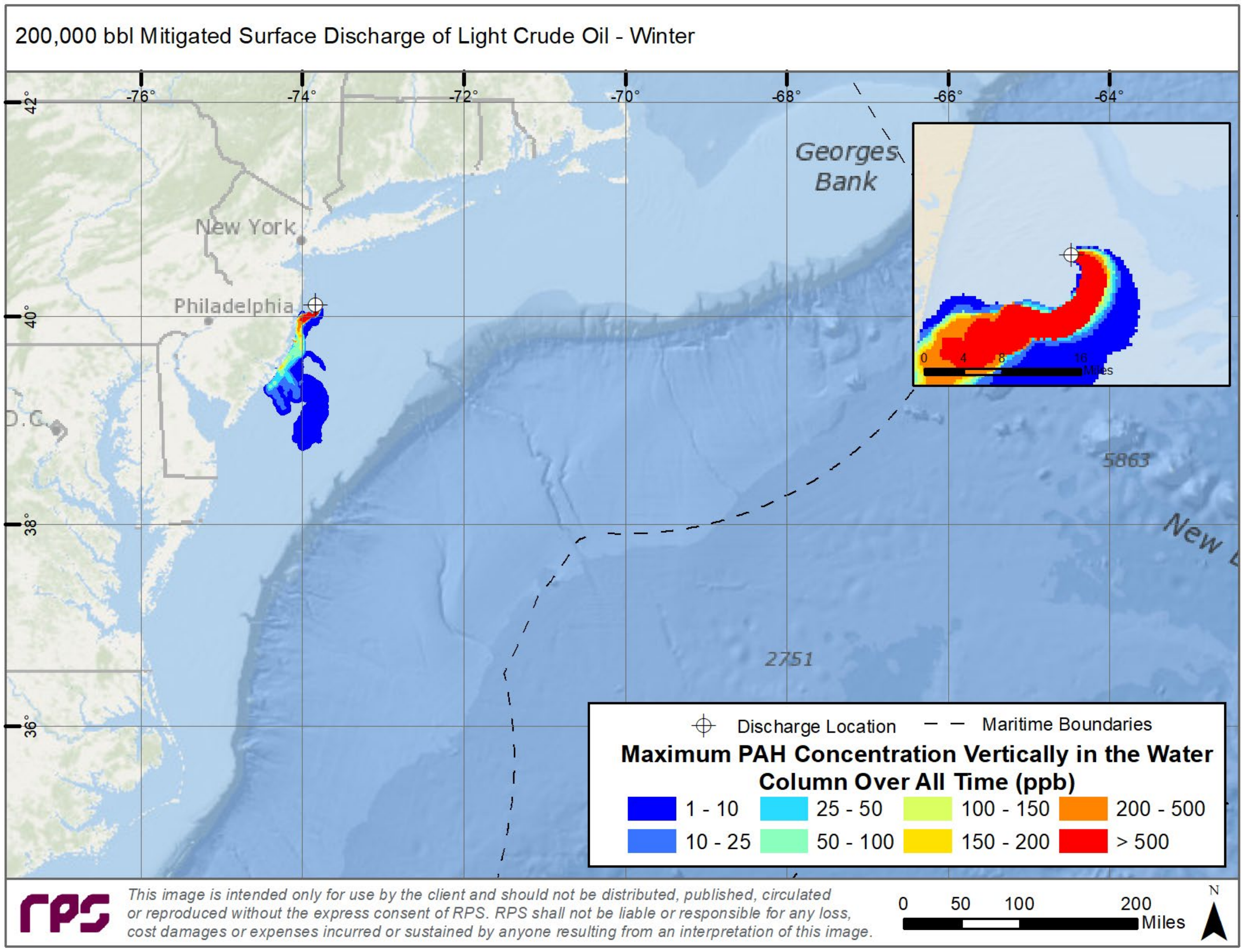


Figure 3-216. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore New Jersey starting on December 7, 2018.

Summer

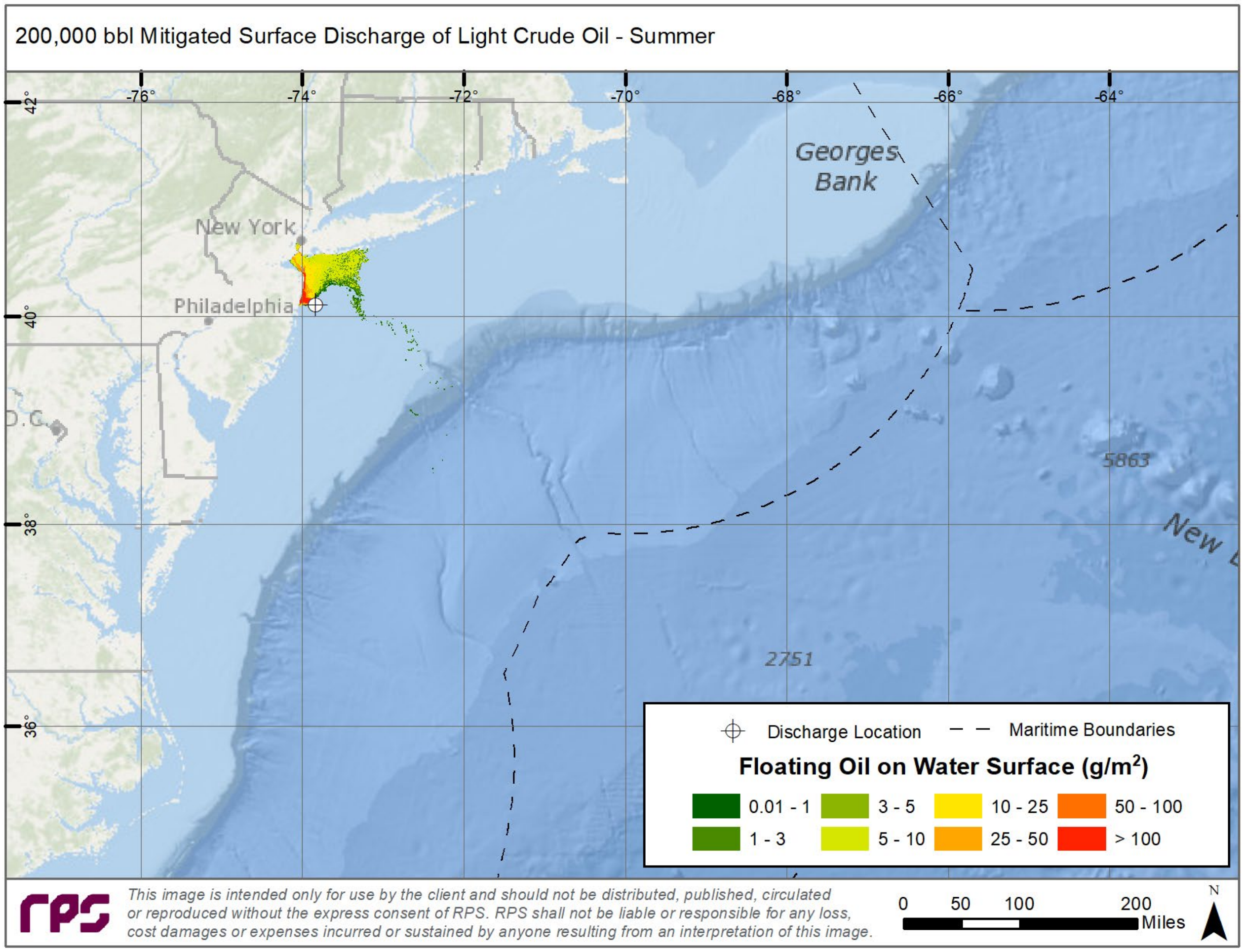


Figure 3-217. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore New Jersey starting on July 21, 2018.

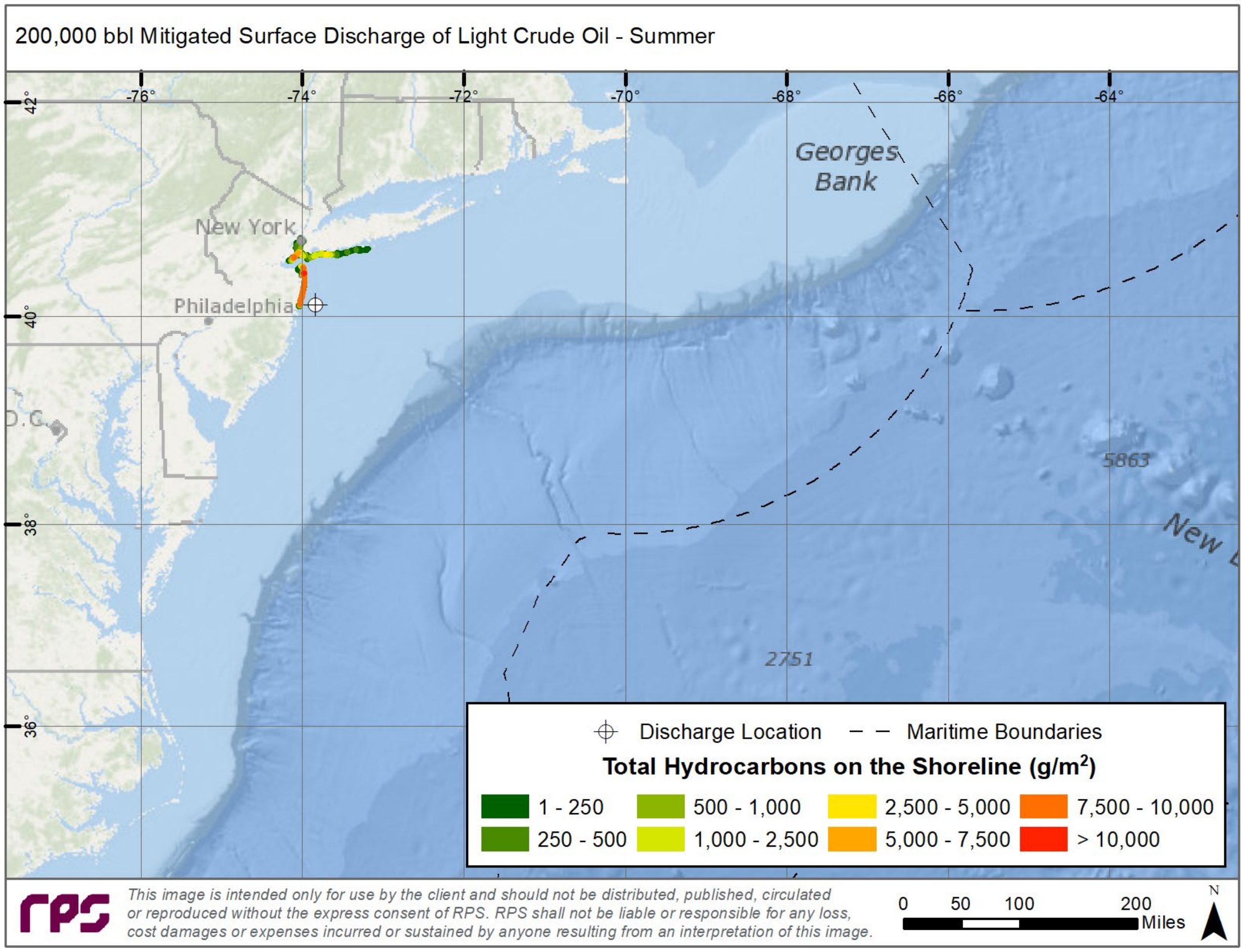


Figure 3-218. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore New Jersey starting on July 21, 2018.

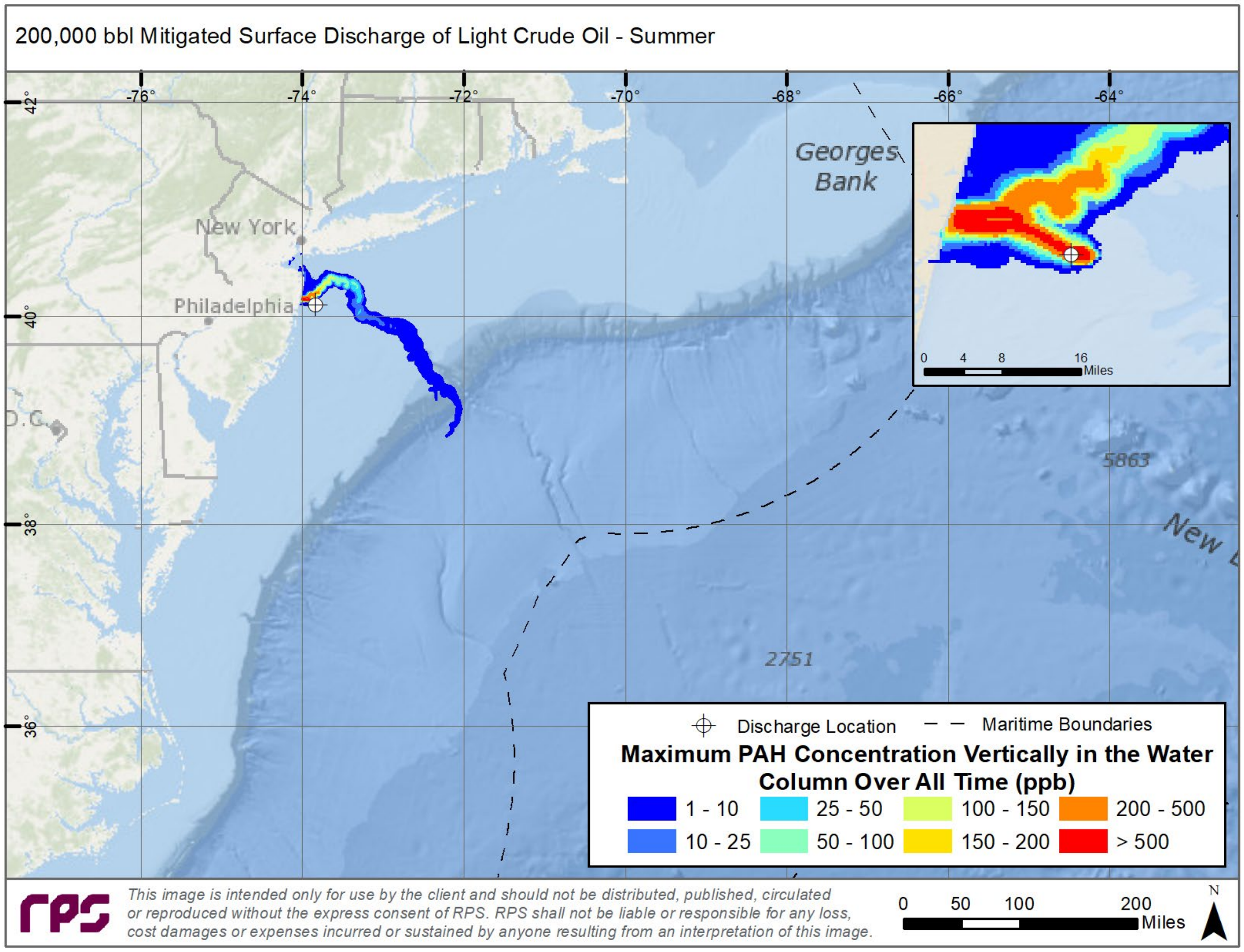


Figure 3-219. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore New Jersey starting on July 21, 2018.

Fall

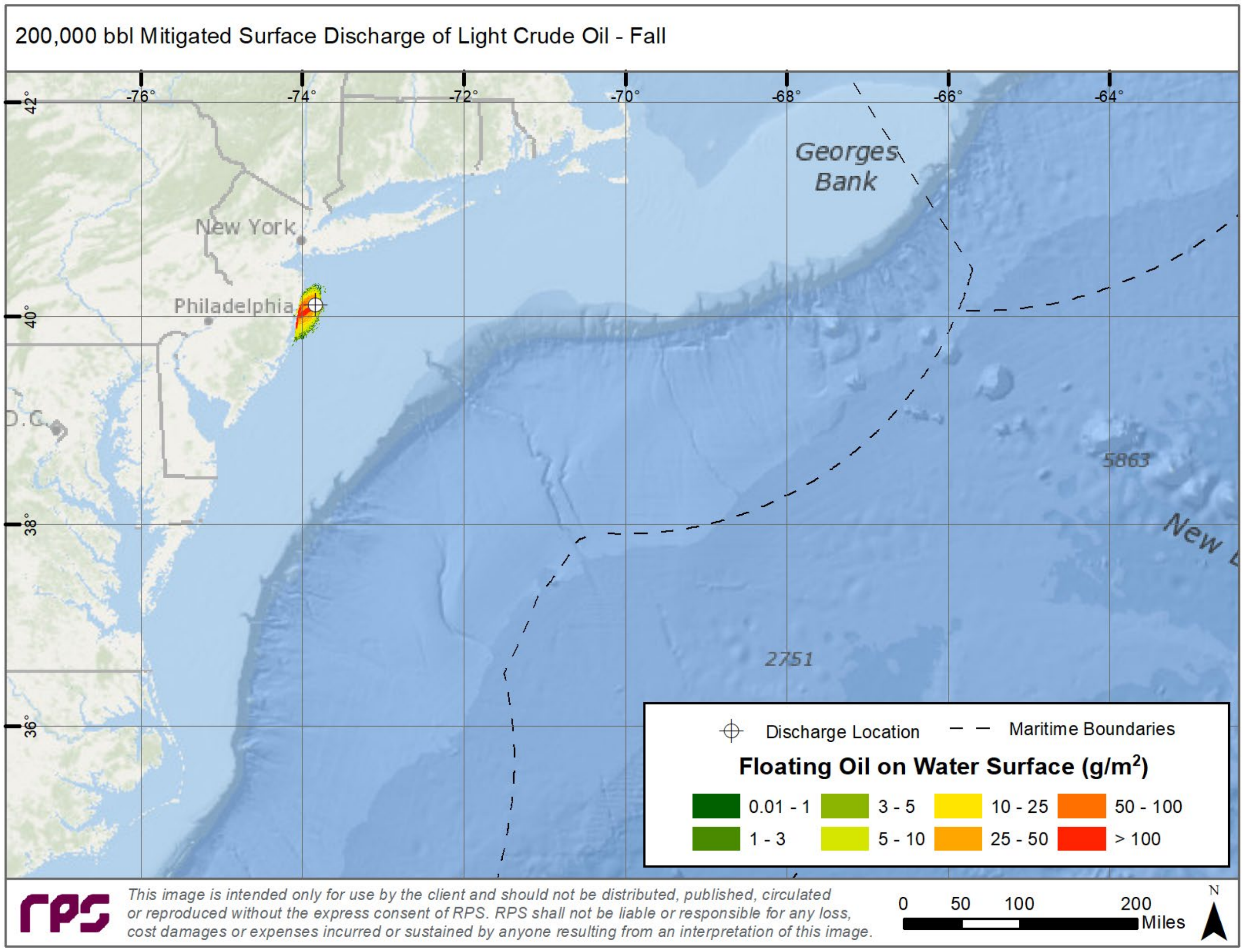


Figure 3-220. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore New Jersey starting on September 13, 2018.

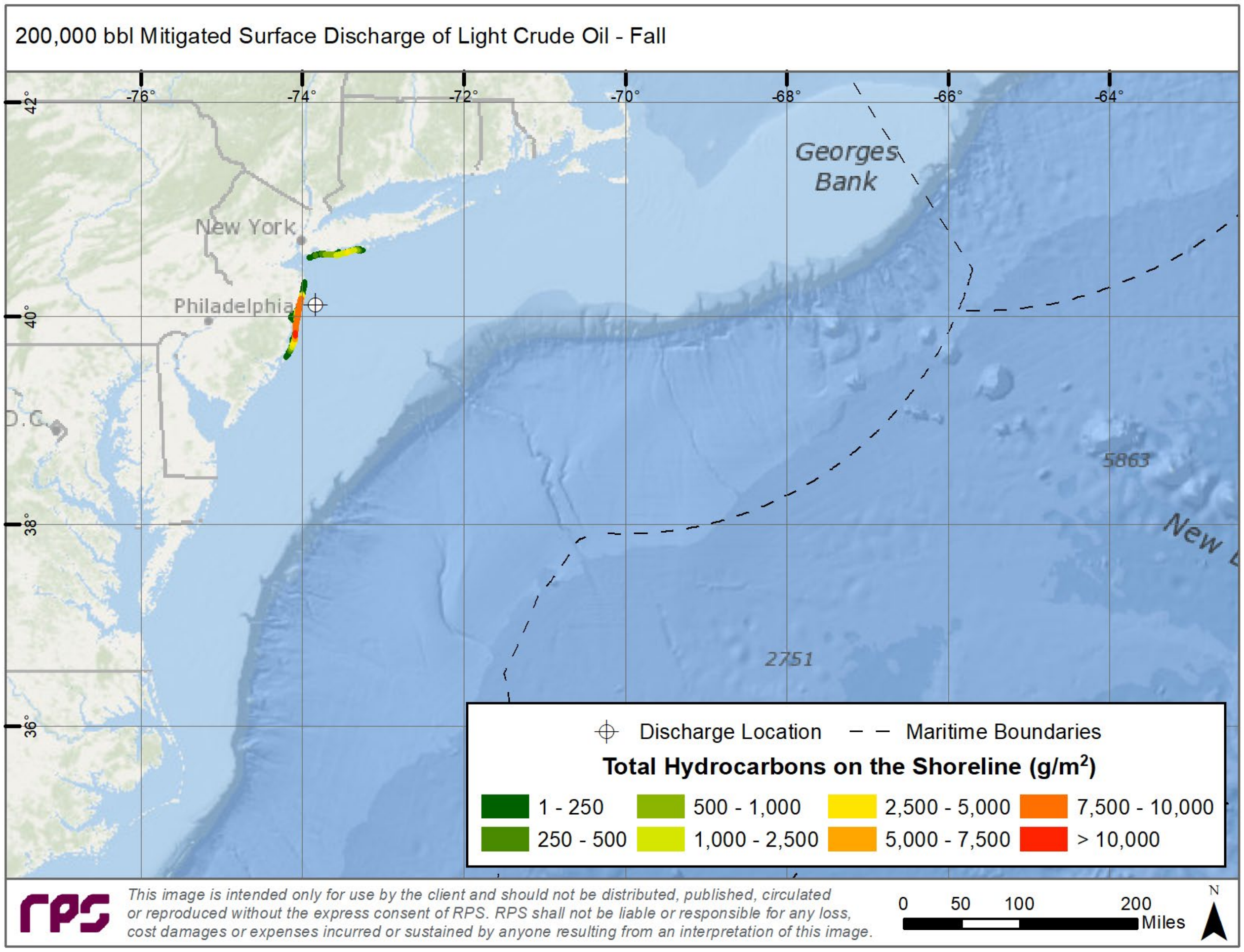


Figure 3-221. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore New Jersey starting on September 13, 2018.

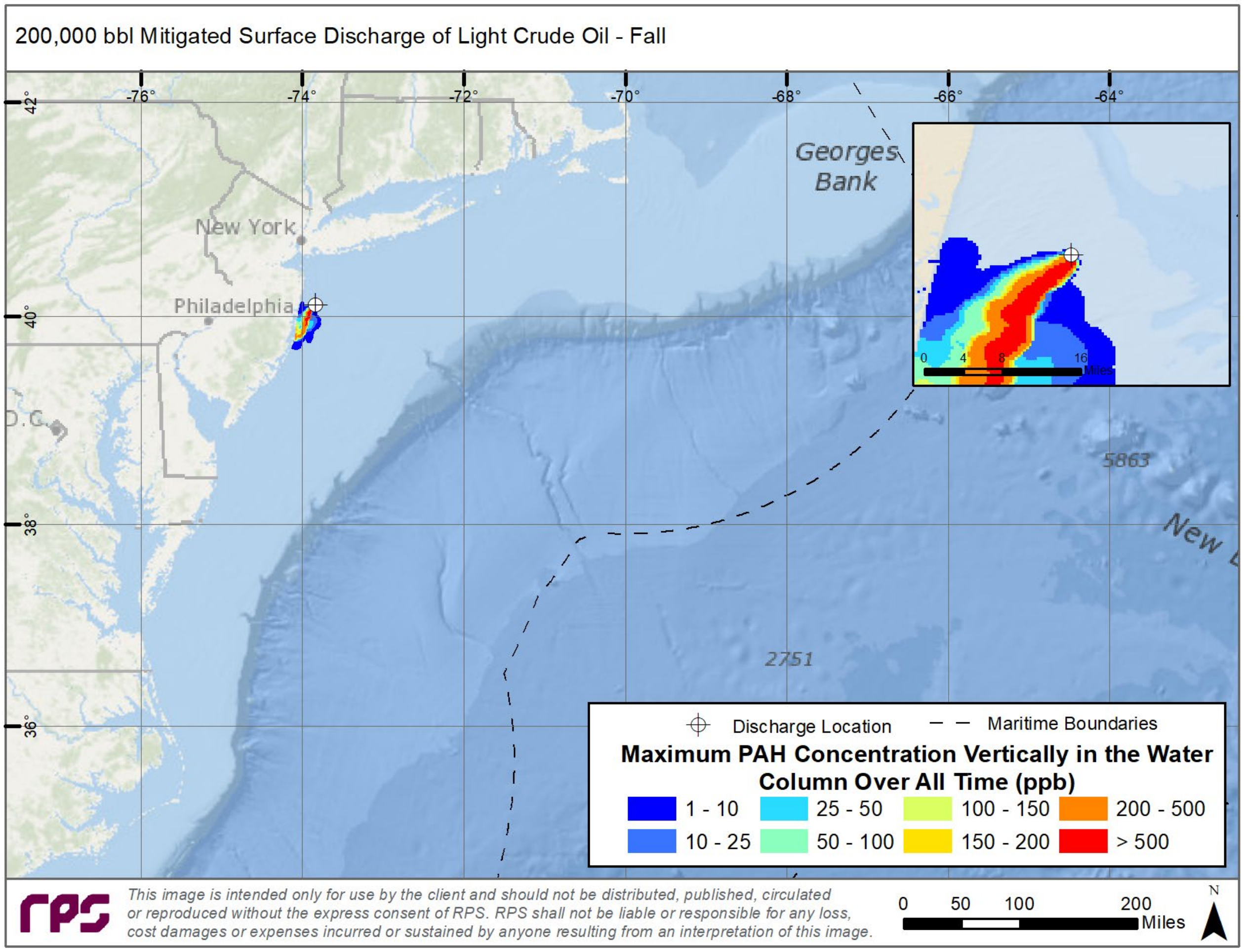


Figure 3-222. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore New Jersey starting on September 13, 2018.

3.3.2.5 Subsurface Unmitigated Release (Well Blowout)

3.3.2.5.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for shallow water blowout of 30,000 bbl/day crude oil over 75 days (900,000 bbl in total) offshore New Jersey started on May 21, 2018. The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Oil evaporated quickly over the first 30 days of the simulation. Emulsification of the crude oil to viscosities > 4,000 cP during the first few days upon release limited entrainment into the water to occur only during the high wind events, causing oil to oscillate from within the water column to the surface during periods of high and low winds (Figure 3-226; Figure 3-227). The mass balance (Figure 3-226) shows that released the oil came ashore beginning 22 days after the spill while strong winds (11 m/s; 22 knots) were blowing from the northeast (Figure 3-227). Approximately 49% of the oil evaporated, 17% of the oil reached shore, 4% of the oil remained in the water column, 10% remained on the surface, and approximately 18% of the oil was biodegraded by the end of the 75-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending furthest to the southeast, up to 410 mi (660 km) where it reaches the boundary of the model domain. Maximum floating oil on the surface was >100 g/m^2 (100 µm, on average) and extended from the release site to the south (Figure 3-223). Lower (<25 g/m^2, i.e., patchy oil, emulsions or sheens) maximum surface oil exposure concentrations were predicted to extend into coastal waters to the east and southeast, offshore of New Jersey, Delaware, and New York. By the end of the 75-day simulation, 530 mi (853 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-224; Table 3-21). Seaward sandy beach was the habitat predicted to have the longest length of shoreline oiled (271 mi; 436 km). Shoreline oiling was predicted along the coasts of Delaware, New Jersey, and New York, with the highest concentrations of oil (7,500-10,000 g/m^2) occurring along the southern seaward coast of New Jersey and the Long Island, New York. In total, 0.4 mi^2 (1.0 km^2) of shoreline habitat in Delaware was oiled >1 g/m^2.

Maximum cumulative PAH concentrations for the worst-case run were >500 ppb and remained near the release location and extending to the east and southwest (Figure 3-225). Lower concentrations, between 1-10 ppb, extended approximately 120 mi (193 km) southwest of the release site. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 75-day simulation.

Table 3-21. Shoreline lengths oiled by >1 g/m^2 (1µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on May 21, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**
Rocky shore	0	0	0	0	0	0
Gravel beach	5	5	5	8	8	8
Sand beach	271	271	261	437	437	421
Mudflat	30	30	27	48	48	44
Wetland	5	5	4	8	8	7
Artificial/manmade shoreline	23	23	0	38	38	0
Total	334	334	298	537	537	479
Landward						

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Rocky shore	16	16	14	26	26	22
Gravel beach	3	3	2	4	4	3
Sand beach	34	34	30	55	55	48
Mudflat	38	37	23	61	59	37
Wetland	64	61	34	103	99	55
Artificial/manmade shoreline	42	42	0	67	67	0
Total	196	193	102	316	311	164
All Shorelines						
Total	530	527	400	854	848	643

Table 3-12 shows the model results for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-228 to Figure 3-236 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In the winter, oil is primarily transported east into waters further offshore, with relatively low concentrations of shoreline oiling predicted along Delaware, New Jersey, and Maryland coasts. In the summer, oil is primarily transport southwest of the release location with highest concentrations predicted directly east and to the southwest, in waters offshore of Delaware, New Jersey, and Maryland. Shoreline oiling was predicted along mainland coastlines of New Jersey, Delaware, Maryland, Virginia, and North Carolina. During the worst-case run to occur in the spring, the highest concentrations of surface oil occur to the west of the release site, with lower concentrations extending south and northeast, over to 300 mi (483 km) from the release site. Shoreline oiling >1 g/m^2 occurred along the New York, New Jersey, Delaware and Maryland coasts.

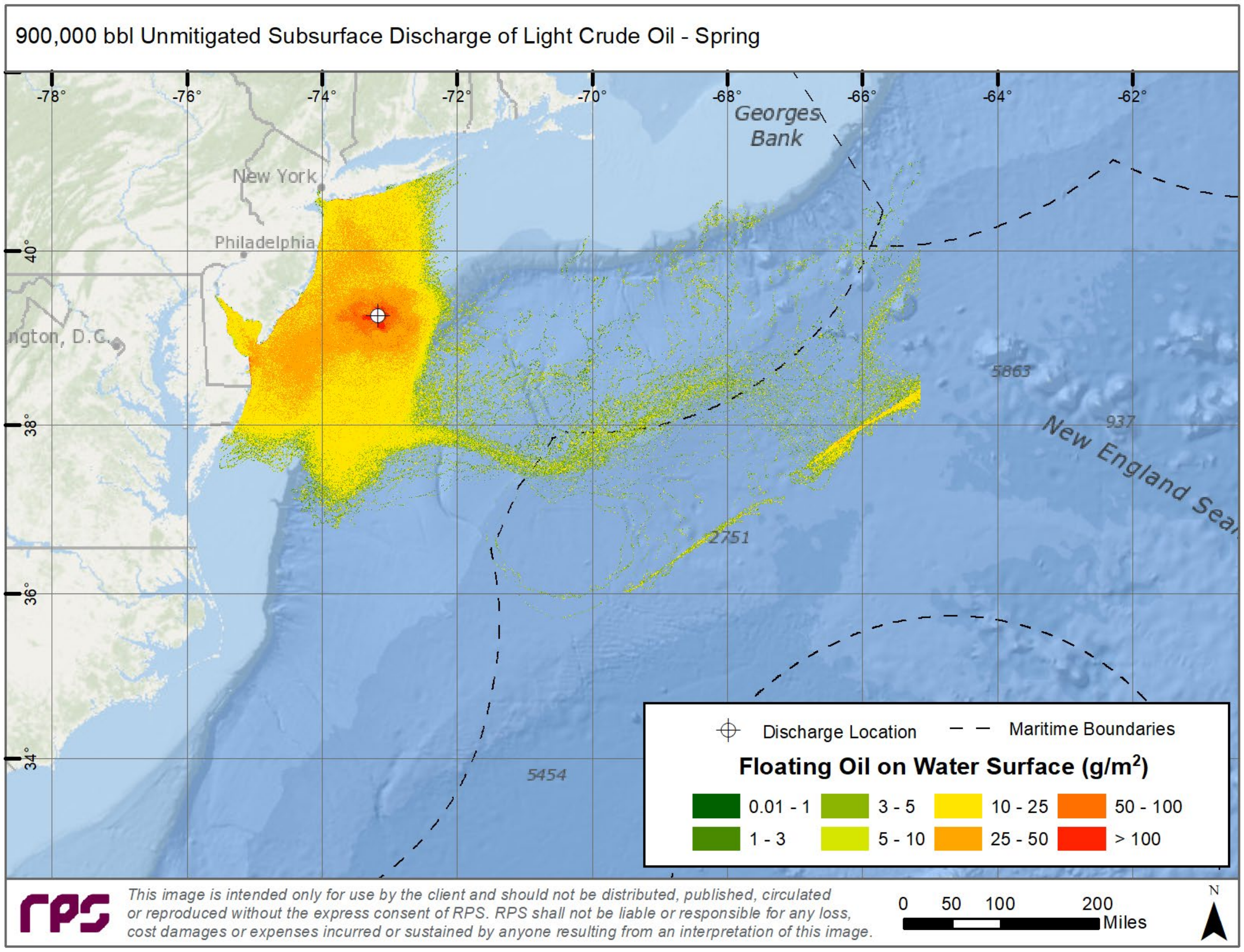


Figure 3-223. Maximum water surface oil exposure concentration at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on May 21, 2018.

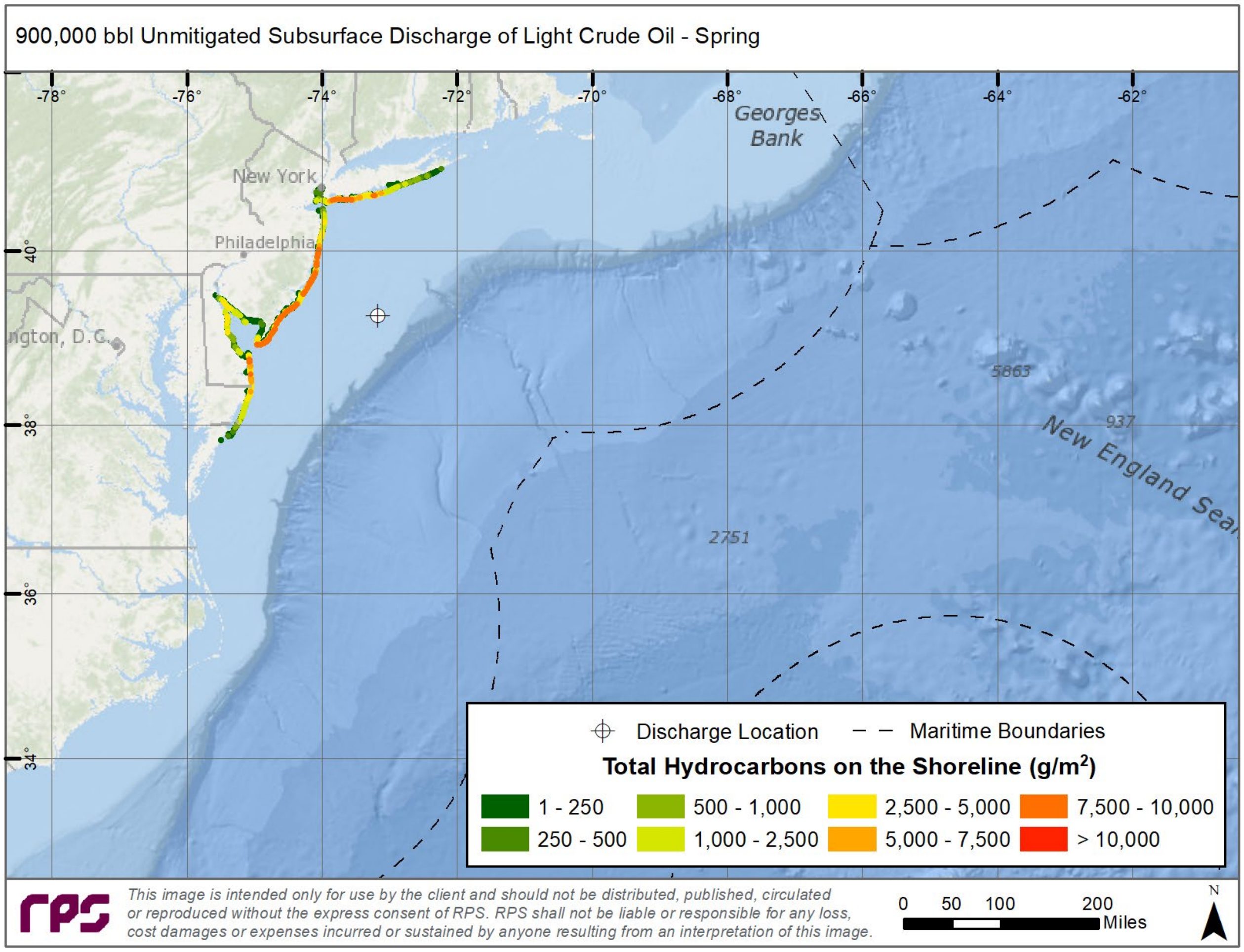


Figure 3-224. Maximum shoreline oil concentration at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled(on an annual basis, in spring), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on May 21, 2018.

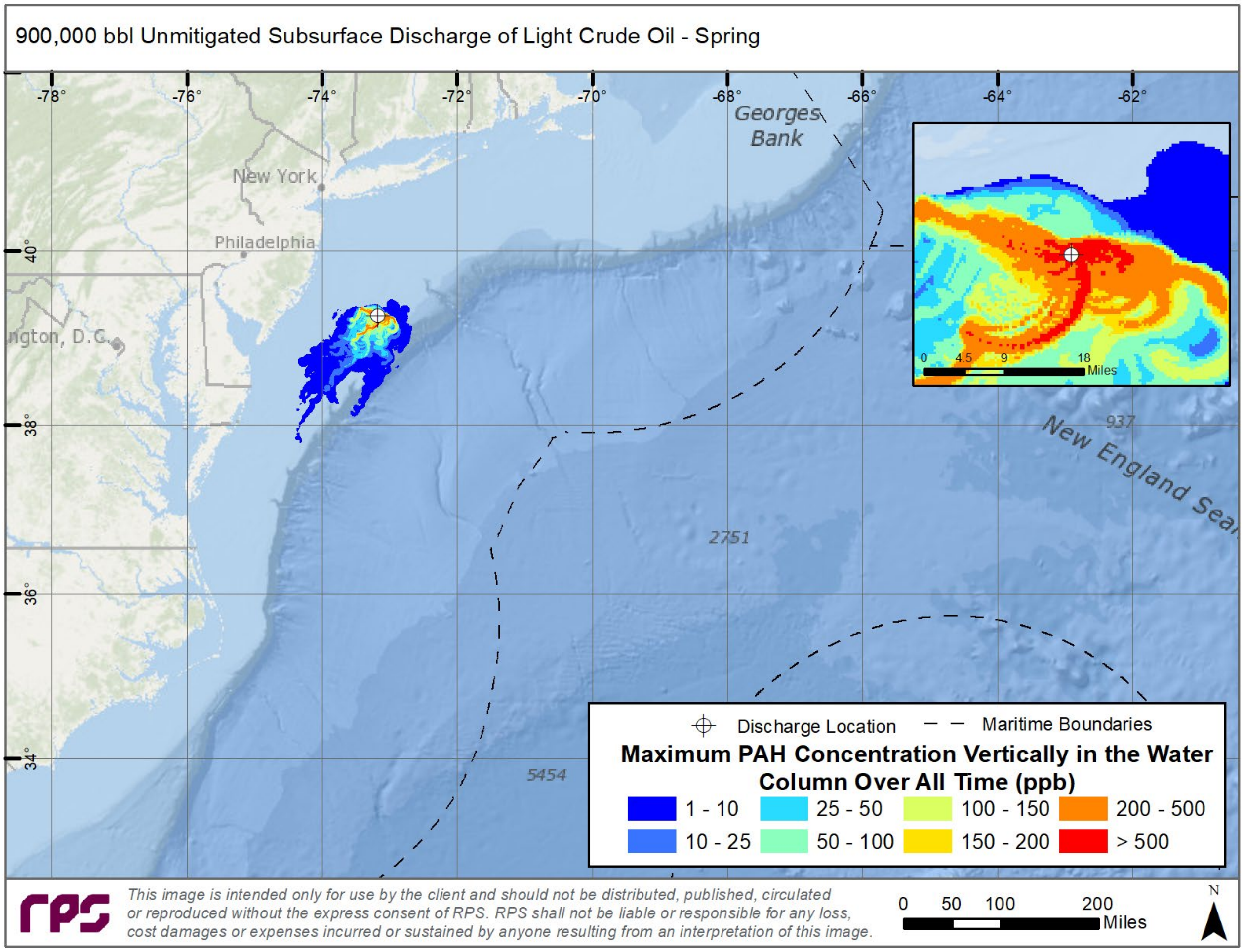


Figure 3-225. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on May 21, 2018.

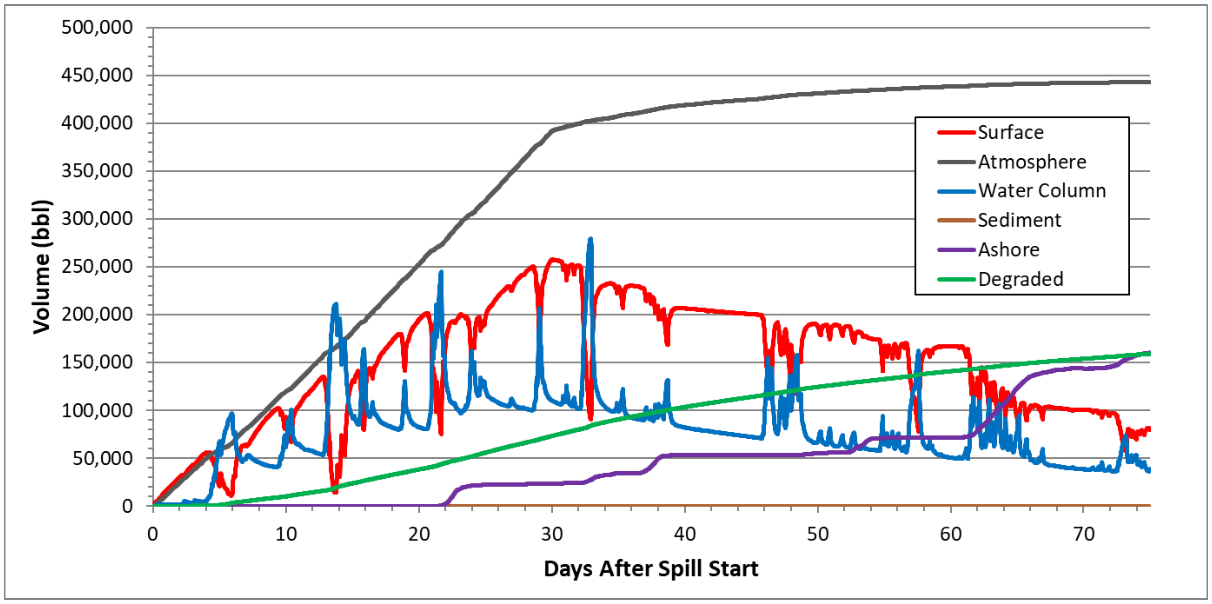


Figure 3-226. Oil volume by environmental compartment over time for an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on May 21, 2018.

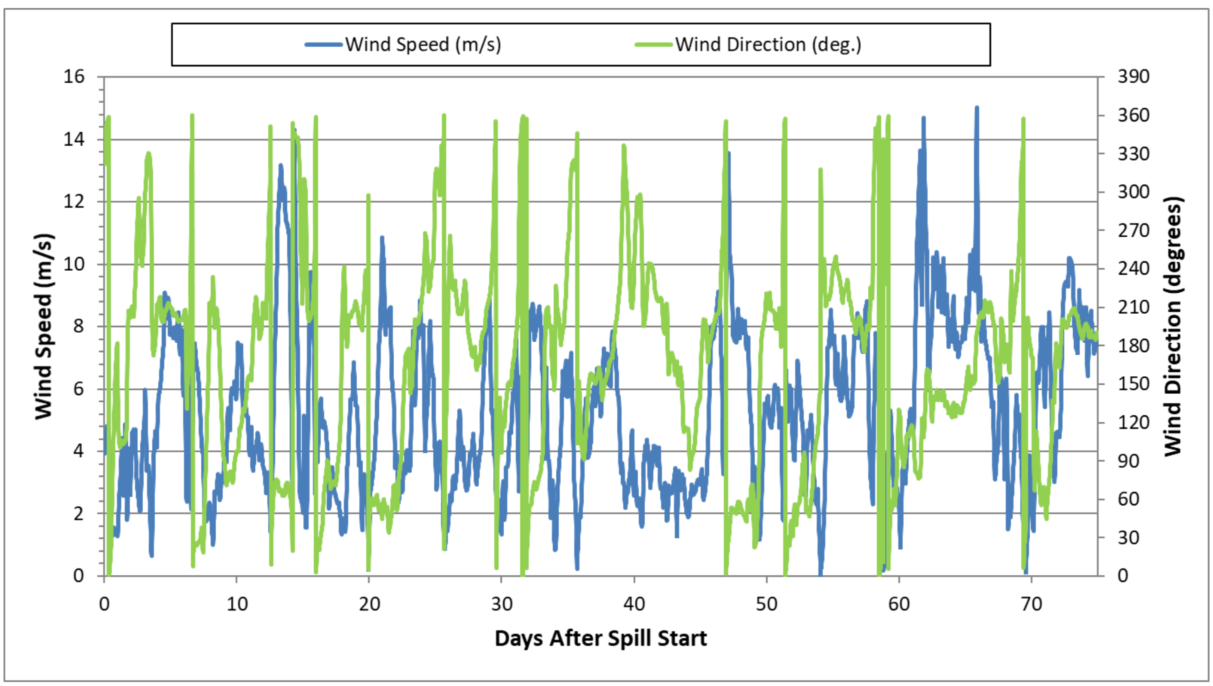


Figure 3-227. Wind speeds (1 m/s = 2 knots) and directions during the unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on May 21, 2018.

3.3.2.5.2 Seasonal Worst-Case Runs

Winter

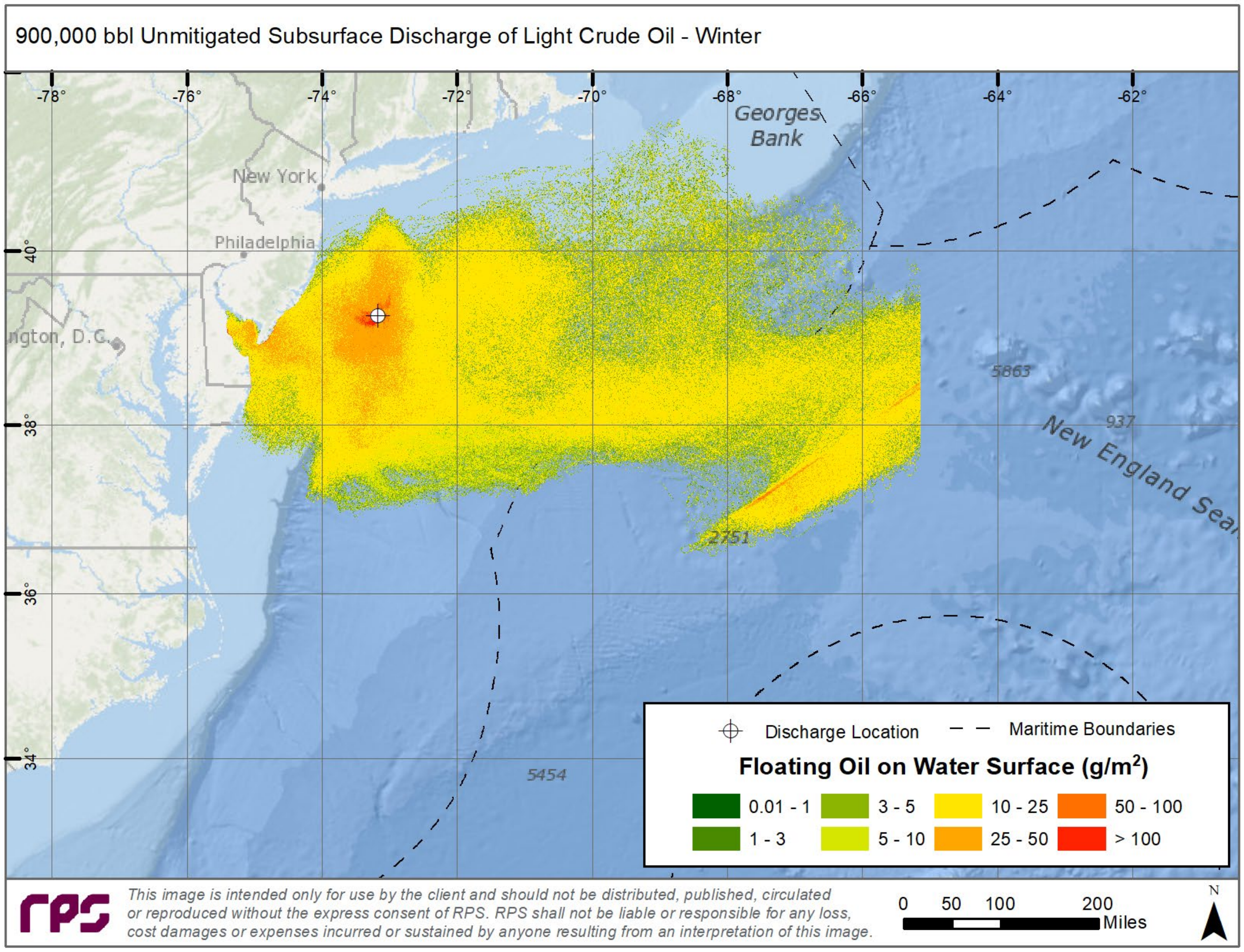


Figure 3-228. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on February 28, 2019.

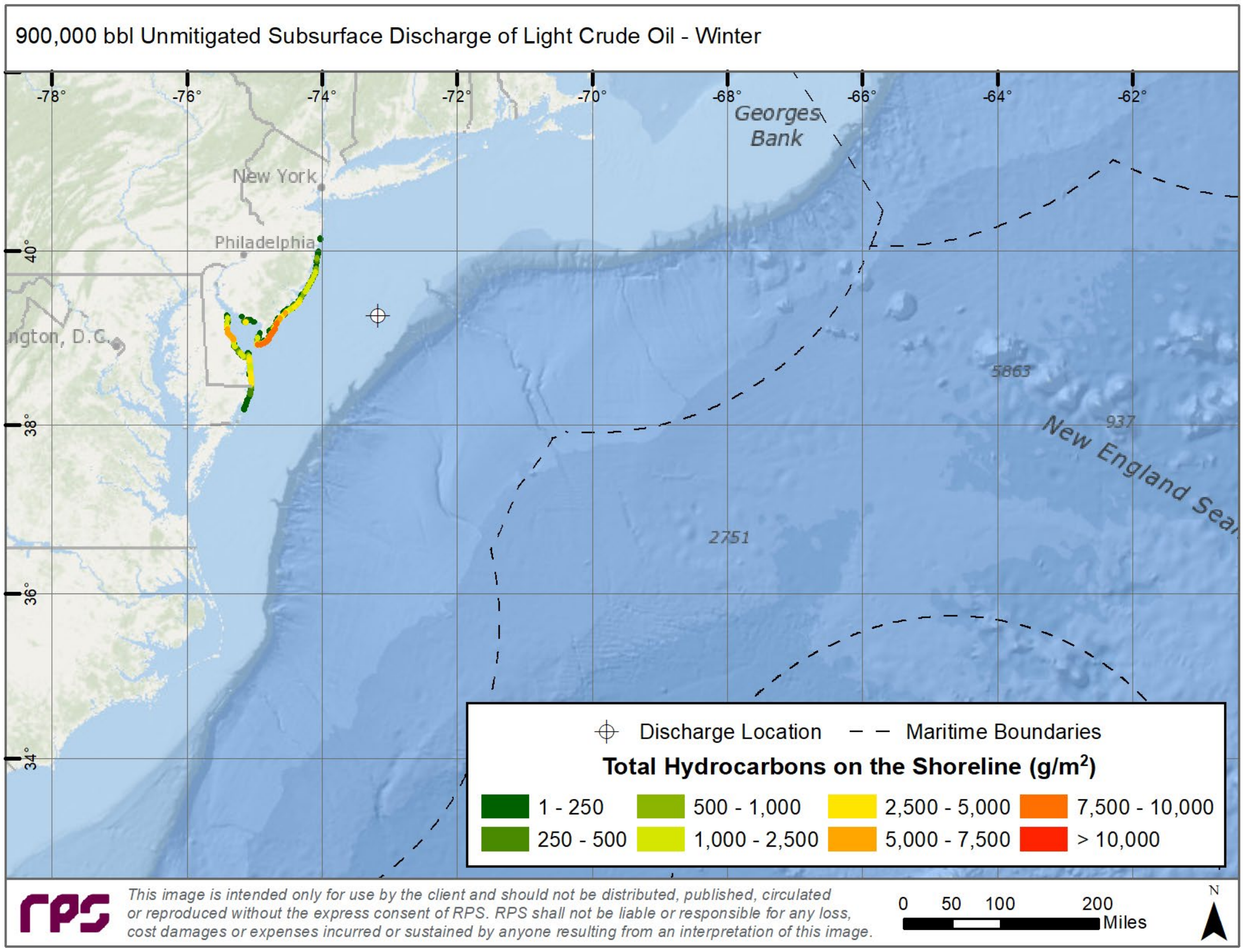


Figure 3-229. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on February 28, 2019.

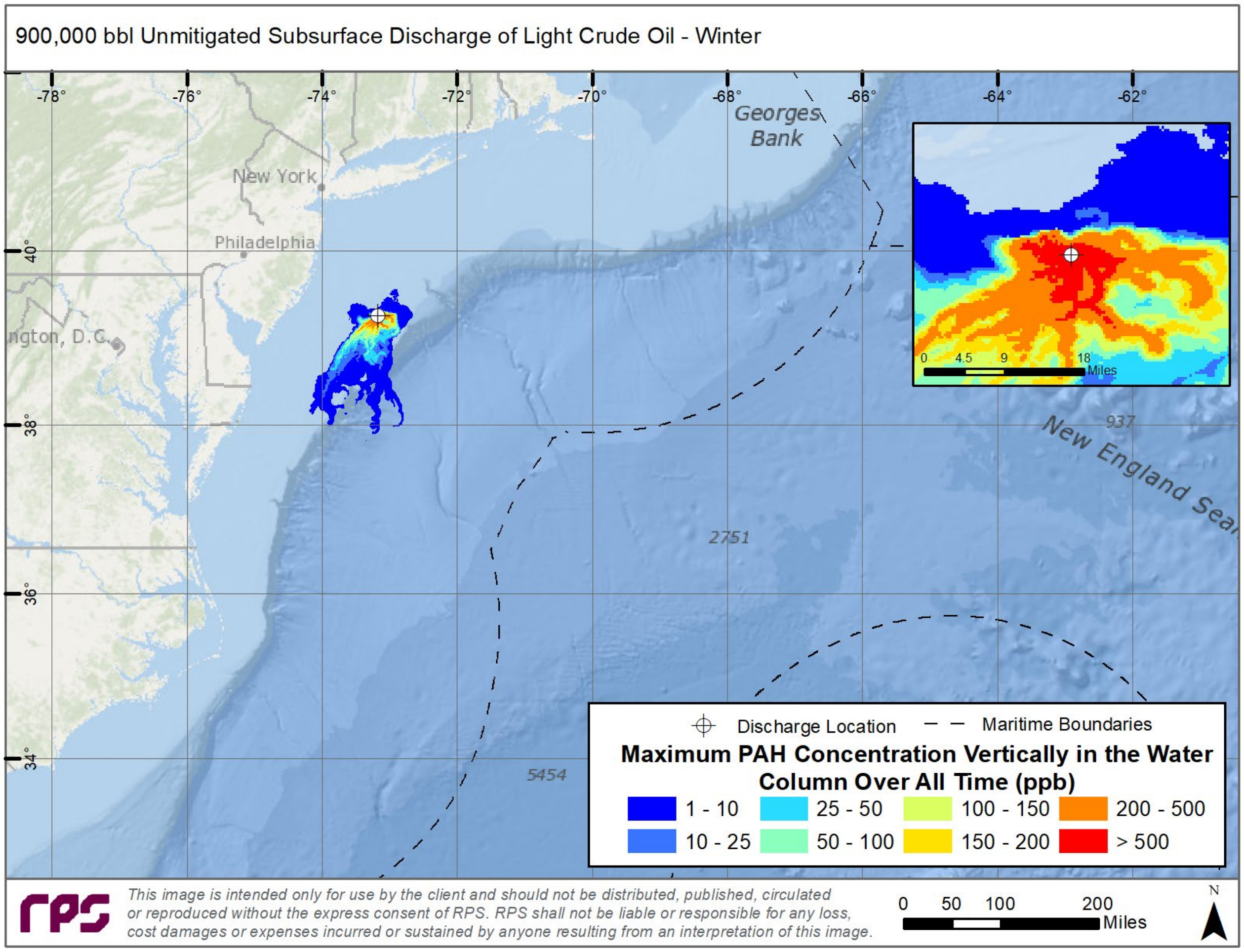


Figure 3-230. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on February 28, 2019.

Summer

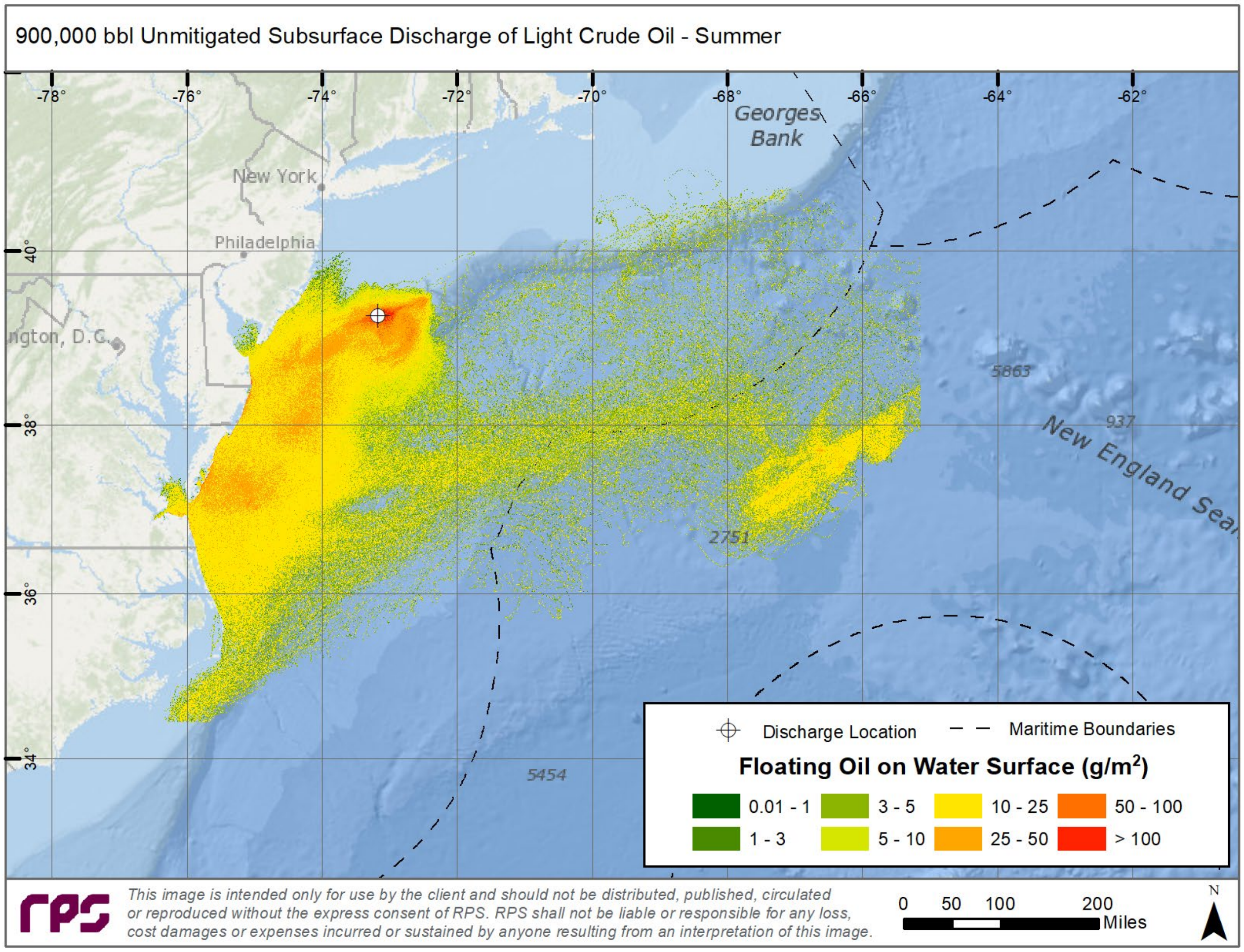


Figure 3-231. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on August 9, 2019.

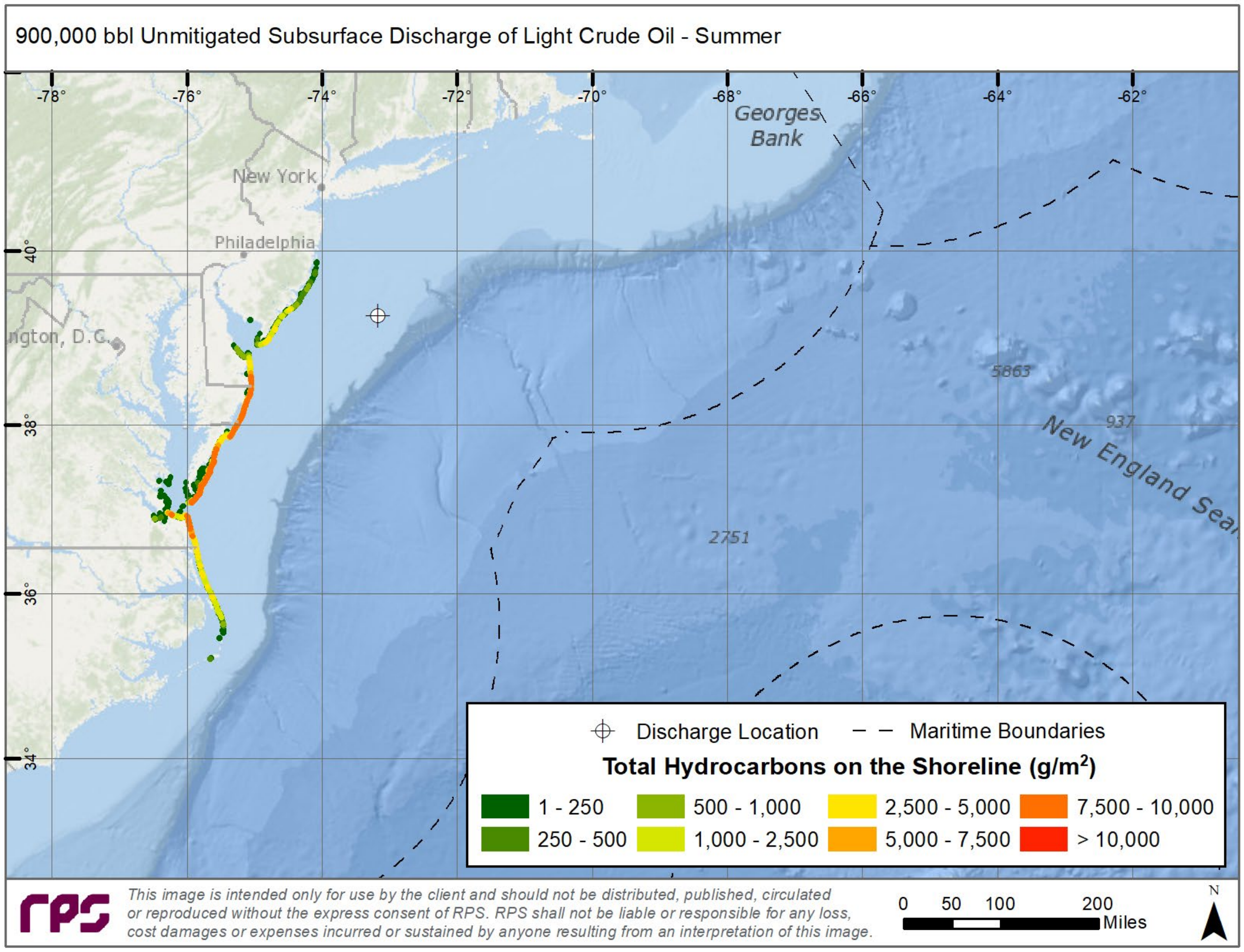


Figure 3-232. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on August 9, 2019.

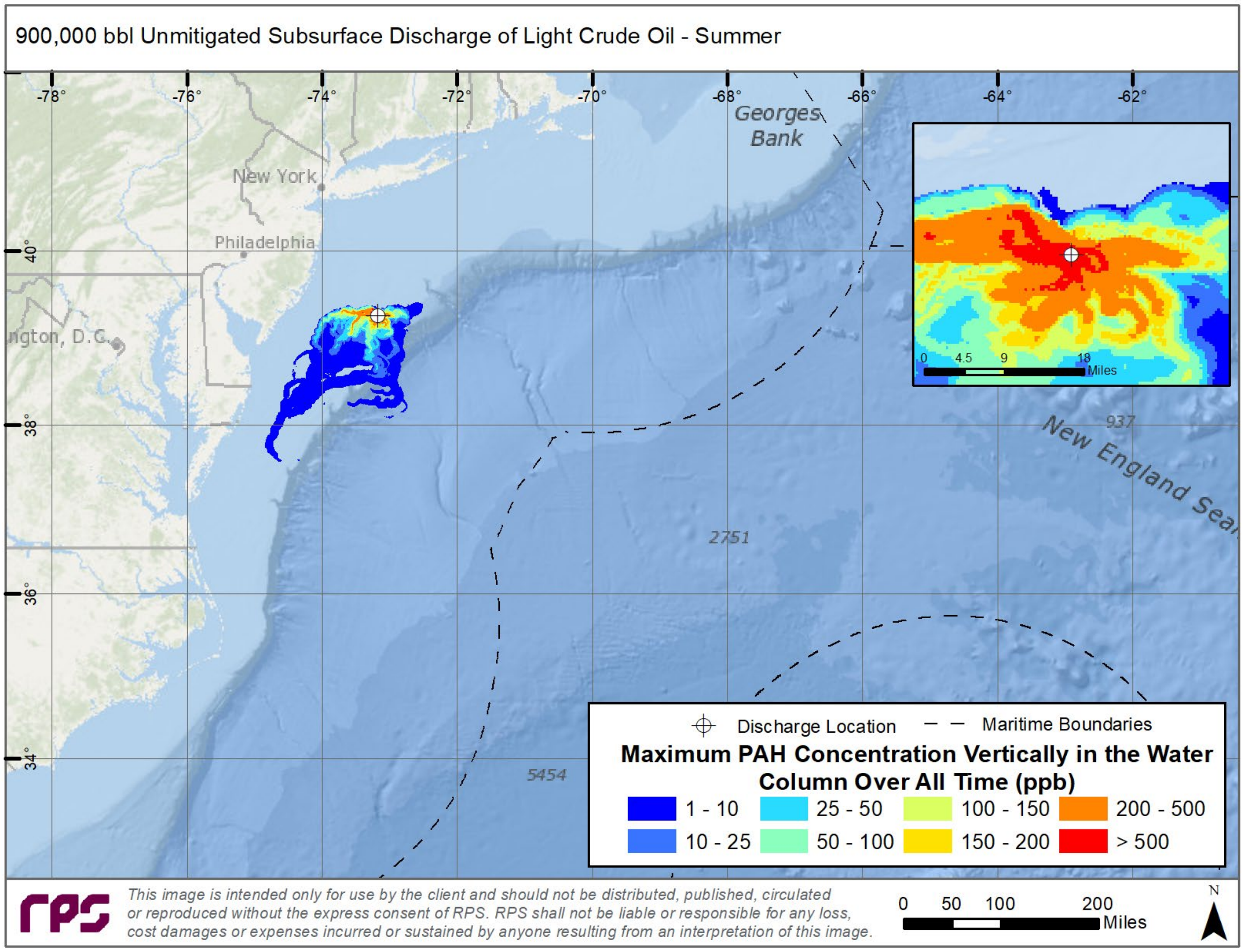


Figure 3-233. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on August 9, 2019.

Fall

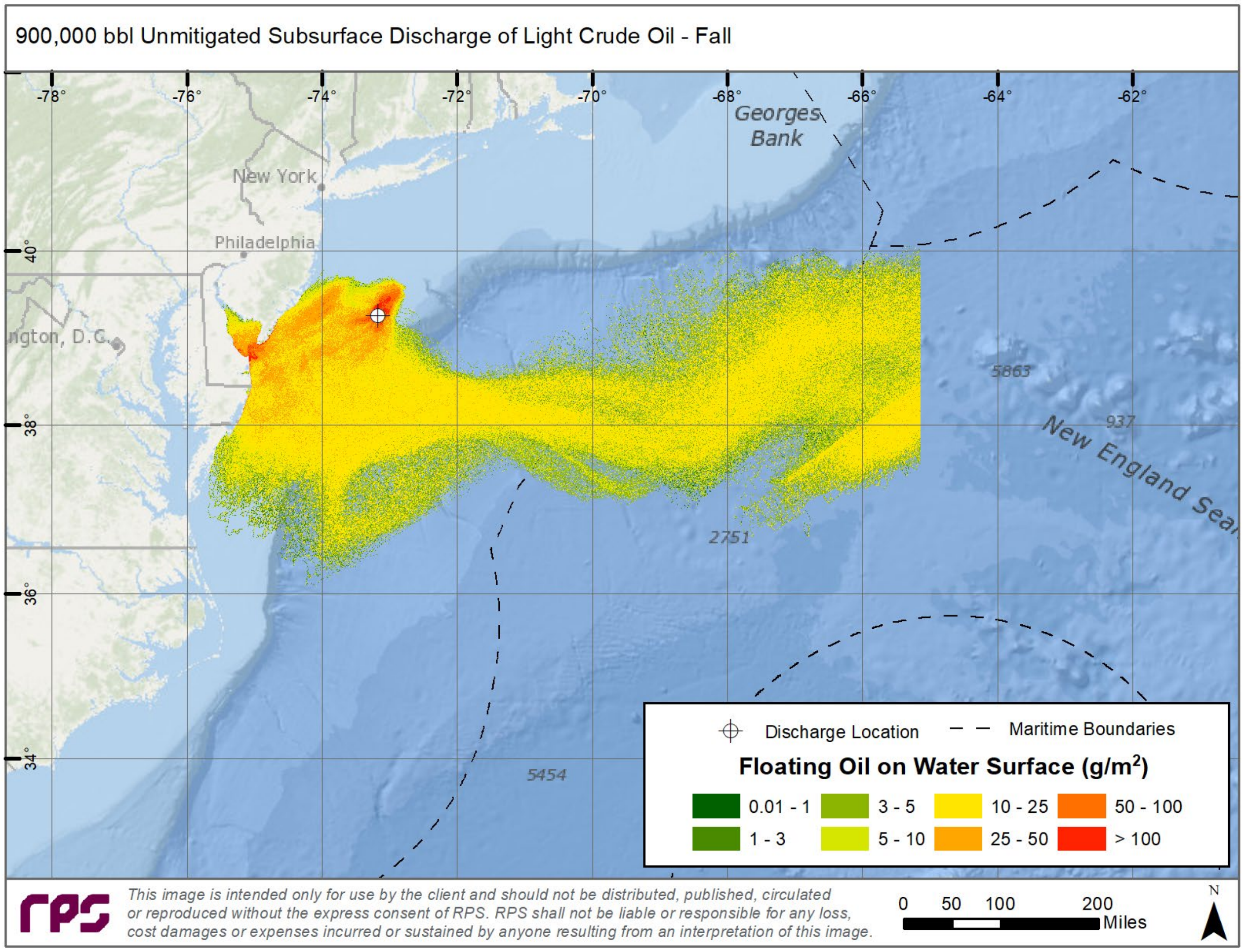


Figure 3-234. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on September 1, 2018.

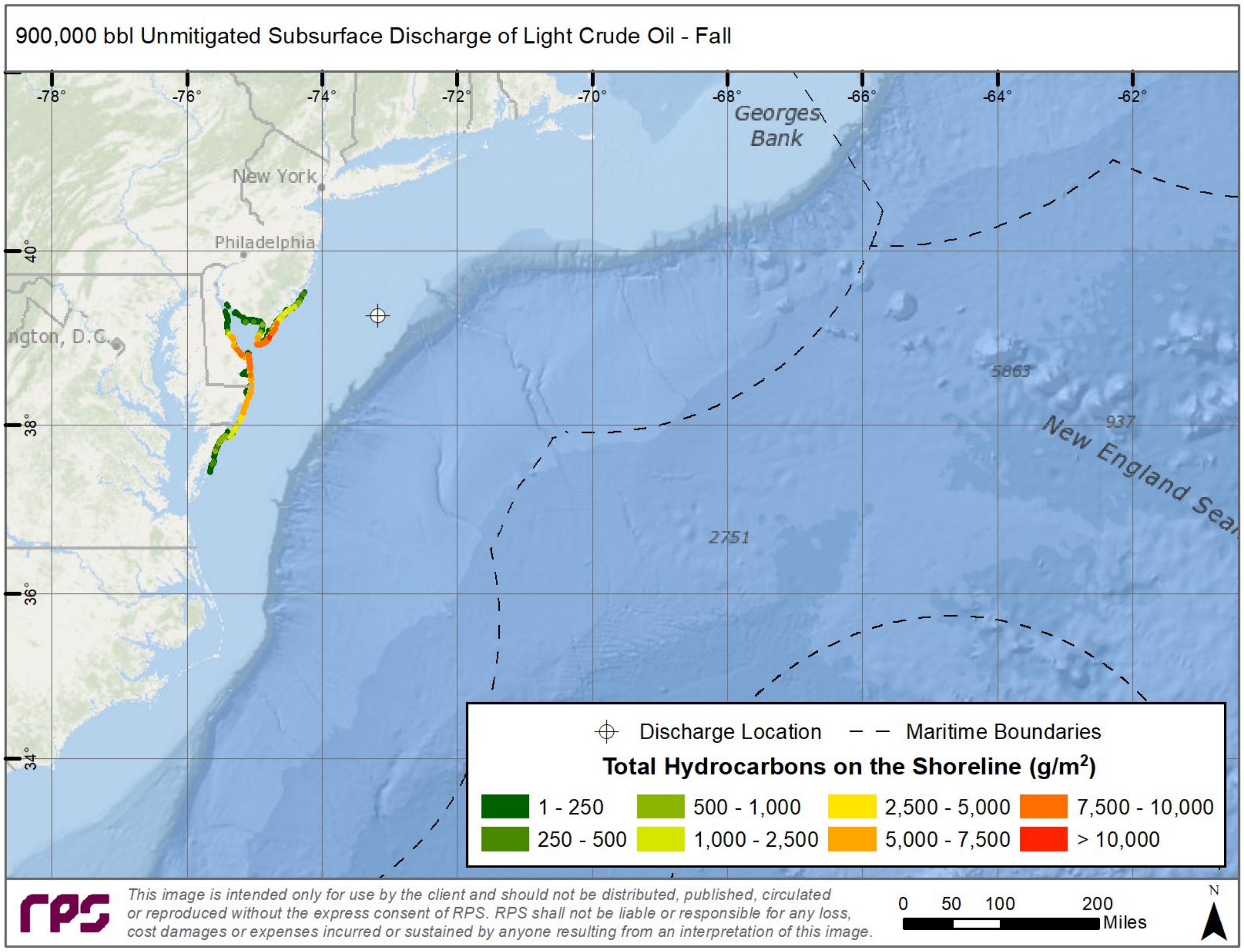


Figure 3-235. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on September 1, 2018.

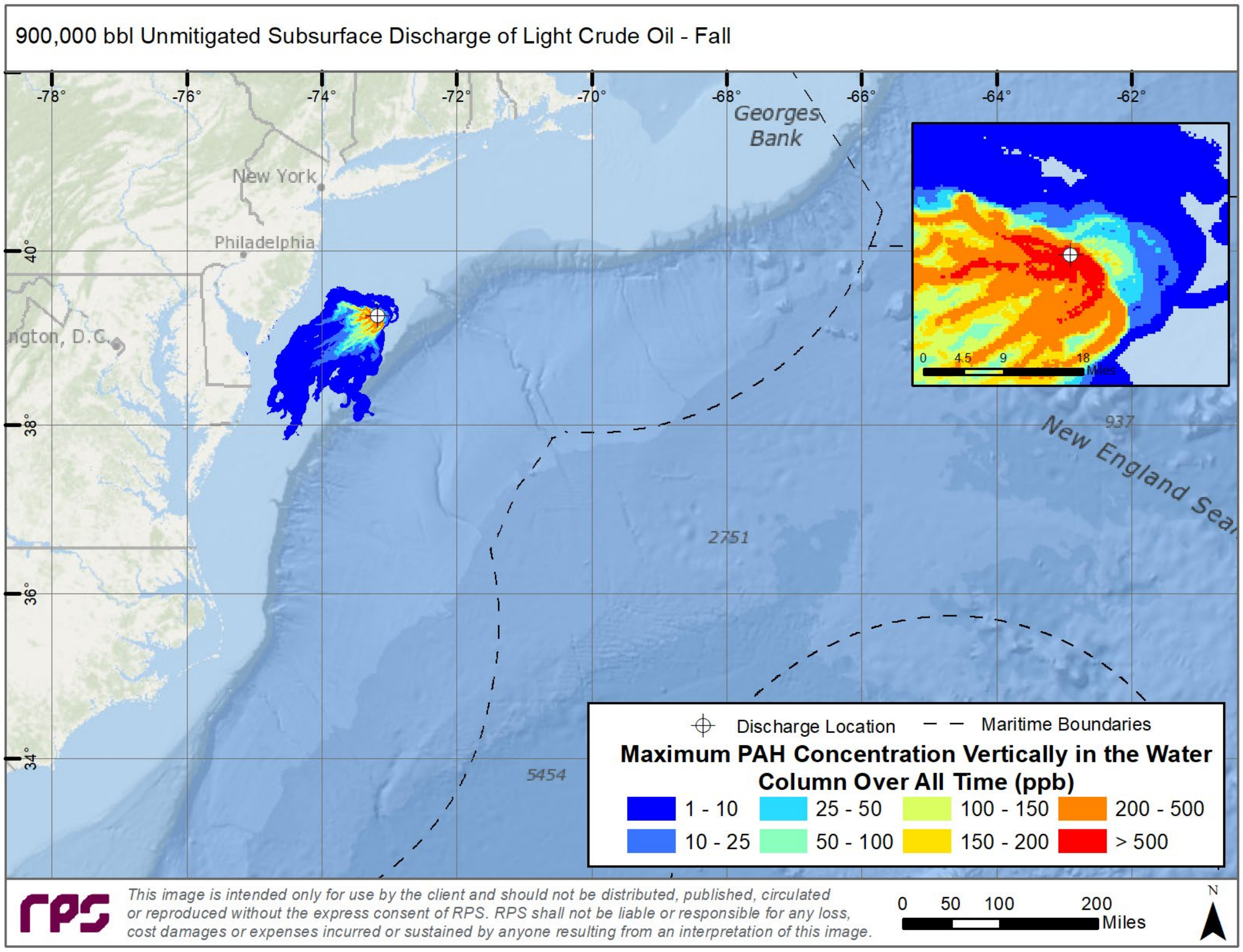


Figure 3-236. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of New Jersey starting on September 1, 2018.

3.3.3 Offshore Virginia

The spill locations used for modeling in Virginia waters were a location of high vessel traffic offshore Virginia at 36.8231°N, 75.7494°W (vessel releases) and offshore Virginia approximately the same distance from shore and depth as Delaware and New Jersey well (canyon) sites at 37.2886°N, 74.7109°W (blowout) (Figure 2-2). The annual and seasonal worst-case runs were selected based on the longest length of shoreline oiling (>1.0 g/m^2) and model start dates are presented in Table 3-22.

Table 3-22. Modeled start dates for the runs offshore Virginia with worst case shoreline oiling on an annual basis and for each of four seasons. The annual worst case for each scenario is presented with an "*" and bolded.

Scenario ID	Spill Site	Spill Event	Spill Volume	Start Date of Worst Case
1	Offshore Virginia	Surface Unmitigated 126 bbl Release During Winter	Low	**1/13/2020***
2		Surface Unmitigated 126 bbl Release During Spring	Low	3/9/2020
3		Surface Unmitigated 126 bbl Release During Summer	Low	6/19/2018
4		Surface Unmitigated 126 bbl Release During Fall	Low	10/13/2019
5		Surface Unmitigated 2,240 bbl Release During Winter	Medium	**1/13/2020***
6		Surface Unmitigated 2,240 bbl Release During Spring	Medium	3/9/2020
7		Surface Unmitigated 2,240 bbl Release During Summer	Medium	7/19/2018
8		Surface Unmitigated 2,240 bbl Release During Fall	Medium	9/21/2019
9		Surface Unmitigated 200k bbl Release During Winter	High	1/13/2020
10		Surface Unmitigated 200k bbl Release During Spring	High	5/28/2018
11		Surface Unmitigated 200k bbl Release During Summer	High	**7/19/2018***
12		Surface Unmitigated 200k bbl Release During Fall	High	9/21/2019
13		Surface Mitigated 200k bbl Release During Winter	High	1/13/2020
14		Surface Mitigated 200k bbl Release During Spring	High	5/28/2018
15		Surface Mitigated 200k bbl Release During Summer	High	**7/19/2018***
16		Surface Mitigated 200k bbl Release During Fall	High	9/21/2019
17		Subsurface Unmitigated 900k bbl Blowout Release During Winter	Well Blowout	2/21/2019
18		Subsurface Unmitigated 900k bbl Blowout Release During Spring	Well Blowout	5/13/2018
19		Subsurface Unmitigated 900k bbl Blowout Release During Summer	Well Blowout	**8/25/2019***
20		Subsurface Unmitigated 900k bbl Blowout Release During Fall	Well Blowout	9/1/2019

Table 3-23 summarizes the final mass balance of the spilled oil at the end of the 30- or 75-day simulations for the Delaware location surface and blowout modeling scenarios, respectively. In all surface release cases, almost half of the released oil evaporated within the first five days of the release.

Table 3-23. Mass balance at the end of the simulation for the worst-case run for shoreline oiling (on an annual basis) for each of the five scenarios at the Virginia release locations.

Spill Scenario	Season	Percent of Oil by End of Simulation				
		Surface	Atmos-phere	Shore-line	Water	Degraded
Low Volume	Winter	5	55	22	8	10
Medium Volume	Winter	3	53	22	11	11
High Volume (unmitigated)	Summer	1	46	39	6	8
High Volume (mitigated)[a]	Summer	0	43	21	8	10
Blowout[b]	Summer	3	45	19	4	22

[a]18% of released oil removed via response methods.
[b]7% of released oil left model domain in which it was no longer tracked.

The length of shoreline oiled by habitat type and area of shoreline oiled inside and outside of Delaware for each of the Virginia location annual worst-case scenarios, including an unmitigated and mitigated trajectory for the high-volume surface release, is presented in Table 3-24 and Table 3-25. Deterministic worst cases occurred in the winter (January 13, 2020) for a low- and medium-volume release and in the summer for a high-volume release (July 19, 2018) and a shallow water blowout (August 25, 2019; Table 3-22). Table 3-26 summarizes the water column exposure results for all four worst-case scenarios and the mitigated high-volume release. Note that the PAH concentrations in the water column are highly variable in space and over time. Thus, durations of exposure are summarized to give some sense of the ephemeral nature of the exposures above thresholds of concern. PAH exposure in the water column and max exposure time increase with spill volume in the unmitigated cases, with exposures occurring below the most conservative threshold during the low volume release and exposures dissipating within 17 hours during the medium volume release. The volume of exposure to PAH within the water column is slightly higher in the unmitigated high-volume release case; however, average PAH concentrations above the two thresholds persist for longer in the environment during the mitigated case.

Table 3-24. Shoreline lengths oiled by >1 g/m^2 for the run with maximum shoreline length oiled (on an annual basis), for each spill scenario offshore Virginia.

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Winter	142	14	0	228	22	0
Medium Volume	Winter	210	173	38	338	278	62
High Volume (unmitigated)	Summer	430	415	245	692	668	395
High Volume (mitigated)	Summer	225	217	122	363	349	196
Blowout	Summer	458	454	340	738	731	548

Table 3-25. Shoreline area oiled by >1 g/m^2 inside and outside of Delaware state territory for the run with maximum shoreline length oiled (on an annual basis), for each spill scenario offshore Virginia.

Spill Scenario	Location	Length Oiled (mi^2)			Length Oiled (km^2)		
		>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Low Volume	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	0.9	0.1	0.0	2.2	0.2	0.0
Medium Volume	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	1.7	1.0	0.2	4.4	2.7	0.6
High Volume (unmitigated)	Delaware	0.03	0.03	0.01	0.1	0.1	0.0
	Outside	19.3	18.1	9.3	50.0	46.8	24.1
High Volume (mitigated)	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	9.0	8.2	3.4	23.3	21.3	8.9
Blowout	Delaware	0.0	0.0	0.0	0.0	0.0	0.0
	Outside	13.5	13.1	7.2	34.9	34.0	18.5

Table 3-26. Modeling results of dissolved PAH exposures in the water column for the four worst-case for shoreline oiling scenarios (by spill volume) for a release offshore of Virginia. (One km^3 is equivalent to 1 billion m^3 and 1.3 billion cubic yards.)

	Low	Medium	High		Blowout
			Unmitigated	Mitigated	
Volume contaminated >1 ppb (km^3)*	0	0.04	13	11	49
Volume contaminated >10 ppb (km^3)*	0	0	1	1	6
Max Exposure Time >1 ppb (hours)**	0	17	449	466	917
Max Exposure Time >10 ppb (hours)**	0	0	300	391	791

* Volume of water which exceeded 1 ppb and 10 ppb at any given time
** Maximum number of hours with exposure concentrations >1 or 10 ppb

3.3.3.1 Surface Unmitigated Release (Low Volume)

3.3.3.1.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a low-volume surface release of 126 bbl crude oil offshore Virginia started on January 13, 2020. Only a thin layer of oil (0.01-1 g/m^2) was predicted to occur on the water surface until it evaporated, went ashore or degraded (Figure 3-237). The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Just under half of the oil released at the surface evaporated quickly, within in the first 5 days. Emulsification of the crude oil to viscosities between 4,000-8,000 cP during the first few days of the release limited entrainment into the water to occur only during the high wind events, causing oil to oscillate from within the water column to the surface during periods of high and low winds (Figure 3-240 and Figure 3-241). The mass balance (Figure 3-240) shows that the released oil came ashore beginning 14 days after the spill while stronger winds (~9 m/s; 18 knots) were blowing from the east-northeast (Figure 3-242). Approximately 55% of the oil evaporated, 22% of the oil reached shore, 8% of the oil remained in the water column, 5% remained on the surface and approximately 10% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted north, towards Kiptopeke, Virginia, and south into coastal waters of Virginia and North Carolina. The maximum surface oil exposure concentration was between 0.01-1 g/m^2 (which would appear as a scattered colorless sheen or dark brown/metallic sheen; French McCay et al. 2011; French McCay et al. 2012; French McCay 2016) (Figure 3-237). By the end of the 30-day simulation, 142 mi (228 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-238; Table 3-27). Most of the oiled shoreline was seaward sandy beach habitat (114 mi; 184 km) along the coast of North Carolina. In total, no shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-25). Maximum cumulative PAH concentrations for the worst-case run did not exceed the threshold of 1 ppb (Figure 3-239). As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-27. Shoreline lengths oiled by >1 g/m^2 (1 µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in winter), for an unmitigated 126 bbl surface release of crude oil offshore of Virginia starting on January 13, 2020.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m²	>10g/m²	>100g/m²	>1g/m²	>10g/m²	>100g/m²
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	114	9	0	184	15	0
Mudflat	22	1	0	35	2	0
Wetland	0	0	0	0	0	0
Artificial/manmade shoreline	2	2	0	3	3	0
Total	138	12	0	222	20	0
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	2	0	0	4	0	0

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Mudflat	0	0	0	0	0	0
Wetland	0	0	0	0	0	0
Artificial/manmade shoreline	2	2	0	3	3	0
Total	4	2	0	6	3	0
All Shorelines						
Total	142	14	0	228	22	0

Table 3-22 shows provides the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-242 through Figure 3-250 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In the spring and fall, oil is primarily transported west and south, with much of the shoreline oiling occurring along the coasts of Virginia and North Carolina. In the summer, oil is transported northeast, where oil makes landfall along the Maryland and Virginia coasts.

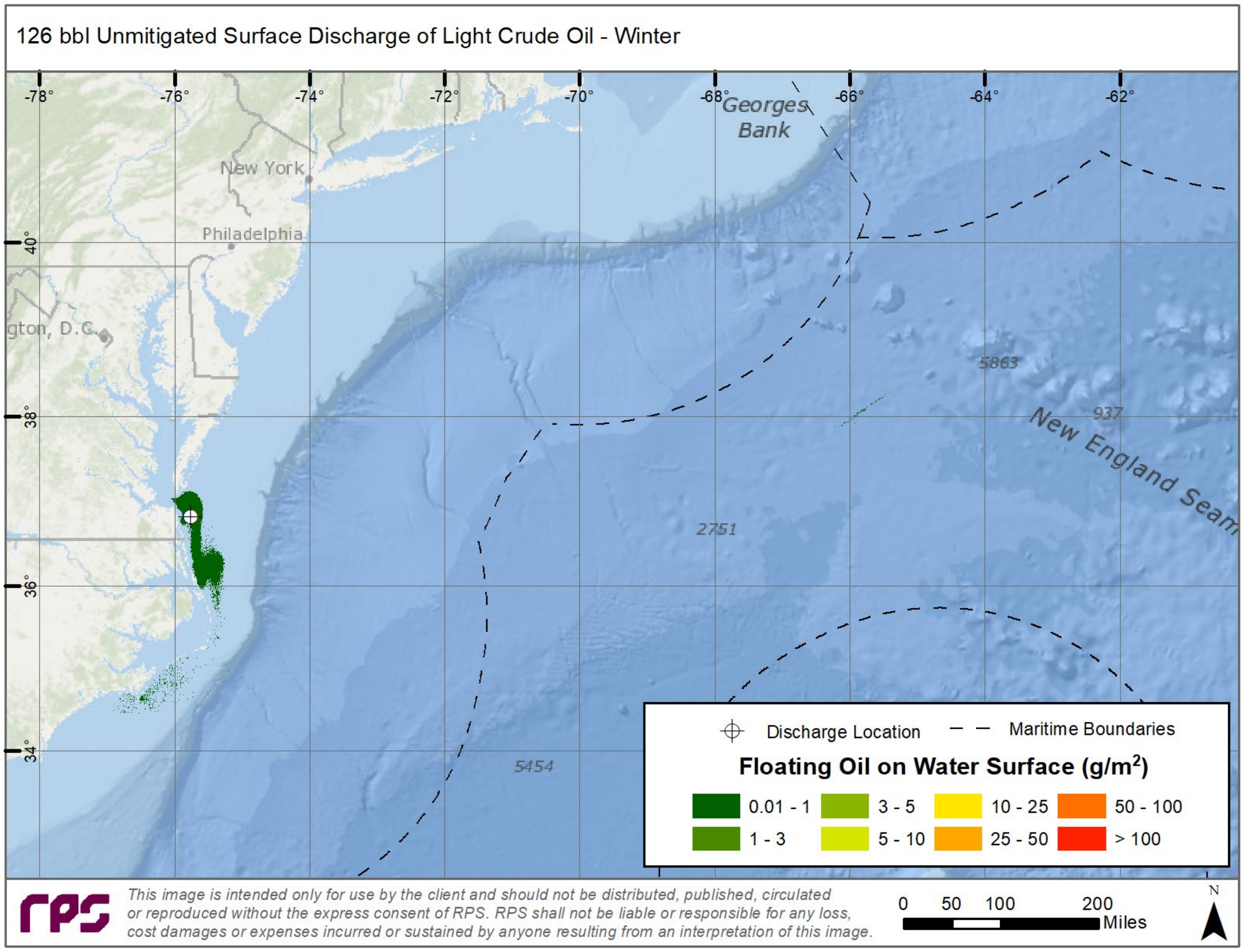


Figure 3-237. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore Virginia starting on January 13, 2020.

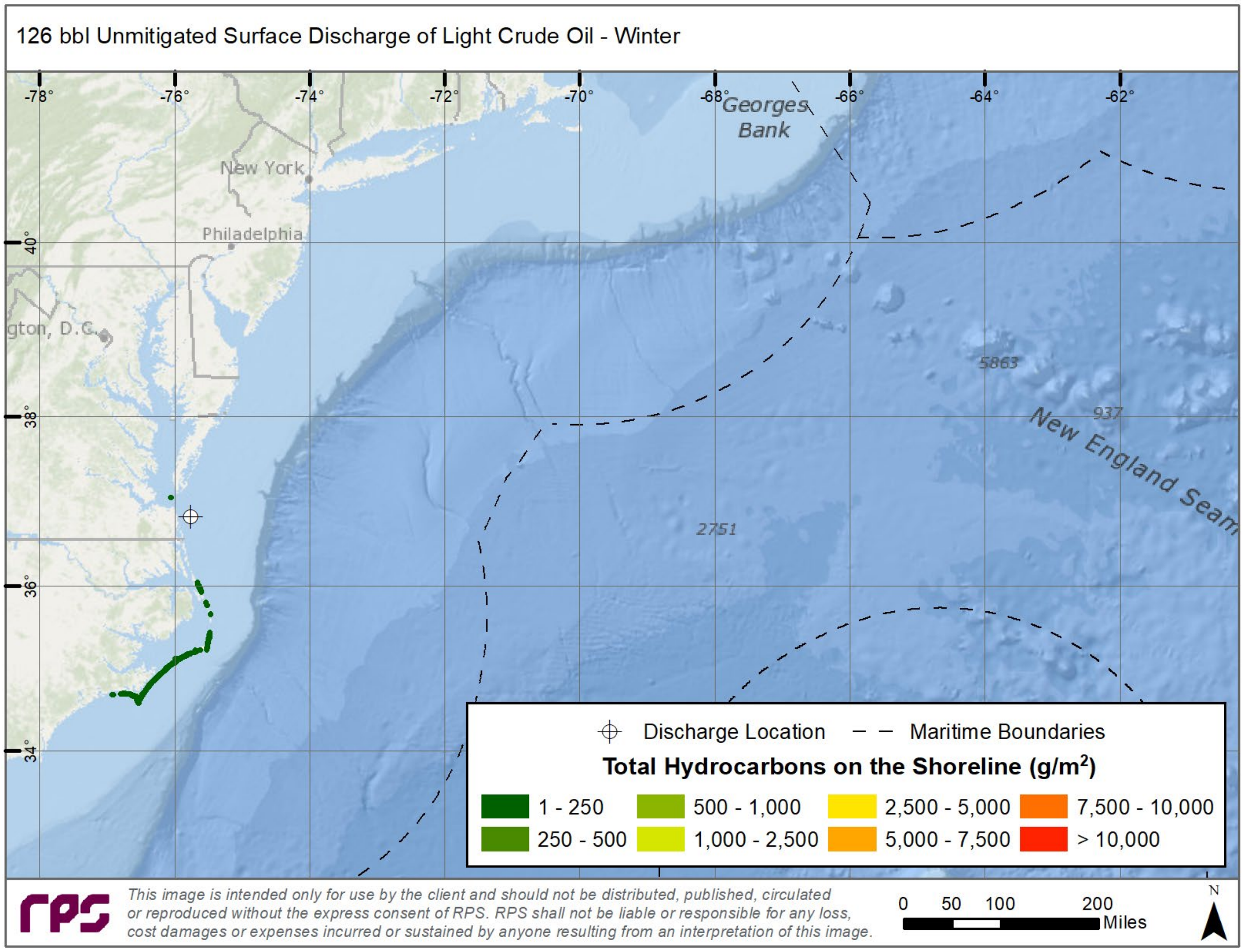


Figure 3-238. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore Virginia starting on January 13, 2020

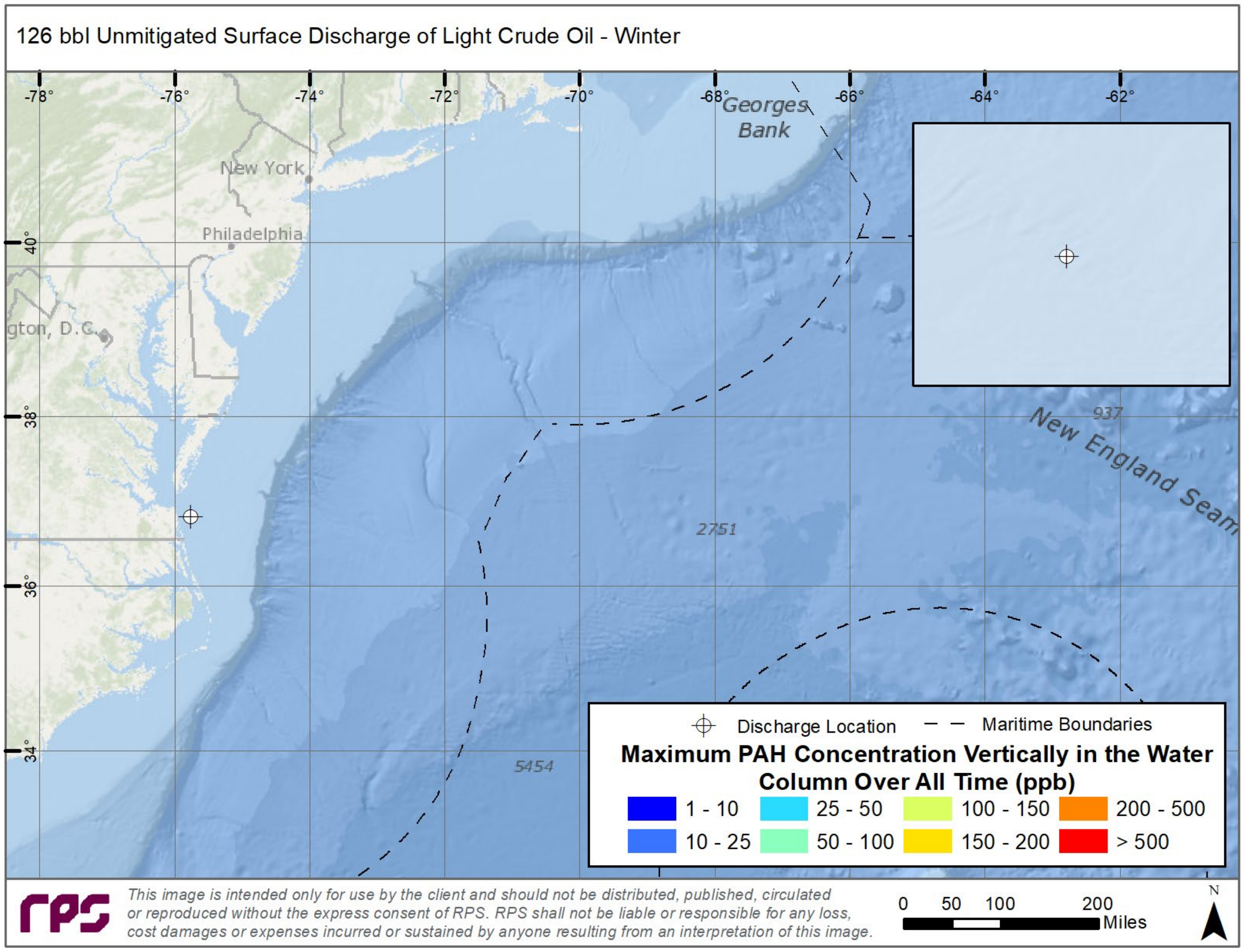


Figure 3-239. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl release of crude oil offshore Virginia starting on January 13, 2020.

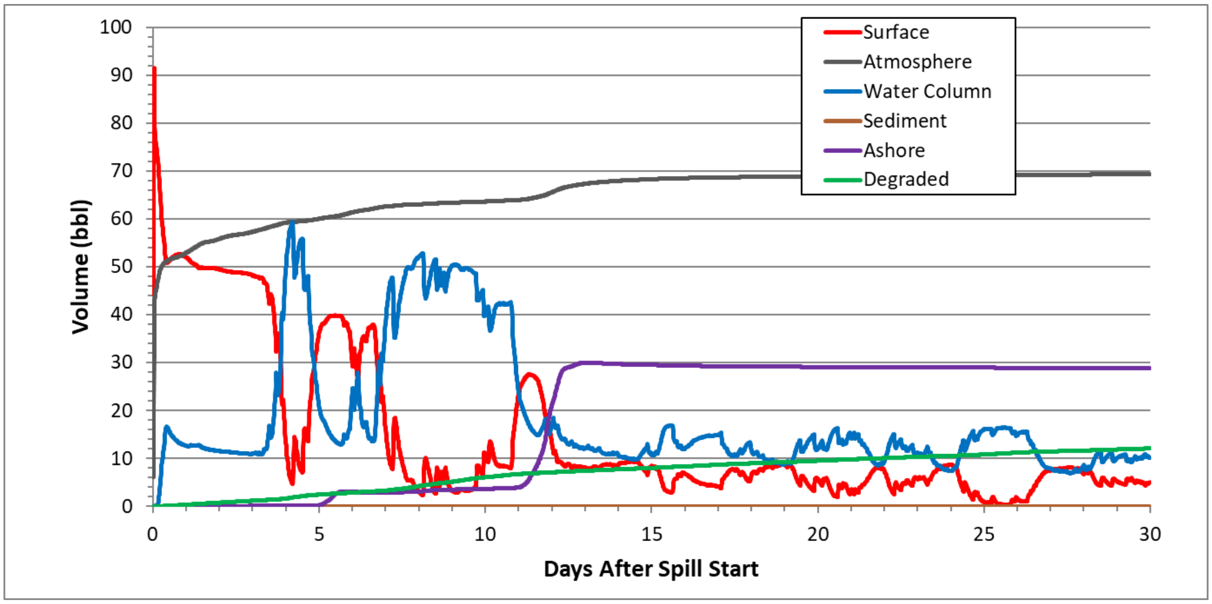


Figure 3-240. Oil volume by environmental compartment over time for a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl surface release of crude oil offshore Virginia starting on January 13, 2020.

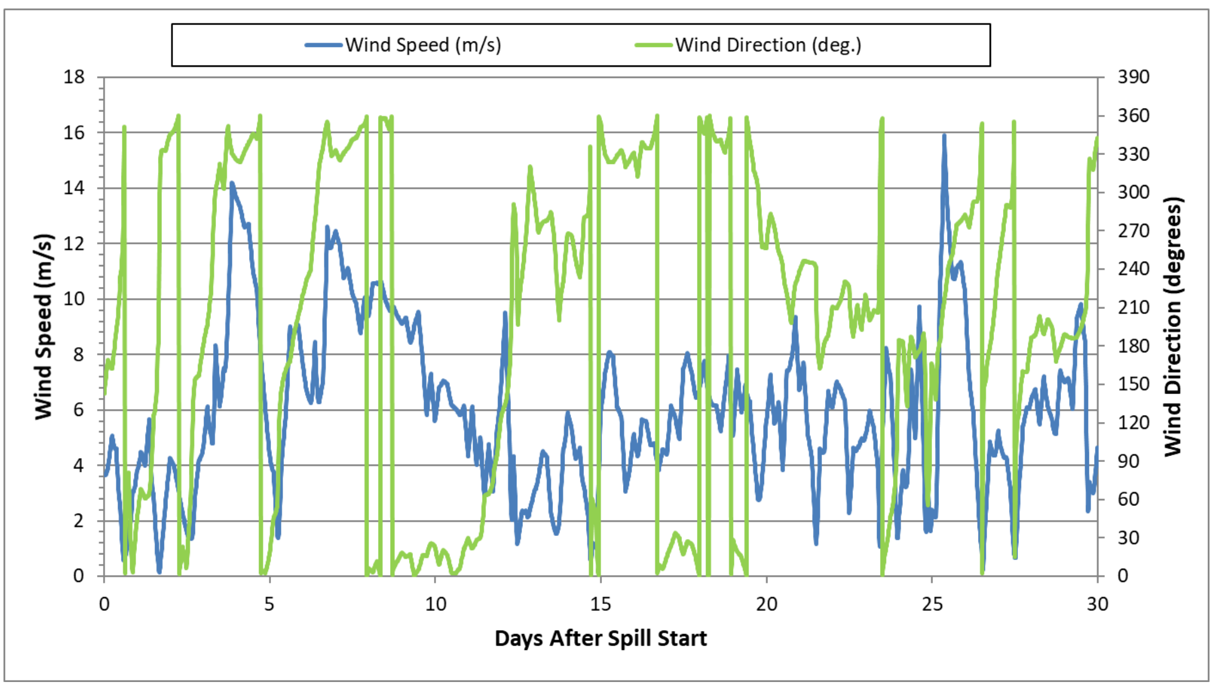


Figure 3-241. Wind speeds (1 m/s = 2 knots) and directions during the 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 126 bbl surface release of crude oil offshore Virginia starting on January 13, 2020.

3.3.3.1.2 Seasonal Worst-Case Runs

Spring

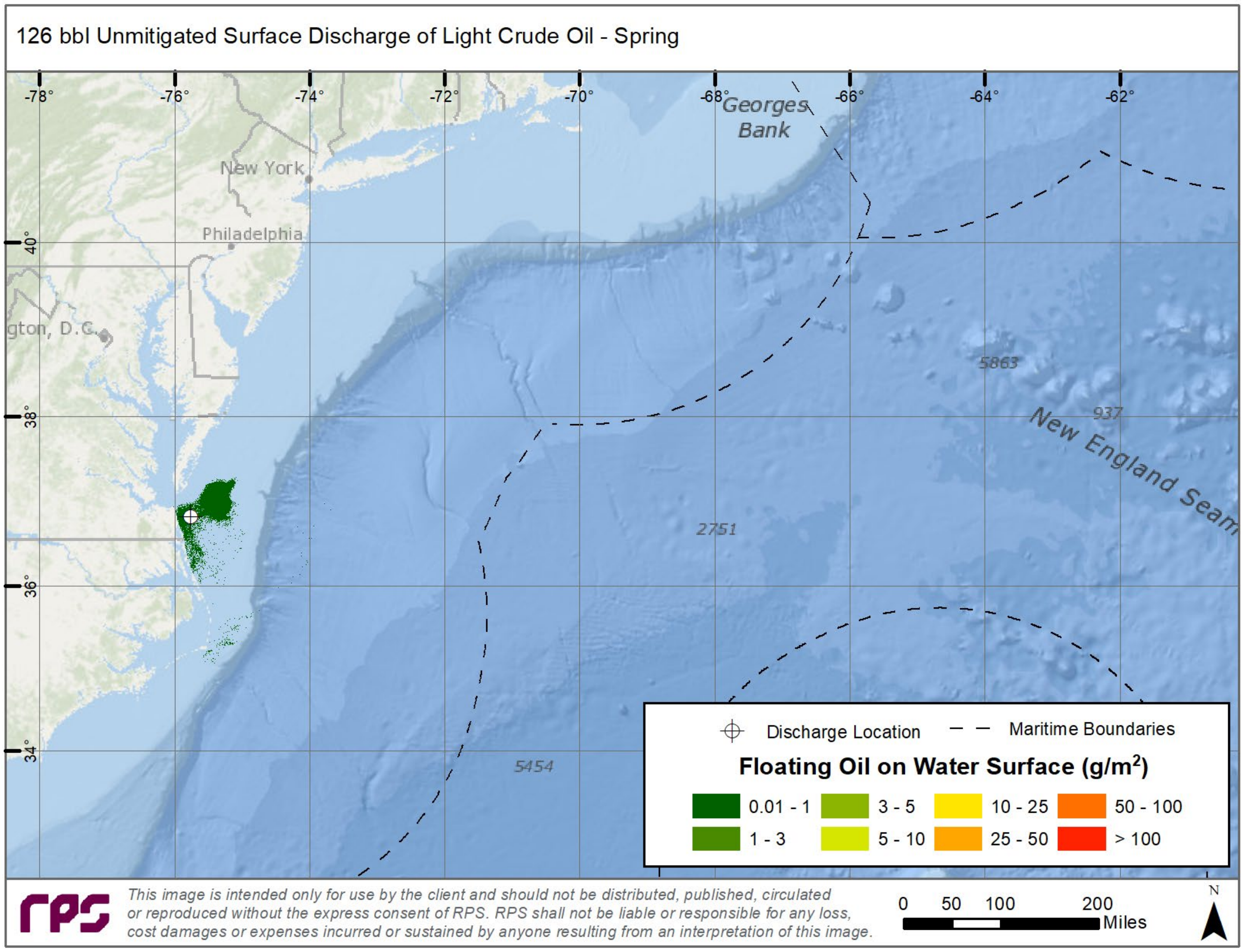


Figure 3-242. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore Virginia starting on March 9, 2020.

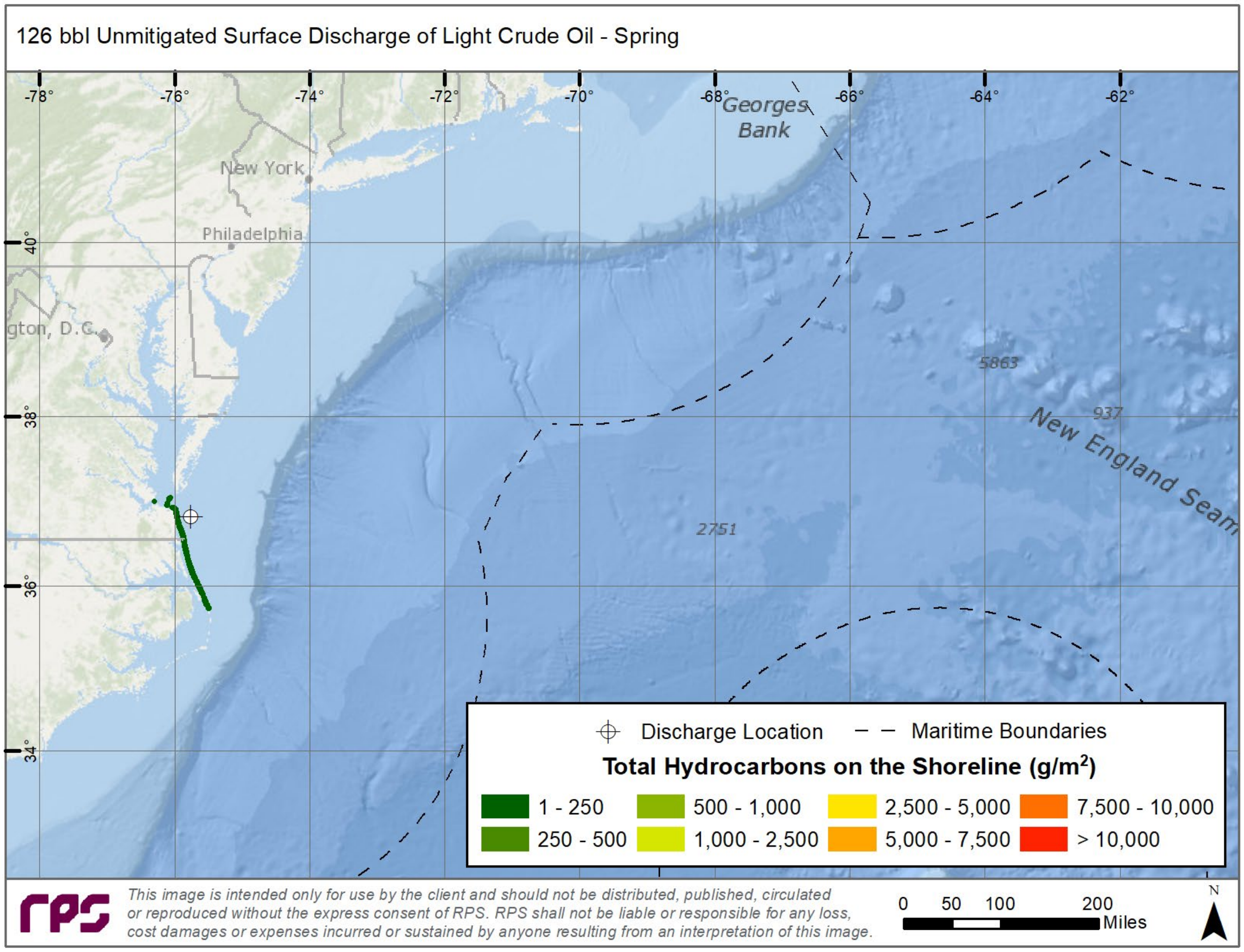


Figure 3-243. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore Virginia starting on March 9, 2020.

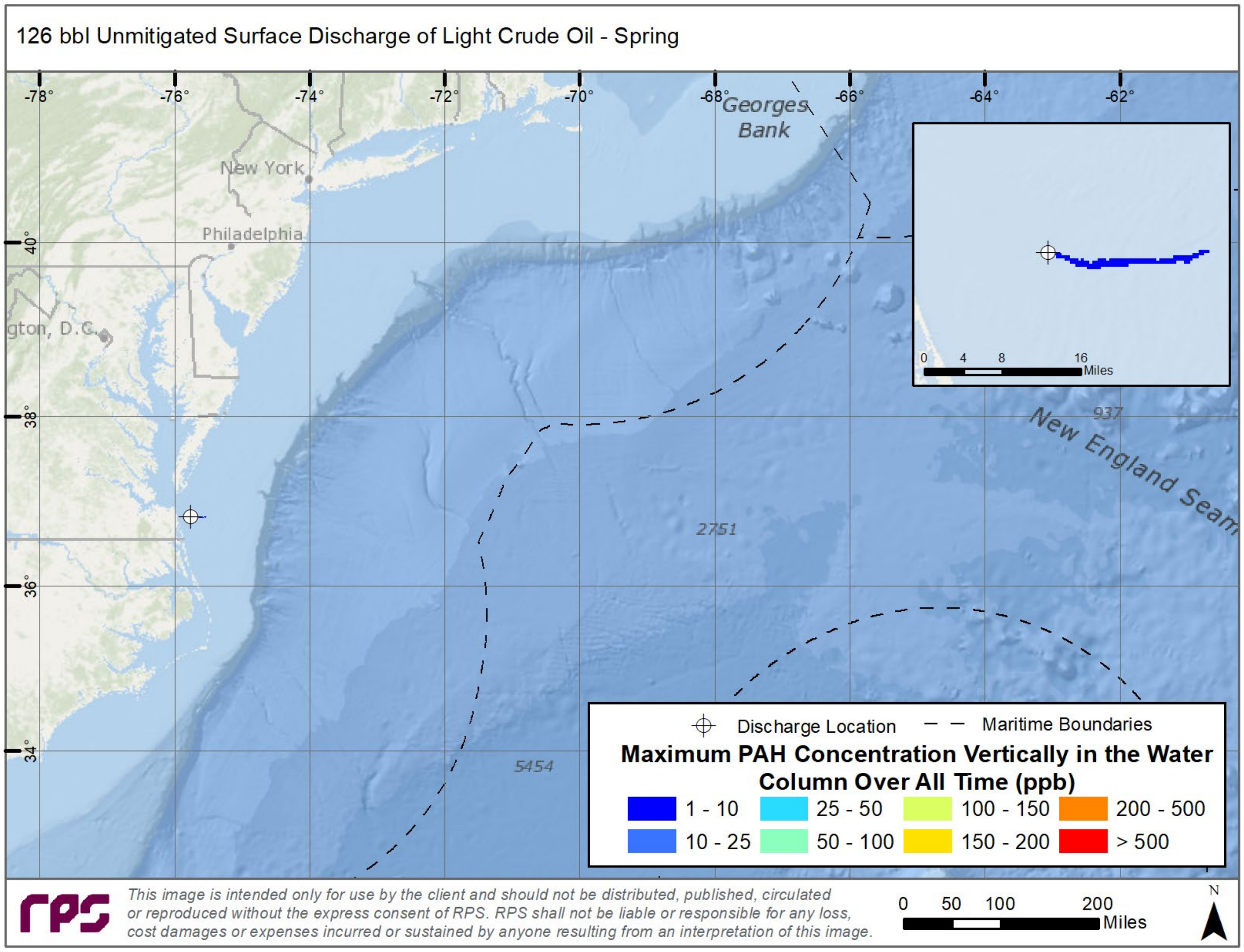


Figure 3-244. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore Virginia starting on March 9, 2020.

Summer

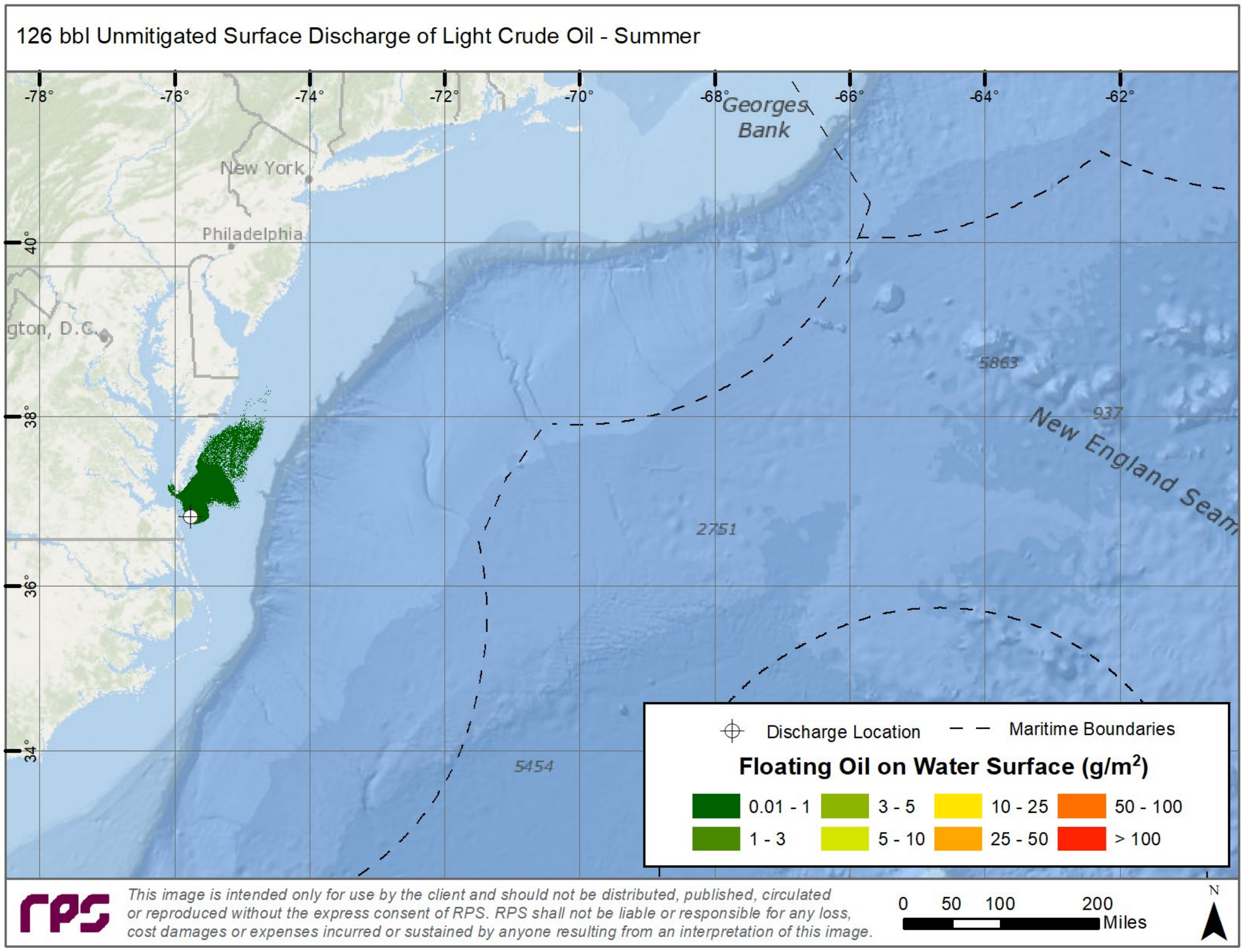


Figure 3-245. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore Virginia starting on June 19, 2018.

126 bbl Unmitigated Surface Discharge of Light Crude Oil - Summer

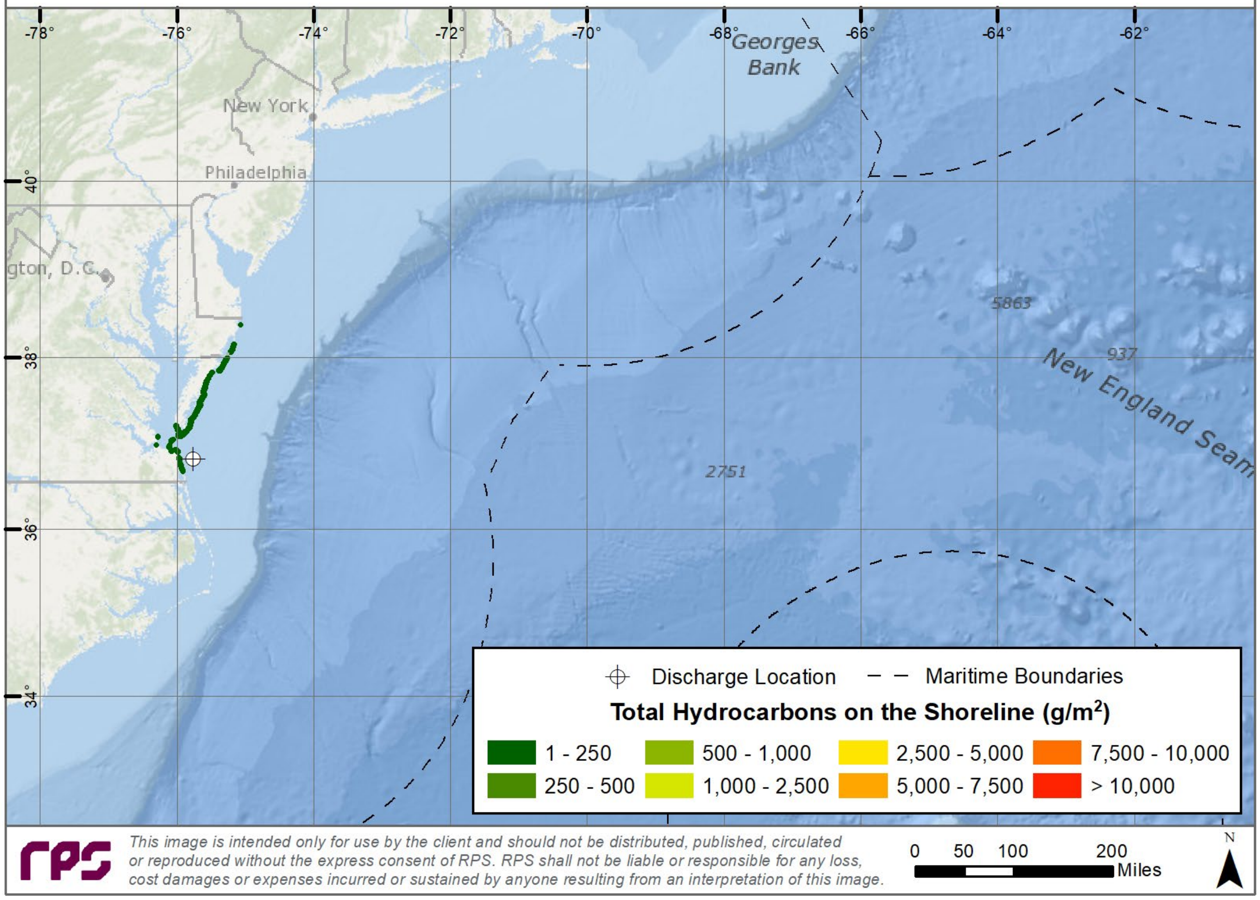


Figure 3-246. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore Virginia starting on June 19, 2018.

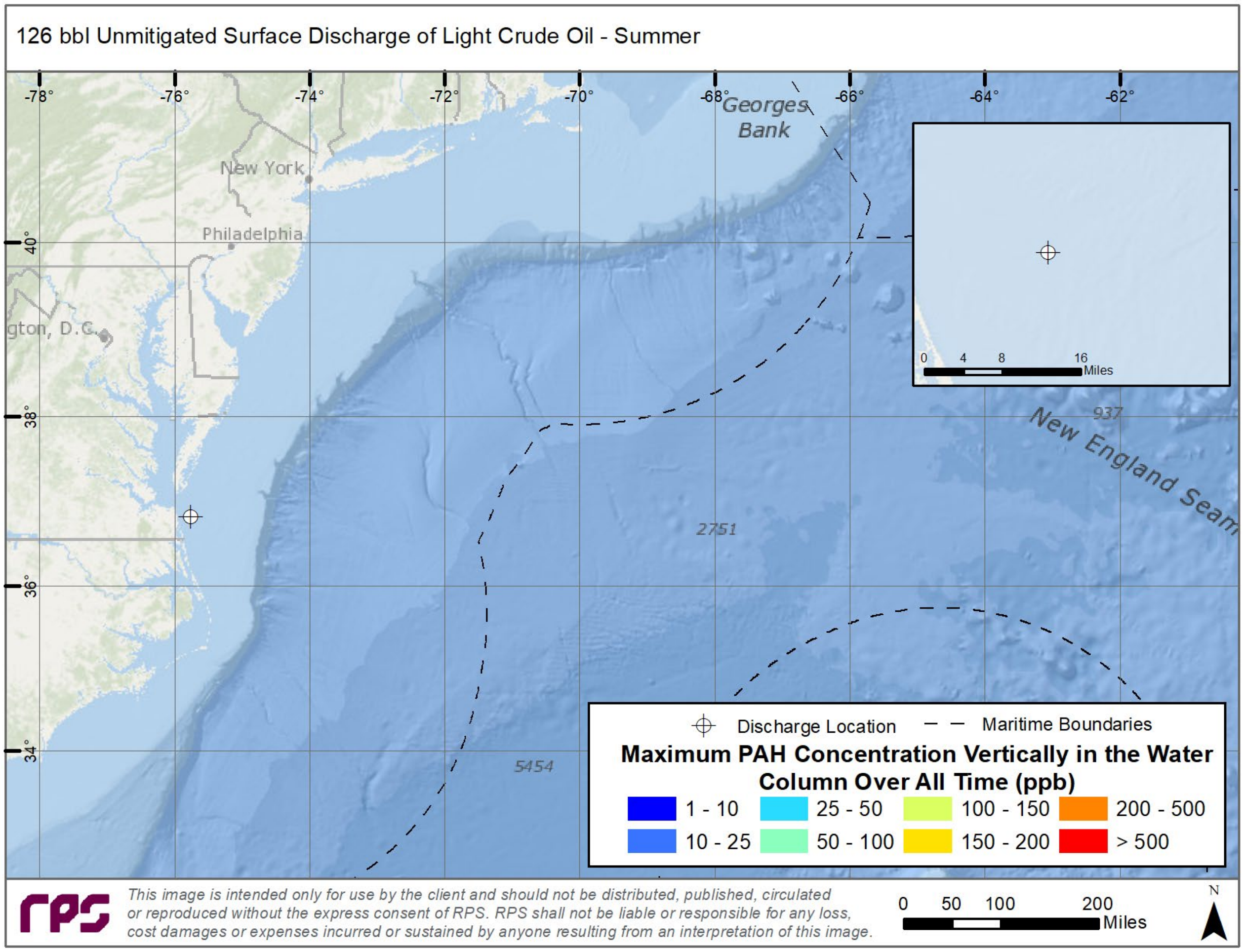


Figure 3-247. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 126 bbl release of crude oil offshore Virginia starting on June 19, 2018.

Fall

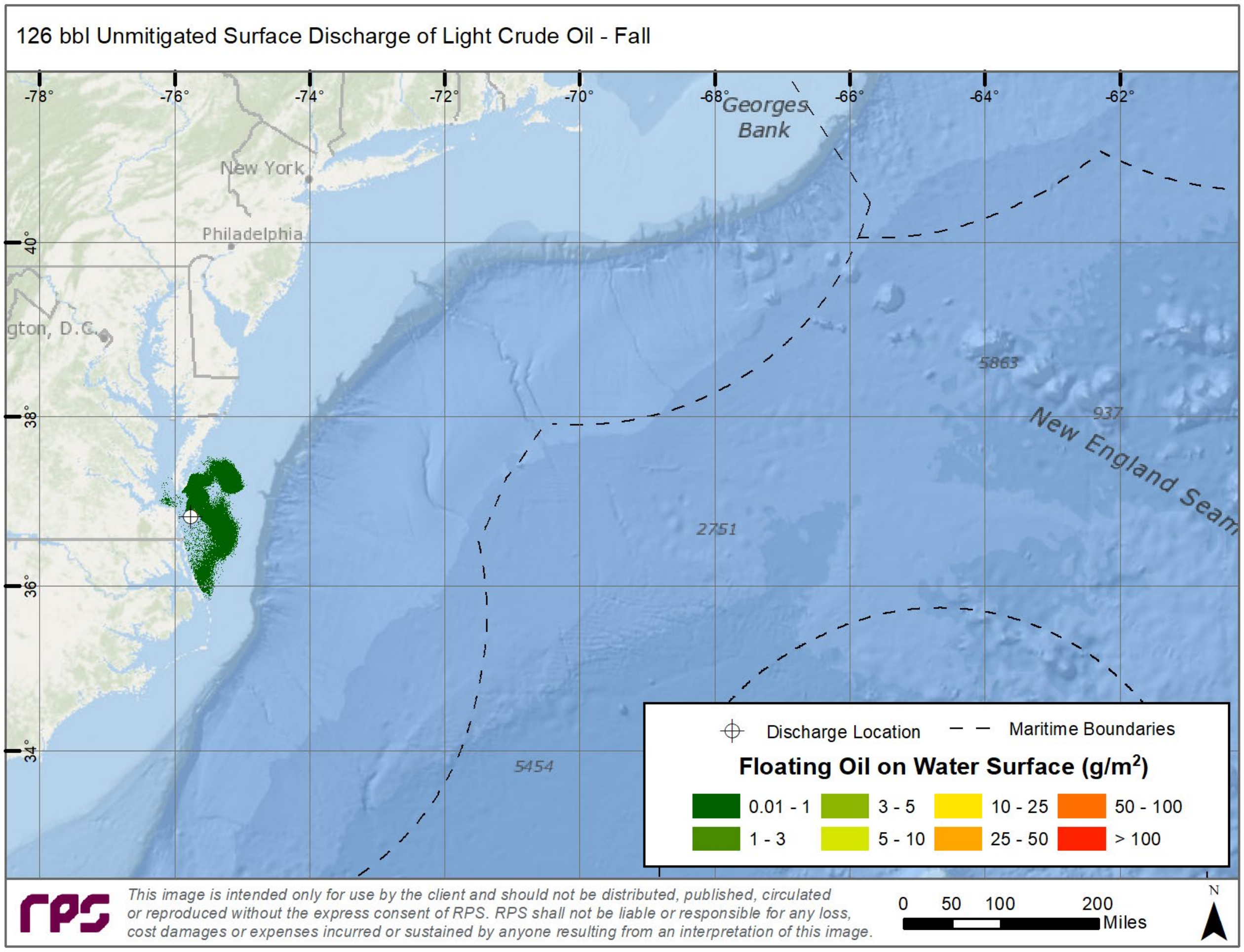


Figure 3-248. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore Virginia starting on October 13, 2019.

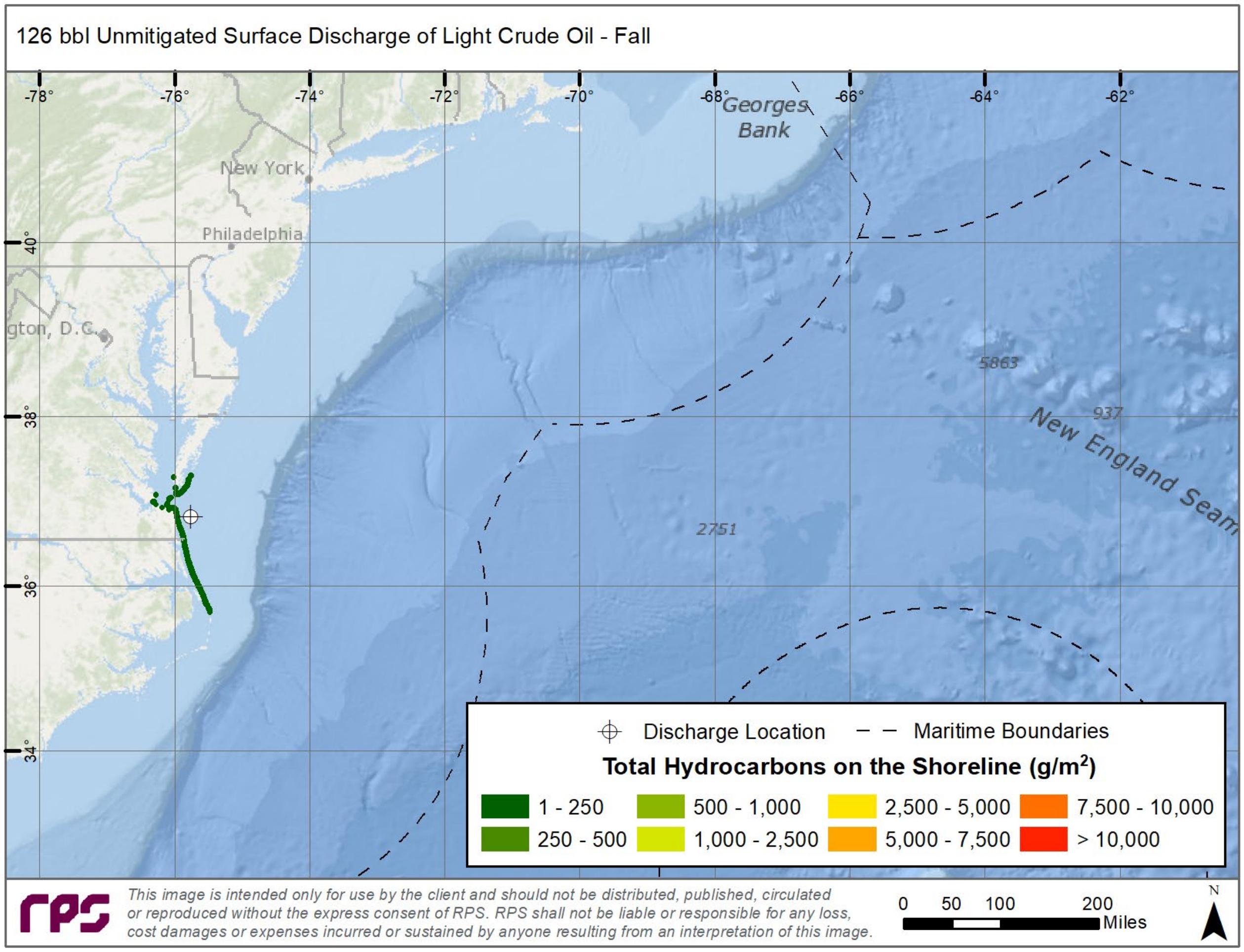


Figure 3-249. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore Virginia starting on October 13, 2019.

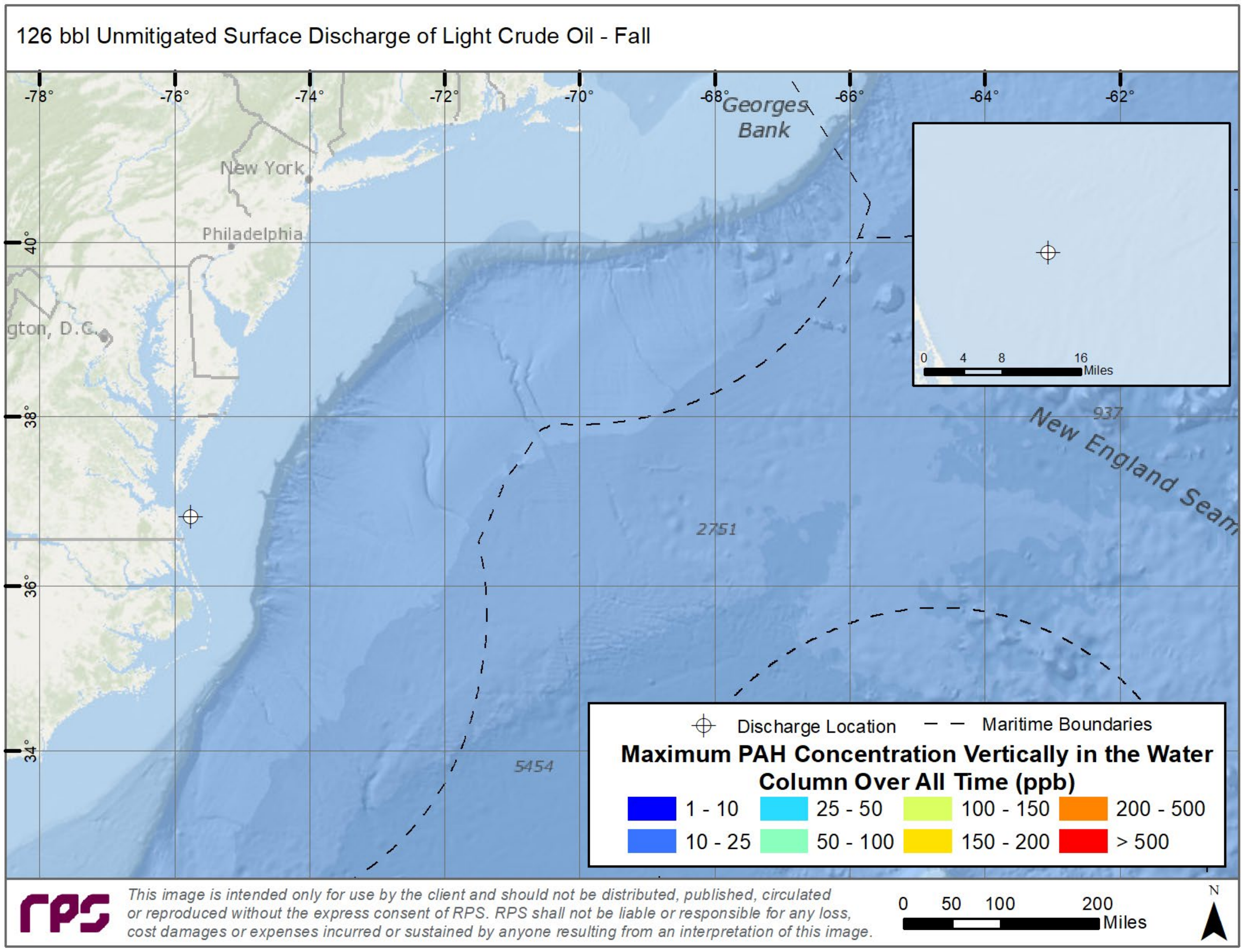


Figure 3-250. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 126 bbl release of crude oil offshore Virginia starting on October 13, 2019.

3.3.3.2 Surface Unmitigated Release (Medium Volume)

3.3.3.2.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a medium-volume surface release of 2,240 bbl crude oil offshore Virginia started on January 13, 2020. Floating oil on the surface was primarily between 0.01-1 g/m^2 with small patches of higher concentrations near the release location (Figure 3-251). The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Over 40% of the oil released at the surface evaporated quickly, within in the first 5 days. Similarly to the low-volume release, emulsification of the crude oil to viscosities > 4,000 cP during the first few days of the release limited entrainment into the water to occur only during the high wind events, causing oil to oscillate from within the water column to the surface during periods of high and low winds (Figure 3-254 and Figure 3-255). The mass balance (Figure 3-254) shows that released the oil came ashore beginning 12 days after the spill while winds from 8-10 m/s; 16-20 knots) were blowing from the northeast a few days before (Figure 3-255). Approximately 53% of the oil evaporated, 22% of the oil reached shore, 11% of the oil remained in the water column, 3% remained on the surface and approximately 11% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted south and east of the release location, extending furthest into offshore waters to the northeast. The highest surface oil exposure concentrations occurred just around the release location. Lower concentrations between 0.01-1 g/m^2 extended northeastward into international waters, and south to coastal waters along Virginia and North Carolina (Figure 3-251). By the end of the 30-day simulation, 210 mi (338 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-252; Table 3-28). Just over 80% of the oiled shoreline was seaward sandy beach (170 mi; 273 km) along the coasts of Virginia and North Carolina. No shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-25). Maximum cumulative PAH concentrations for the worst-case run were between 1-10 ppb and remained near the release location to the northeast (Figure 3-253). As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-28. Shoreline lengths oiled by >1 g/m^2 (1µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in winter), for an unmitigated 2,240 bbl surface release of crude oil offshore of Virginia starting on January 13, 2020.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Sand beach	170	143	36	273	230	58
Mudflat	28	24	2	44	38	4
Wetland	1	0	0	1	0	0
Artificial/manmade shoreline	3	3	0	4	4	0
Total	201	169	38	323	273	61
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	4	2	0	6	3	0
Mudflat	2	0	0	3	0	0
Wetland	2	0	0	4	0	0
Artificial/manmade shoreline	2	2	0	3	3	0
Total	10	3	0	15	5	0
All Shorelines						
Total	210	173	38	338	278	62

Table 3-22 provides the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-242 through Figure 3-250 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In the spring, oil is primarily transported east and south, with much of the shoreline oiling occurring along the coasts of Virginia and North Carolina. In the summer, oil is transported northwest directly into Chesapeake Bay, with shoreline oiling predicted along both shores of the bay and the seaward coasts of Maryland and Virginia. The worst-case run to occur within the fall predicted floating oiling to occur concentrically around the spill site, with the highest concentrations directly northeast. Shoreline oil was predicted along the coasts of Virginia and North Carolina.

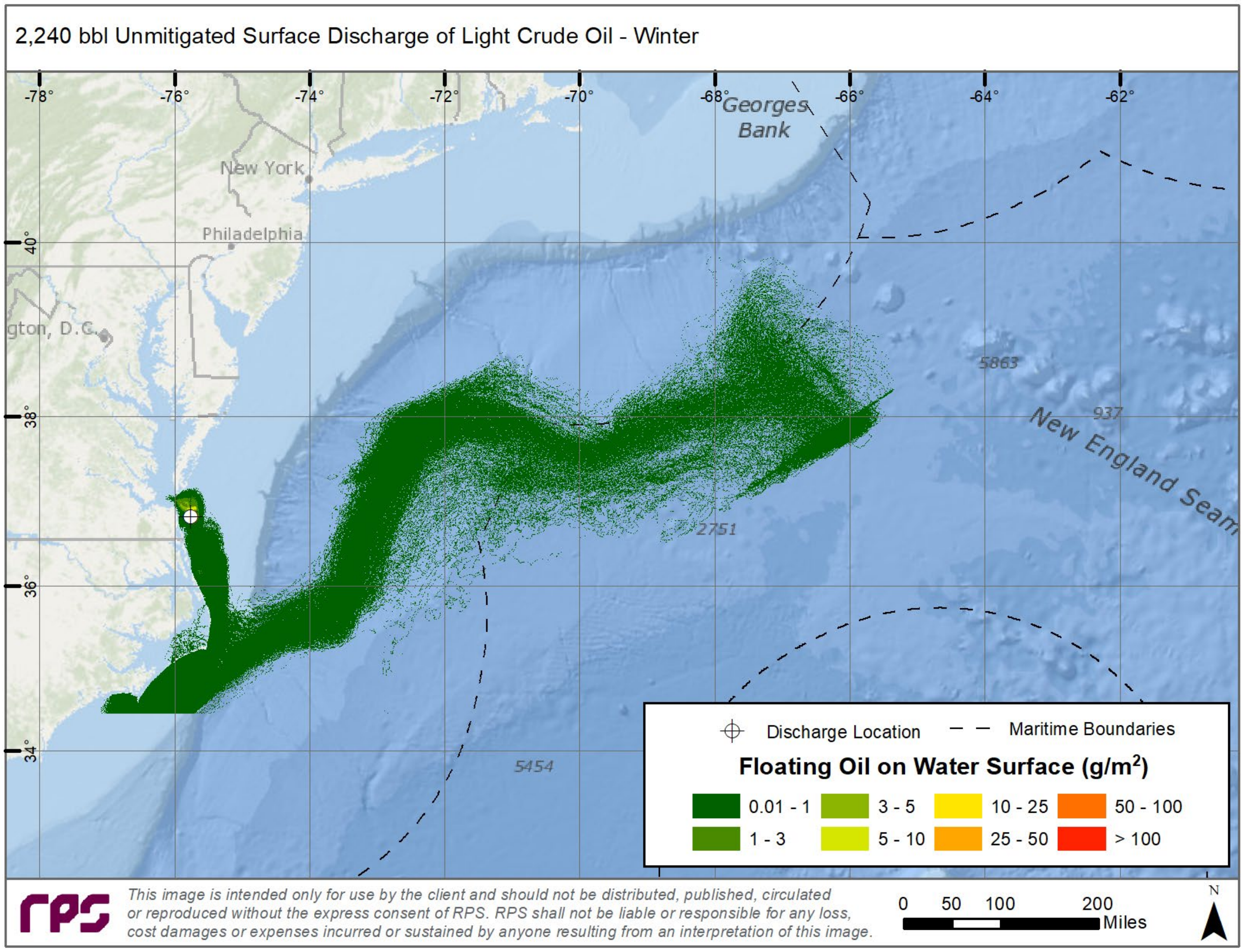


Figure 3-251. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl release of crude oil offshore Virginia starting on January 13, 2020.

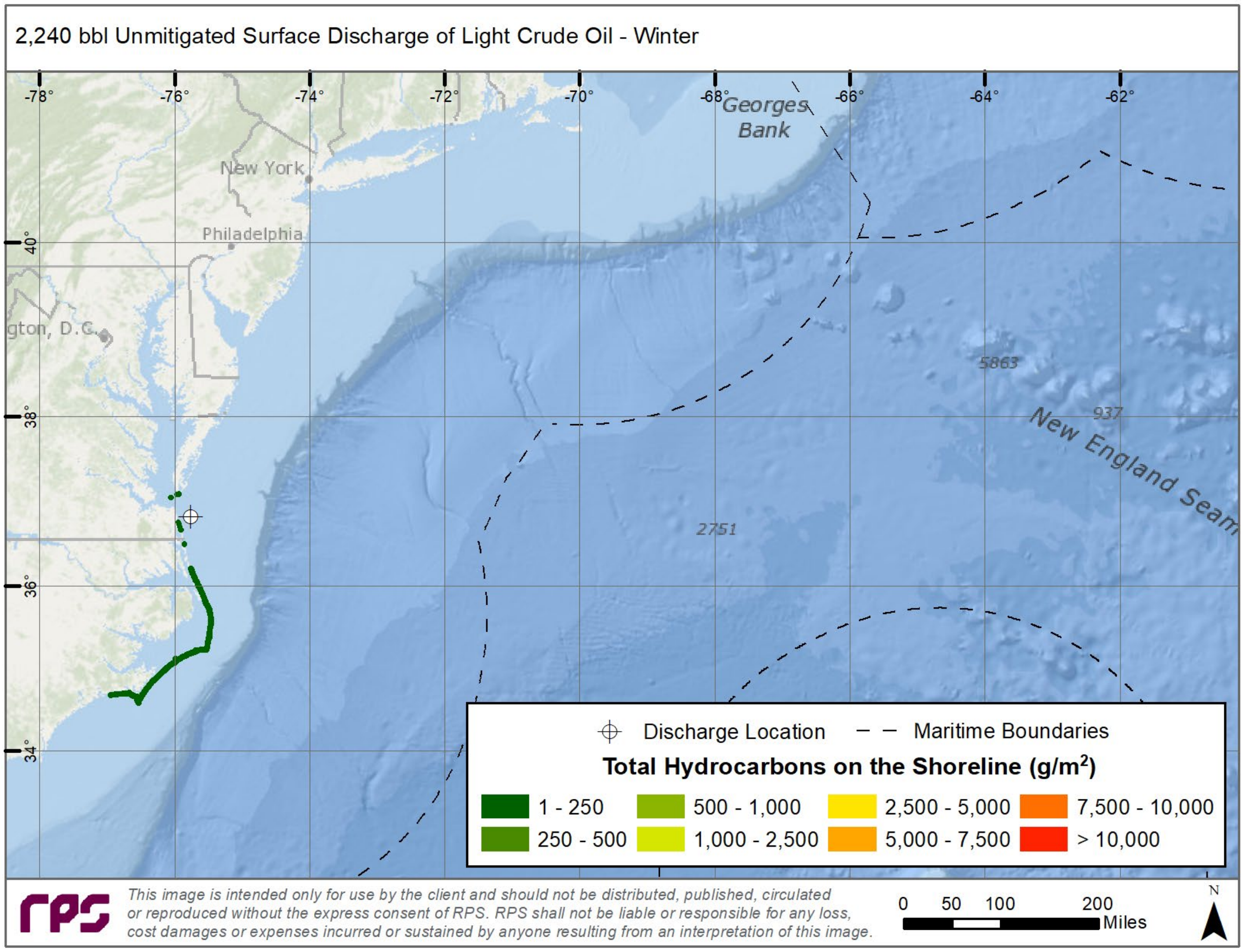


Figure 3-252. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl release of crude oil offshore Virginia starting on January 13, 2020.

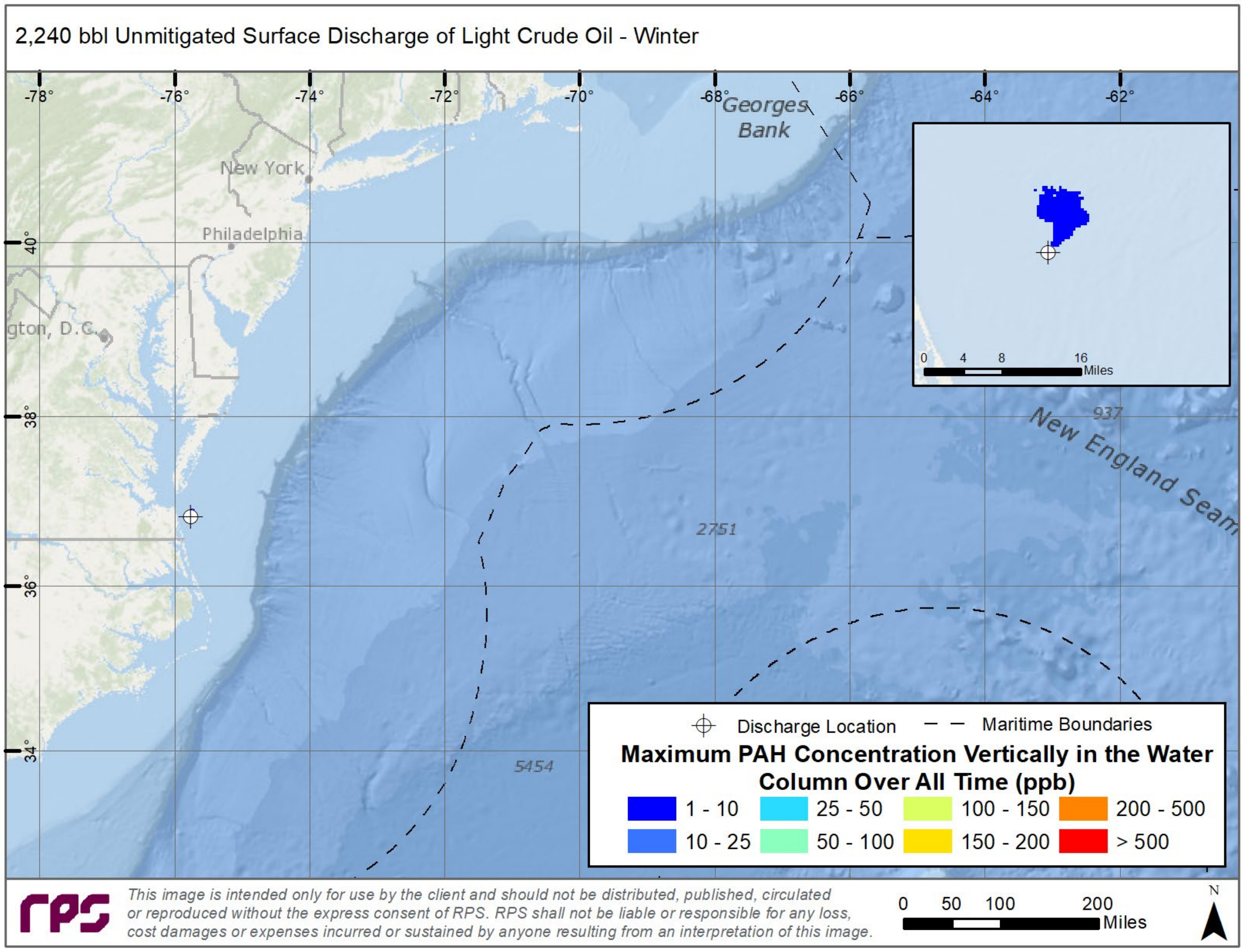


Figure 3-253. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl release of crude oil offshore Virginia starting on January 13, 2020.

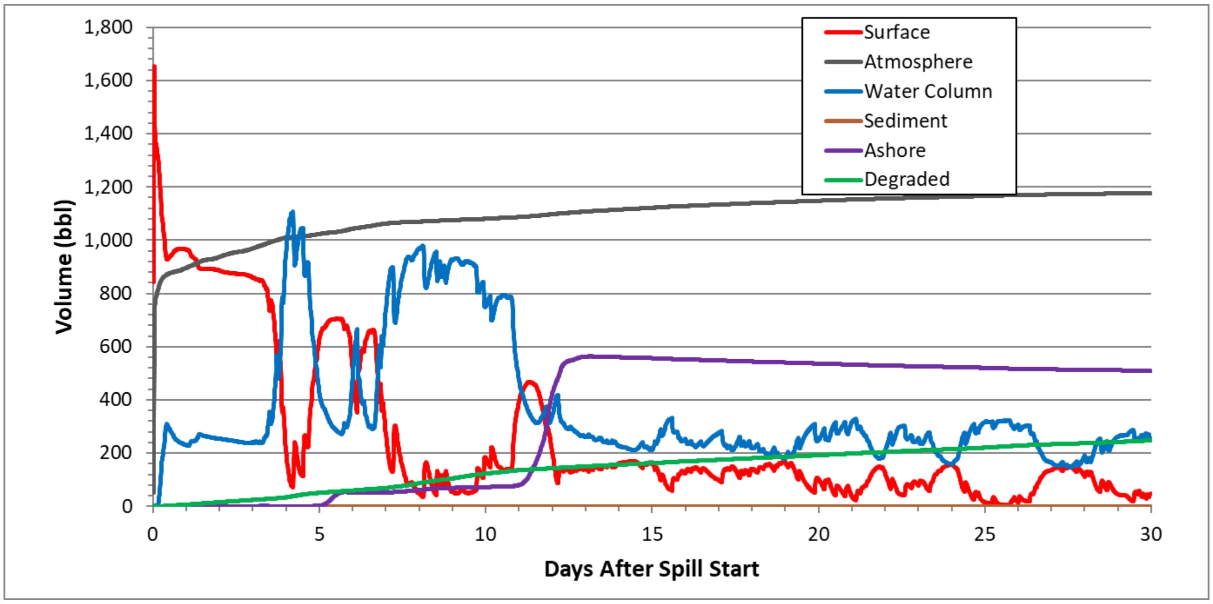


Figure 3-254. Oil volume by environmental compartment over time for a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl surface release of crude oil offshore Virginia starting on January 13, 2020.

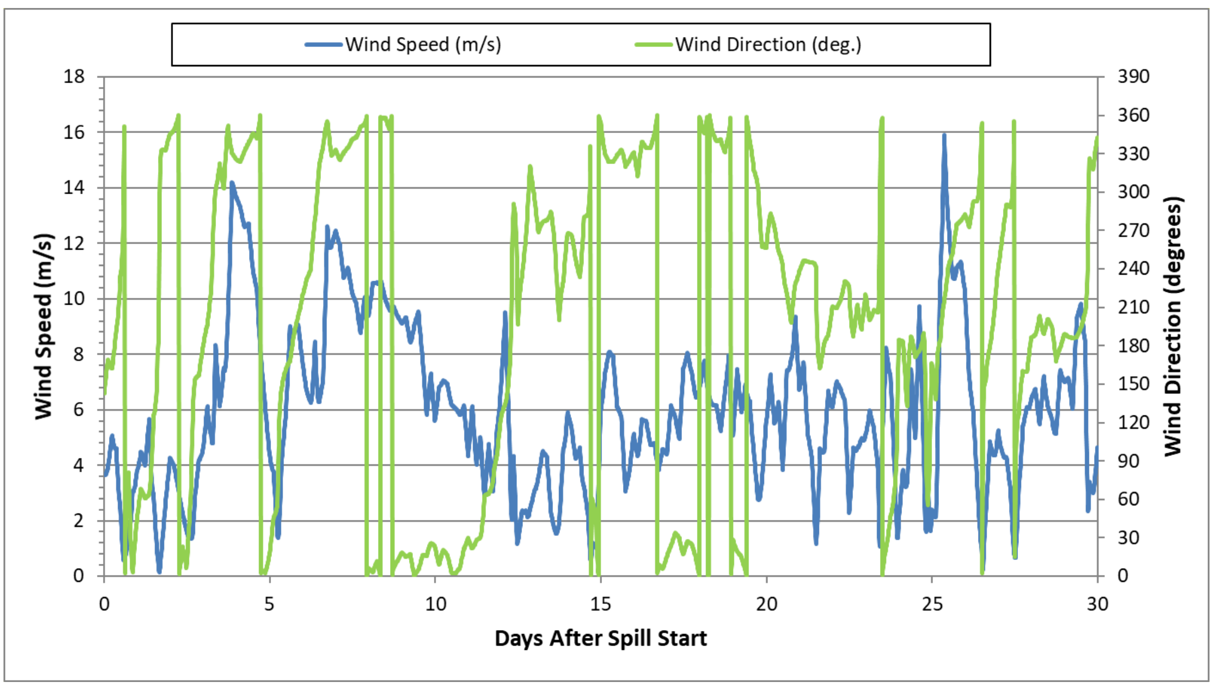


Figure 3-255. Wind speeds (1 m/s = 2 knots) and directions during the 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 2,240 bbl surface release of crude oil offshore Virginia starting on January 13, 2020.

3.3.3.2.2 Seasonal Worst-Case Runs

Spring

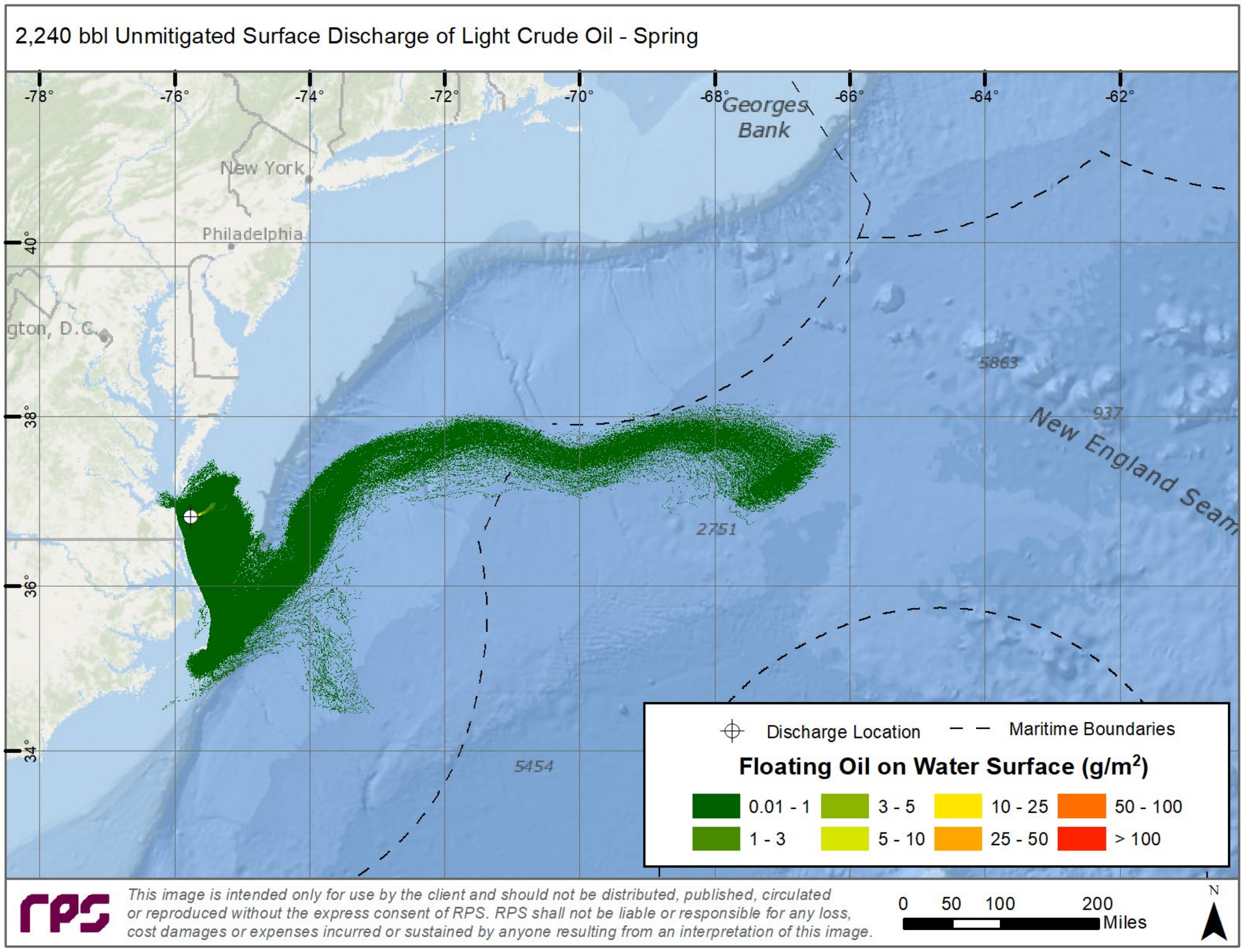


Figure 3-256. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore Virginia starting on March 9, 2020.

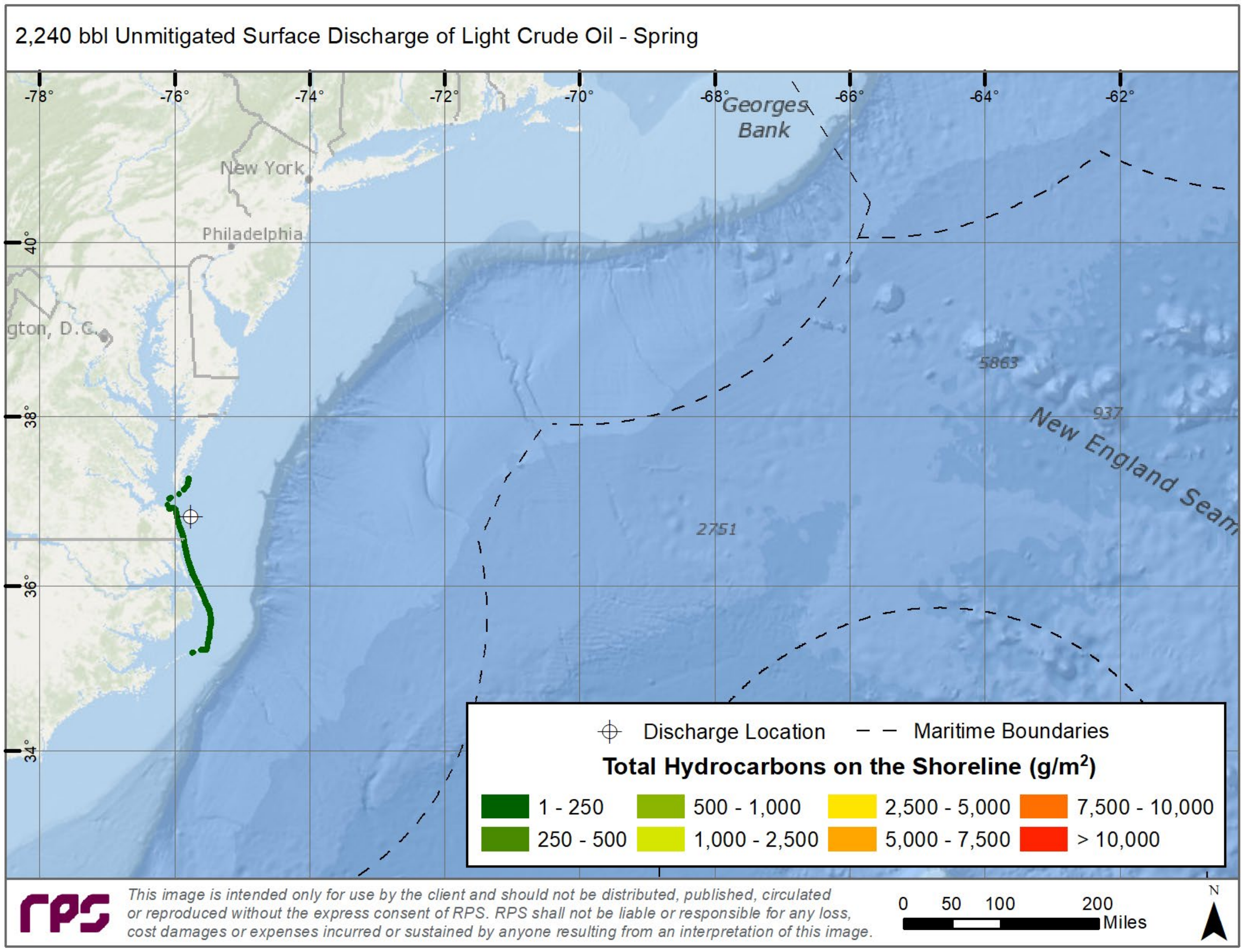


Figure 3-257. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore Virginia starting on March 9, 2020.

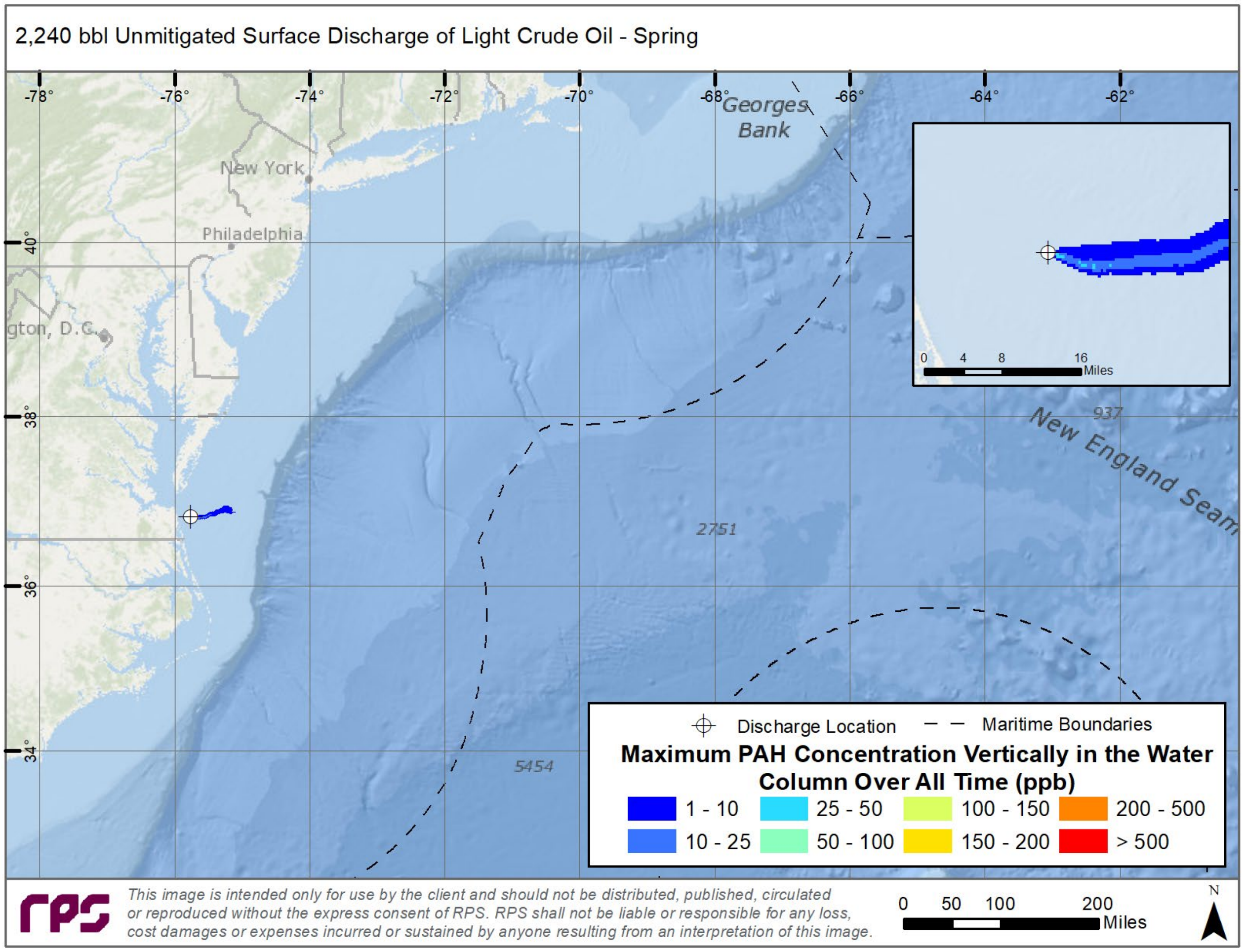


Figure 3-258. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 2,240 bbl release of crude oil offshore Virginia starting on March 9, 2020.

Summer

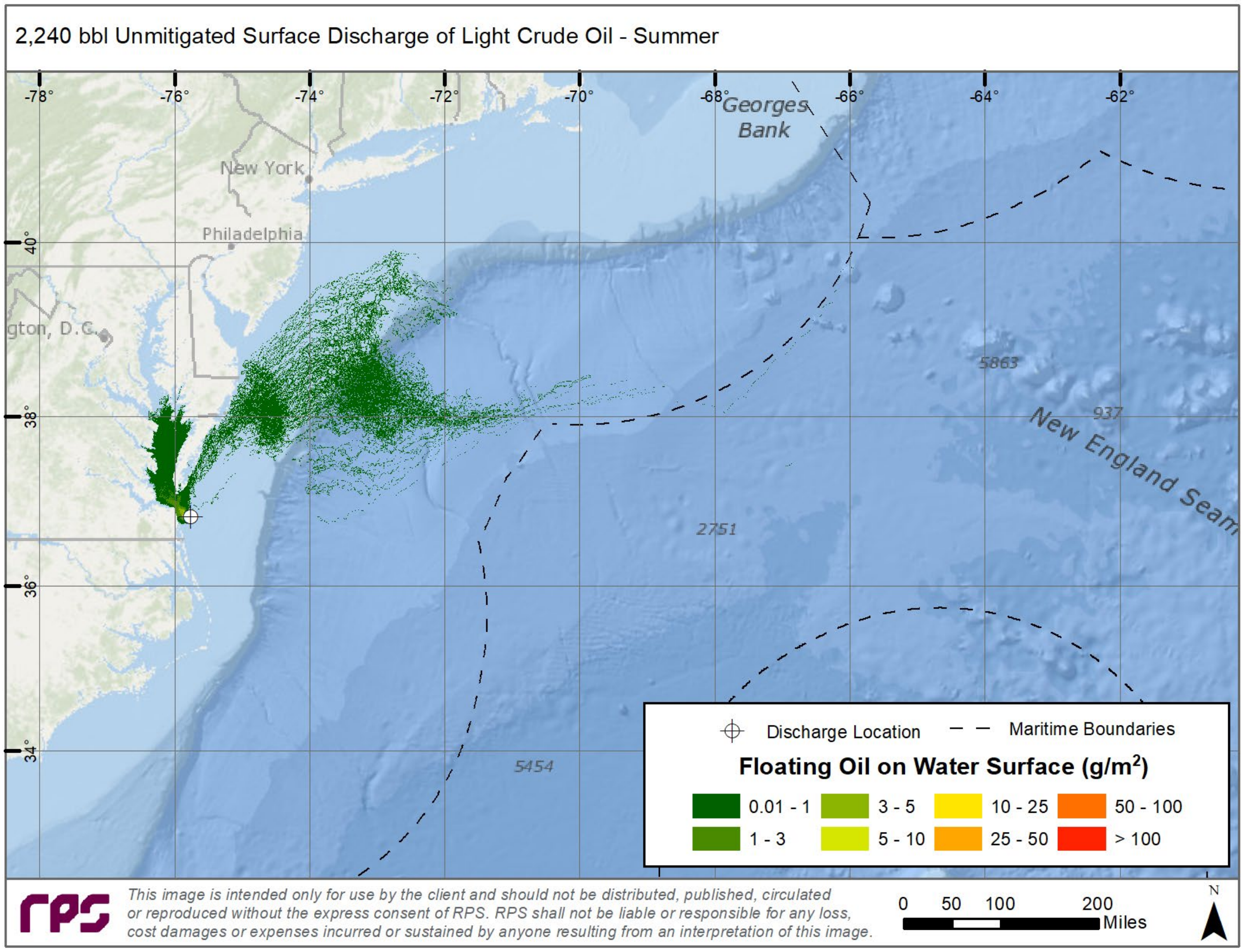


Figure 3-259. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore Virginia starting on July 19, 2018.

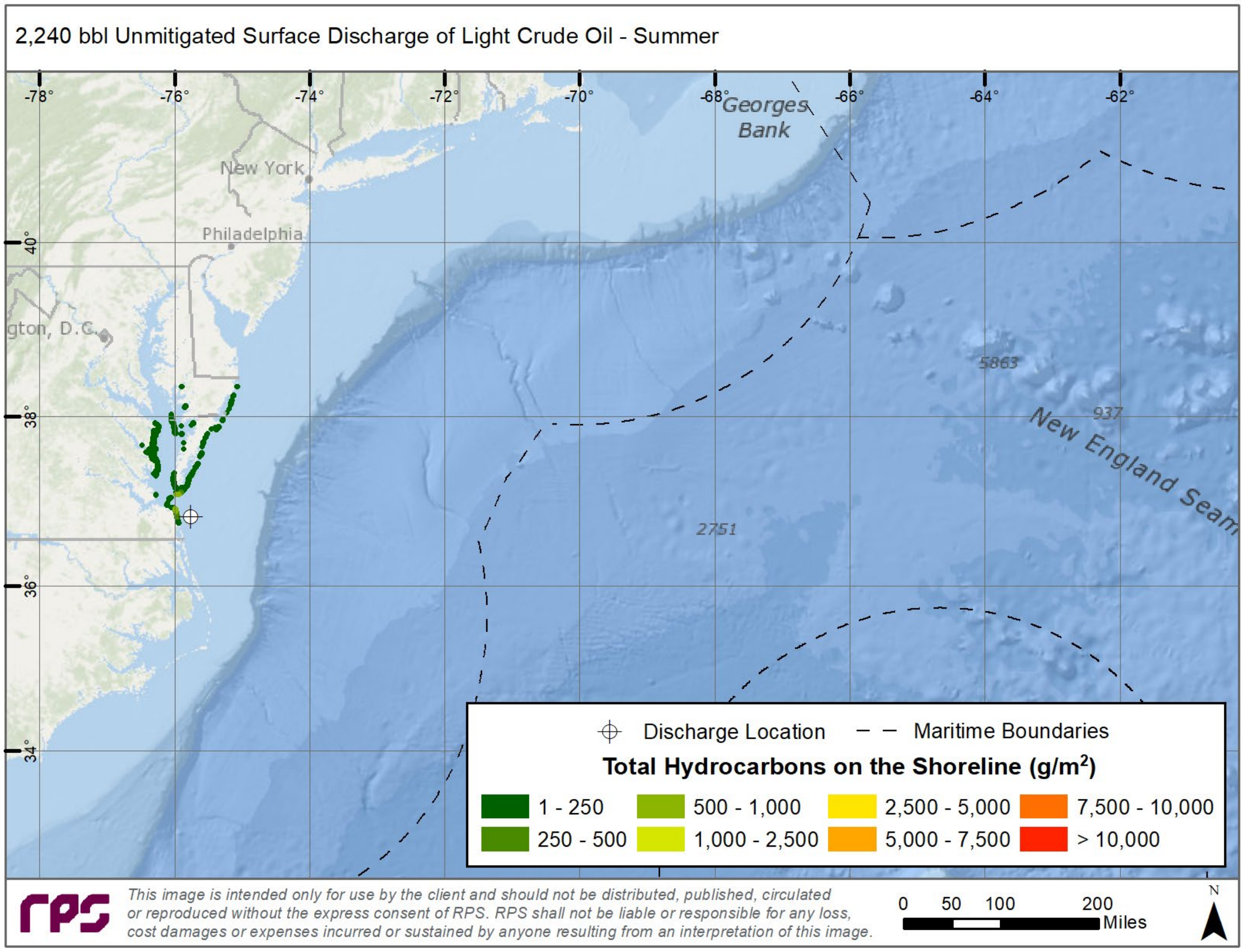


Figure 3-260. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore Virginia starting on July 19, 2018.

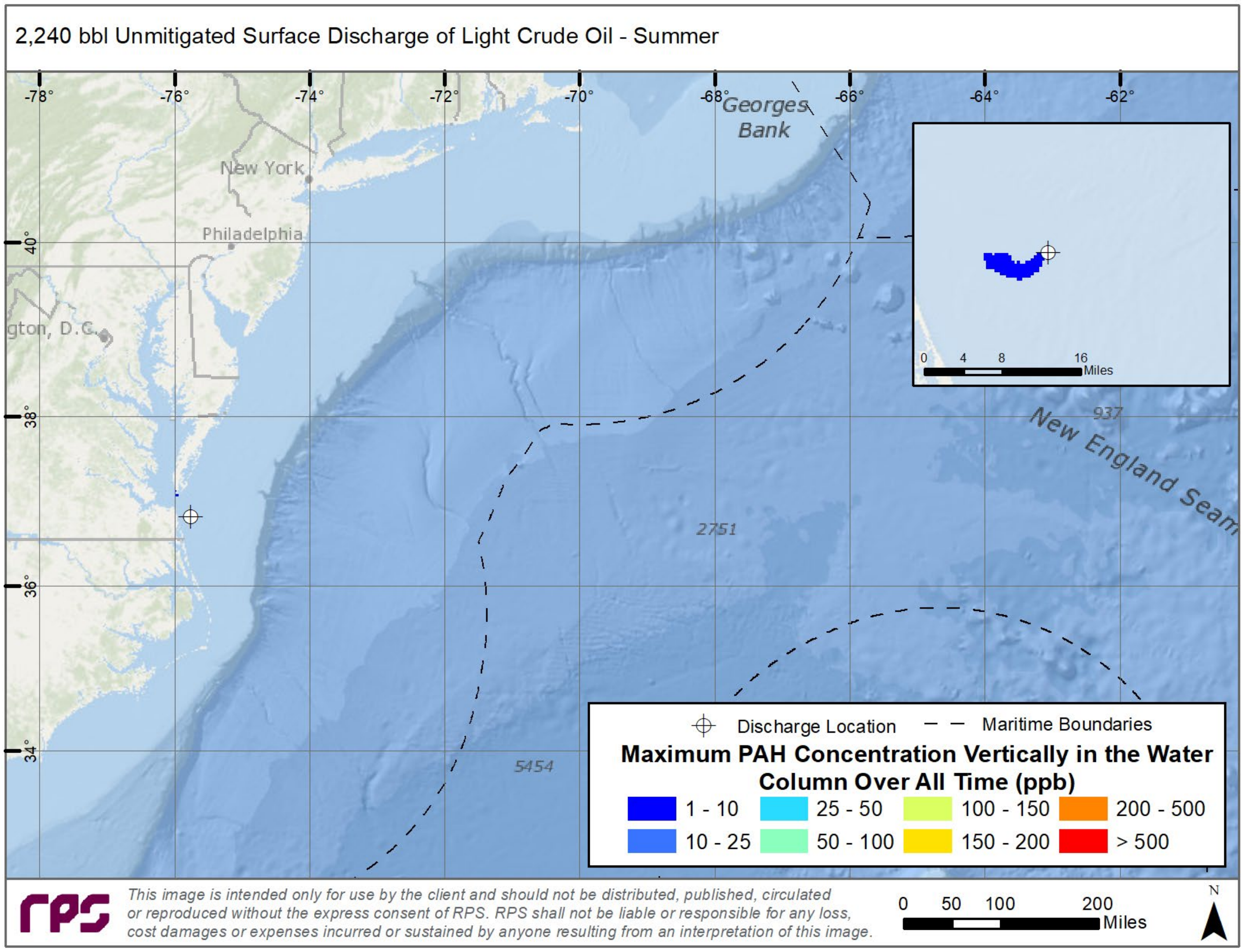


Figure 3-261. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 2,240 bbl release of crude oil offshore Virginia starting on July 19, 2018.

Fall

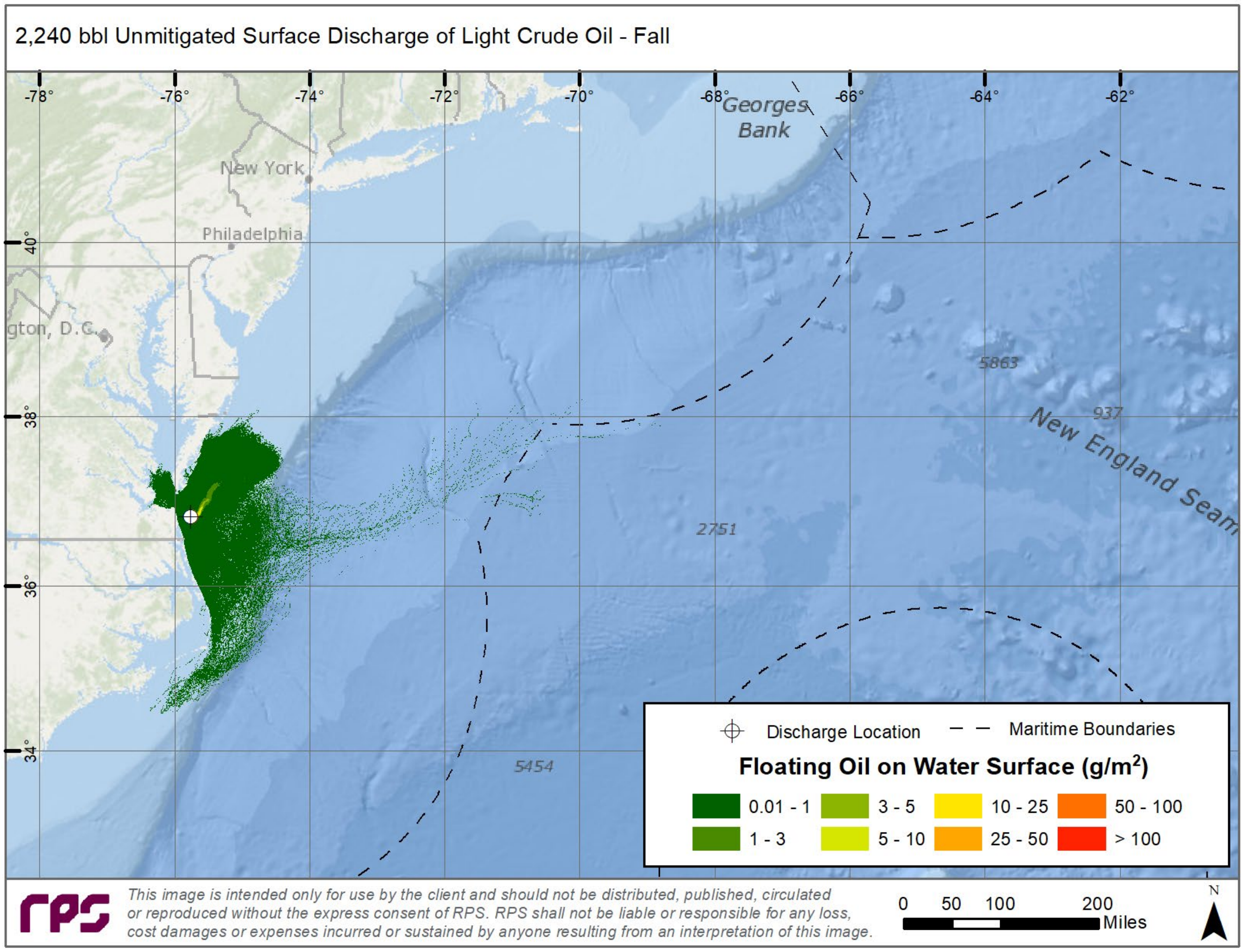


Figure 3-262. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore Virginia starting on October 13, 2019.

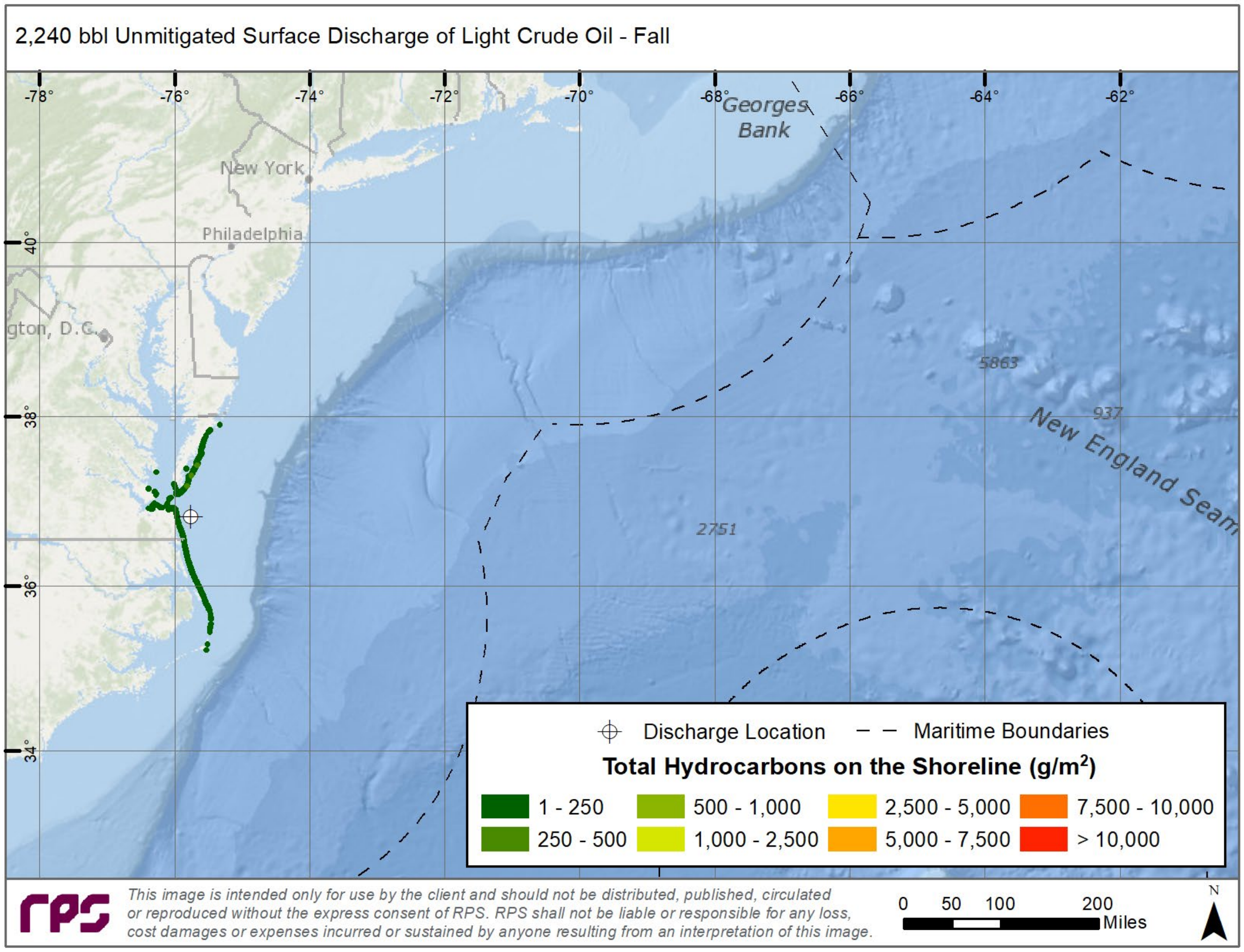


Figure 3-263. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore Virginia starting on October 13, 2019.

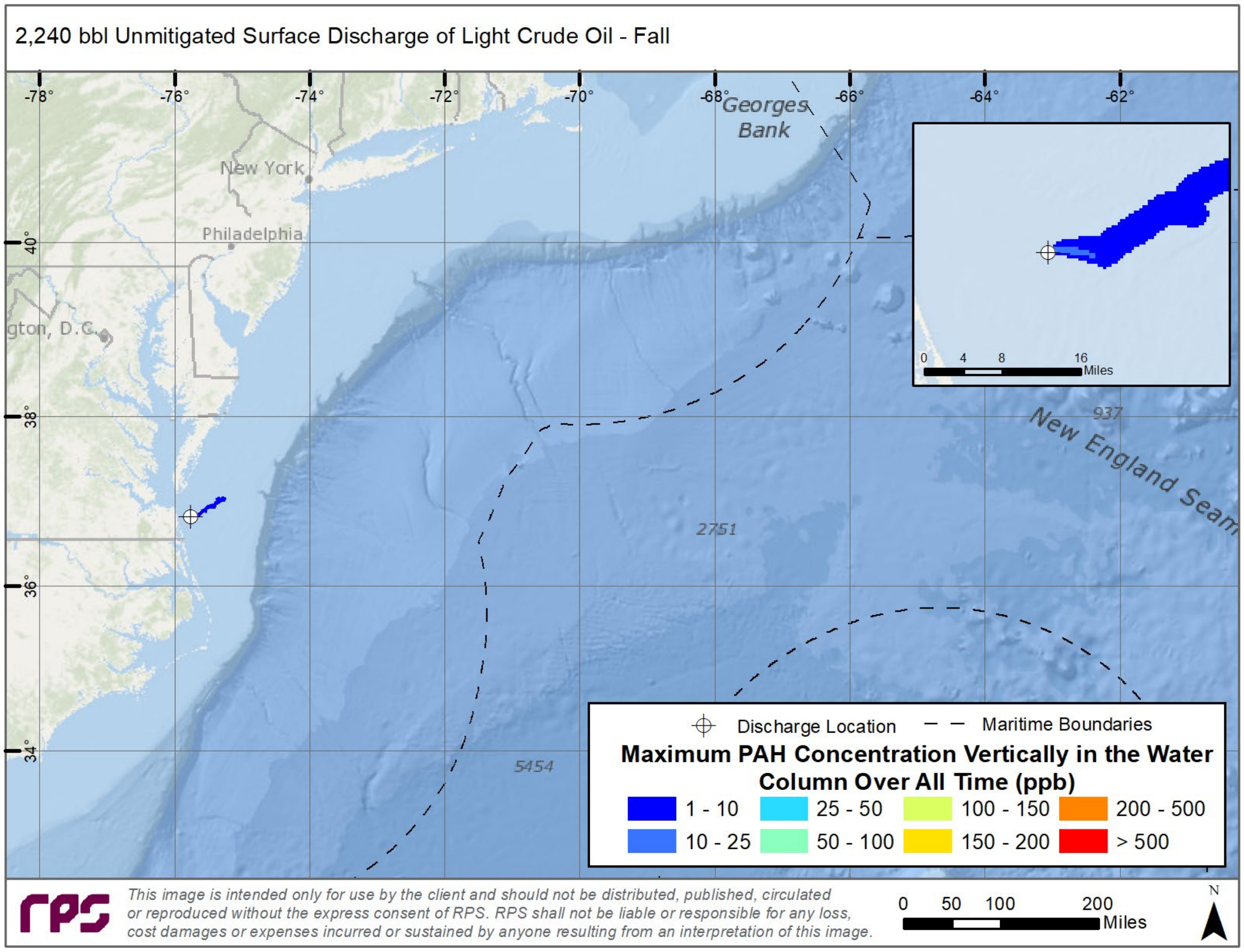


Figure 3-264. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 2,240 bbl release of crude oil offshore Virginia starting on October 13, 2019.

3.3.3.3 Surface Unmitigated Release (High Volume)

3.3.3.3.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a high-volume surface release of 200,000 bbl crude oil offshore Virginia started on July 19, 2018. The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. Over 40% of the oil released at the surface evaporated quickly, within in the first 5 days. Strong winds (8-14 m/s; 16-28 knots) within the first 7 days of the release resulted in increased water column entrainment during that period; however, weak winds (<8 m/s; 16 knots) throughout the remainder of the simulation limited entrainment (Figure 3-268 and Figure 3-269). The mass balance (Figure 3-268) shows that released the oil came ashore beginning 2 days after the spill while strong winds (up to 14 m/s; 28 knots) were blowing from the southeast, transporting oil into Chesapeake Bay (Figure 3-269). Approximately 46% of the oil evaporated, 39% of the oil reached shore, 6% of the oil remained in the water column, 1% remained on the surface, and approximately 8% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted north and northwest of the release location, towards Chesapeake Bay and the seaward coast of Virginia. The highest concentrations (>100 g/m^2 (100 µm, on average) of floating oil predicted to the northeast, just within the bay (Figure 3-265). Lower (<25 g/m^2, i.e., patchy oil, emulsions or sheens) maximum surface oil exposure concentrations were also predicted to extend to the north of the release site as well, into Chesapeake Bay up to the mouth of the Potomac River. By the end of the 30-day simulation, 430 mi (692 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-266; Table 3-29). Landward mudflats were predicted to have the longest length of shoreline oiled (179 mi; 288 km). Shoreline oiling was predicted along the coasts of Delaware, New Jersey, Maryland, and Virginia, with the highest concentrations of oil (>10,000 g/m^2) occurring along the southern seaward coast of Virginia, near Virginia Beach. In total, 0.03 mi^2 (0.1 km^2) of shoreline habitat in Delaware was oiled >1 g/m^2 (Table 3-25). Maximum cumulative PAH concentrations for the worst-case run were <500 ppb and remained near the release location (Figure 3-267). Lower concentrations, between 1-10 ppb, extended to the north into Chesapeake Bay and along the nearshore, coastal waters of Virginia. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-29. Shoreline lengths oiled by >1 g/m^2 (1 µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated 200,000 bbl surface release of crude oil offshore of Virginia starting on July 19, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	133	132	111	213	213	179
Mudflat	4	4	3	7	7	5
Wetland	1	0	0	1	0	0
Artificial/manmade shoreline	1	1	0	2	2	0
Total	139	138	115	223	223	185
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Sand beach	42	41	34	67	67	55
Mudflat	179	168	86	288	271	138
Wetland	30	27	11	48	43	17
Artificial/manmade shoreline	40	40	0	65	65	0
Total	291	277	130	468	446	210
All Shorelines						
Total	430	415	245	692	668	395

Table 3-22 provides the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-270 to Figure 3-278 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In both the spring and fall, the highest concentrations of floating oil occur to the north of the release site, with shoreline oiling occurring along the coasts of Virginia and North Carolina. In the winter, oil is transported to the south, in nearshore waters off the coast of North Carolina, and east offshore waters following the Gulf Stream.

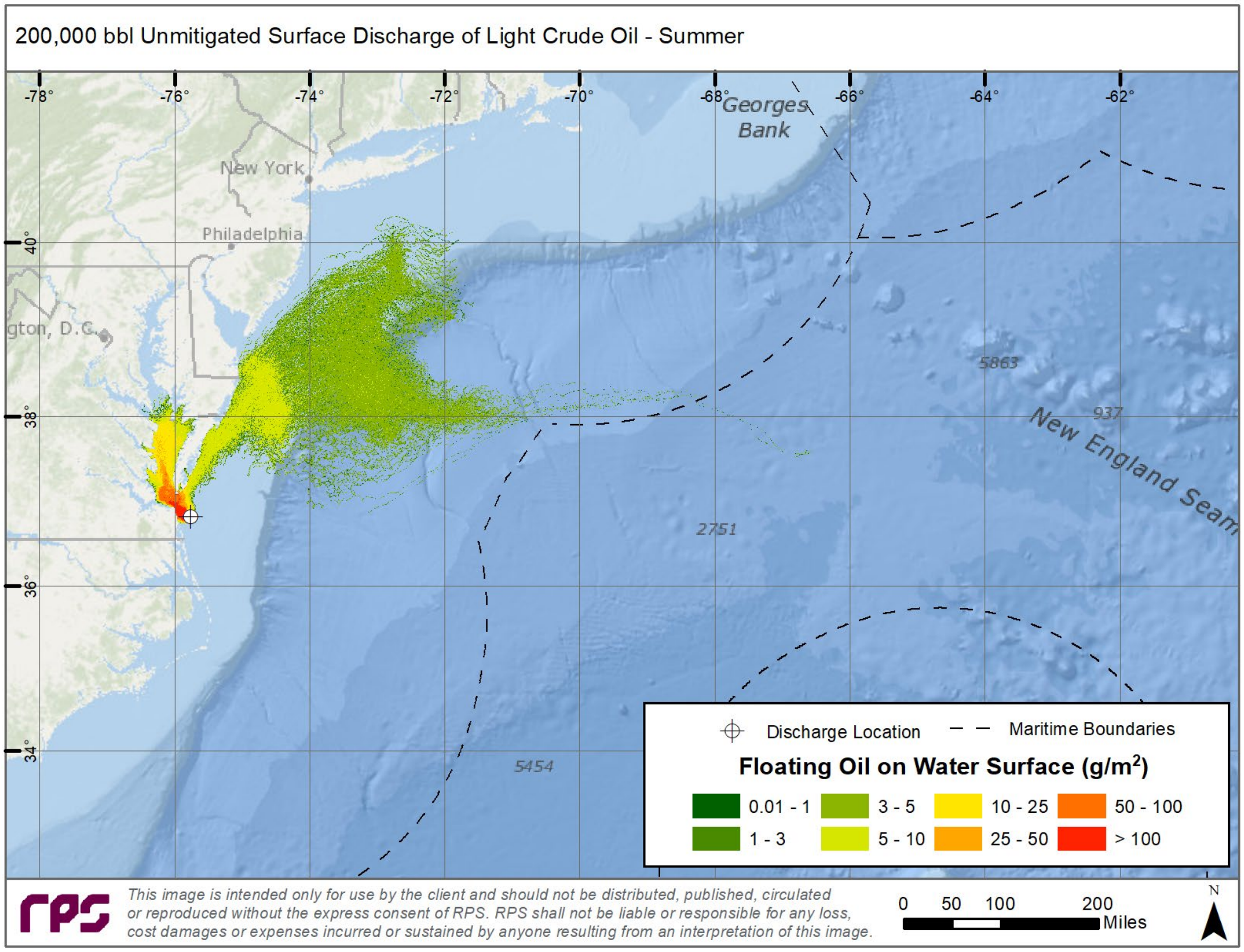


Figure 3-265. Maximum water surface oil exposure concentration at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Virginia starting on July 19, 2018.

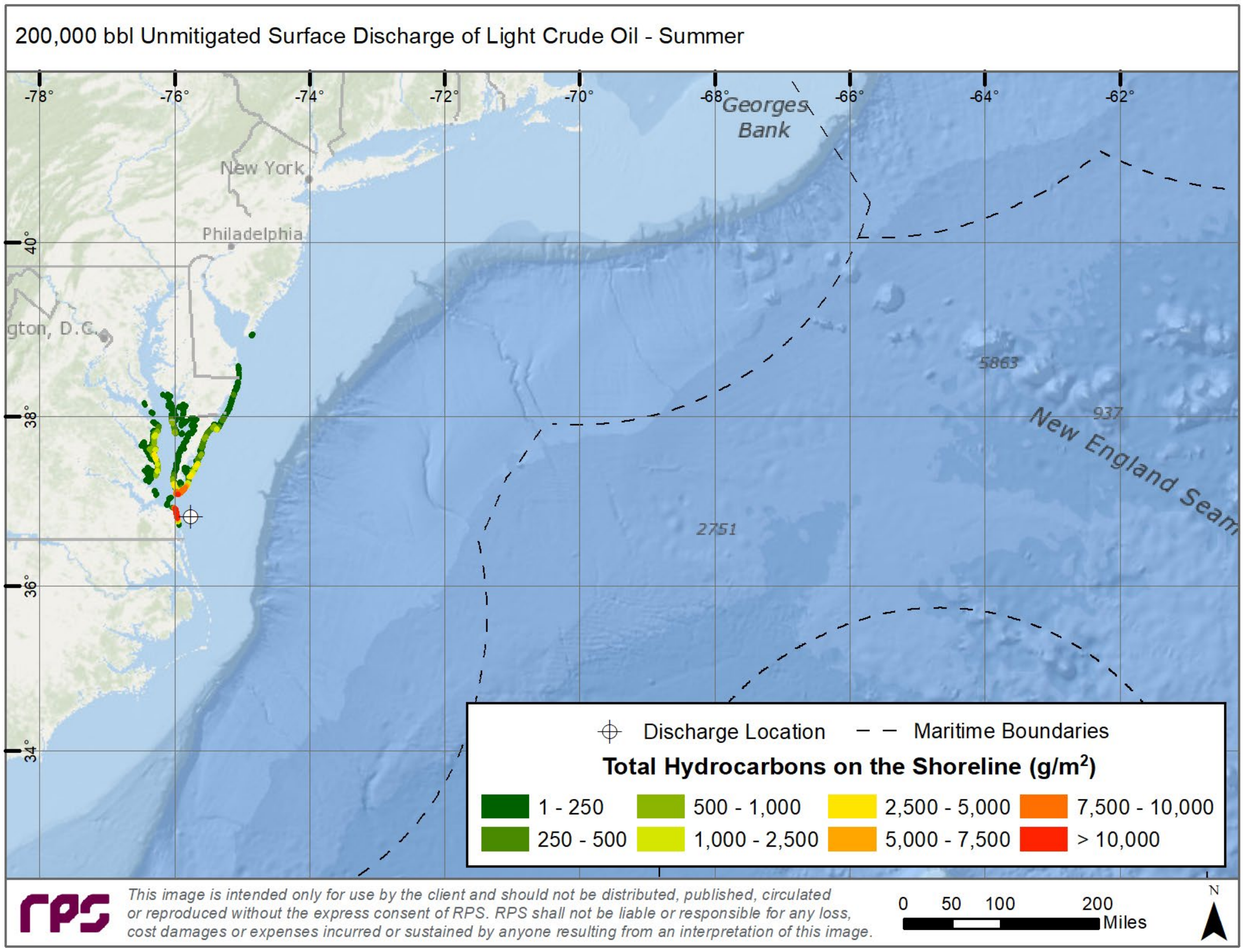


Figure 3-266. Maximum shoreline oil concentration at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Virginia starting on July 19, 2018.

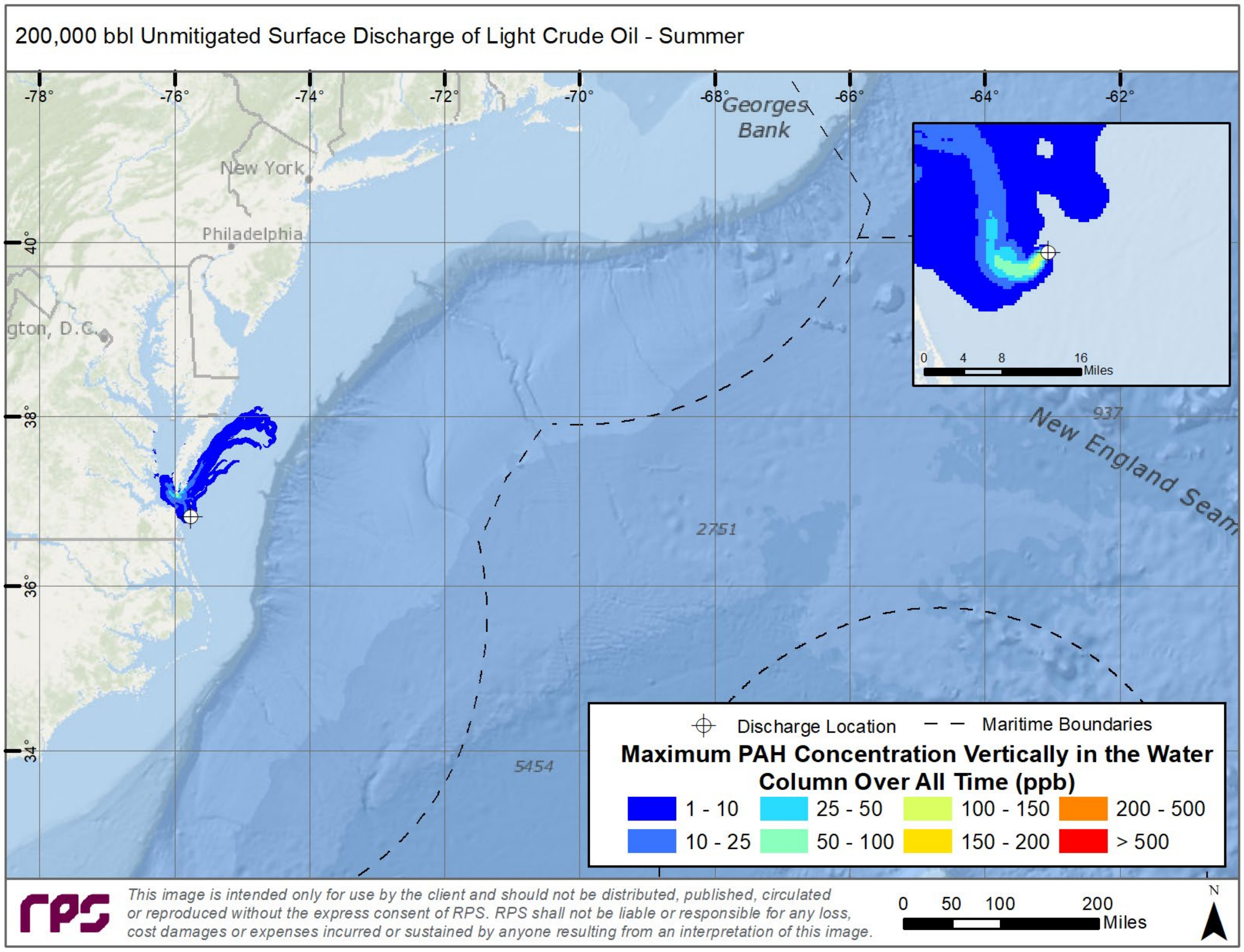


Figure 3-267. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Virginia starting on July 19, 2018.

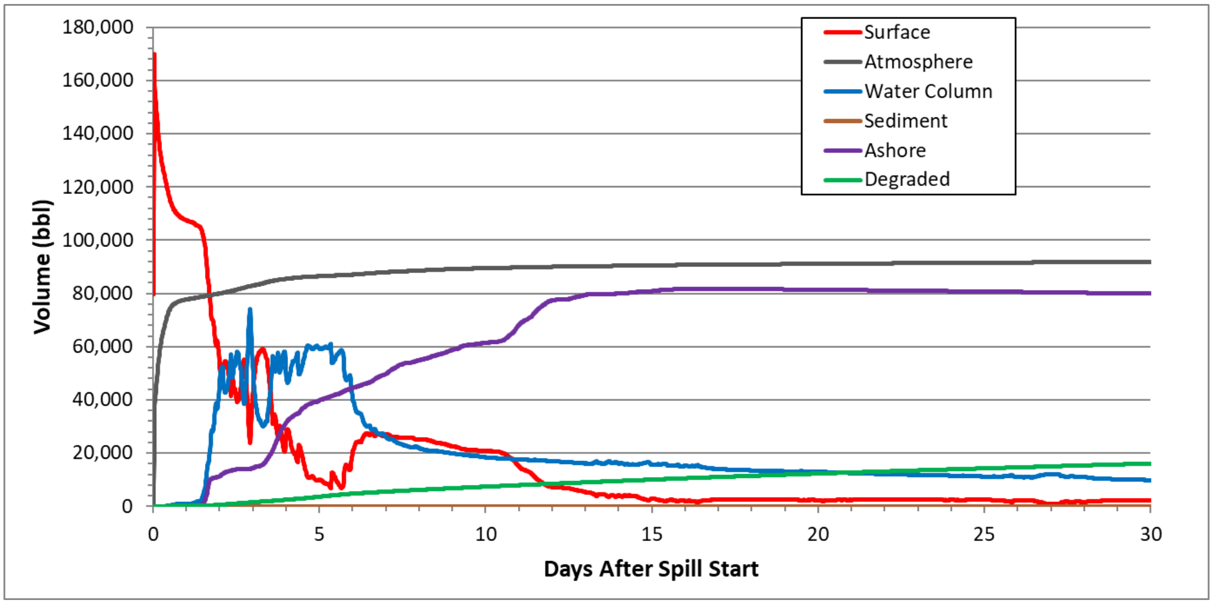


Figure 3-268. Oil volume by environmental compartment over time for an unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl surface release of crude oil offshore of Virginia starting on July 19, 2018.

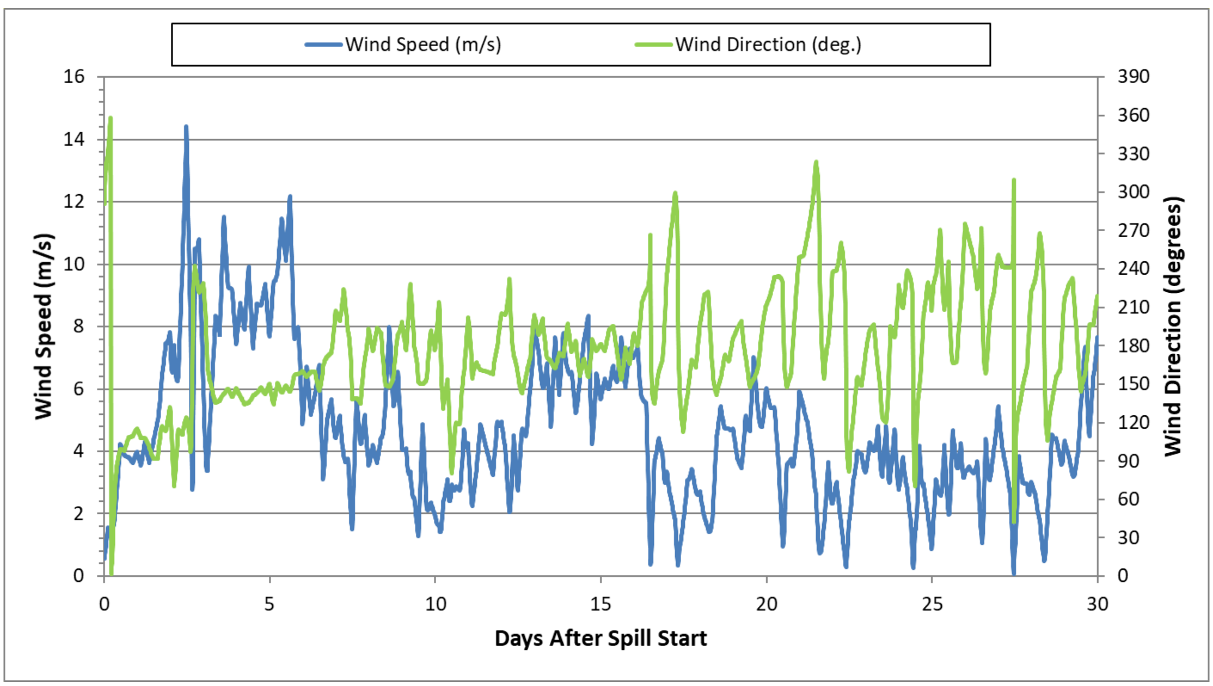


Figure 3-269. Wind speeds (1 m/s = 2 knots) and directions during the unmitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl surface release of crude oil offshore of Virginia starting on July 19, 2018.

3.3.3.3.2 Seasonal Worst-Case Runs

Winter

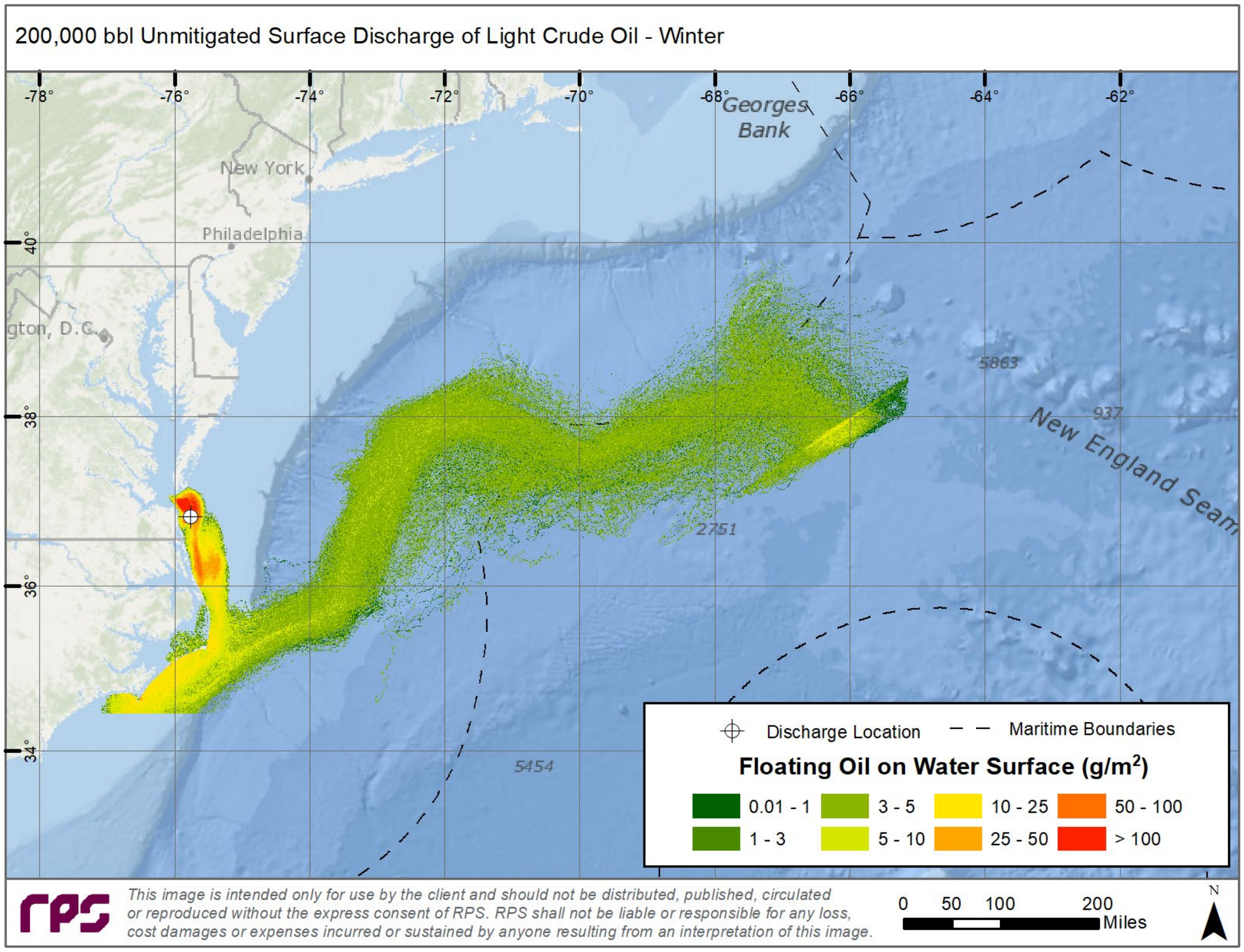


Figure 3-270. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Virginia starting on January 13, 2020.

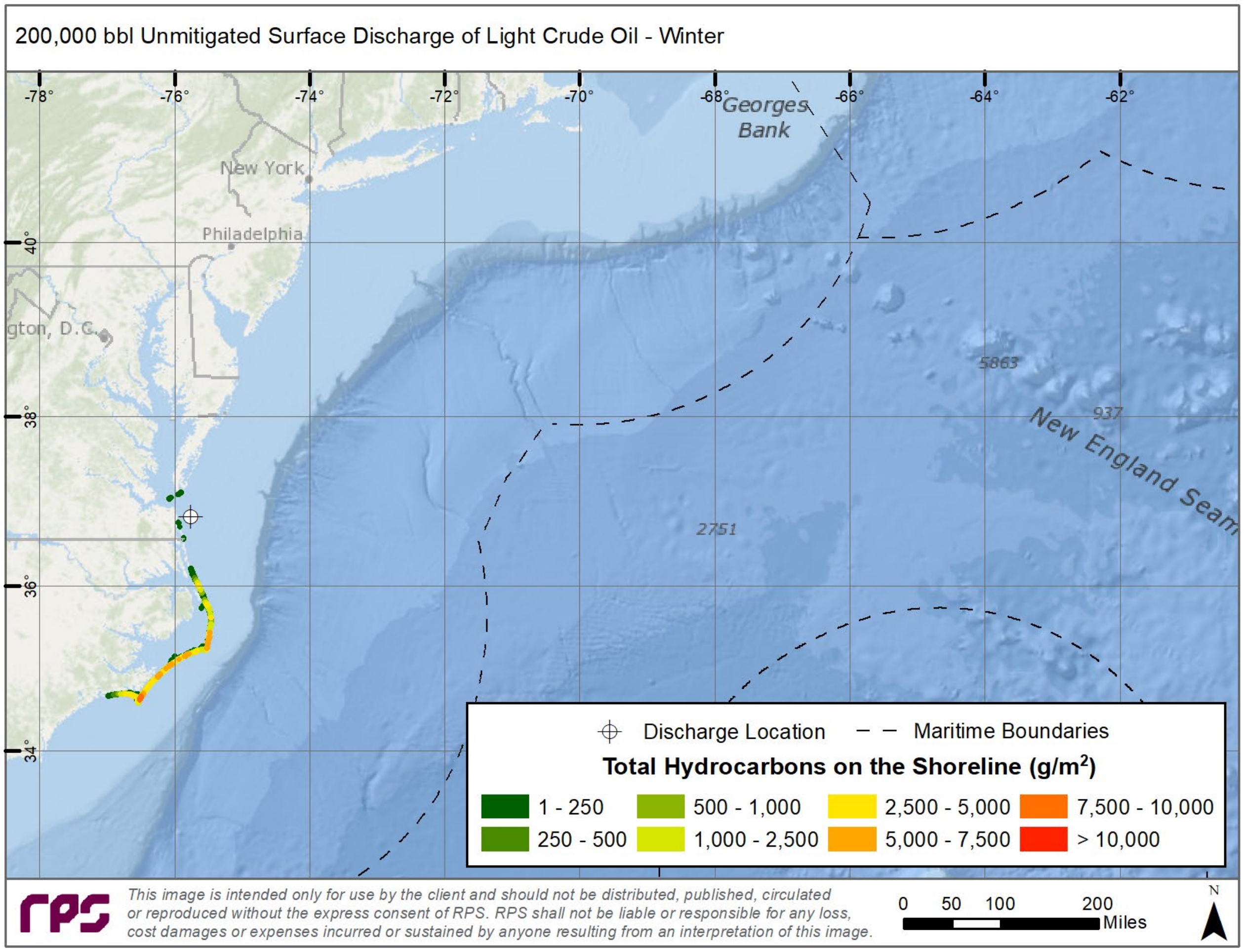


Figure 3-271. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Virginia starting on January 13, 2020.

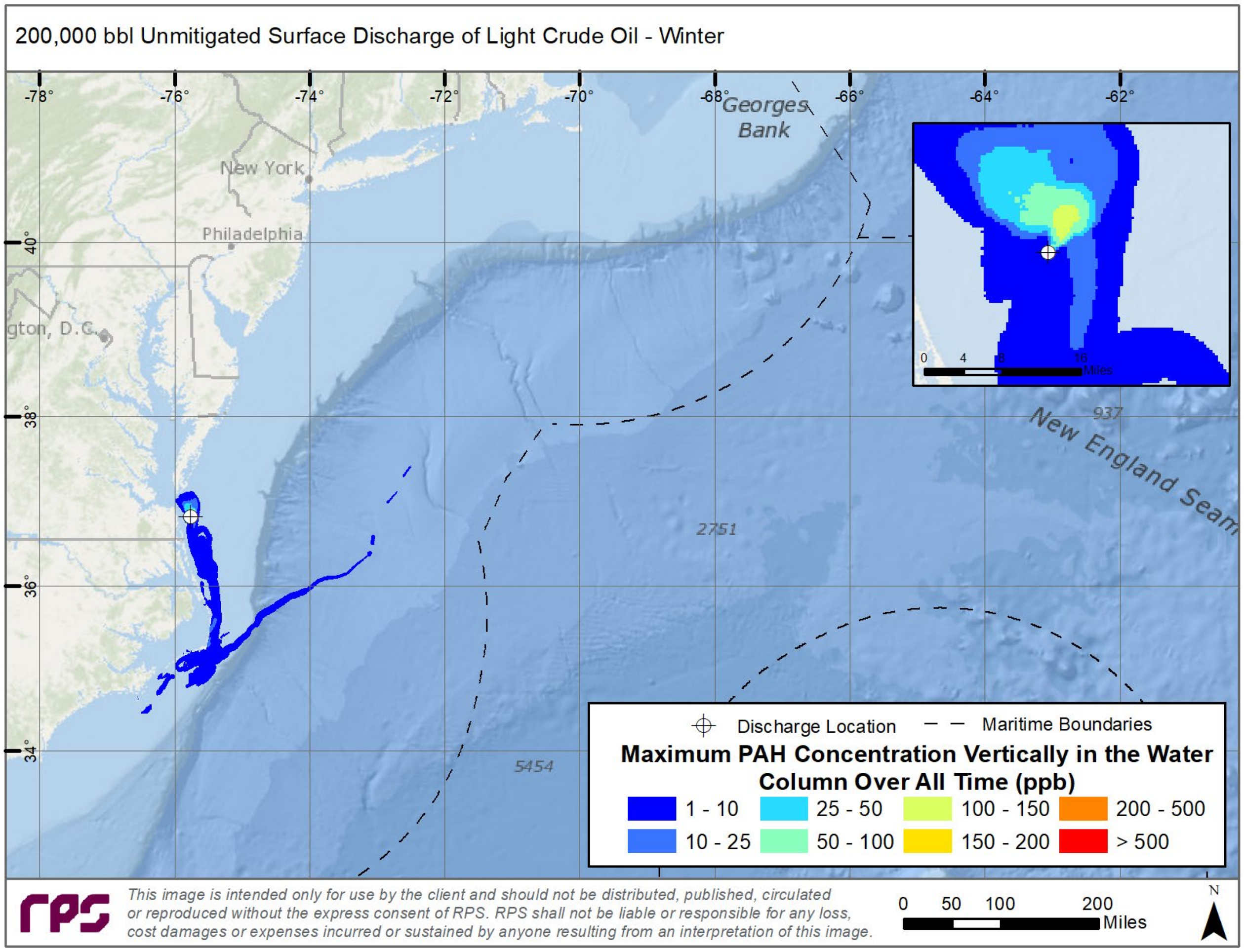


Figure 3-272. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Virginia starting on January 13, 2020.

Spring

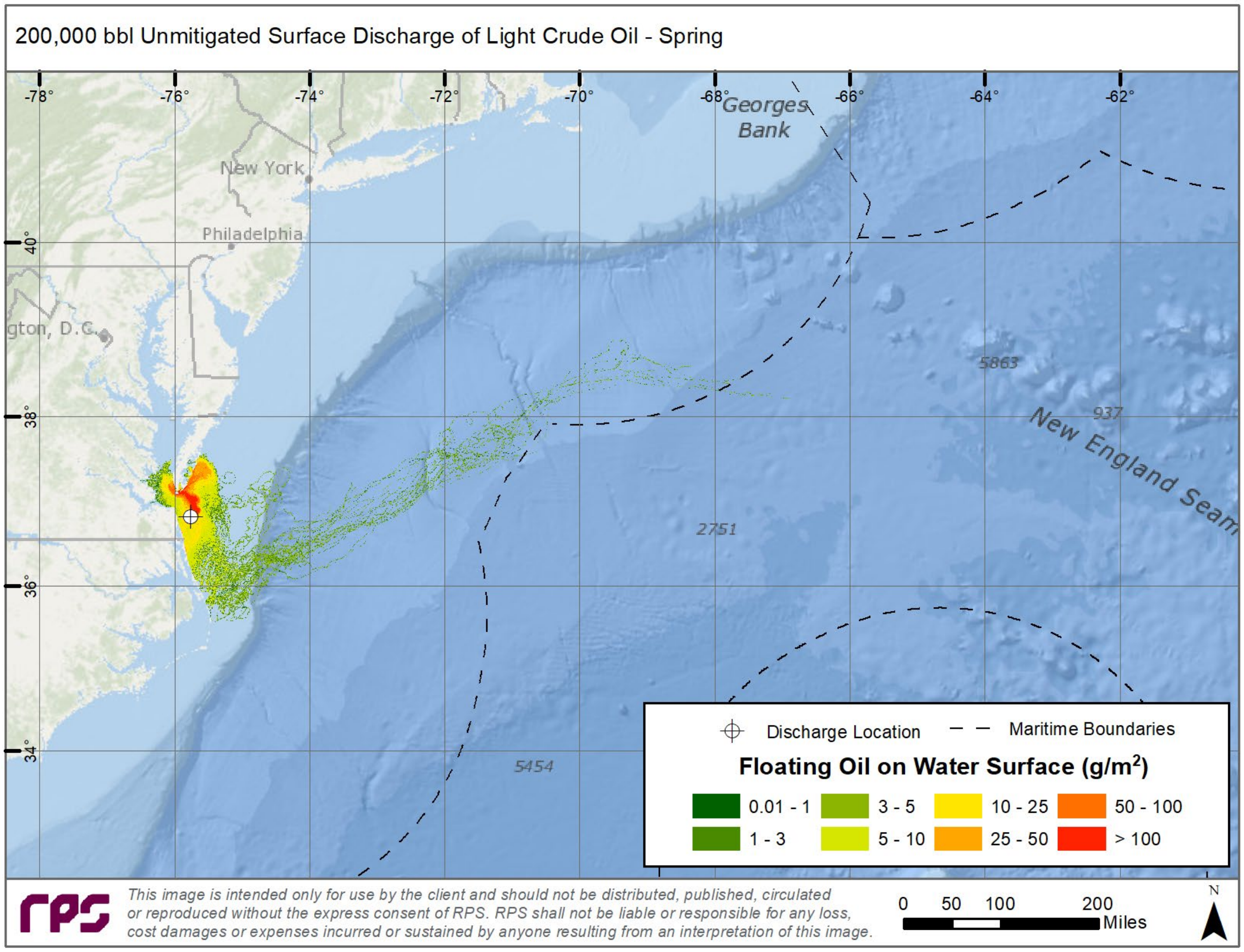


Figure 3-273. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Virginia starting on May 28, 2018.

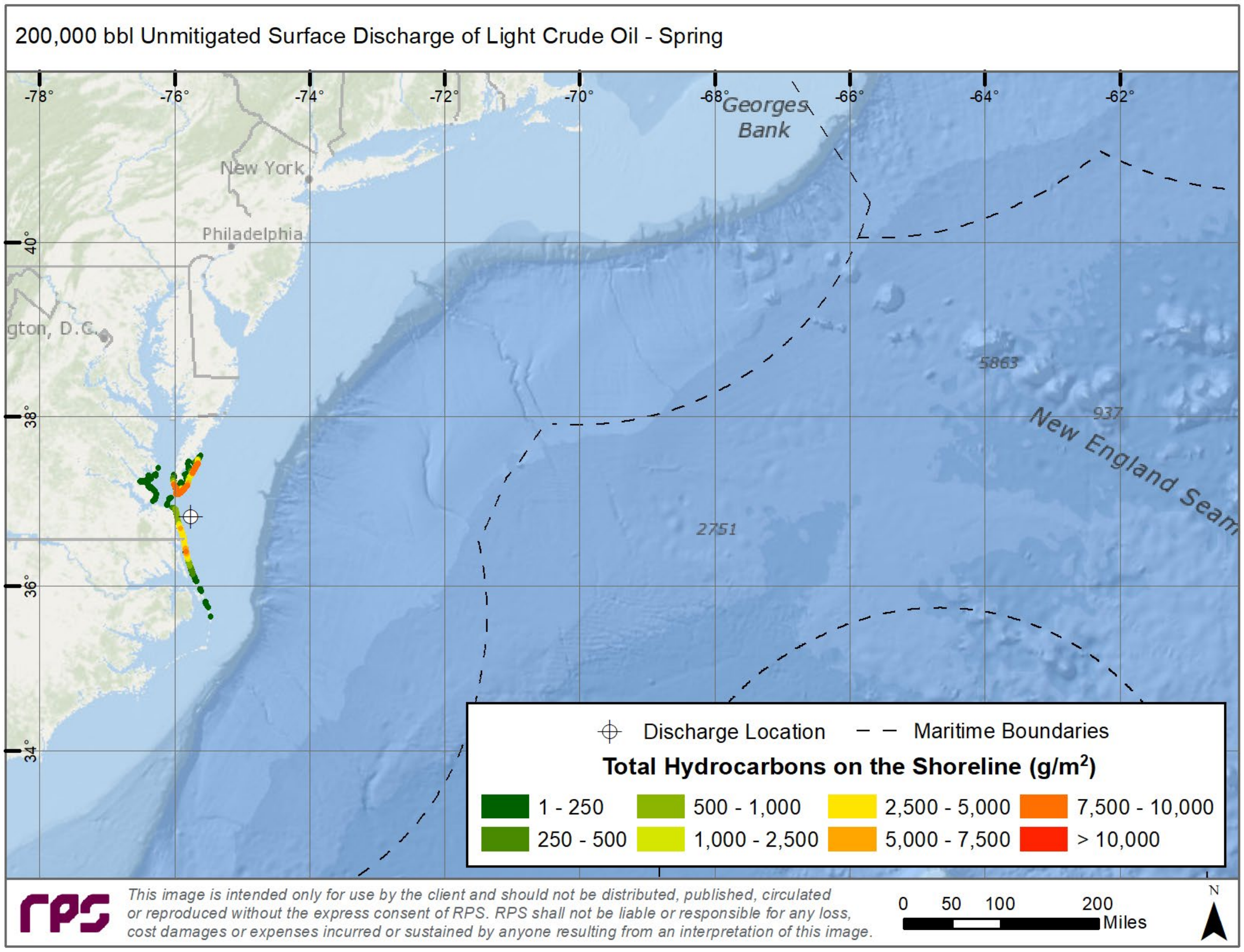


Figure 3-274. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Virginia starting on May 28, 2018.

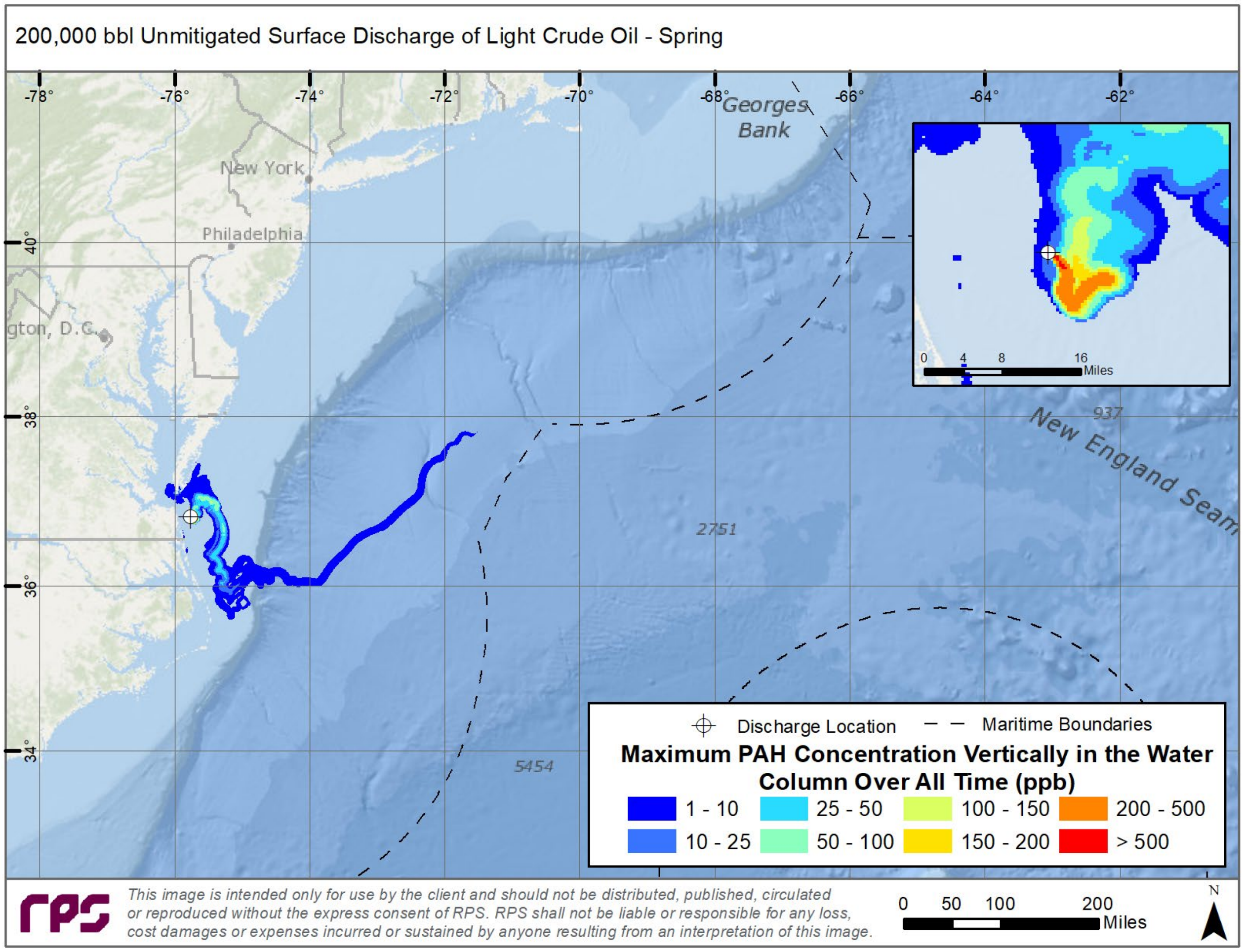


Figure 3-275. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Virginia starting on May 28, 2018.

Fall

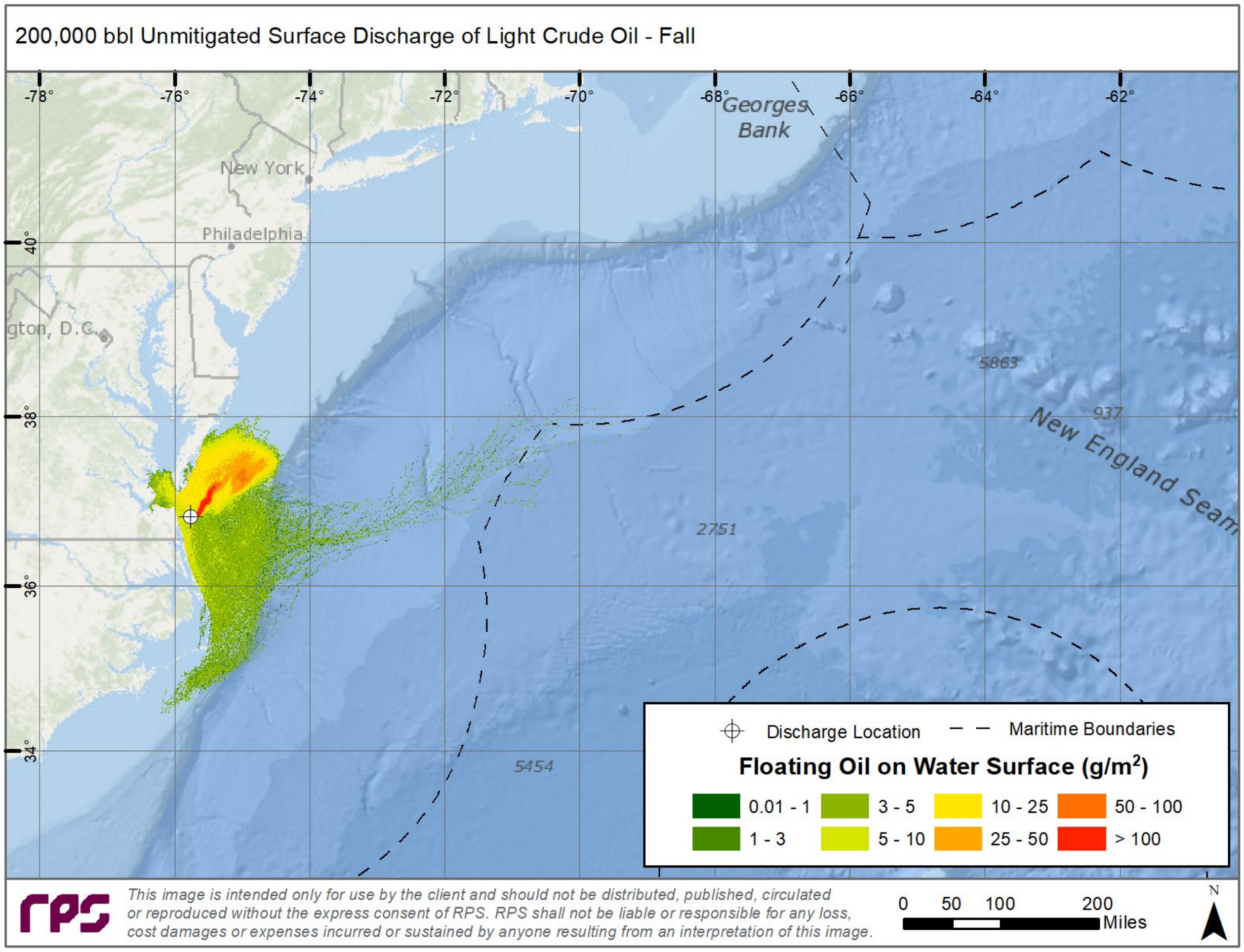


Figure 3-276. Maximum water surface oil exposure concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Virginia starting on September 21, 2019.

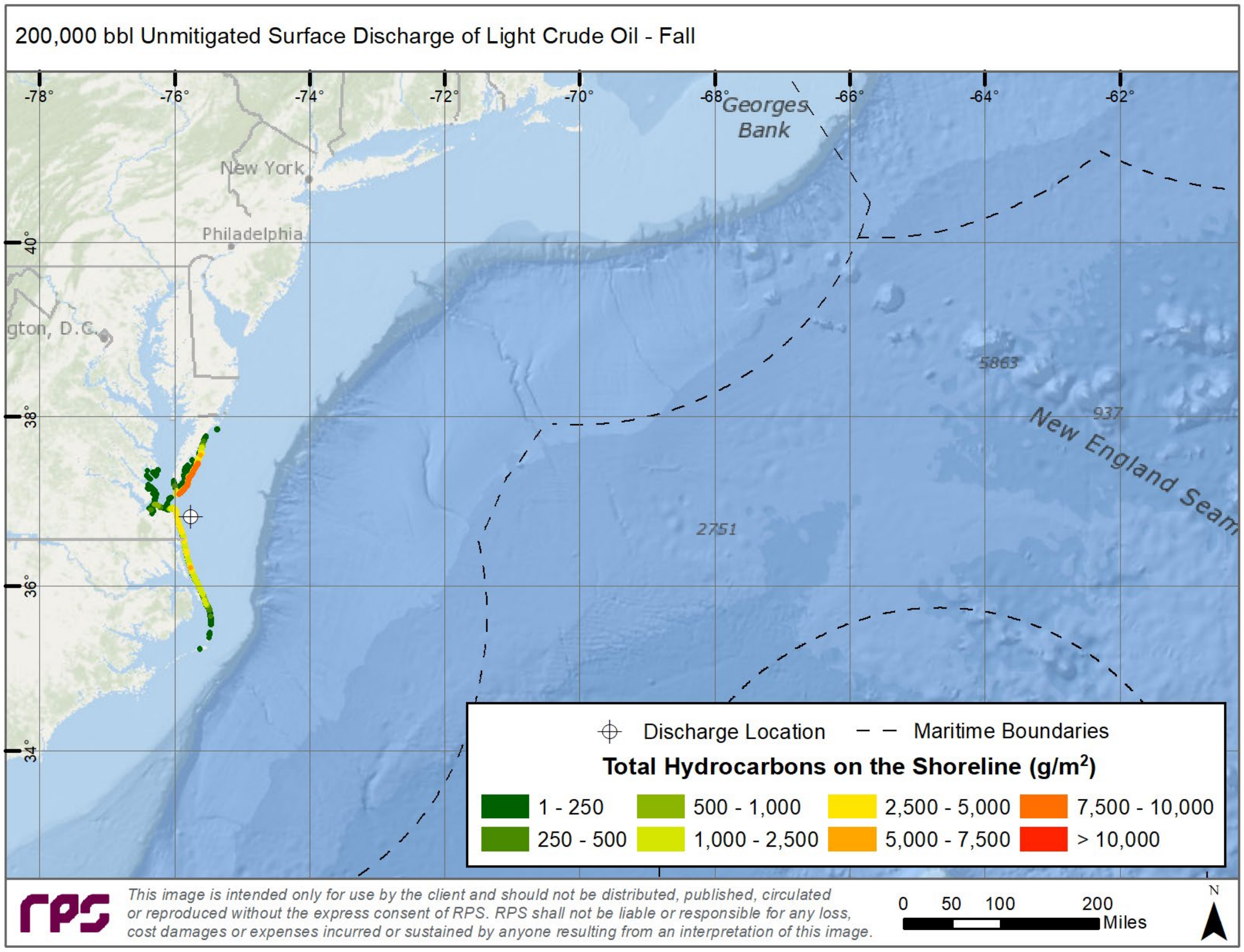


Figure 3-277. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Virginia starting on September 21, 2019.

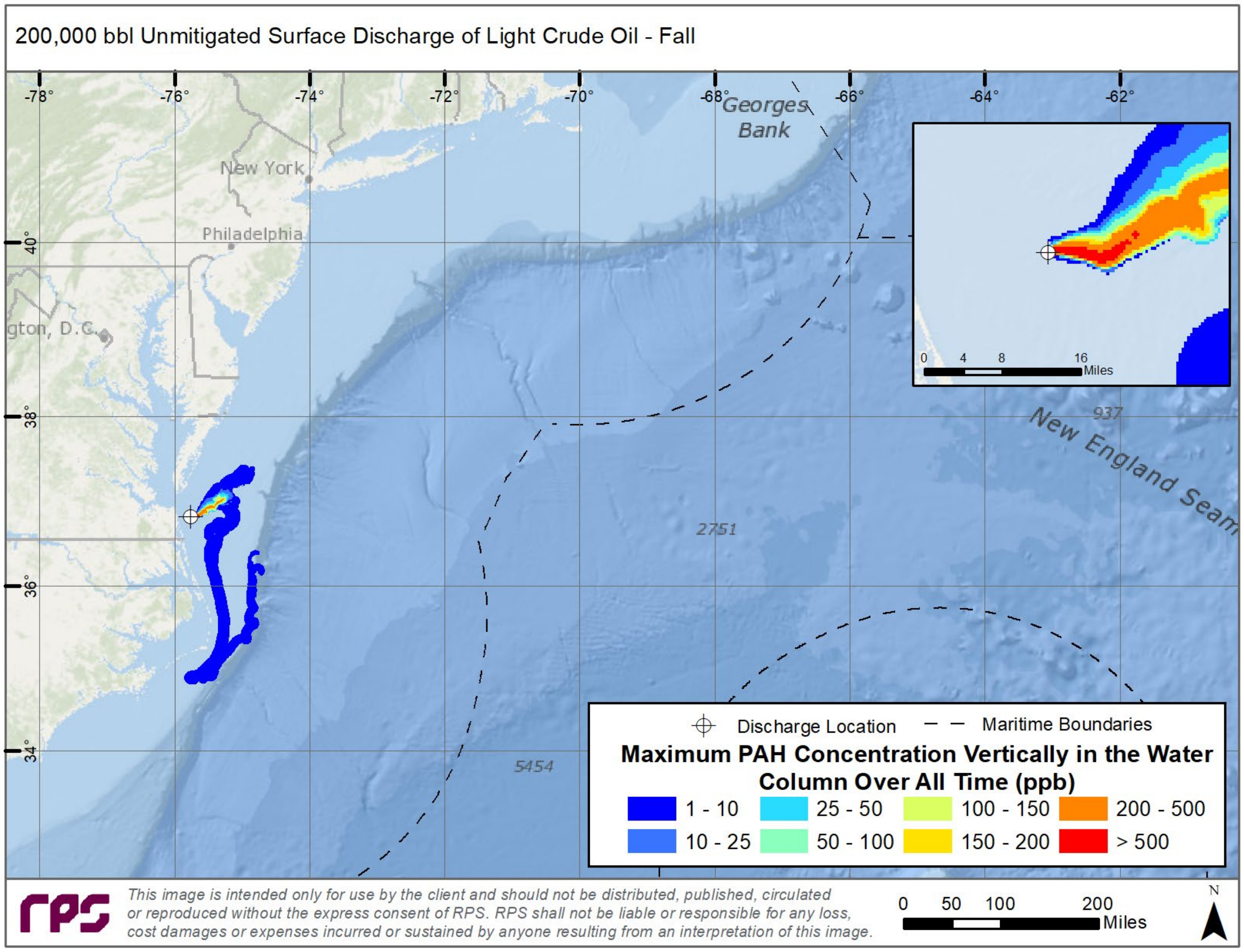


Figure 3-278. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Virginia starting on September 21, 2019.

3.3.3.4 Surface Mitigated Release (High Volume)

3.3.3.4.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for a mitigated high-volume surface release of 200,000 bbl crude oil offshore Virginia started on July 19, 2018. Response measures simulated for this case included deployment of surface dispersant, mechanical removal, and ISB. Removal began 24 hours upon release with oil removed steadily increasing over the 30-day simulation (Figure 3-282). Evaporation of just under 40% of the released oil occurred within the first days after the crude oil release. As with the unmitigated high-volume crude oil release, the high wind event early in the simulation allowed for increased entrainment of oil into the water column. Entrainment and water column oiling continues throughout the simulation as the use of dispersants increases the breakdown oil into small droplets, which enhances entrainment (Figure 3-282 and Figure 3-283). The mass balance (Figure 3-282) shows that no oil remained on the surface while approximately 43% of the oil evaporated, 21% of the oil reached shore, 8% of the oil remained in the water column, 18% was removed via response, and 10% of the oil was biodegraded by the end of the 30-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted to the north of the release location, through Chesapeake Bay and within the nearshore and offshore waters of Maryland and Virginia. Maximum floating oil on the surface was >100 g/m^2 (100 µm, on average) and extended to the northwest from the release site (Figure 3-279). Lower (<25 g/m^2, i.e., patchy oil, emulsions or sheens) maximum surface oil exposure concentrations were predicted to extend just into Chesapeake Bay. Response measures considerably decreased the maximum surface floating oil exposure in the worst-case run when compared to the unmitigated case (Figure 3-265 and Figure 3-279). By the end of the 30-day simulation, 225 mi (363 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-280; Table 3-30). Landward mudflat and seaward sandy beach were the habitats predicted to have the longest length of shoreline oiled (89 mi [143 km] and 80 mi [129 km], respectively). Shoreline oiling was predicted along the coasts of Maryland and Virginia, with the highest concentrations of oil (>10,000 g/m^2) occurring near Virginia Beach, Virginia. No shoreline habitat in Delaware was predicted to be oiled >1 g/m^2 in the event of a high-volume crude oil release offshore of Virginia (Table 3-25). Maximum cumulative PAH concentrations for the worst-case run were <500 ppb and remained near the release location, primarily extending north (Figure 3-281). Lower concentrations, between 1-10 ppb, also extended to the north into Chesapeake Bay and in the nearshore waters of Virginia. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 30-day simulation.

Table 3-30. Shoreline lengths oiled by >1 g/m^2 for the run with maximum shoreline length oiled (on an annual basis, in summer), for a mitigated 200,000 bbl surface release of crude oil offshore of Virginia starting on July 19, 2018.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**	**>1g/m^2**	**>10g/m^2**	**>100g/m^2**
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	80	80	65	129	129	104
Mudflat	4	4	3	6	6	4
Wetland	1	1	0	1	1	0
Artificial/manmade shoreline	1	1	0	2	2	0
Total	86	86	68	138	138	109

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	26	26	21	42	42	34
Mudflat	89	81	32	143	131	51
Wetland	6	5	1	9	8	2
Artificial/manmade shoreline	19	19	0	31	31	0
Total	140	131	54	225	211	87
All Shorelines						
Total	225	217	122	363	349	196

Table 3-22 provides the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-284 to Figure 3-292 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In the winter, oil is transported concentrically just around the spill site and further south into nearshore and offshore waters of Virginia and North Carolina. In the spring, oil is transported north into Chesapeake Bay and nearshore waters off the coast of Virginia, with shoreline oiling occurring along the coasts of Virginia and North Carolina. During the worst-case run to occur in the fall, the highest concentrations of surface oil are predicted northeast of the spill site, with shoreline oiling predicted in Virginia.

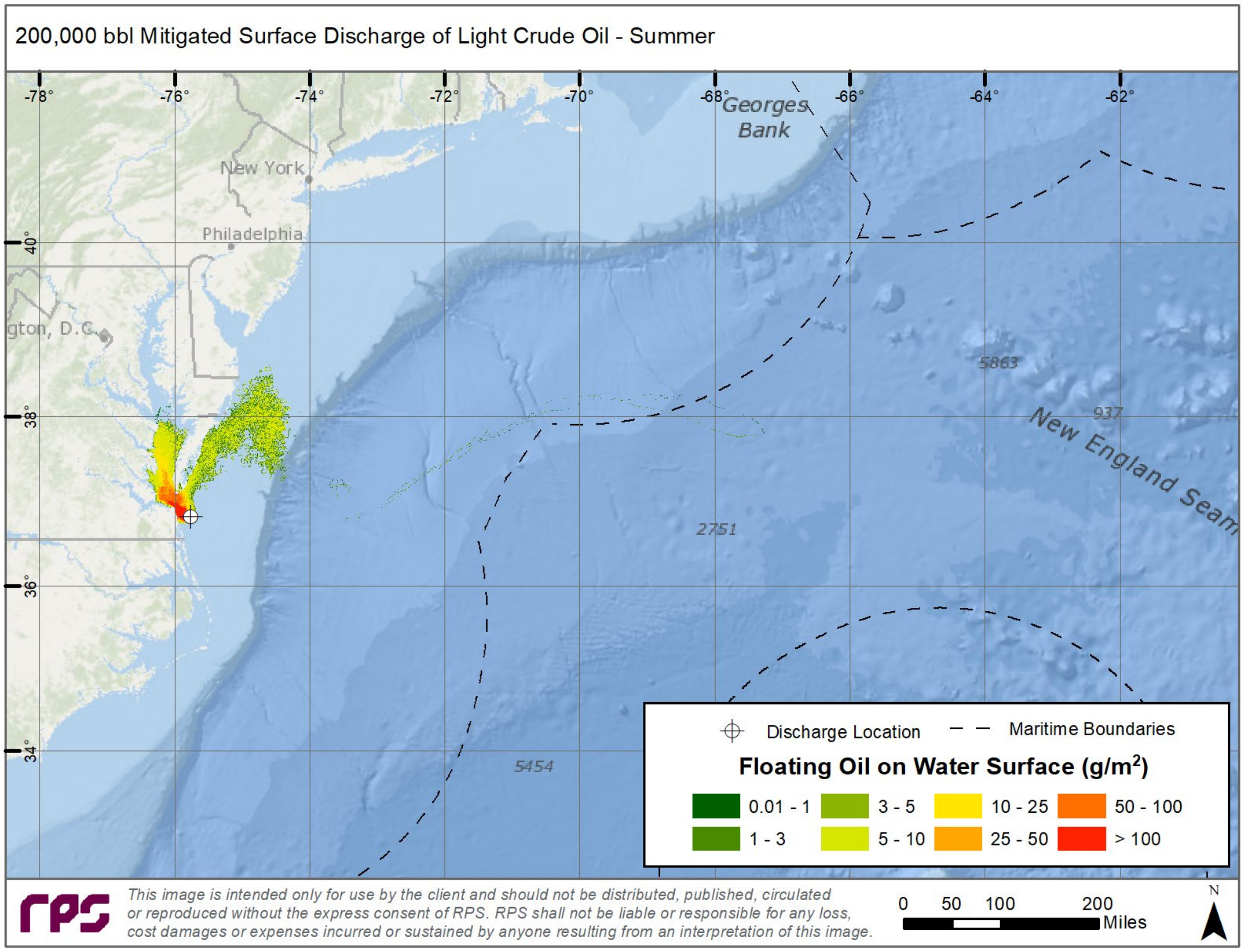


Figure 3-279. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Virginia starting on July 19, 2018.

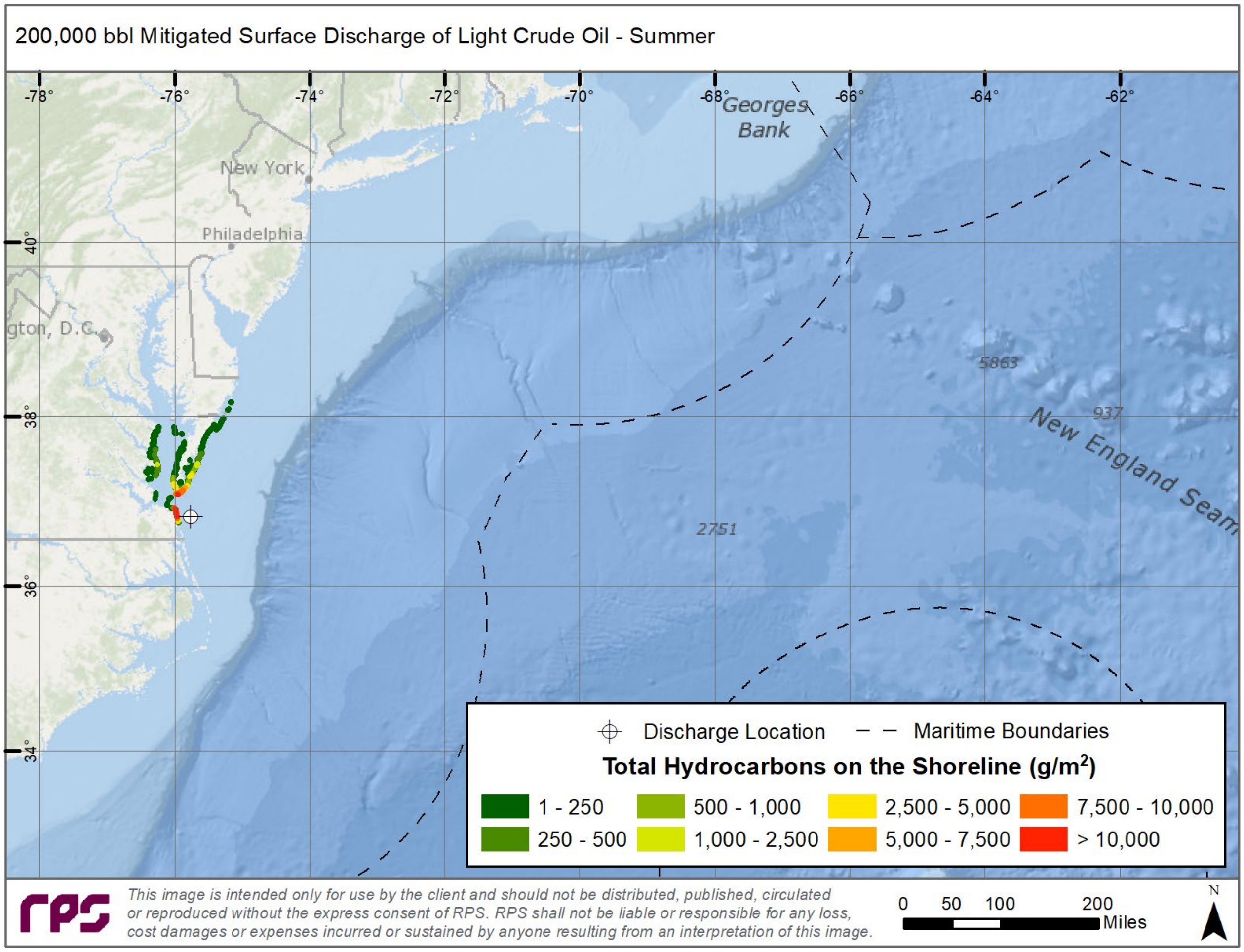


Figure 3-280. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Virginia starting on July 19, 2018.

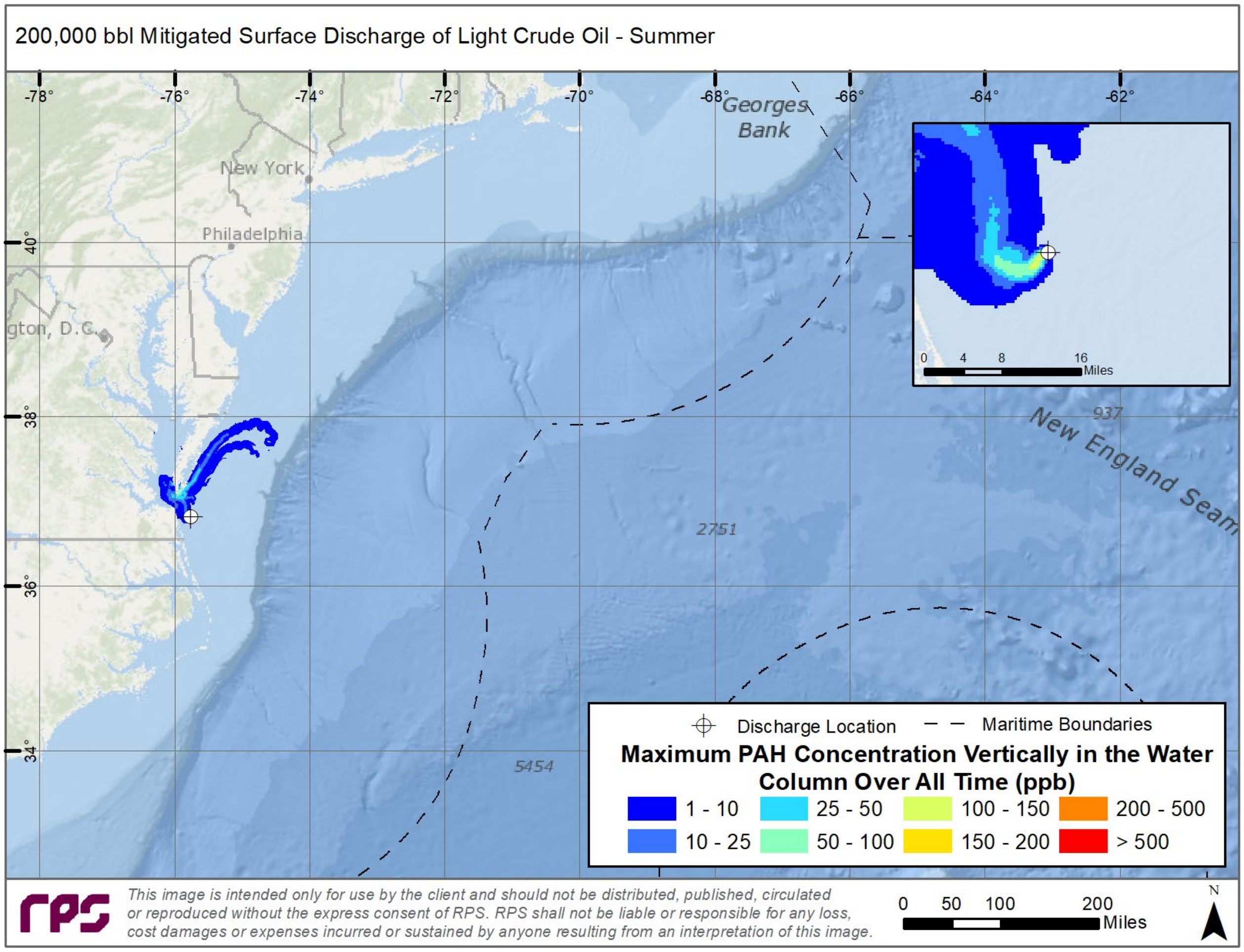


Figure 3-281. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl release of crude oil offshore of Virginia starting on July 19, 2018

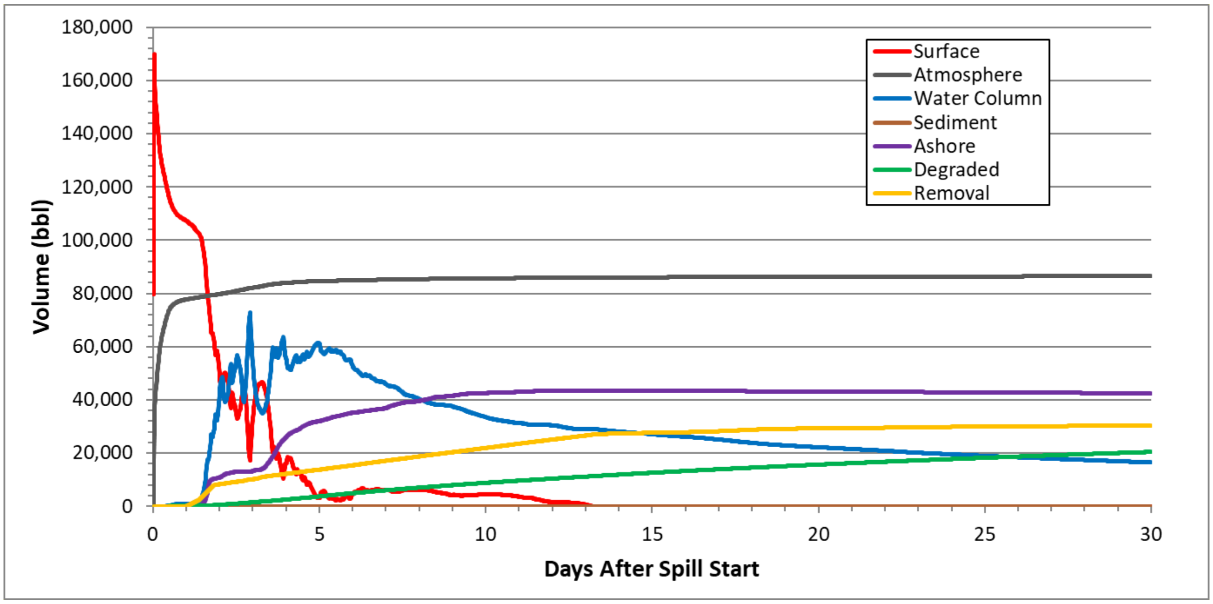


Figure 3-282. Oil volume by environmental compartment over time for a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl surface release of crude oil offshore of Virginia starting on July 19, 2018.

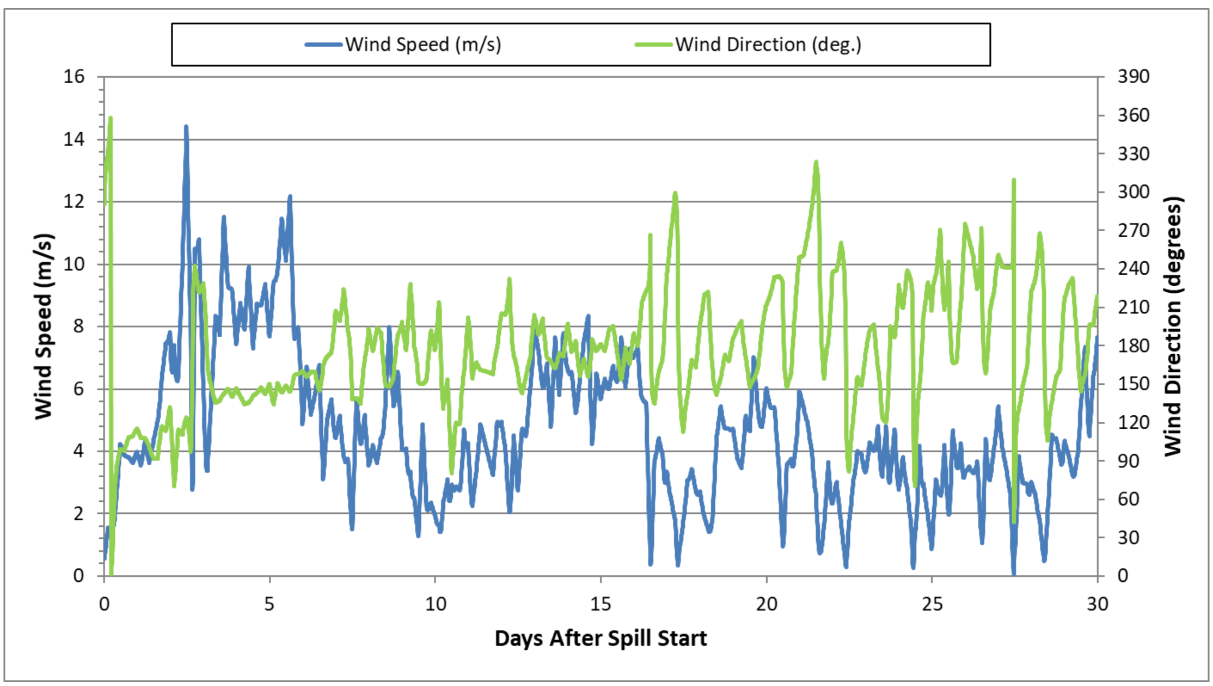


Figure 3-283. Wind speeds (1 m/s = 2 knots) and directions during the mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer) for a 200,000 bbl surface release of crude oil offshore of Virginia starting on July 19, 2018.

3.3.3.4.2 Seasonal Worst-Case Runs

Winter

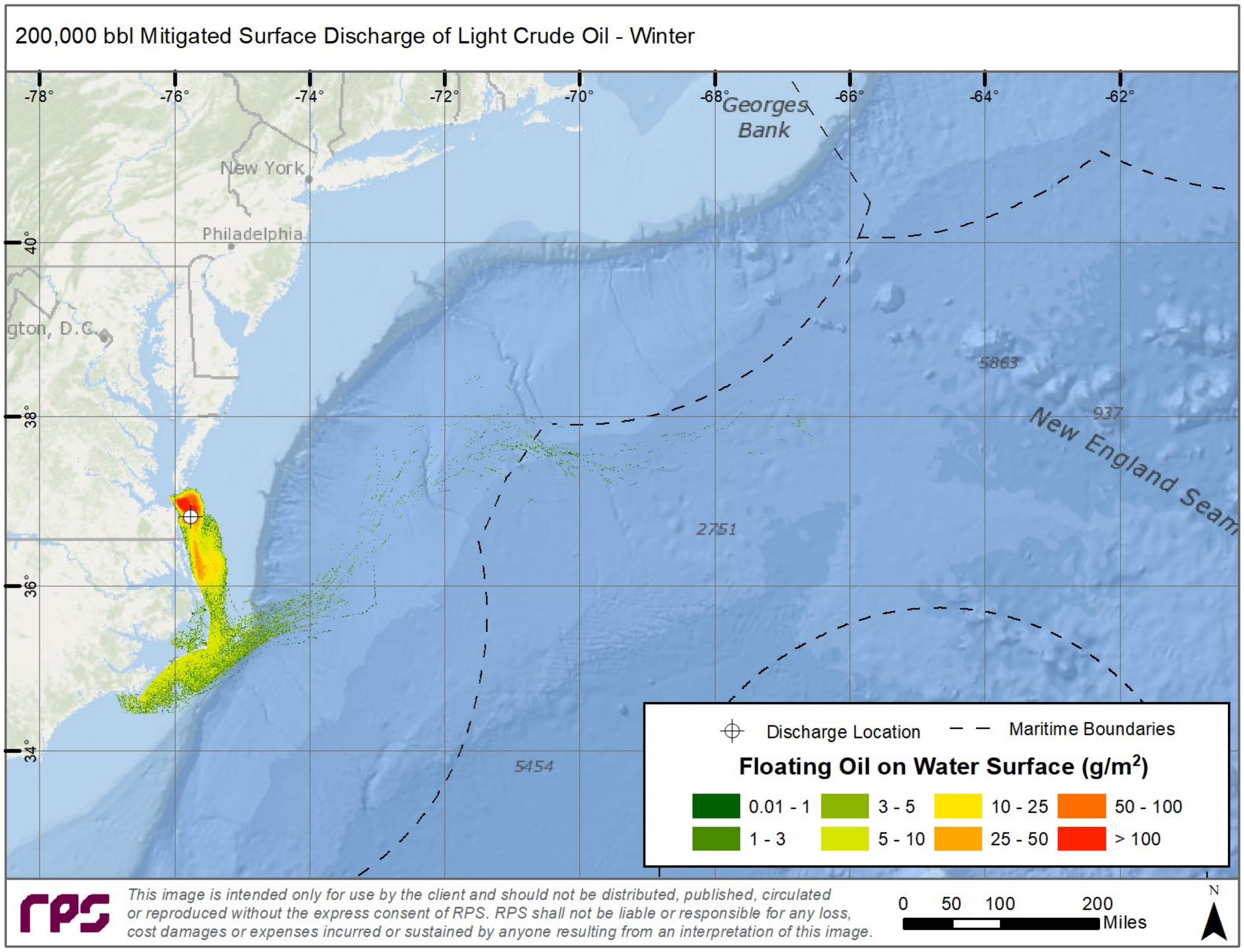


Figure 3-284. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Virginia starting on January 13, 2020.

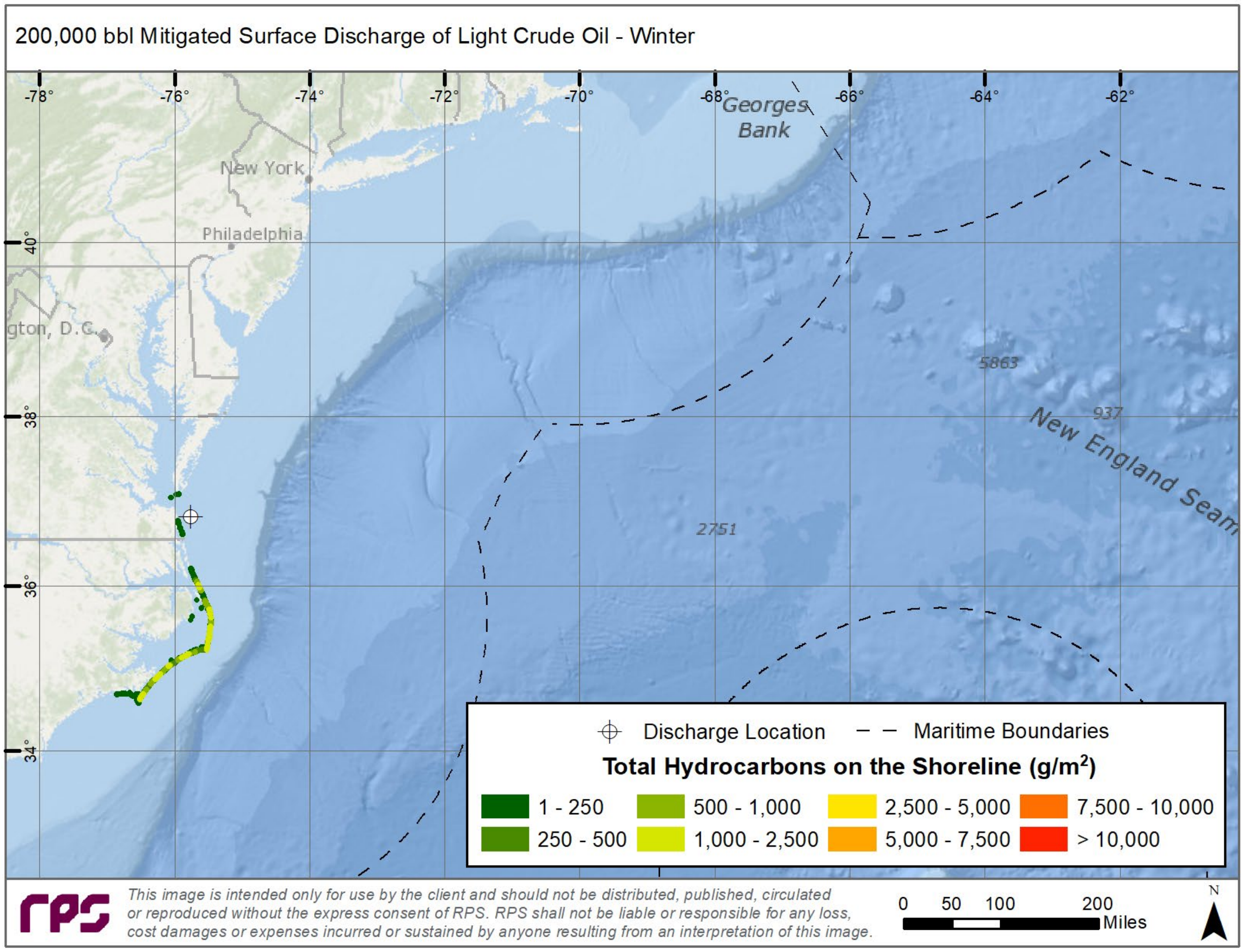


Figure 3-285. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Virginia starting on January 13, 2020.

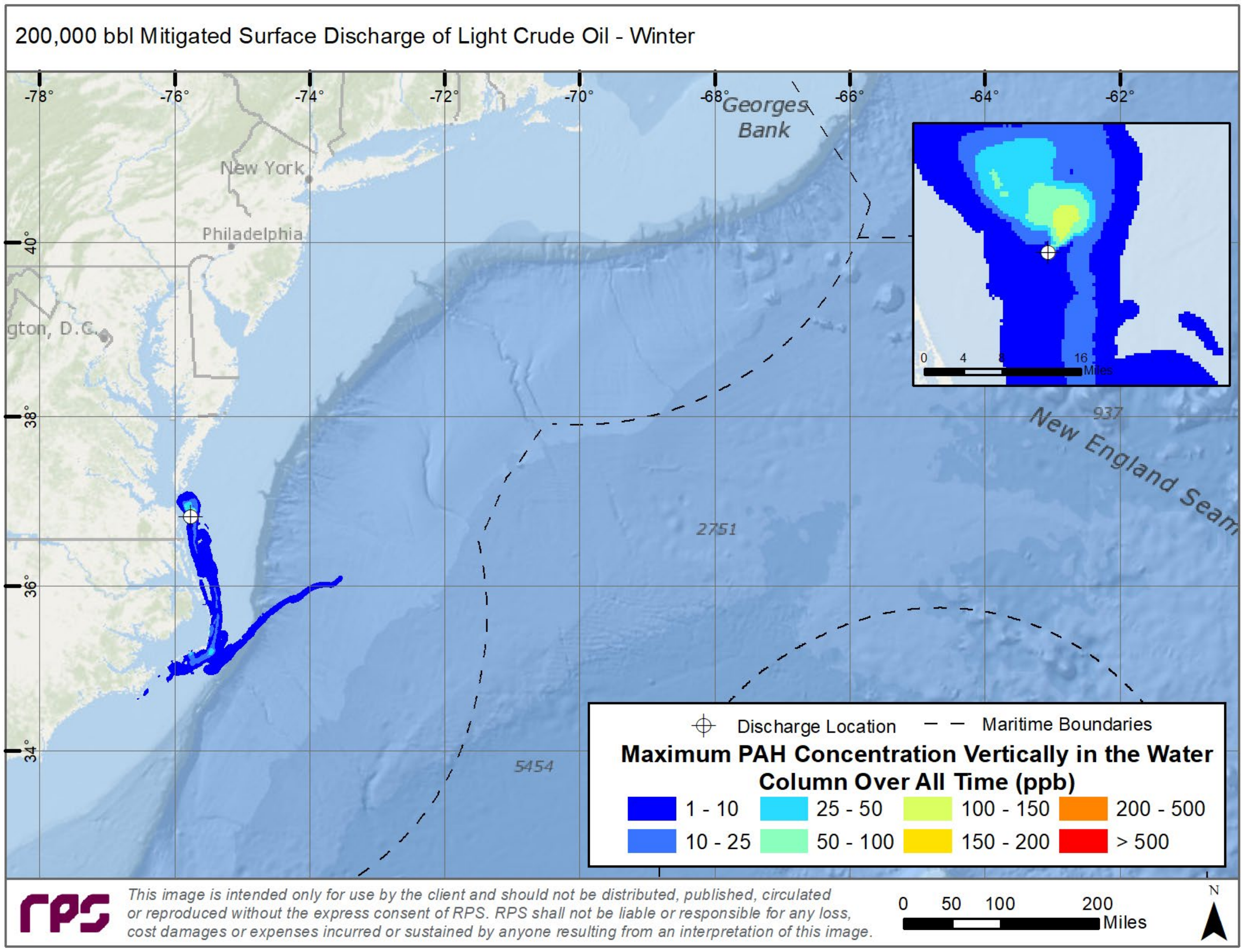


Figure 3-286. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for a 200,000 bbl release of crude oil offshore Virginia starting on January 13, 2020.

Spring

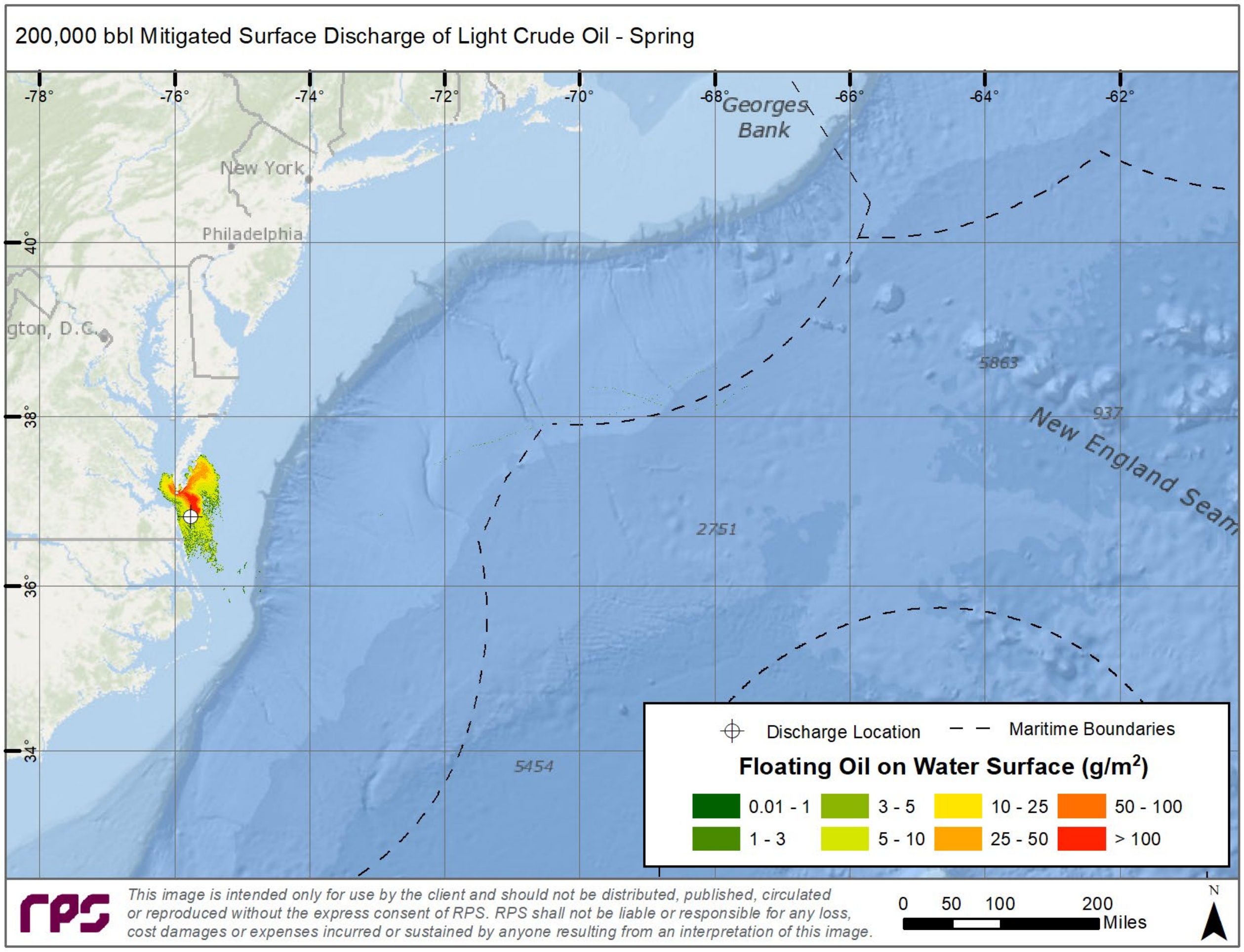


Figure 3-287. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Virginia starting on May 28, 2018.

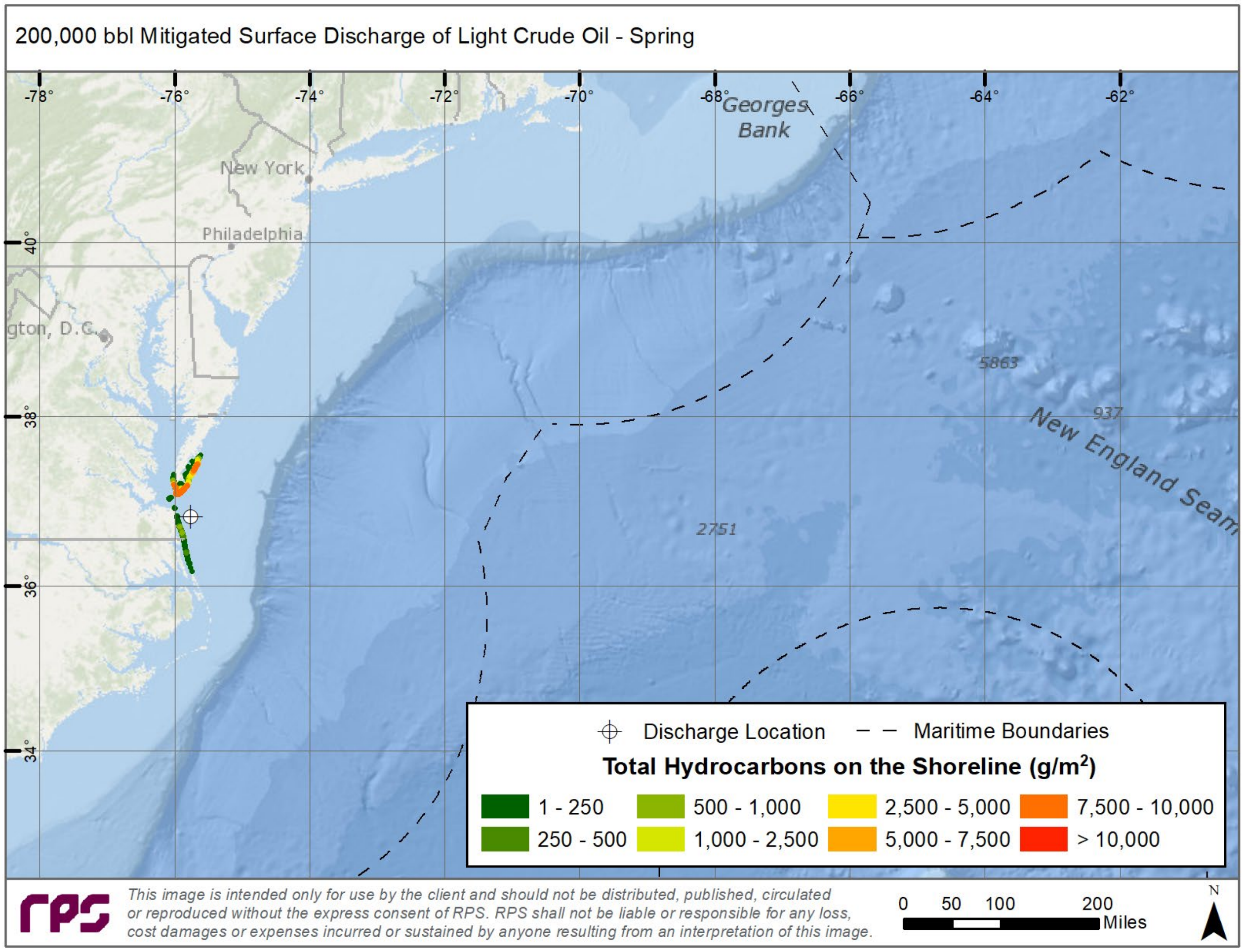


Figure 3-288. Maximum shoreline oil concentration at any point in time throughout a 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 126 bbl release of crude oil offshore Virginia starting on May 28, 2018.

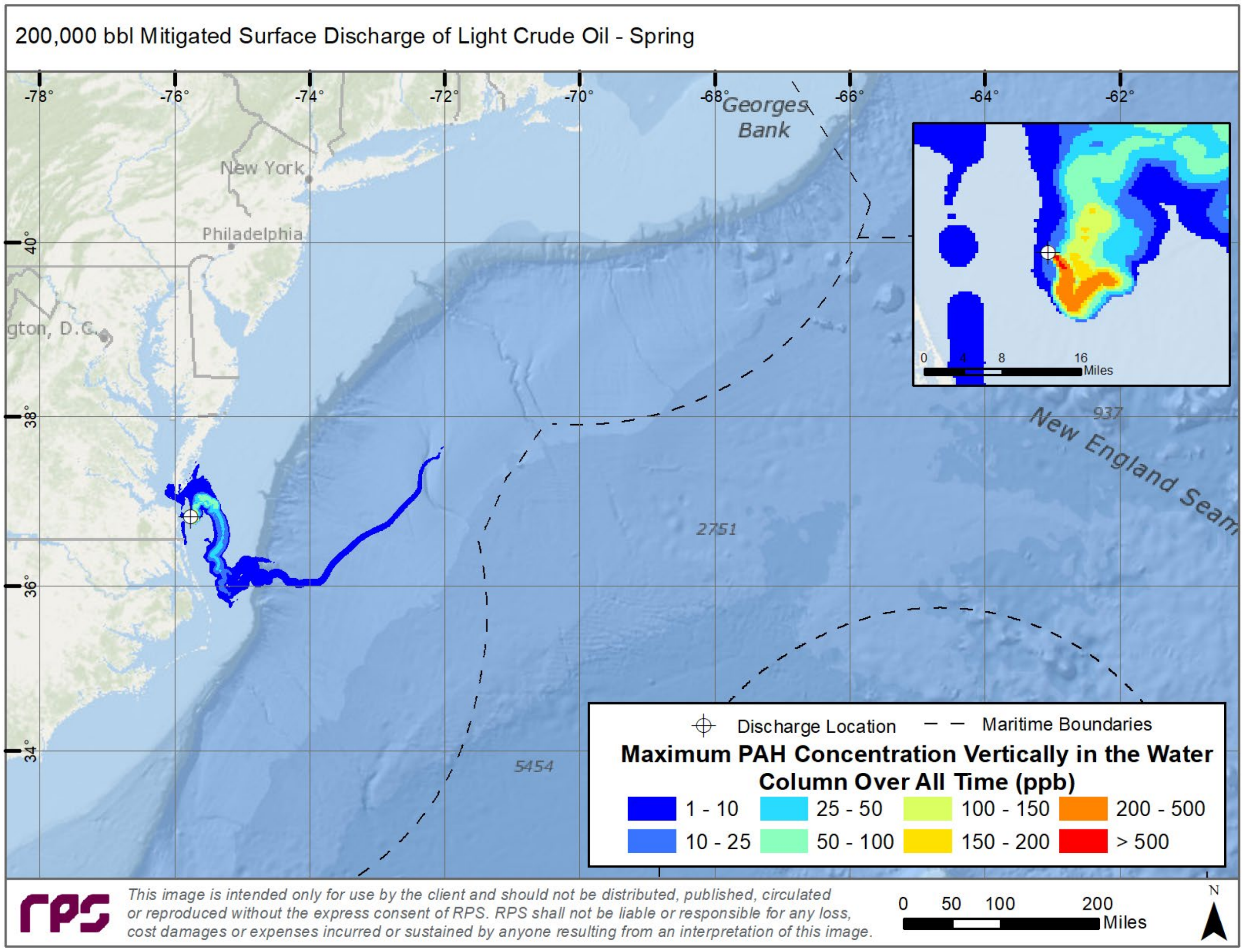


Figure 3-289. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for a 200,000 bbl release of crude oil offshore Virginia starting on May 28, 2018.

Fall

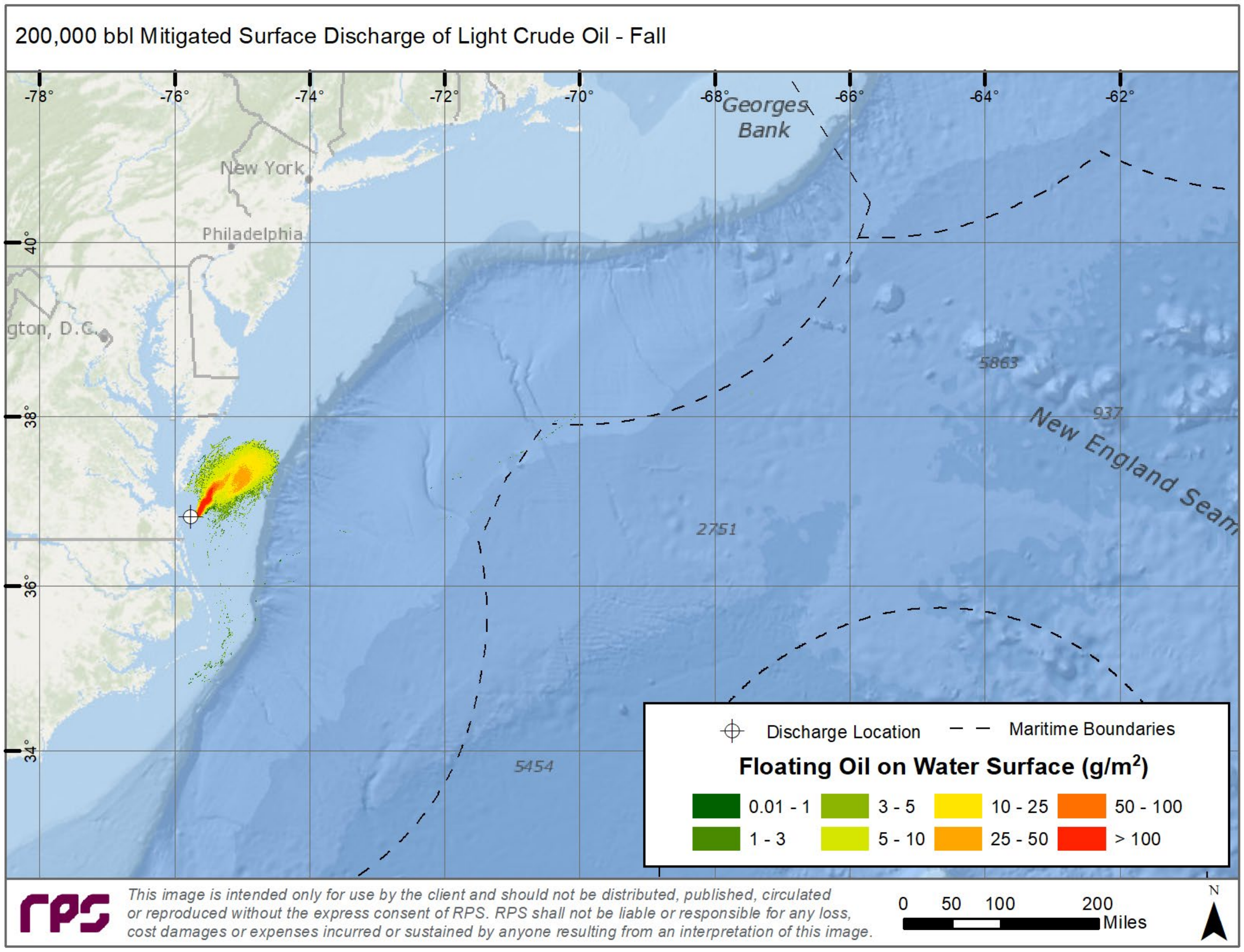


Figure 3-290. Maximum water surface oil exposure concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Virginia starting on September 21, 2019.

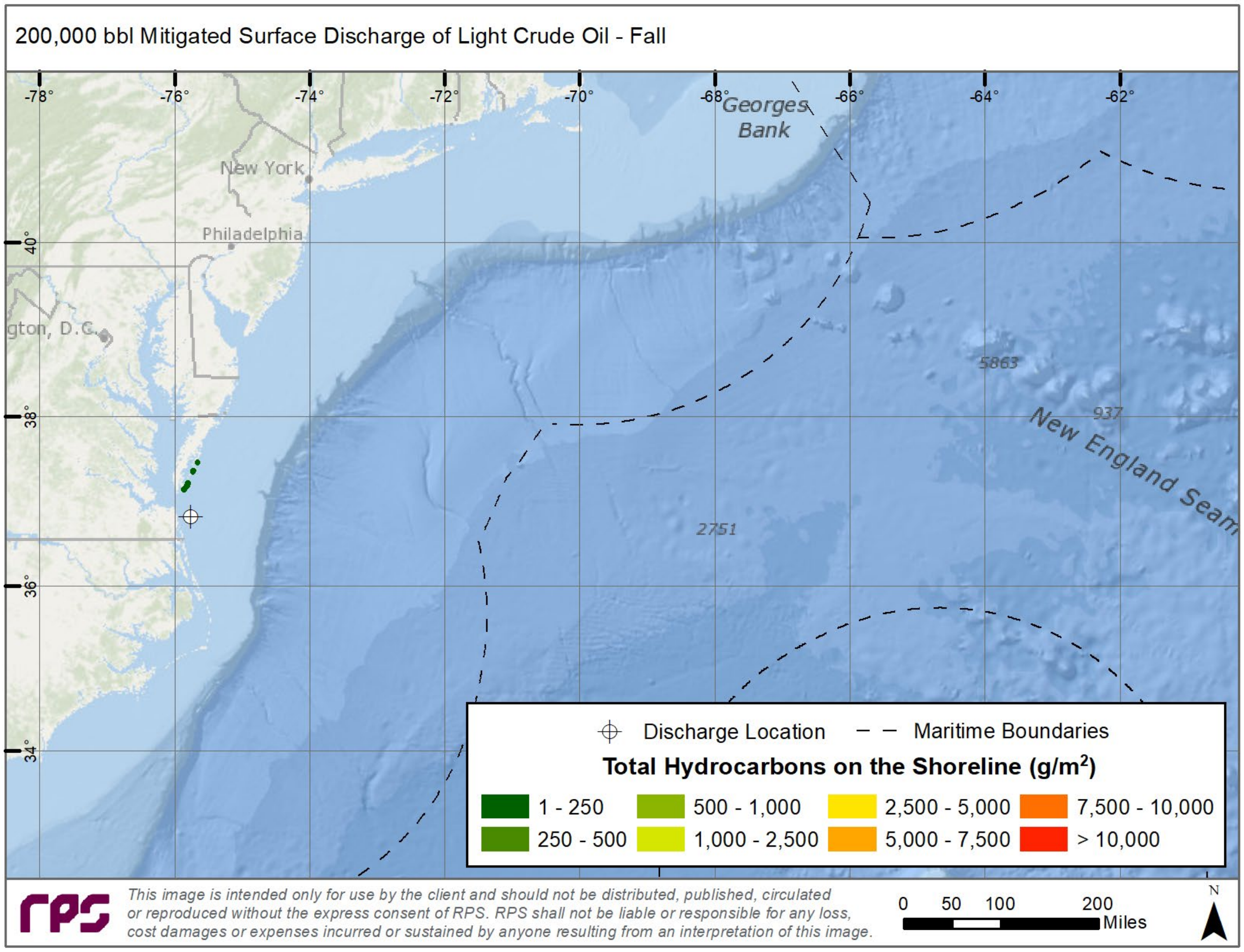


Figure 3-291. Maximum shoreline oil concentration at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Virginia starting on September 21, 2019

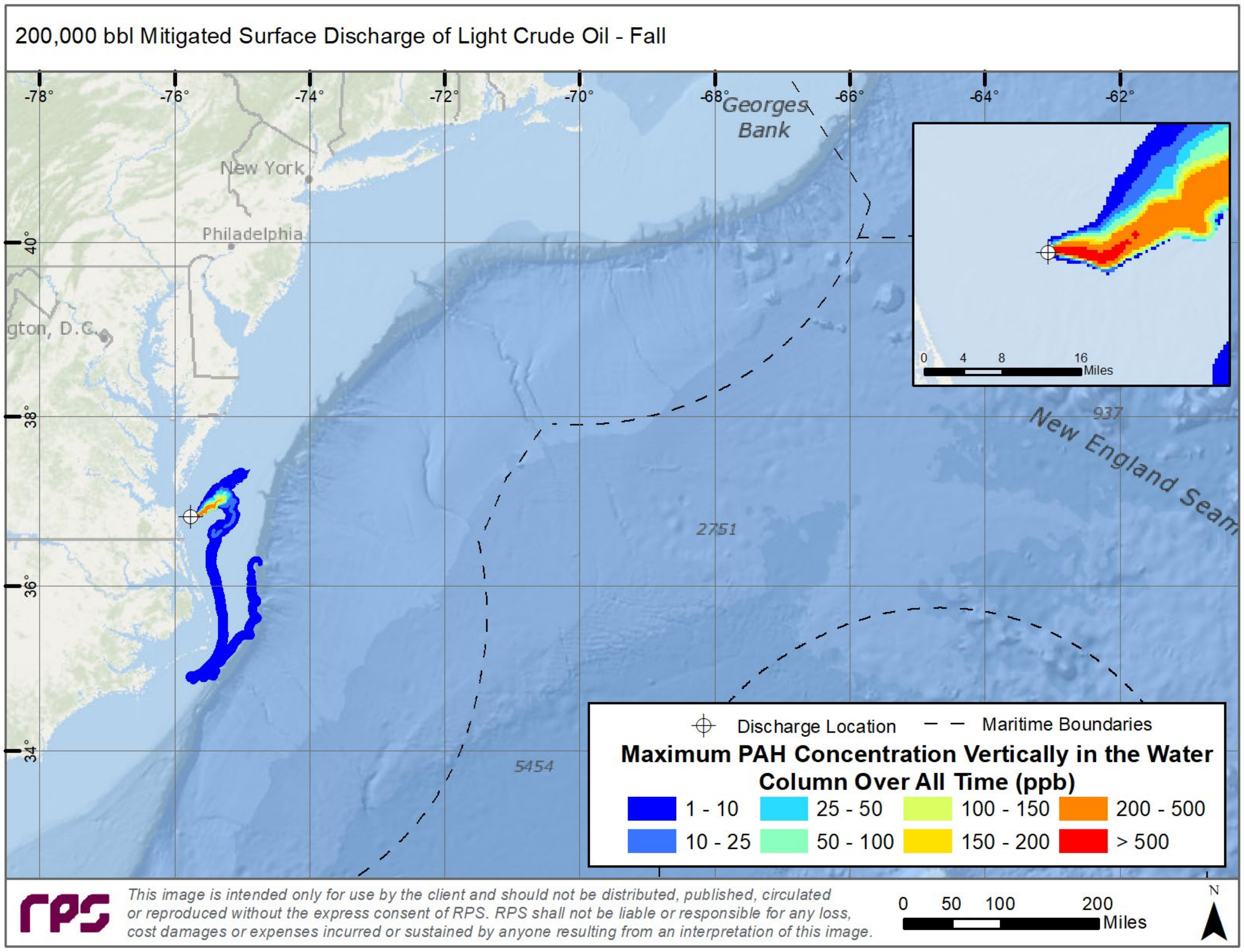


Figure 3-292. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a mitigated 30-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for a 200,000 bbl release of crude oil offshore Virginia starting on September 21, 2019.

3.3.3.5 Subsurface Unmitigated Release (Well Blowout)

3.3.3.5.1 Annual Worst-Case Run

The individual simulation resulting in maximum shoreline length oiled (on an annual basis) for shallow water blowout of 30,000 bbl/day crude oil over 30 days (900,000 bbl in total) offshore Virginia started on August 25, 2019. Oil evaporated quickly and consistently as it was released over the 30 days. Emulsification of the crude oil to viscosities > 4,000 cP during the first few days upon release limited entrainment into the water to occur only during the high wind events (>10 m/s; 20 knots), causing oil to oscillate from within the water column to the surface during periods of high and low winds. The mass balance (Figure 3-296) shows that released the oil came ashore beginning 21 days after the spill while strong winds (12 m/s; 24 knots) were blowing from the northeast (Figure 3-297). Approximately 45% of the oil evaporated, 19% of the oil reached shore, 4% of the oil remained in the water column, 3% remained on the surface, and approximately 22% of the oil was biodegraded by the end of the 75-day model simulation.

For the worst-case run (maximum shoreline length oiled on an annual basis), the spread of surface floating oil was predicted concentrically around the release location, extending furthest to the east, up to 650 mi (1,046 km) where it reaches the boundary of the model domain. Maximum floating oil on the surface was >100 g/m^2 (100 µm, on average) and primarily extended from the release site to the west (Figure 3-293). Lower (25-50 g/m^2) maximum surface oil exposure concentrations were predicted to extend into coastal waters to the northwest and southwest, offshore of Virginia and North Carolina. By the end of the 75-day simulation, 458 mi (738 km) of shoreline was contaminated by >1 g/m^2 of oil (Figure 3-294; Table 3-31). Seaward sandy beach and landward mudflat habitats were predicted to have the longest length of shoreline oiled (234 mi [377 km] and 124 mi [200 km], respectively). Shoreline oiling was predicted along the landward and seaward coasts of Maryland, Virginia, and North Carolina, with the highest concentrations of oil (7,500-10,000 g/m^2) occurring along much of the Virginia coast and the northern seaward coast of North Carolina. No shoreline habitat in Delaware was oiled >1 g/m^2 during the worst-case blowout run offshore of Virginia (Table 3-25). Maximum cumulative PAH concentrations for the worst-case run were >500 ppb and remained near the release location (Figure 3-295). Lower concentrations, between 1-10 ppb, extended to the southwest and southeast of the release site. As mentioned above, PAH concentrations in the water column are highly variable in space and over time and this map shows the cumulative vertical maximum PAH concentration in the water column over 75-day simulation.

Table 3-31. Shoreline lengths oiled by >1 g/m^2 (1µm, on average) for the run with maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on August 25, 2019.

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Seaward	>1g/m^2	>10g/m^2	>100g/m^2	>1g/m^2	>10g/m^2	>100g/m^2
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0
Sand beach	234	234	227	377	377	366
Mudflat	7	7	6	11	11	9
Wetland	1	1	1	2	2	1
Artificial/manmade shoreline	1	1	0	2	2	0
Total	244	244	234	392	392	376
Landward						
Rocky shore	0	0	0	0	0	0
Gravel beach	0	0	0	0	0	0

Shoreline Type	Length Oiled (mi)			Length Oiled (km)		
Sand beach	47	47	44	75	75	72
Mudflat	124	121	59	200	194	95
Wetland	9	8	3	14	13	5
Artificial/manmade shoreline	35	35	0	56	56	0
Total	215	211	106	346	339	171
All Shorelines						
Total	458	454	340	738	731	548

Table 3-22 provides the modeled dates for the worst case (in terms of shoreline length oiled) runs for each season. Figure 3-298 to Figure 3-306 present surface, shoreline, and maximum water column PAH concentration results for the three other seasons. In the winter, oil is primarily transported east into waters further offshore, with relatively low concentrations of shoreline oiling predicted along the coast of North Carolina. In the spring, oil is transported concentrically around the release site, with highest concentrations predicted primarily southwest in waters offshore of Virginia and North Carolina. Shoreline oiling was predicted along mainland coastlines of Massachusetts, Rhode Island, Delaware, New Jersey, New York, Maryland, Virginia, and North Carolina. During the worst-case run to occur in the fall, the highest concentrations of surface oil occur to the west of the release site, with lower concentrations extending south and east, over to 650 mi (1,046 km) from the release site and outside of the model domain. Shoreline oiling >1 g/m^2 occurred along the Maryland, Virginia, and North Carolina coasts.

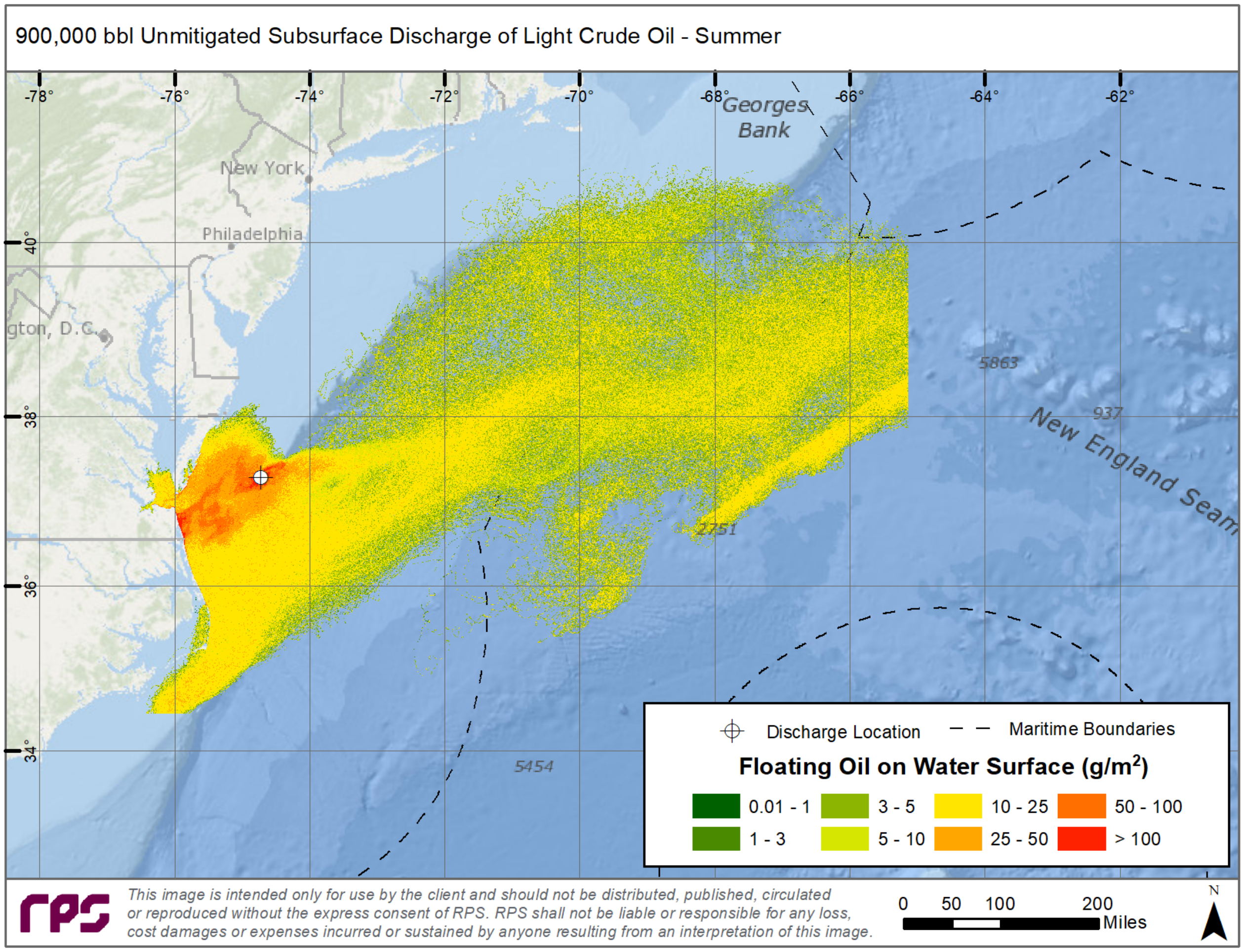


Figure 3-293. Maximum water surface oil exposure concentration at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on August 25, 2019.

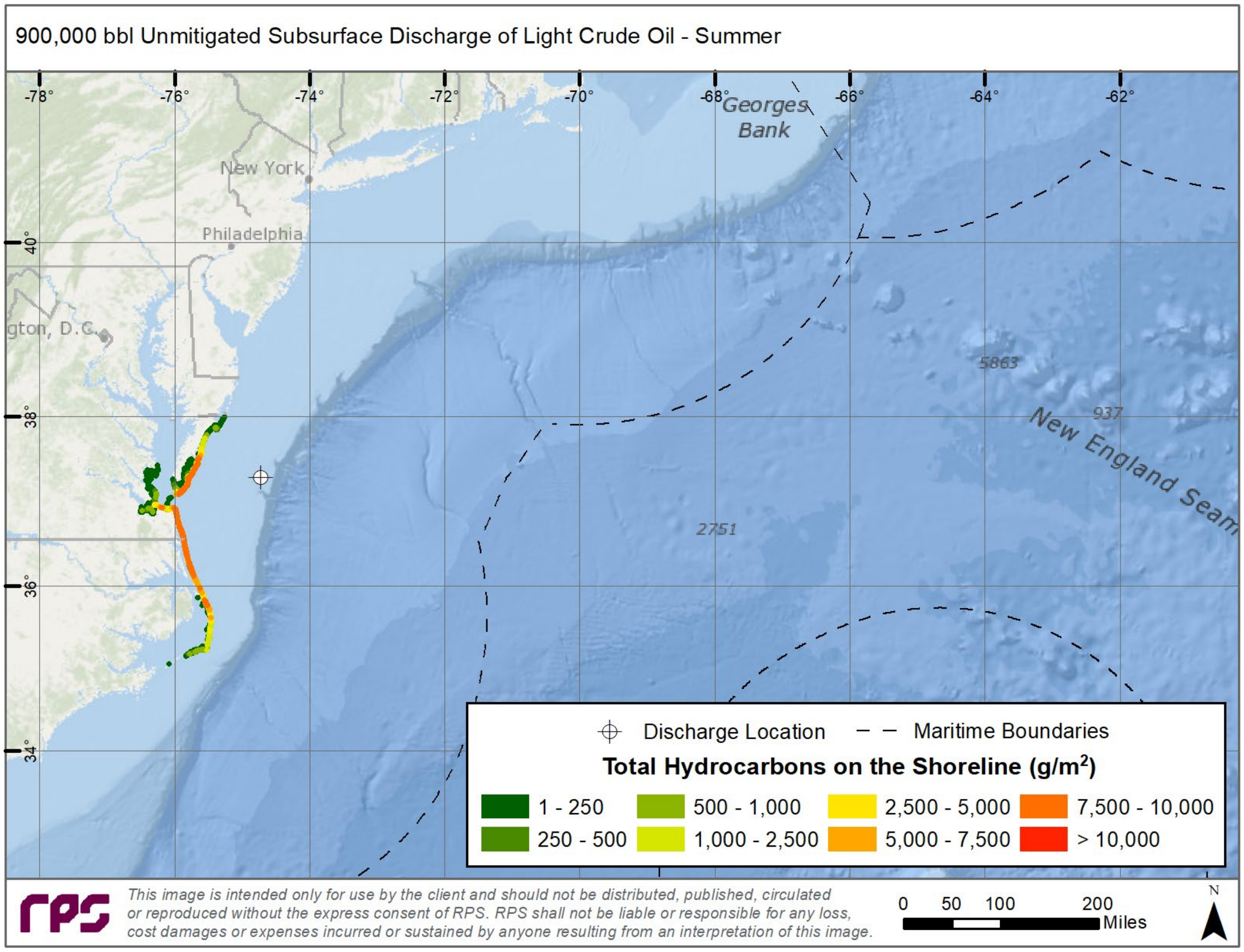


Figure 3-294. Maximum shoreline oil concentration at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled(on an annual basis, in summer), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on August 25, 2019.

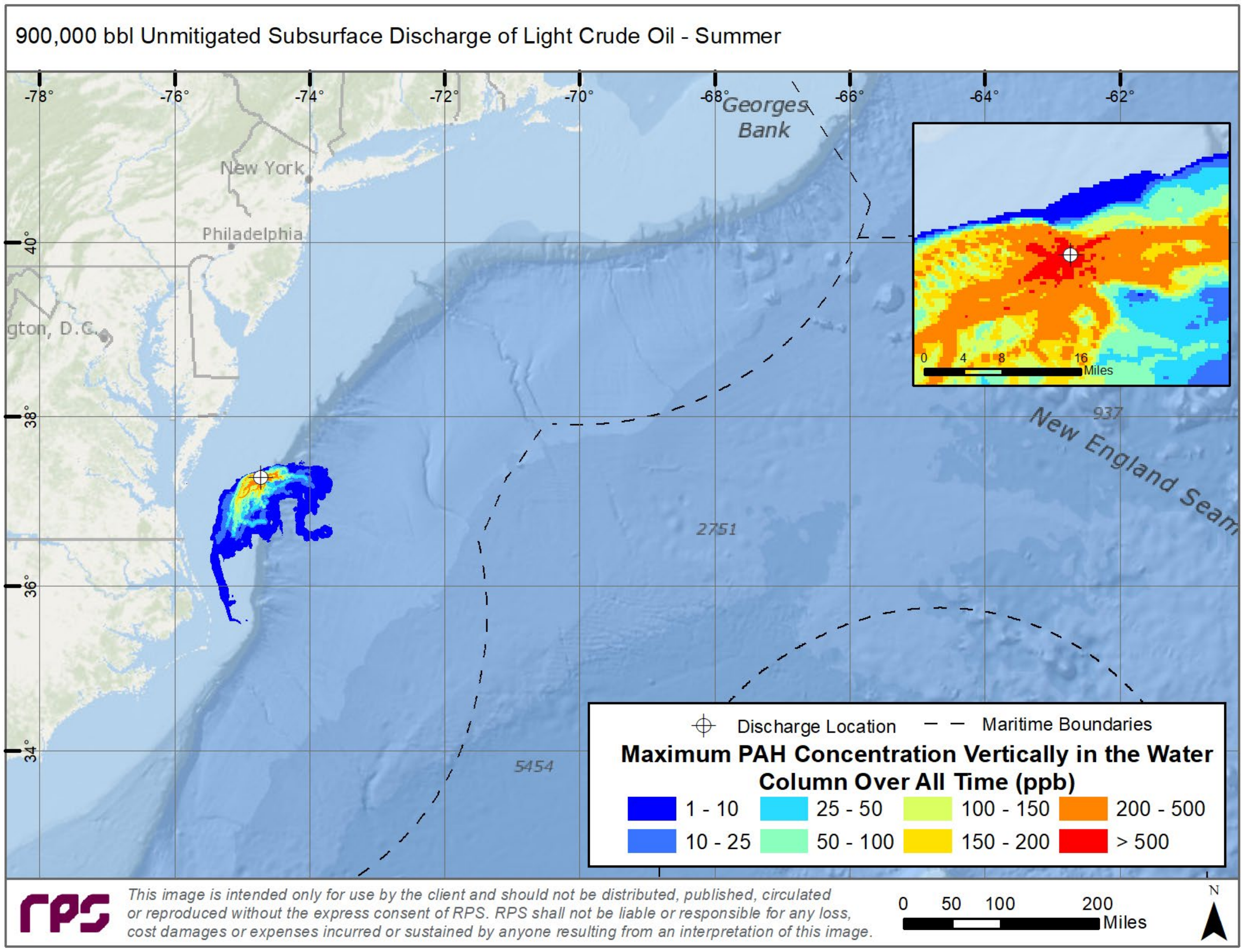


Figure 3-295. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on August 25, 2019.

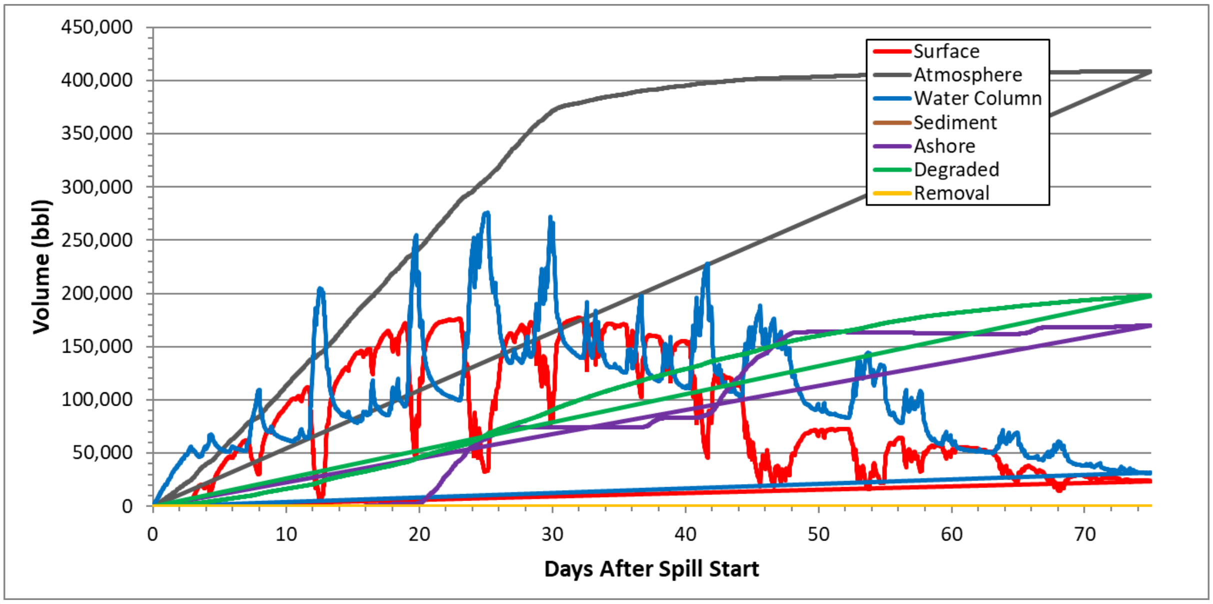


Figure 3-296. Oil volume by environmental compartment over time for an unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on August 25, 2019.

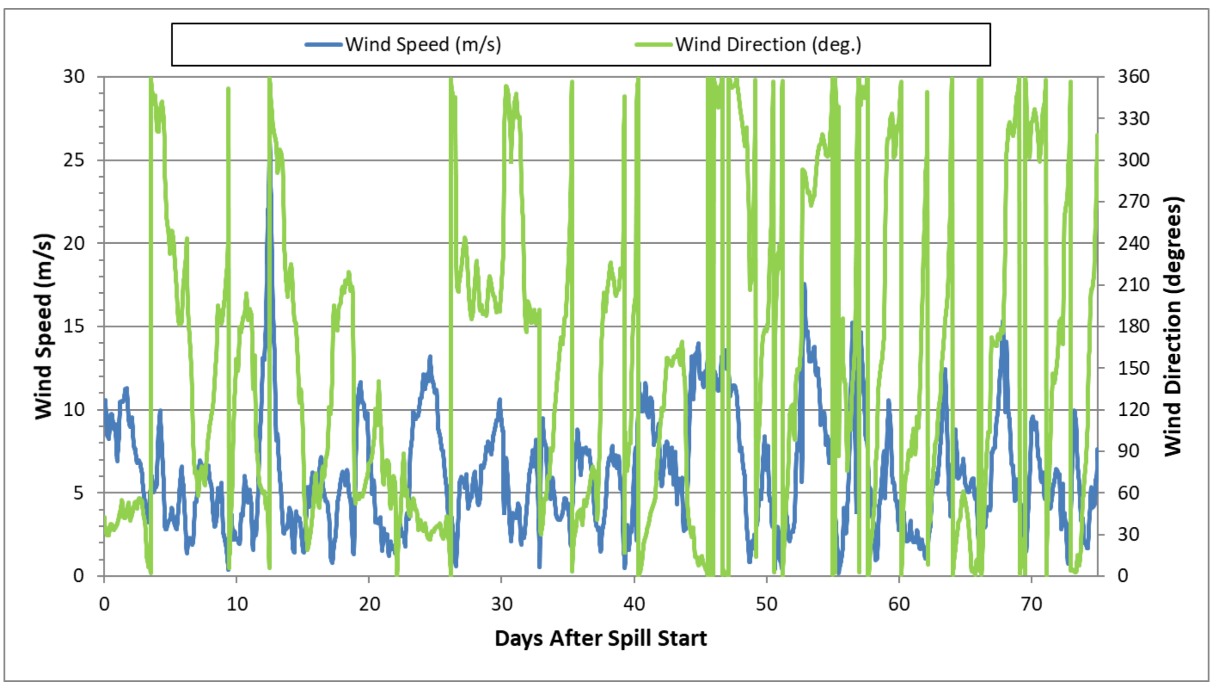


Figure 3-297. Wind speeds (1 m/s = 2 knots) and directions during the unmitigated 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in summer), for an unmitigated subsurface spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on August 25, 2019.

3.3.3.5.2 Seasonal Worst-Case Runs

Winter

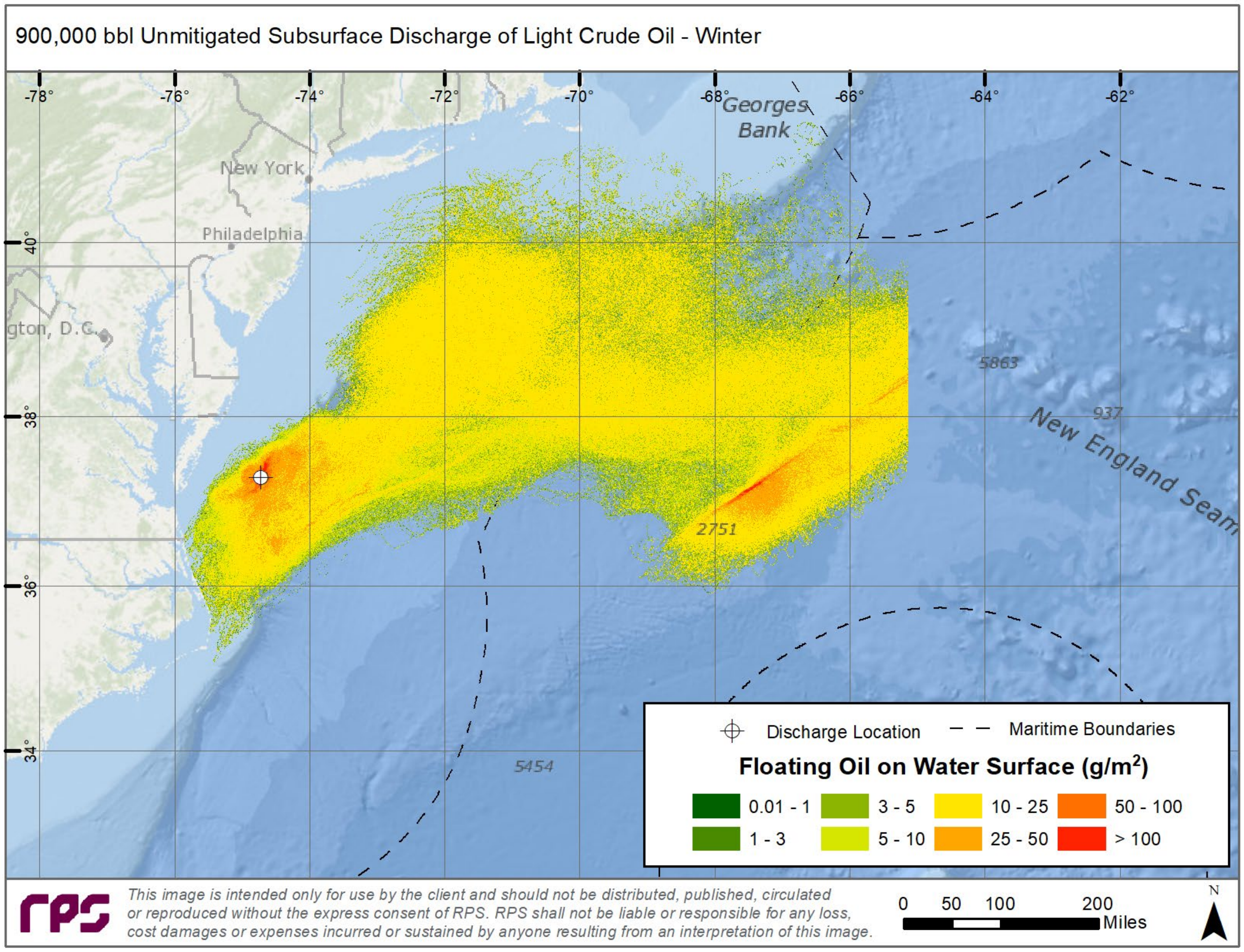


Figure 3-298. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on February 21, 2019.

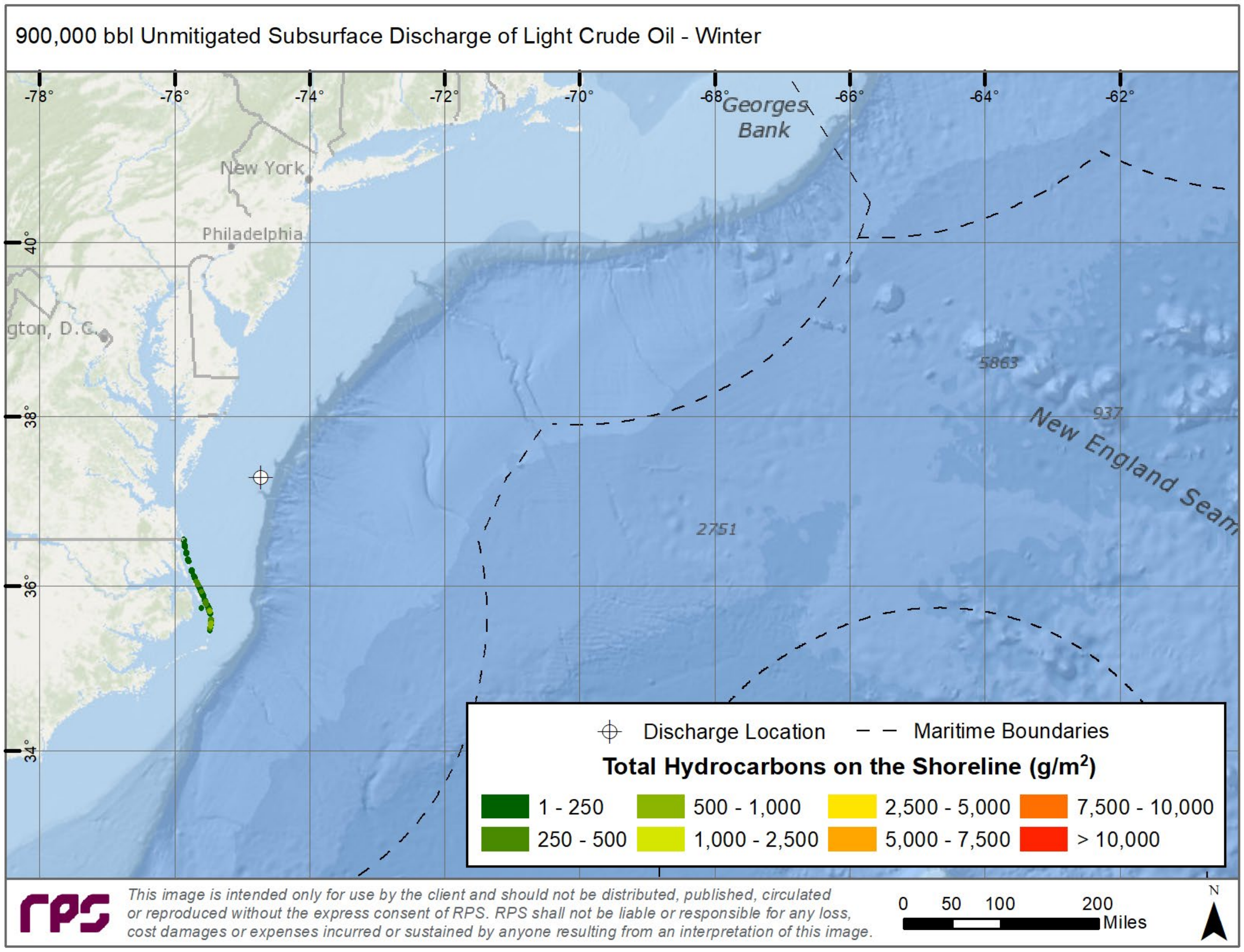


Figure 3-299. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on February 21, 2019.

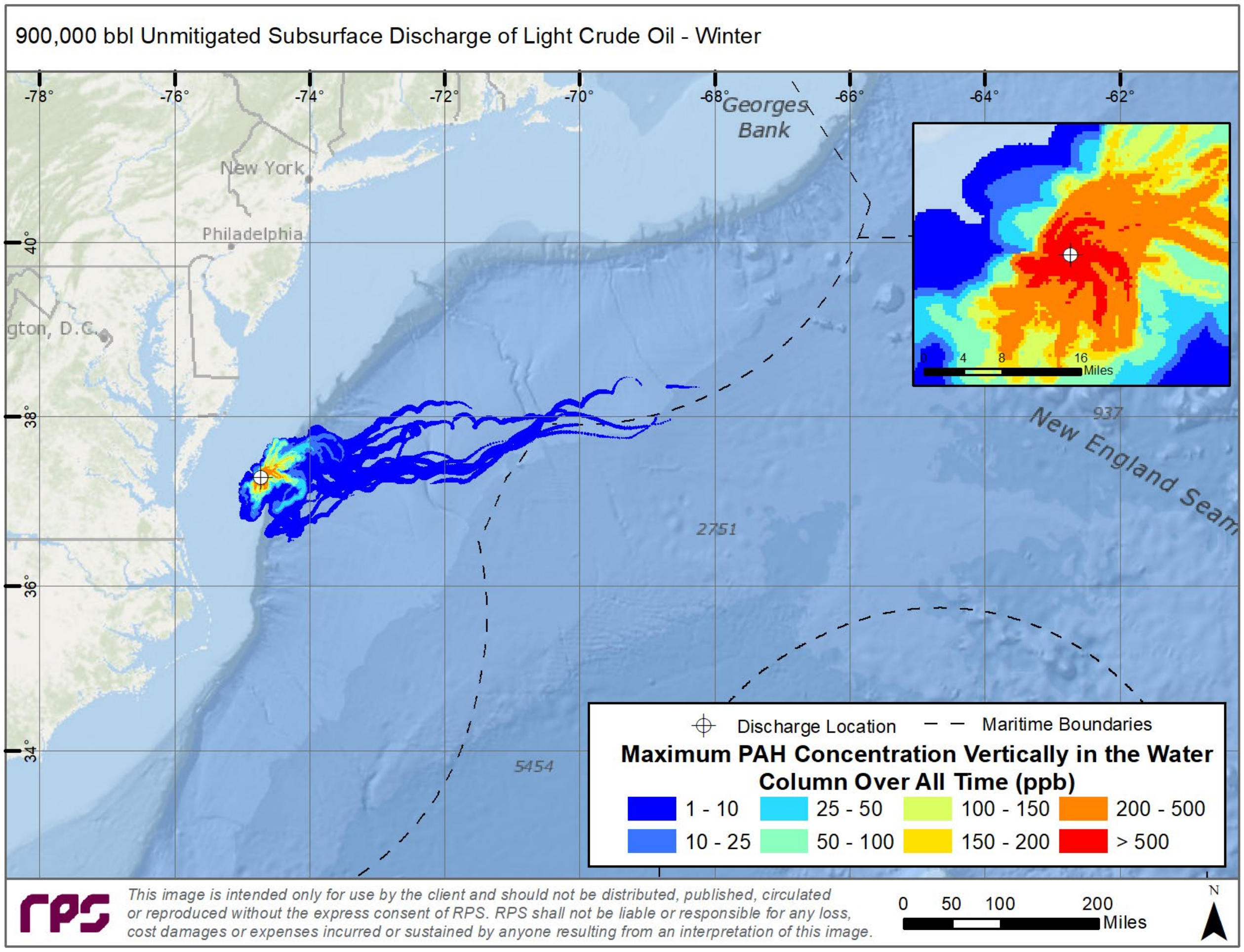


Figure 3-300. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in winter) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on February 21, 2019.

Spring

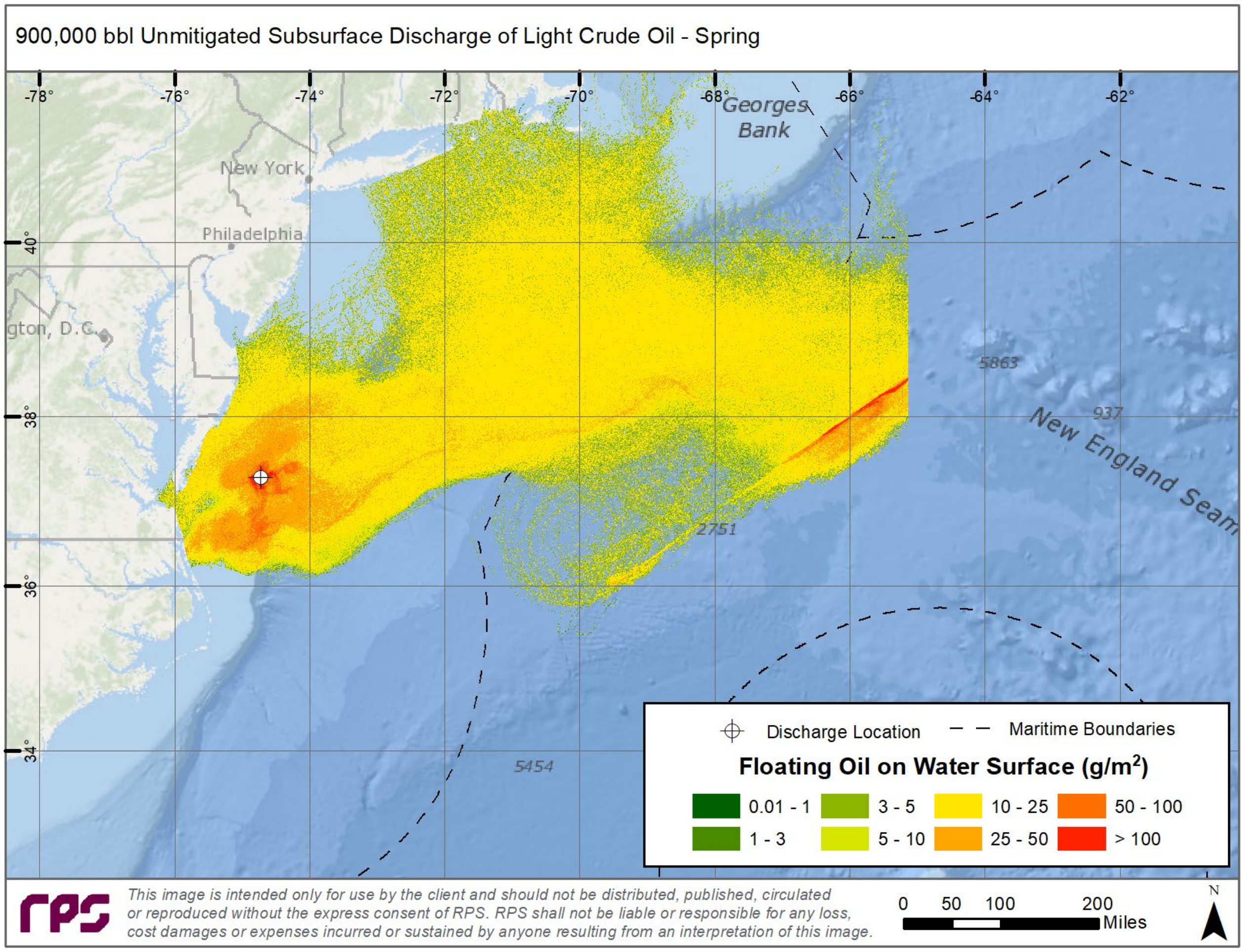


Figure 3-301. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on May 13, 2018.

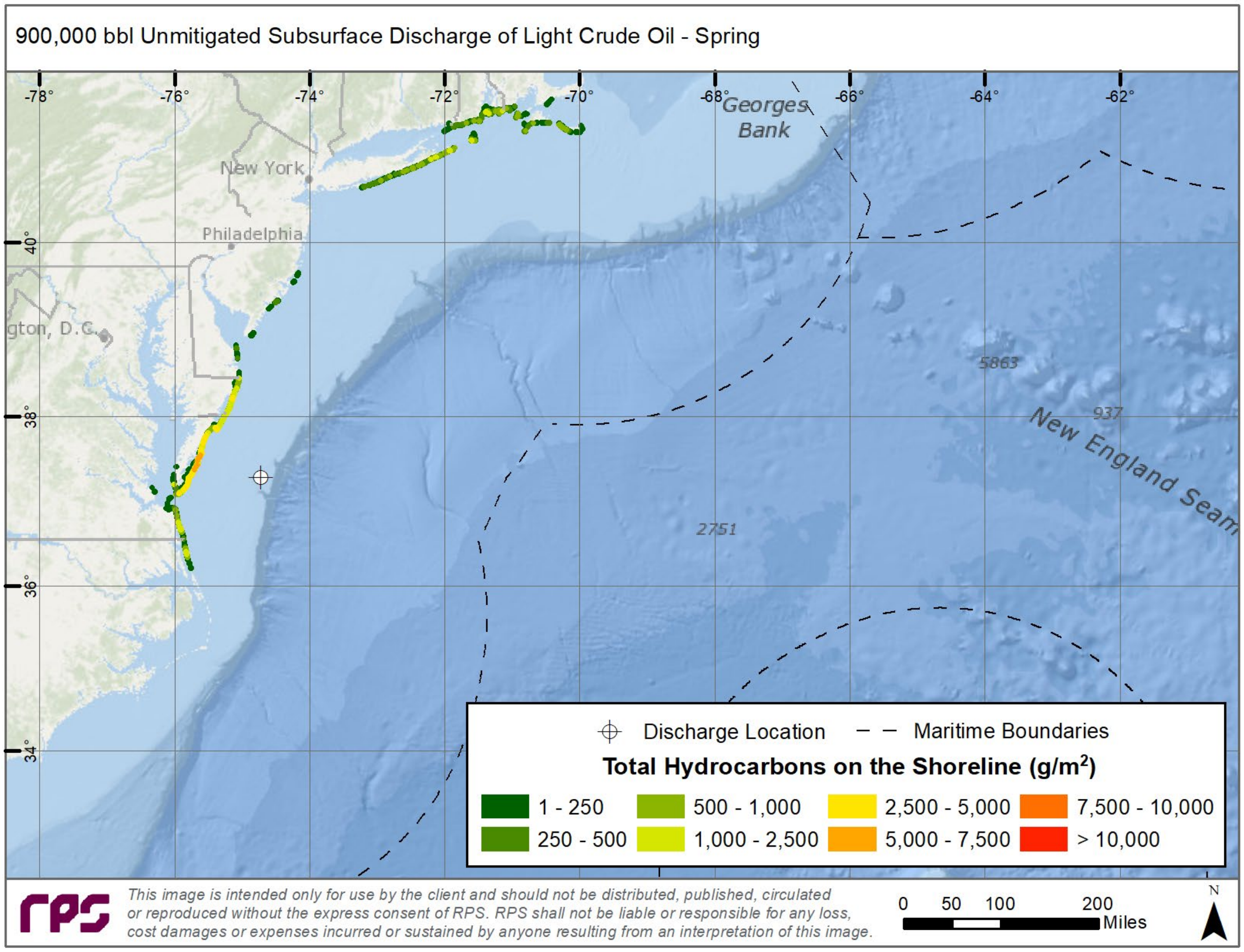


Figure 3-302. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on May 13, 2018.

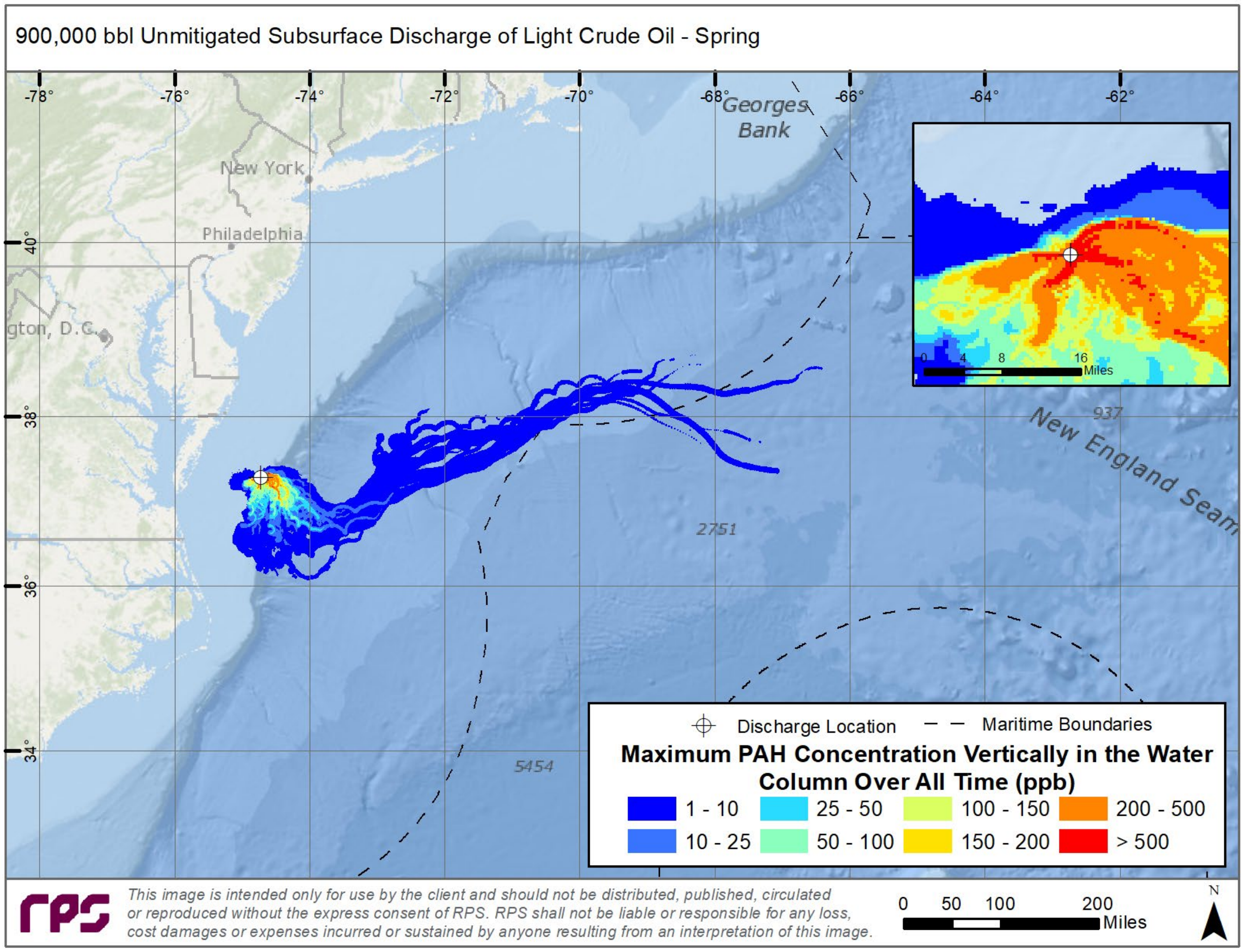


Figure 3-303. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in spring) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on May 13, 2018.

Fall

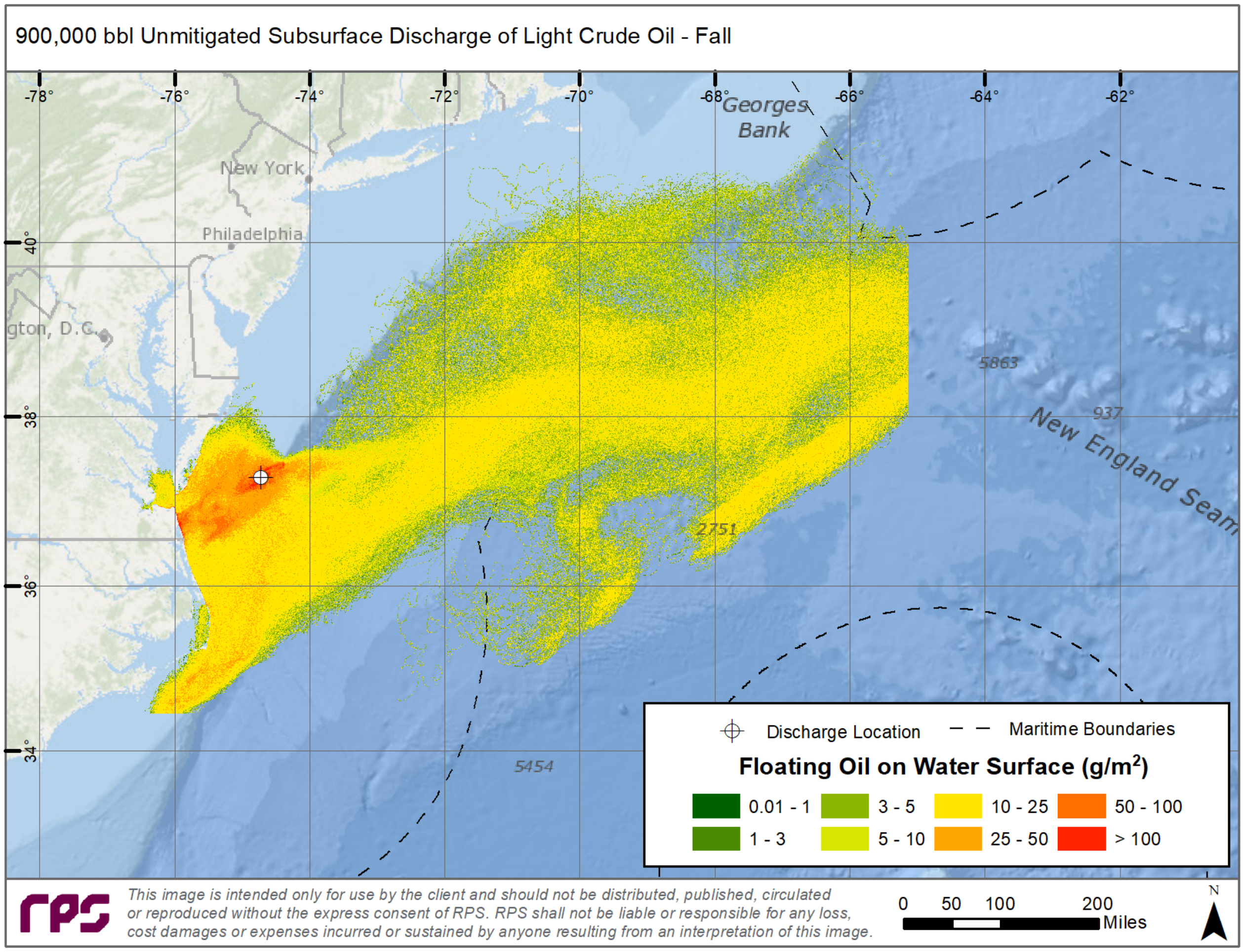


Figure 3-304. Maximum water surface oil exposure concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on September 1, 2019.

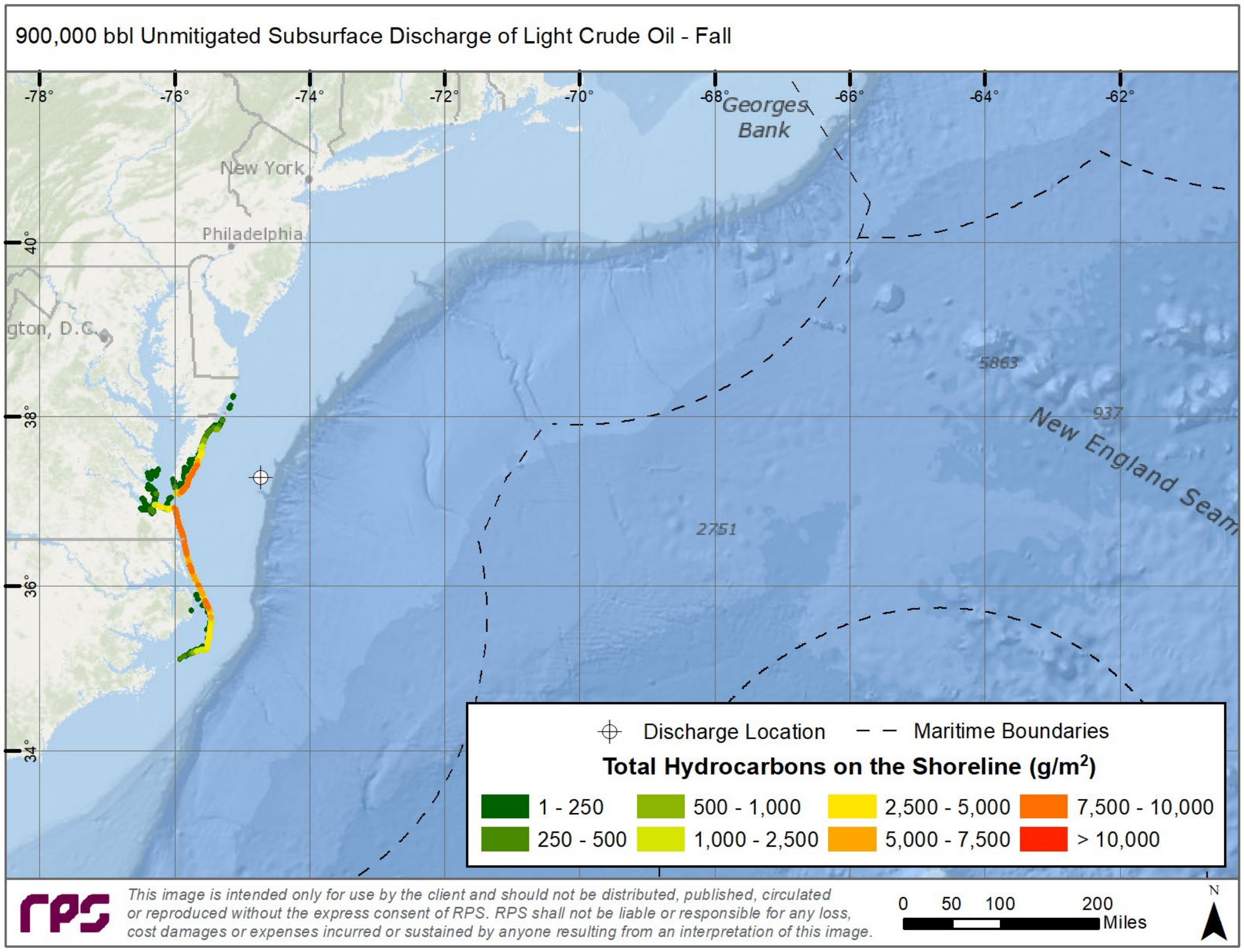


Figure 3-305. Maximum shoreline oil concentration at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on September 1, 2019.

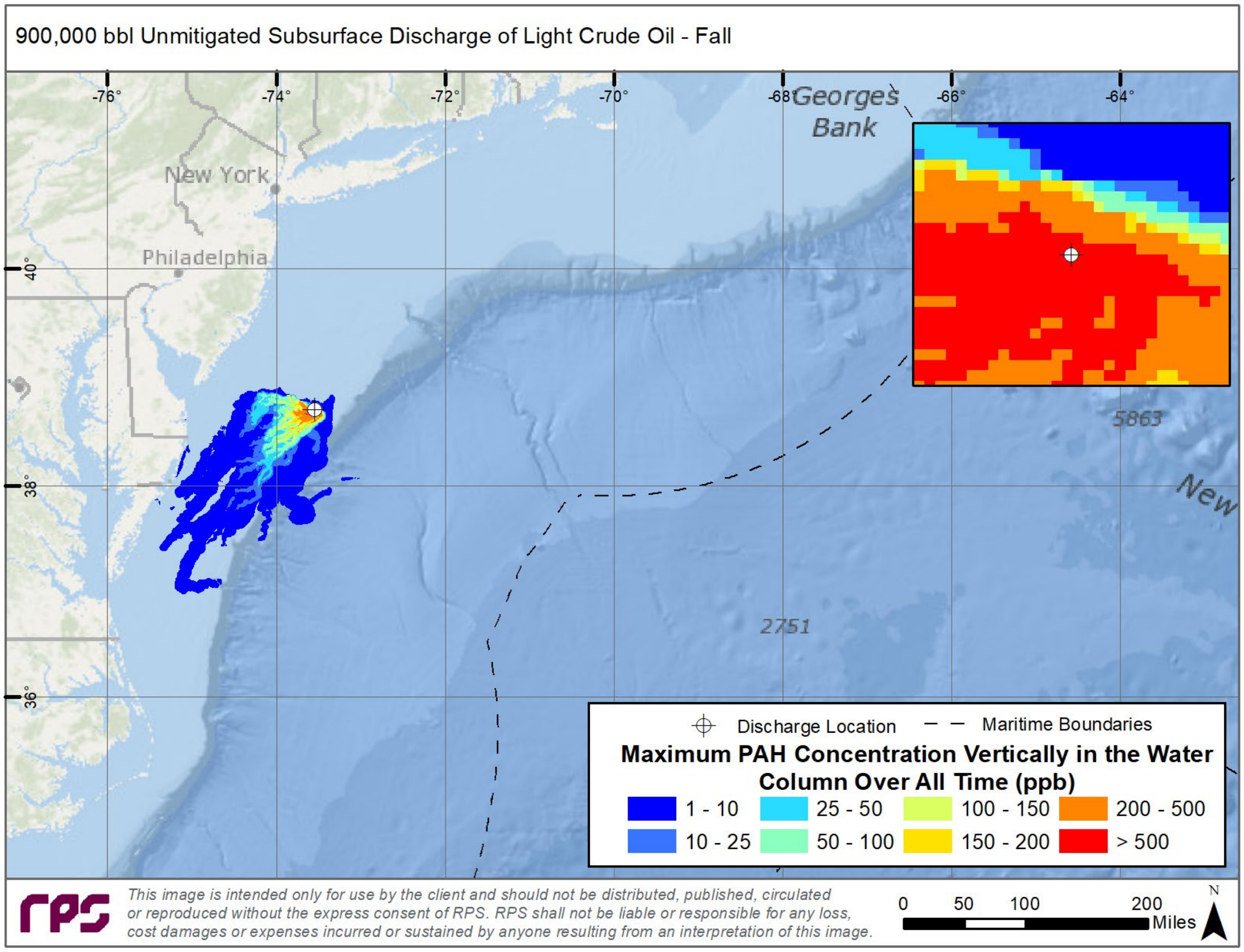


Figure 3-306. Vertical maximum dissolved aromatic (PAH) concentration in the water column at any point in time throughout a 75-day simulation of the run that led to the maximum shoreline length oiled (on an annual basis, in fall) for an unmitigated spill of 900,000 bbl (30,000 bbl/day released over 30 days) of crude oil offshore of Virginia starting on September 1, 2019.

4 DISCUSSION AND CONCLUSIONS

For the individual simulations representing the worst case with respect to shoreline oiling, the spill trajectories and oil fate are products of the environmental conditions on the selected date of the spills as well as the weathering properties of the oil. The crude oil used in this modeling study (MC252) is a light crude (API=37) with relatively low viscosity when fresh. The nature of the light crude generally leads to more evaporation and less surface/shoreline oiling at the end of the simulation, as compared to a heavier crude or fuel oil. The maximum surface oil exposure concentration was >100 g/m^2 (which would appear as the dark true color of the oil or as the color of emulsions; NOAA 2016; Bonn 2009, 2011) within the immediate vicinity of each release location.

With one representative oil type used throughout the study, the model results are primarily controlled by the release volume, site location, and the use of response measures. Three of the six modeled spill locations are located 10 - 17 mi (16 - 27 km) offshore New Jersey, Delaware, and Virginia in areas of high vessel traffic and were chosen for simulations of vessel spills of 126 bbl; 2,240 bbl; and 200,000 bbl of crude oil. The other three sites were located 50 - 70 mi (80 - 113 km) offshore of New Jersey, Delaware, and Virginia in areas identified by BOEM and BSEE as potential lease sites and were chosen for subsea blowout models of 30,000 bbl/day over 30 days (900,000 bbl in total).

Overall, the small and medium volume surface releases resulted in surface oil footprints with concentrations < 5 g/m^2 and shoreline concentrations <250 g/m^2 spanning between 140-300 mi (225-482 km). The surface footprints remained in nearshore waters of the state in which the spill occurred. The unmitigated high-volume surface releases resulted in larger footprints and higher concentrations of surface oil (>100 g/m^2) and shoreline oiling (>7,500 g/m^2) than those including mitigating response activities. These footprints were generally large, with lower concentrations (<1 g/m^2) often reaching the continental shelf, and in a few cases, international waters.

When comparing the mitigated and unmitigated high-volume spill scenarios, the trajectories of the highest concentrations of floating oil followed similar paths. However, differences can be noted in the overall size of the surface and shoreline footprints and the specific locations exposed to low concentrations. The subsurface blowouts resulted in very large surface oil footprints, with low concentrations of surface oil (<1 g/m^2) reaching upwards of 600 miles east to the end of the model domain. The shoreline length oiled reaches 638 mi (1,026 km) in the most extreme case.

Table 4-1 summarizes the final mass balance of the spilled oil at the end of the 30- or 75-day simulation. Most of the biodegradation occurred after oil was entrained into the water, becoming more bioavailable to the microbes. Eventually the oil in the water would degrade. Thus, the sum of the mass left in the water column at the end of the simulation and that already degraded primarily represents that oil that was dispersed in the water column, ultimately degrading. Oil residuals on shore that did not evaporate would either be cleaned up or remain on shore until it degrades.

The mass balance breakdown did not differ greatly between scenarios due to the fact the same oil type was modeled. The type of release does slightly impact the overall mass balance, with a high percent of oil degrading from the subsea blowout cases. As previously stated, the properties of the light crude oil modeled allow for a large percentage (40-55%) of the oil to evaporate in all cases.

Table 4-1. Mass balance at the end of the simulation for the worst-case run for shoreline oiling (on an annual basis) for each of the 15 offshore scenarios.

Spill Scenario	Season	Percent of Oil by End of Simulation				
		Surface	Atmos-phere	Shore-line	Water	Degraded
Delaware Low Volume	Summer	<1	52	29	7	11
Delaware Medium Volume	Summer	<1	49	31	8	12
Delaware High Volume (unmitigated)	Summer	<1	44	29	10	16
Delaware High Volume (mitigated)[a]	Summer	0	40	<1	16	20
Delaware Blowout[b]	Spring	8	47	19	4	19.7
New Jersey Low Volume	Spring	2	53	30	6	9
New Jersey Medium Volume	Spring	2	51	31	6	10
New Jersey High Volume (unmitigated)	Spring	4	46	28	9	13
New Jersey High Volume (mitigated)[a]	Spring	<1	44	11	9	12.8
New Jersey Blowout[b]	Spring	10	49	17	4	18
Virginia Low Volume	Winter	5	55	22	8	10
Virginia Medium Volume	Winter	3	53	22	11	11
Virginia High Volume (unmitigated)	Summer	1	46	39	6	8
Virginia High Volume (mitigated)[c]	Summer	0	43	21	8	10
Virginia Blowout[d]	Summer	3	45	19	4	22

[a]23% of released oil removed via response methods.
[b]2% of released oil left model domain in which it was no longer tracked.
[c]18% of released oil removed via response methods.
[d]7% of released oil left model domain in which it was no longer tracked.

The location of the release site, relative to the shoreline was not an indicator for length of shoreline oiled. As seen in Table 4-2 the length of shoreline oiled was primarily a result of the volume of oil released. The length of shoreline oiled increased with the volume for each scenario with the subsea blowouts oiling the longest stretch of shoreline, although released furthest shore. When response options were used, the length of shoreline oiled dropped considerably when compared to the unmitigated scenarios. The lengths of shoreline remaining oiled above threshold concentrations of concern at the end of 30 or 75 days are summarized in Table 4-2.

Table 4-2. Length of shoreline oiled at 30 or 75 days after the release for the worst-case run (on an annual basis) for shoreline oiling for each of the 15 offshore scenarios.

Spill Scenario	Season	Length Oiled (mi)			Length Oiled (km)		
		>1g/m²	>10g/m²	>100g/m²	>1g/m²	>10g/m²	>100g/m²
Delaware Low Volume	Summer	141	44	0	227	71	0
Delaware Medium Volume	Summer	234	177	49	376	285	79
Delaware High Volume (unmitigated)	Summer	354	340	263	569	564	424
Delaware High Volume (mitigated)[a]	Summer	76	76	48	123	122	77
Delaware Blowout[b]	Spring	638	634	497	1,027	1,021	800
New Jersey Low Volume	Summer	140	51	0	226	82	0
New Jersey Medium Volume	Summer	218	161	43	351	259	70
New Jersey High Volume (unmitigated)	Summer	307	305	215	494	491	347
New Jersey High Volume (mitigated)[a]	Summer	191	190	135	307	305	217
New Jersey Blowout[b]	Spring	530	527	400	854	848	643
Virginia Low Volume	Winter	142	14	0	228	22	0
Virginia Medium Volume	Winter	210	173	38	338	278	62
Virginia High Volume (unmitigated)	Summer	430	415	245	692	668	395
Virginia High Volume (mitigated)[c]	Summer	225	217	122	363	349	196
Virginia Blowout[d]	Summer	458	454	340	738	731	548

Potential exposures to dissolved aromatic concentrations in surface waters are summarized in Table 4-3 as volumes where fish eggs and larvae and other plankton may be adversely affected. The concentrations were primarily composed of PAHs and were highly variable in space and over time. Thus, durations of exposure were summarized to give some sense of the ephemeral nature of the exposures above thresholds of concern for fish and invertebrates. Table 4-3 lists results of the overall duration of exposure to > 10 ppb, the threshold where lethal impacts to plankton and sublethal impacts to juvenile and adult fish and invertebrates have been observed. These exposure durations are the times when any parcel of water in any location exceeded the threshold. However, all of the volumes affected were not exposed for the full duration this summary suggests. Most of the water parcels (and biota within them) were exposed for several hours, and not for days. In any case, given the very large oil spill volumes of the high volume and blowout scenarios assumed spilled, the effects on water column biota could be felt over several billion cubic yards, if sensitive species and life stages are present in the affected volumes.

Table 4-3. Modeled dissolved PAH exposure volumes (i.e., exposed at any instant in time) and overall duration of exposure (in any location) in surface waters for the worst-case for shoreline oiling simulations (annually) for each of the scenarios. (One km^3 is equivalent to 1 billion m^3 and 1.3 billion cubic yards.)

Spill Scenario	Season	Volume Contaminated		Max Exposure Time	
		>1 ppb (km^3)*	>10 ppb(km^3)*	>1 ppb (hours)**	>10 ppb (hours)**
Delaware Low Volume	Summer	0.003	0	4	0
Delaware Medium Volume	Summer	0.2	0.008	46	6
Delaware High Volume (unmitigated)	Summer	10	2	537	182
Delaware High Volume (mitigated)[a]	Summer	11	3	507	274
Delaware Blowout[b]	Spring	40	6	927	746
New Jersey Low Volume	Summer	0.0001	0	2	0
New Jersey Medium Volume	Summer	0.1	0.0005	31	2
New Jersey High Volume (unmitigated)	Summer	10	2	662	177
New Jersey High Volume (mitigated)[a]	Summer	10	2	538	263
New Jersey Blowout[b]	Spring	33	6	977	770
Virginia Low Volume	Winter	0	0	0	0
Virginia Medium Volume	Winter	0.04	0	17	0
Virginia High Volume (unmitigated)	Summer	13	1	449	300
Virginia High Volume (mitigated)[c]	Summer	11	1	466	391
Virginia Blowout[d]	Summer	49	6	917	791

* Volume of water which exceeded 1 ppb and 10 ppb at any given time
** Maximum number of hours with exposure concentrations >1 or 10 ppb

5 REFERENCES

Beardsley, R.C., and Boicourt, W.C., 1981. On estuarine and continental-shelf circulation in the Middle Atlantic Bight. Evolution of Physical Oceanography: Scientific Surveys in Honor of Henry Stommel, B. A. Warren and C. Wunsch, Eds., MIT Press, 198–233.

Bejarano, A.C., J. Michel, J. Rowe, Z. Li, D. French McCay, L. McStay and D.S. Etkin. 2013. Environmental Risks, Fate and Effects of Chemicals Associated with Wind Turbines on the Atlantic Outer Continental Shelf. US Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Herndon, VA. OCS Study BOEM 2013-213.

Bock, M., H. Robinson, R. Wenning, D, French McCay, J. Rowe, A. H. Walker. 2018. Comparative Risk Assessment of Spill Response Options for a Deepwater Oil Well Blowout: Part II. Relative Risk Methodology. Mar. Pollut. Bull. 133:984–1000. http://dx.doi.org/10.1016/j.marpolbul.2018.05.032.

Bonn Agreement. 2009. Bonn Agreement Aerial Operations Handbook, 2009. London, UK. Available: http://www.bonnagreement.org/site/assets/files/1081/ba-aoh revision 2 april 2012-1.pdf, Accessed 4 June 2015.

Bonn Agreement, 2011. Bonn Agreement Oil Appearance Code Photo Atlas. Available: http://www.bonnagreement.org/site/assets/files/1081/photo_atlas_version_20112306-1.pdf. Accessed: April 2017.

Buchholz, K., A. Krieger, J. Rowe, D. Schmidt Etkin, D. French-McCay, M. Gearon, M. Grennan, and J. Turner, 2016. Worst Case Discharge Scenarios for Oil and Gas Offshore Facilities and Oil Spill Response Equipment Capabilities. Bureau of Safety and Environmental Enforcement (BSEE), Oil Spill Preparedness Division (OSPD), Washington, DC, February 29, 2016, 172p.[https://www.bsee.gov/site-page/worst-case-discharge-scenarios-for-oil-and-gas-offshore-facilities-and-oil-spill-response]

Bureau of Ocean Energy Management (BOEM). 2012. Outer Continental Shelf, Oil and Gas Leasing Program: 2012-2017, Final Programmatic Environmental Impact Statement. July 2012. U.S. Department of the Interior, Bureau of Ocean Energy Management, OCS EIS/EA BOEM 2012-030, 2057p. [https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Leasing/Five_Year_Program/2012-2017_Five_Year_Program/2012-2017_Final_PEIS.pdf]

Bureau of Ocean Energy Management, Gulf of Mexico OCS Region (BOEM), 2013. Gulf of Mexico OCS Oil and Gas Lease Sales: 2014 and 2016. Eastern Planning Area Lease Sales 225 and 226. Draft Environmental Impact Statement. Volumes I and II. BOEM 2013-0116. http://www.boem.gov/Environmental-Stewardship/Environmental-Assessment/NEPA/nepaprocess.aspx#Recent%20NEPA%20Documents

Bureau of Ocean Energy Management (BOEM), 2017a. Catastrophic Spill Event Analysis: High-Volume, Extended-Duration Oil Spill Resulting from Loss of Well Control on the Gulf of Mexico Outer Continental Shelf. 1st Revision. BOEM Report BOEM 2017-007. https://www.boem.gov/sites/default/files/environmental-stewardship/Environmental-Assessment/NEPA/Catastrophic-Spill-Event-Analysis.pdf

Bureau of Ocean Energy Management (BOEM), 2017b. Gulf of Mexico OCS. Oil and Gas Lease Sales: 2017-2222. Gulf of Mexico Lease Sales 249, 250, 251, 252, 253, 254, 256, 257, 259, and 261. Final Multisale Environmental Impact Statement. OCS EIS/EA BOEM 2017-009. https://www.boem.gov/sites/default/files/environmental-stewardship/Environmental-Assessment/NEPA/BOEM-EIS-2017-009-v1.pdf

Bureau of Ocean Energy Management (BOEM), 2017c. Final Supplemental Environmental Impact Statement for the Proposed 2018 Gulf of Mexico Lease Sales. OCS EIS/EA BOEM 2017-074. https://www.boem.gov/sites/default/files/environmental-stewardship/Environmental-Assessment/NEPA/BOEM-EIS-2017-074_v1.pdf

Bureau of Ocean Energy Management (BOEM), 2017d. Gulf of Mexico OCS. Oil and Gas Lease Sales: 2017-2222. Gulf of Mexico Lease Sales 249, 250, 251, 252, 253, 254, 256, 257, 259, and 261. Final Multisale Environmental Impact Statement. OCS EIS/EA BOEM 2017-009. https://www.boem.gov/sites/default/files/environmental-stewardship/Environmental-Assessment/NEPA/BOEM-EIS-2017-009-v1.pdf

Bureau of Ocean Energy Management (BOEM), 2017e. Final Supplemental Environmental Impact Statement for the Proposed 2018 Gulf of Mexico Lease Sales. OCS EIS/EA BOEM 2017-074. https://www.boem.gov/sites/default/files/environmental-stewardship/Environmental-Assessment/NEPA/BOEM-EIS-2017-074_v1.pdf

Csanady, G. T., and Hamilton, P., 1988: Circulation of slopewater. Continental Shelf Research, 8, 565–624.

Drévillon, M., Bourdallé-Badie, R., Derval, C., Lellouche, J.M., Rémy, E., Tranchant, B., Benkiran, M., Greiner, E., Guinehut, S., Verbrugge, N., and Garric, G., 2008. The GODAE/Mercator-Ocean global ocean forecasting system: results, applications and prospects. Journal of Operational Oceanography, 1(1), pp.51-57.

Egbert, G.D., and Erofeeva, S.Y., 2002. Efficient inverse modeling of barotropic ocean tides. Journal of Atmospheric and Oceanic technology, 19(2), pp.183-204.

Etkin, D.S., D. French McCay, and J. Rowe. 2006. Modelling to evaluate effectiveness of variations in spill response strategy. In: Proceedings of the 29th AMOP Technical Seminar on Environmental Contamination and Response, Environment Canada. 29:879-892.

French, D.P., and H. Rines. 1997. Validation and use of spill impact modeling for impact assessment. In: Proceedings, 1997 International Oil Spill Conference. Fort Lauderdale, Florida, American Petroleum Institute Publication No. 4651, Washington, DC, pp.829-834.

French, D.P., Rines, H., Masciangioli, P., 1997. Validation of an Orimulsion spill fates model using observations from field test spills. In: Proceedings of the 20th AMOP Technical Seminar, Environment and Climate Change Canada, Ottawa, ON, Canada, vol. 20. pp. 933–961.

French McCay, D.P. 2002. Development and application of an oil toxicity and exposure model, OilToxEx. Environmental Toxicology and Chemistry 21(10): 2080-2094. [DOI: 10.1002/etc.5620211011]

French McCay, D.P. 2003. Development and application of damage assessment modeling: Example assessment for the North Cape oil spill. Marine Pollution Bulletin 47 (9-12): 341-359. [DOI: 10.1016/S0025-326X(03)00208-X]

French McCay, D.P. 2004. Oil spill impact modeling: Development and validation. Environmental Toxicology and Chemistry 23 (10): 2441-2456. [https://doi.org/10.1897/03-382]

French McCay, D.P., and J.J. Rowe. 2004. Evaluation of Bird Impacts in Historical Oil Spill Cases Using the SIMAP Oil Spill Model. In: Proceedings of the 27th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp. 421-452.

French-McCay, D.P, N. Whittier, D. Aurand, C. Dalton, J. J. Rowe, S. Sankaranarayanan, and H.-S. Kim, 2005. Use of Probabilistic Trajectory and Impact Modeling to Assess Consequences of Oil Spills with Various Response Strategies. In Proceedings of the 28th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp. 253-271.

French McCay, D.P. 2009. State-of-the-Art and Research Needs for Oil Spill Impact Assessment Modeling. In Proceedings of the 32nd AMOP Technical Seminar on Environmental Contamination and Response, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp. 601-653.

French McCay, D., D. Reich, J. Michel, D. Etkin, L. Symons, D. Helton and J. Wagner, 2012. Oil Spill Consequence Analyses of Potentially-Polluting Shipwrecks. In Proceedings of the 35th AMOP Technical Seminar on Environmental Contamination and Response, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada.

French McCay, D., M.S. Gearon, Y.H. Kim, K. Jayko and T. Isaji, 2014. Modeling Oil Transport and Fate in the Beaufort Sea. In Proceedings of the 37th AMOP Technical Seminar on Environmental Contamination and Response, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp.40-64.

French-McCay, D.P., Jayko, K., Li, Z., Horn, M., Kim, Y., Isaji, T., Crowley, D., Spaulding, M., Decker, L., Turner, C., Zamorski, S., Fontenault, J., Shmookler, R., Rowe, J.J., 2015. Technical Reports for Deepwater Horizon Water Column Injury Assessment – WC_TR14: Modeling Oil Fate and Exposure Concentrations in the Deepwater Plume and Cone of Rising Oil Resulting From the Deepwater Horizon Oil Spill. DWH NRDA Water Column Technical Working Group Report. Prepared for National Oceanic and Atmospheric Administration by RPS ASA, South Kingstown, RI, USA. September 29, 2015. Administrative Record no. DWH-AR0285776.pdf. https://www.doi.gov/ deepwaterhorizon/adminrecord.

French McCay, D. 2016. Potential effects thresholds for oil spill risk assessments. In: Proceedings of the 39th AMOP Technical Seminar on Environmental Contamination and Response, 7–9 June 2016, Halifax, Nova Scotia (CA). Emergencies Science Division, Environment Canada; Ottawa, ON, Canada. p. 285–303. French-McCay, D.P. and J.J. Rowe. 2004. Evaluation of bird impacts in historical oil spill cases using the SIMAP oil spill model. In Proceedings of the 27th AMOP Technical Seminar, Environment and Climate Change Canada, Ottawa, ON, Canada, 27, 421-452.

French-McCay, D.P., Li, Z., Horn, M., Crowley, D., Spaulding, M., Mendelsohn, D., Turner, C., 2016. Modeling oil fate and subsurface exposure concentrations from the Deepwater Horizon oil spill. In: Proceedings of the 39th AMOP Technical Seminar, Environment and Climate Change Canada, Ottawa, ON, Canada, vol. 39. pp. 115–150.

French-McCay, D., D. Crowley, J. Rowe, M. Bock, H. Robinson, R. Wenning, A. H. Walker, J. Joeckel, and T. Parkerton. 2018a. Comparative Risk Assessment of Spill Response Options for a Deepwater Oil Well Blowout: Part I. Oil Spill Modeling. Mar. Pollut. Bull. 133:1001–1015.

French-McCay, D. K. Jayko, Z. Li, M. Horn, T. Isaji, M. Spaulding. 2018b. Volume II: Appendix II - Oil Transport and Fates Model Technical Manual. In: Galagan, C.W., D. French-McCay, J. Rowe, and L. McStay, editors. Simulation Modeling of Ocean Circulation and Oil Spills in the Gulf of Mexico. Prepared by RPS ASA for the US Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2018-039040; 422 p.

French-McCay, D., M. Horn, Z. Li, D. Crowley, M. Spaulding, D. Mendelsohn, K. Jayko, Y. Kim, T. Isaji, J. Fontenault, R. Shmookler, and J. Rowe. 2018c. Volume III: Data Collection, Analysis and Model Validation. In: Galagan, C.W., D. French-McCay, J. Rowe, and L. McStay, editors. Simulation Modeling of Ocean Circulation and Oil Spills in the Gulf of Mexico. Prepared by RPS ASA for the US Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2018-039; 313 p.

French-McCay, D., D. Crowley, J. Rowe, M. Bock, H. Robinson, R. Wenning, A. H. Walker, J. Joeckel, and T. Parkerton. 2018d. Comparative Risk Assessment of Spill Response Options for a Deepwater Oil Well Blowout: Part I. Oil Spill Modeling. Mar. Pollut. Bull. 133:1001–1015.

General Bathymetric Chart of the Oceans (GEBCO). 2003. Centenary Edition of the GEBCO Digital Atlas, published on behalf of the Intergovernmental Oceanographic Commission (IOC) and the International Hydrographic Organization (IHO) as part of the General Bathymetric Chart of the Oceans; British Oceanographic Data Centre (BODC), Liverpool.

Haidvogel, D.B., Arango, H., Budgell, W.P., Cornuelle, B.D., Curchitser, E., Di Lorenzo, E., Fennel, K., Geyer, W.R., Hermann, A.J., Lanerolle, L., and Levin, J., 2008. Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the Regional Ocean Modeling System. Journal of Computational Physics, 227(7), pp.3595-3624.

Janjic, Z., Black, T., Pyle, M., Rogers, E., Chuang, H. Y., and DiMego, G., 2005. High resolution applications of the WRF-NMM, paper presented at 21st Conference on Weather Analysis and Forecasting/17th Conference on Numerical Weather Prediction, American Meteorological Society, Washington, 545 DC.

Ji, Z.-G., Johnson, W.R., Marshall, C.F., Rainey, G.B. & Lear, E.M. 2002. Oil-Spill Risk Analysis: Gulf of Mexico Outer Continental Shelf (OCS) Lease Sales, Central Planning Area and Western Planning Area, 2003-2007, and Gulfwide OCS Program, 2003-2042. Minerals Management Service: Herndon, VA, OCS Report 2002-032.

Lehr, W., Bristol, S., Possolo, A. et al. 2010. Oil budget calculator, Deepwater Horizon, Technical Documentation. A report to the national incident command. The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team, http://www.restorethegulf.gov/sites/default/files/documents/pdf/OilBudgetCalc_Full_HQ-Print_111110.pdf, November 2010. (Accessed on April 1, 2012).

Lentz, S.J., 2008. Observations and a model of the mean circulation over the Middle Atlantic Bight continental shelf. Journal of Physical Oceanography, 38(6), pp.1203-1221.

Li, Z., Spaulding, M., McCay, D. F., Crowley, D., & Payne, J. R. 2017. Development of a unified oil droplet size distribution model with application to surface breaking waves and subsea blowout releases considering dispersant effects. Marine pollution bulletin, 114(1), 247-257.

Locarnini, R. A., Mishonov, A. V., Baranova, O. K., Boyer, T. P., Zweng, M. M., Garcia, H. E., Reagan, J. R., Seidov, D., Weathers, K., Paver, C. R., and Smolyar, I., 2018. World Ocean Atlas 2018, Volume 1: Temperature. A. Mishonov Technical Ed.; NOAA Atlas NESDIS 81, 52 pp.

NOAA. 2010. Characteristics of Response Strategies: A Guide for Spill Response Planning in Marine Environments. U.S. Department of Commerce, U.S. Coast Guard, U.S. Environmental Protection Agency, American Petroleum Institute.

National Oceanic and Atmospheric Administration (NOAA). 2016. Open water oil identification job aid for aerial observation. U.S. Department of Commerce, Office of Response and Restoration [http://response.restoration.noaa.gov/oil-and-chemical-releases/oil-releases/resources/open-water-oil-identification-job-aid.html]

National Oceanic and Atmospheric Administration (NOAA), 2020. Environmental Sensitivity Index (ESI) Maps. Available: https://response.restoration.noaa.gov/esi. Accessed: 2020.

Moody, J.A., Butman, B., Beardsley, R.C., Brown, W.S., Daifuku, P., Irish, J.D., Mayer, D.A., Mofjeld, H.O., Petrie, B., Ramp, S., Smith, P., and Wright, W.R., 1984. Atlas of Tidal Elevation and Current Observations on the Northeast American Continental Shelf and Slope. US Geological Survey Bulletin, 1611, 1-122.

Riker, R.J., F.N. Caggiano, A.J. Baragona, J.E. Baum, and E.J. Linky, 1981.Deepwater Port Alternatives for New Jersey. The Port Authority of New York & New Jersey. https://www.govinfo.gov/content/pkg/CZIC-he554-n5-d44-1982-v-1/html/CZIC-he554-n5-d44-1982-v-1.htm

Shchepetkin, A.F., and McWilliams, J.C., 2005. The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean modelling, 9(4), pp.347-404.

Song, Y., and Haidvogel, D., 1994. A semi-implicit ocean circulation model using a generalized topography-following coordinate system. Journal of Computational Physics, 115(1), pp.228-244.

Walker, A.H., D. Scholz, M. McPeek, D. French-McCay, J. Rowe, M. Bock, H. Robinson, and R. Wenning. 2018. Comparative Risk Assessment of Spill Response Options for a Deepwater Oil Well Blowout: Part III. Stakeholder Engagement. Mar. Pollut. Bull. 133:970–983. https://doi.org/10.1016/j.marpolbul.2018.05.009.

Wilson, R. R., C. Perham, D. P. French-McCay, R. Balouskus. 2018. Potential impacts of offshore oil spills on polar bears in the Chukchi Sea, Environmental Pollution, Volume 235, April 2018, Pages 652-659, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2017.12.057.

Zweng, M. M., Reagan, J. R., Seidov, D., Boyer, T. P., Locarnini, R. A., Garcia, H. E., Mishonov, A. V., Baranova, O. K., Weathers, K., Paver, C. R., and Smolyar, I., 2018. World Ocean Atlas 2018, Volume 2: Salinity. A. Mishonov Technical Ed.; NOAA Atlas NESDIS 82, 50 pp.

ANNEX A. DESCRIPTION OF SIMAP OIL TRANSPORT AND FATE MODEL

The analysis was performed using the model system developed by Applied Science Associates (ASA) called SIMAP (Spill Impact Model Analysis Package). SIMAP originated from the oil fates and biological effects submodels in the Natural Resource Damage Assessment Models for Coastal and Marine Environments (NRDAM/CME) and Great Lakes Environments (NRDAM/GLE), which ASA developed in the early 1990s for the U.S. Department of the Interior for use in “type A” Natural Resource Damage Assessment (NRDA) regulations under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). The most recent version of the type A models, the NRDAM/CME (Version 2.4, April 1996) was published as part of the CERCLA type A NRDA Final Rule (Federal Register, May 7, 1996, Vol. 61, No. 89, p. 20559-20614). The technical documentation for the NRDAM/CME is in French et al. (1996). This technical development involved several in-depth peer reviews, as described in the Final Rule.

While the NRDAM/CME and NRDAM/GLE were developed for simplified NRDAs of small spills in the United States, SIMAP is designed to evaluate fates and effects of both real and hypothetical spills in marine, estuarine and freshwater environments worldwide. Additions and modifications to prepare SIMAP were made to increase model resolution, allow modification and site-specificity of input data, allow incorporation of temporally varying current data, evaluate subsurface releases and movements of subsurface oil, track multiple chemical components of the oil, enable stochastic modeling, and facilitate analysis of results.

Below is a brief description of the trajectory and fate models in SIMAP. Detailed descriptions of the algorithms and assumptions in the model are in published papers (French-McCay, 2003; 2004; French-McCay et al 2018).

A.1 Physical Fates Model

The three-dimensional physical fates model estimates distribution (as mass and concentrations) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments. Oil fate processes included are oil spreading (gravitational and by shearing), evaporation, transport, randomized dispersion, emulsification, entrainment (natural and facilitated by dispersant), 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.

Oil is a mixture of hydrocarbons of varying physical, chemical, and toxicological characteristics. In the model, oil is represented by component categories, and the fate of each component is tracked separately.

The “pseudo-component” approach (Payne et al., 1984; 1987; French et al., 1996; Jones, 1997; Lehr et al., 2000) is used, where chemicals in the oil mixture are grouped by physical-chemical properties, and the resulting component category behaves as if it were a single chemical with characteristics typical of the chemical group.

The most toxic components of oil to aquatic organisms are low molecular weight aromatic compounds (monoaromatic and polycyclic aromatic hydrocarbons, MAHs and PAHs), which are both volatile and soluble in water. Their acute toxic effects are caused by non-polar narcosis, where toxicity is related to the octanol-water partition coefficient (K_{ow}), a measure of hydrophobicity. The more hydrophobic the compound, the more toxic it is likely to be. However, as K_{ow} increases, the compound also becomes less soluble in water, and so there is less exposure to aquatic organisms. The toxicity of compounds having $\log(K_{ow})$ values greater than about 6 is limited by their very low solubility in water, and consequent low bioavailability to aquatic biota (French-McCay, 2002, Di Toro et al., 2000). Thus, the potential for acute effects is the result of a balance between bioavailability (exposure), toxicity once exposed, and duration of exposure. French-McCay (2002) contains a full description of the oil toxicity model in SIMAP, and French-McCay (2002) describes the implementation of the toxicity model in SIMAP.

Because of these considerations, the SIMAP fates model focuses on tracking the lower molecular weight aromatic components divided into chemical groups based on volatility, solubility, and hydrophobicity. In the model, the oil is treated as comprising eight components (defined in Table A-1). Six of the components (i.e., all but the two non-volatile residual components representing non-volatile aromatics and aliphatics) evaporate at rates specific to the pseudo-component. Solubility is strongly correlated with volatility, and the solubility of aromatics is higher than aliphatics of the same volatility. The MAHs are the most soluble, the 2-ring PAHs are less soluble, and the 3-ring PAHs slightly soluble (Mackay et al., 1992). Both the solubility and toxicity of the non-aromatic hydrocarbons are much less than for the aromatics, and dissolution (and water concentrations) of non-aromatics is safely ignored. Thus, dissolved concentrations are calculated only for each of the three soluble aromatic pseudo-components.

This number of components provides sufficient accuracy for the evaporation and dissolution calculations, particularly given the time frame (minutes) over which dissolution occurs from small droplets and the rapid resurfacing of large droplets (see discussion above). The alternative of treating oil as a single compound with empirically-derived rates (e.g., Stiver and Mackay, 1984) does not provide sufficient accuracy for environmental effects analyses because the effects to water column organisms are caused by MAHs and PAHs, which had specific properties that differ from the other volatile and soluble compounds. The model has been validated both in predicting dissolved concentrations and resulting toxic effects, supporting the adequacy of the use of this number of pseudo-components (French-McCay, 2003).

Table A-1. Definition of four distillation cuts and the eight pseudo-components in the model (Monoaromatic Hydrocarbons, MAHs; Benzene + Toluene + Ethylbenzene + Xylene, BTEX; Polycyclic Aromatic Hydrocarbons, PAHs).

Characteristic	Volatile and Highly Soluble	Semi-volatile and Soluble	Low Volatility and Slightly Soluble	Residual (non-volatile and very low solubility)
Distillation cut	1	2	3	4
Boiling Point (°C)	<180	180 - 265	265 - 380	>380
Molecular Weight	50 - 125	125 - 168	152 - 215	>215
Log(K_{ow})	2.1-3.7	3.7-4.4	3.9-6.0	>6.0
Aliphatic components: Number of Carbons	volatile aliphatics: C4 – C10	semi-volatile aliphatics: C10 – C15	low-volatility aliphatics: C15 – C20	non-volatile aliphatics: >C20
Aromatic component name: included compounds	MAHs: BTEX, MAHs to C3-benzenes	2 ring PAHs: C4-benzenes, naphthalene, C1-, C2-naphthalenes	3 ring PAHs: C3-, C4-naphthalenes, 3-4 ring PAHs with log(K_{ow}) <6.0	$\geq$4 ring aromatics: PAHs with log(K_{ow}) >6.0 (very low solubility)

The lower molecular weight aromatics dissolve from the whole oil and are partitioned in the water column and sediments according to equilibrium partitioning theory (French et al., 1996; French-McCay, 2004). The residual fractions in the model are composed of non-volatile and insoluble compounds that remain in the “whole oil” that spreads, is transported on the water surface, strands on shorelines, and disperses into the water column as oil droplets or remains on the surface as tar balls. This is the fraction that composes black oil, mousse, and sheen.

The schematic in Figure A-1 depicts oil fates processes simulated in open water conditions, while the schematic in Figure A-2 depicts oil fates processes that are simulated at and near the shoreline. Because oil contains many chemicals with varying physical-chemical properties, and the environment is spatially and temporally variable, the oil rapidly separates into different phases or parts of the environment:

- Surface oil
- Emulsified oil (mousse) and tar balls
- Oil droplets suspended in the water column
- Oil adhering to suspended particulate matter in the water
- Dissolved lower molecular weight components (MAHs, PAHs, and other soluble components) in the water column
- Oil on and in the sediments
- Dissolved lower molecular weight components (MAHs, PAHs, and other soluble components) in the sediment pore water

- Oil on and in the shoreline sediments and surfaces

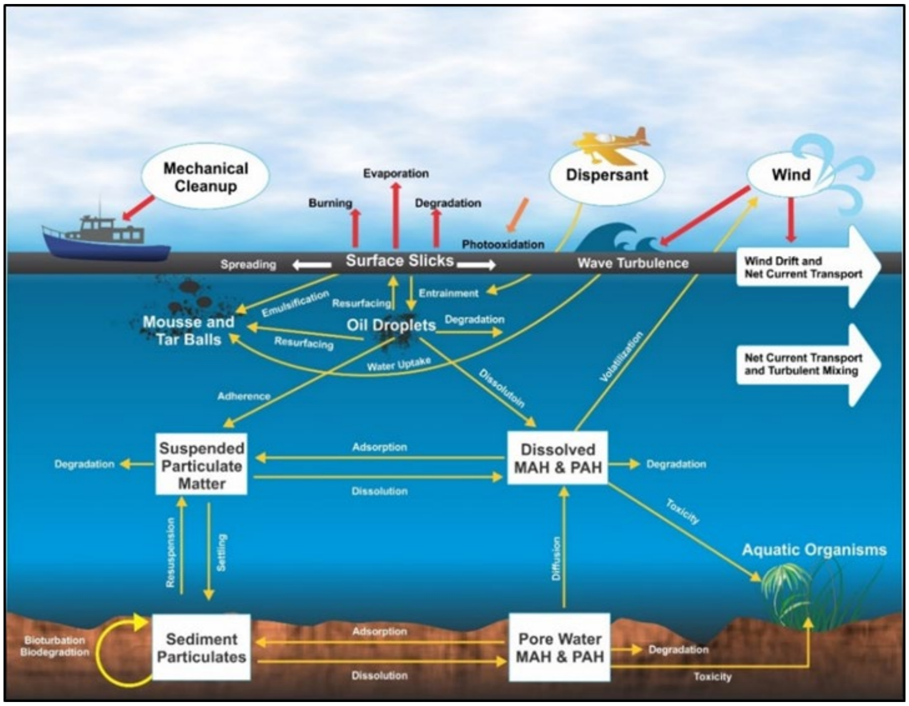


Figure A-1. Simulated oil fates processes in open water.

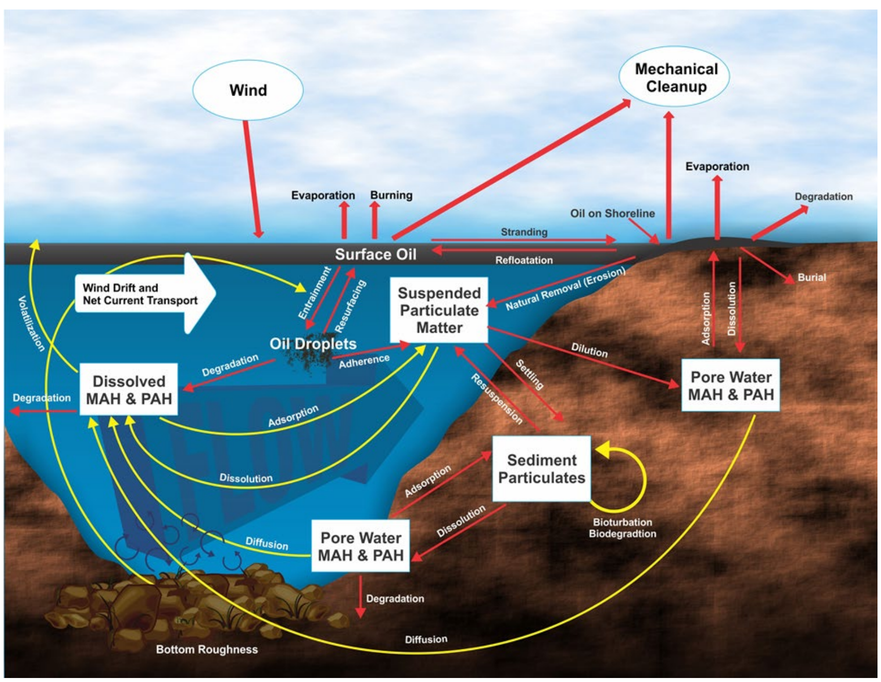


Figure A-2. Simulated oil fates processes at the shoreline.

The schematics in Figures A-1 and A-2 represent oil fates processes that are simulated in the model:

- Spreading is the thinning and broadening of surface slicks caused by gravitational forces and surface tension. This occurs rapidly after oil is spilled on the water surface. The rate of spreading is faster if oil viscosity is lower. Viscosity decreases as temperature increases. Viscosity increases as oil emulsifies.
- Transport is the process where oil is carried by currents.
- Turbulent dispersion: Typically, there are also “sub-scale” currents (not included in the current data), better known as turbulence that move oil and mix it both in three dimensions. The process by which turbulence mixes and spreads oil components on the water surface and in the water is called turbulent dispersion.
- Evaporation is the process where volatile components of the oil diffuse from the oil and enter the gaseous phase (atmosphere). Evaporation from surface and shoreline oil increases as the oil surface area, temperature, and wind speed increase. As lighter components evaporate off, the remaining “weathered” oil becomes more viscous.
- Emulsification is the process where water is mixed into the oil, such that the oil makes a matrix with embedded water droplets. The resulting mixture is commonly called mousse. It is technically referred to as a water-in-oil emulsion. The rate of emulsification increases with increasing wind speed and turbulence on the surface of the water. Viscosity increases as oil emulsifies.
- Entrainment is the process where waves break over surface oil and carry it as droplets into the water column. At higher wind speeds, or where currents and bottom roughness induce turbulence, wave heights may reach a threshold where they break. In open waters, waves break beginning at about 12 knots of wind speed and wave breaking increases as wind speed becomes higher. Thus, entrainment becomes increasingly important (higher rate of mass transfer to the water) the higher the wind speed. As turbulence from whatever source increases, the oil droplet sizes become smaller. Application of chemical dispersant increases the entrainment rate of oil and decreases droplet size at a given level of turbulence. Entrainment rate is slower, and droplet size is larger, as oil viscosity increases (by emulsification and evaporation loss of lighter volatile components). The droplet size determines how fast and whether the oil resurfaces.
- Resurfacing of entrained oil rapidly occurs for larger oil droplets. Smaller droplets resurface when the wave turbulence decreases. The smallest droplets do not resurface, as typical turbulence levels in the water keep them in suspension indefinitely. Local winds at the water surface can also prevent oil from surfacing. Resurfaced oil typically forms sheens. In open water where currents are relatively slow, surface slicks are usually blown down wind faster than the underlying water, resurfacing

droplets come up behind the leading edge of the oil, effectively spreading the slicks in the down-wind direction.

- Dissolution is the process where water-soluble components diffuse out of the oil into the water. Dissolution rate increases the higher the surface area of the oil relative to its volume. As the surface area to volume ratio is higher for smaller spherical droplets, the smaller the droplets the higher the dissolution rate. The higher the wave turbulence, the smaller the droplets of entrained oil. Dissolution from entrained small droplets is much faster than from surface slicks in the shape of flat plates. The soluble components are also volatile, and evaporation from surface slicks is faster than dissolution into the underlying water. Thus, the processes of evaporation and dissolution are competitive, with evaporation the dominant process for surface oil.
- Volatilization of dissolved components from the water to the atmosphere occurs as they are mixed and diffuse to the water surface boundary and enter the gas phase. Volatilization rate increase with increasing air and water temperature.
- Adsorption of dissolved components to particulate matter in the water occurs because the soluble components are only sparingly so. These compounds (MAHs and PAHs) preferentially adsorb to particulates when the latter are present. The higher the concentration of suspended particulates, the more adsorption. Also, the higher the molecular weight of the compound, the less soluble, and the more the compound adsorbs to particulate matter.
- Adherence is the process where oil droplets combine with particles in the water. If the particles are suspended sediments, the combined oil/suspended sediment agglomerate is heavier than the oil itself and heavier than the water. If turbulence subsides sufficiently, the oil-sediment agglomerates will settle.
- Sedimentation (settling) is the process where oil-sediment agglomerates and particles with adsorbed sparingly-soluble components (MAHs and PAHs) settle to the bottom sediments. Adherence and sedimentation can be an important pathway of oil in near shore areas when waves are strong and subsequently subside. Generally, oil-sediment agglomerates transfer more PAH to the bottom than sediments with PAHs that were adsorbed from the dissolved phase in the water column.
- Resuspension of settled oil-sediment particles and particles with adsorbed sparingly-soluble components (MAHs and PAHs) may occur if current speeds and turbulence exceed threshold values where cohesive forces can be overcome.

- Diffusion is the process where dissolved compounds move from higher to lower concentration areas by random motion of molecules and micro-scale turbulence. Dissolved components in bottom and shoreline sediments can diffuse out to the water where concentrations are relatively low. Bioturbation, groundwater discharge and hyporheic flow of water through stream-bed sediments can greatly increase the rate of diffusion from sediments (see below).
- Dilution occurs when water of lower concentration is mixed into water with higher concentration by turbulence, currents, or shoreline groundwater.
- Bioturbation is the process where animals in the sediments mix the surface sediment layer while burrowing, feeding, or passing water over their gills. In open-water soft-bottom environments, bioturbation effectively mixes the surface sediment layer about 10 cm thick (in non-polluted areas).
- Degradation is the process where oil components are changed either chemically or biologically (biodegradation) to another compound. It includes breakdown to simpler organic carbon compounds by bacteria and other organisms, photo-oxidation by solar energy, and other chemical reactions. Higher temperature and higher light intensity (particularly ultraviolet wavelengths) increase the rate of degradation.
- Floating oil may strand on shorelines and refloat as water levels rise, allowing the oil to move further down current (downstream).

For a spill on the water surface, the gravitational spreading occurs very rapidly (within hours) to a minimum thickness. Thus, the area exposed to evaporation is high relative to the oil volume. Evaporation proceeds faster than dissolution. Thus, most of the volatiles and semi-volatiles evaporate, with a smaller fraction dissolving into the water. Degradation (photo-oxidation and biodegradation) also occurs at a relatively slow rate compared to these processes.

Evaporation is more rapid as the wind speed increases. However, above about 12 knots (6 m/s) of wind speed and in open water, white caps begin to form, and the breaking waves entrain oil as droplets into the water column. Higher wind speeds (and turbulence) increase entrainment and results in smaller droplet sizes. From Stokes Law, larger droplets resurface faster and form surface slicks. Thus, a dynamic balance evolves between entrainment and resurfacing. As high-wind events occur, the entrainment rate increases. When the winds subside to less than 12 knots, the larger oil droplets resurface and remain floating. Similar dynamics occur in turbulent streams.

The smallest oil droplets remain entrained in the water column for an indefinite period. Larger oil droplets rise to the surface at varying rates. While the droplets are under water, dissolution of the light and soluble components occurs. Dissolution rate is a function of the surface area available. Thus, most dissolution occurs from droplets, as opposed to from surface slicks, since droplets had a higher surface area to volume ratio, and they are not in contact with the atmosphere (and so the soluble components do not preferentially evaporate as they do from surface oil).

If oil is released or driven underwater, it forms droplets of varying sizes. More turbulent conditions result in smaller droplet sizes. From Stokes Law, larger droplets rise faster, and surface if the water is shallow. Resurfaced oil behaves as surface oil after gravitational spreading has occurred. The surface oil may be re-entrained. The smallest droplets in most cases remain in the water permanently. As a result of the higher surface area per volume of small droplets, the dissolution rate is much higher from subsurface oil than from floating oil on the water surface.

Because of these interactions, the majority of dissolved constituents (which are of concern because of potential effects on aquatic organisms) are from droplets entrained in the water. For a given spill volume and oil type/composition, with increasing turbulence either at the water surface and/or at the sediments: there is an increasing amount of oil entrained; the oil is increasingly broken up into smaller droplets; there is more likelihood of the oil remaining entrained rather than resurfacing; and the dissolved concentrations will be higher. Entrainment and dissolved concentrations increase with (1) higher wind speed, (2) increased turbulence from other sources of turbulence (waves on a beach, rapids, and waterfalls in rivers, etc.), (3) subsurface releases (especially under higher pressure and turbulence), and (4) application of chemical dispersants. Chemical dispersants both increase the amount of oil entrained and decrease the oil droplet size. Thus, chemical dispersants increase the dissolution rate of soluble components.

These processes that increase the rate of supply of dissolved constituents are balanced by loss terms in the model: (1) transport (dilution), (2) volatilization from the dissolved phase to the atmosphere, (3) adsorption to suspended particulate material and sedimentation, and (4) degradation (photo-oxidation or biologically mediated). Also, other processes slow the entrainment rate: (1) emulsification increases viscosity and slows or eliminates entrainment; (2) adsorption of oil droplets to suspended particulate material and settling removes oil from the water; (3) stranding on shorelines removes oil from the water; and (4) mechanical cleanup removes mass from the water surface and shorelines. Thus, the model-predicted concentrations are the resulting balance of all these processes and the best estimates based on our quantitative understanding of the individual processes.

The algorithms used to model these processes are described in French-McCay (2004) and French-McCay et al. (2018). Lagrangian elements (spillets) are used to simulate the movements of oil components in three dimensions over time. Surface floating oil, subsurface droplets, and dissolved components are tracked in separate spillets. Transport is the sum of advective velocities by currents input to the model, surface wind drift, vertical movement according to buoyancy, and randomized turbulent diffusive velocities in three dimensions. The vertical diffusion coefficient is computed as a function of wind speed in the surface wave-mixed layer. The horizontal and deeper water vertical diffusion coefficients are model inputs.

The oil (whole and as pseudo-components) separates into different phases or parts of the environment, i.e., surface slicks; emulsified oil (mousse) and tar balls; oil droplets suspended in the water column; dissolved lower molecular weight components (MAHs and PAHs) in the water column; oil droplets adhered and hydrocarbons adsorbed to suspended particulate matter in the water; hydrocarbons on and in the sediments; dissolved MAHs and PAHs in the sediment pore water; and hydrocarbons on and in the shoreline sediments and surfaces.

A.2 References

Di Toro, D.M., J.A. McGrath and D.J. Hansen, 2000. Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. I. Water and tissue. Environmental Toxicology and Chemistry 19(8): 1951-1970.

French D, Reed M, Jayko K, Feng S, Rines H et al. 1996. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), Technical Documentation, Vol. I–V. Final Report. Washington (DC): USDOI. April 1996. Report No.: PB96-501788. Contract No.: Available from: NTIS, Springfield, VA 22161.

French, D.P. and H. Rines, 1997. Validation and use of spill impact modeling for impact assessment. Proceedings, 1997 International Oil Spill Conference, Fort Lauderdale, Florida, American Petroleum Institute Publication No. 4651, Washington, DC, pp-829-834.

French, D.P., H. Rines and P. Masciangioli, 1997. Validation of an Orimulsion spill fates model using observations from field test spills. Proceedings, Twentieth Arctic and Marine Oil Spill Program Technical Seminar, Vancouver, Canada, June 10-13, 1997.

French-McCay, D.P., 2002. Development and Application of an Oil Toxicity and Exposure Model, OilToxEx. Environmental Toxicology and Chemistry 21(10): 2080-2094.

French-McCay DP. 2003. Development and application of damage assessment modeling: example assessment for the North Cape Oil Spill. Marine Poll Bull. 47(9–12):341–359.

French-McCay DP. 2004. Oil spill impact modeling: development and validation. Environ. Toxicol. and Chem. 23 (10): 2441–2456.

French-McCay, DP, Mueller C, Jayko K, Longval B, Schroeder M et al. 2007. Evaluation of field-collected data measuring fluorescein dye movements and dispersion for dispersed oil transport modeling. In: Proceedings of the 30th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, 5–7 June 2007. Emergencies Science Division Environment Canada; Ottawa, ON, Canada. p. 713–754.

French-McCay, D. K. Jayko, Z. Li, M. Horn, T. Isaji, M. Spaulding. 2018. Volume II: Appendix II - Oil Transport and Fates Model Technical Manual. In: Galagan, C.W., D. French-McCay, J. Rowe, and L. McStay, editors. Simulation Modeling of Ocean Circulation and Oil Spills in the Gulf of Mexico. Prepared by RPS ASA for the US Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2018-039040; 422 p.

Jones RK. 1997. A simplified pseudo-component of oil evaporation model. In: Proceedings of the 20th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, 3–5 June. 1997. Vancouver, British Columbia. Emergencies Science Division, Environment Canada, Ottawa, ON, Canada. p. 43–61.

Lehr, W.J., D. Wesley, D. Simecek-Beatty, R. Jones, G. Kachook and J. Lankford, 2000. Algorithm and interface modifications of the NOAA oil spill behavior model. In Proceedings of the 23rd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Vancouver, BC, Environmental Protection Service, Environment Canada, pp. 525-539.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. I-IV. Lewis Publishers, Inc, Chelsea, Michigan.

Payne, J.R., B.E. Kirstein, G.D. McNabb, Jr., J.L. Lambach, R. Redding R.E. Jordan, W. Hom, C. deOliveria, G.S. Smith, D.M. Baxter, and R. Gaegel, 1984. Multivariate analysis of petroleum weathering in the marine environment – sub Arctic. Environmental Assessment of the Alaskan Continental Shelf, OCEAP, Final Report of Principal Investigators, Vol. 21 and 22, Feb. 1984, 690p.

Payne, J.R., B.E. Kirstein, J.R. Clayton, Jr., C. Clary, R. Redding, G.D. McNabb, Jr., and G. Farmer, 1987. Integration of suspended particulate matter and oil transportation study. Final Report. Minerals Management Service, Environmental Studies Branch, Anchorage, AK. Contract No. 14-12-0001-30146, 216 p.

Stiver, W. and D. Mackay, 1984. Evaporation rate of oil spills of hydrocarbons and petroleum mixtures. Environmental Science and Technology 18: 834-840.

ANNEX B. OIL PROPERTY DATA

B.1 Definitions of Oil Properties

Definitions of the common physical properties for oil are defined below:

Boiling point—The boiling point (BP) of a liquid is the temperature above which it becomes a gas.

Density—the degree of compactness of a substance or the amount of matter of an object relative to its volume. The units are weight per volume, such as g/ml or kg/m^3.

Specific gravity—the ratio of the density of a substance to the density of a standard (water for liquids). This determines if the crude oil would sink or float—a substance with a specific gravity lower than 1 will float in fresh water. API gravity is short for American Petroleum Institute gravity, an inverse measure based on specific gravity that is used to determine the weight of petroleum liquids in comparison to water. If a liquid has API gravity of more than 10 it is considered a light oil that floats on fresh water.

Viscosity—a quantity expressing the magnitude of internal friction or a measure of how easily the oil would flow. The viscosity of crude oil generally increases as the temperature decreases and decreases as temperature increases. As such, the crude oil in the pipeline has more difficulty flowing if it becomes freezing or cold in the winter and requires more pressure to be pumped through the pipeline. Dynamic viscosities measured in centiPoise (cP; 1 centiPoise = 1 millipascal-second, mPa-s) are used in the oil spill model.

Pour Point—the temperature (degrees Celsius, C) below which the liquid loses its flow characteristics. If crude oil has a high pour point, it will be associated with a high paraffin content, which is associated with a large proportion of plant material.

Interfacial Tension—the force that holds the surface of a particular phase together (liquid/liquid or gas/liquid). For oil and seawater, the units are milli-Newton per meter (mN/m).

Mousse water content—maximum percent of water (by volume) in an oil emulsion. Emulsion is the dispersion of droplets of one liquid in another in which it is not soluble. Mousse is a common name for a water-in-oil emulsion.

Octanol-water partition coefficient—An index of relative solubility in water; the octanol-water partition coefficient (Kow) is defined as the ratio of a chemical's concentration in the octanol phase to its concentration in the aqueous phase of a two-phase octanol/water system. Values of Kow are thus, unitless.

SARA—saturates, aromatics, resins and asphaltenes are measured by a SARA analysis (see description of methods by Environment Canada, 2018), with units of percent by weight (% wt).

Toxicity—the degree to which a chemical substance or a particular mixture of substances can adversely affect an organism via its concentration in the organism or surrounding water.

Vapor Pressure— the pressure exerted by a vapor in thermodynamic equilibrium with its condensed phases at a given temperature in a closed system. The vapor pressure is an indication of a liquid's evaporation rate (units used are atm = atmosphere)

B.2 Oil Properties Crude Oil

The crude oil used is a light crude oil due to its low density. Crude oil is refined in the Midwest and Gulf Coast regions in the United States and has an API gravity of about 36 – 43. The API gravity of Gulf crude oil is typically lower than crude oil from Montana, Manitoba, and North and South Dakota, which had an API gravity of about 42 – 43. Bulk properties are listed in Table B-1. The pseudo-component concentrations in the oil, based on distillation data and measured percentages of light aromatic compounds of a typical Gulf of Mexico oil (French-McCay et al. 2018), are listed in Tables B-2 and B-3.

Table B-1. Model inputs for physical-chemical properties of crude oil.

Property	Description	Source	Values
Density	Density (kg/m^3) at 30°C	Stout, 2015	837
API	API gravity	Environment Canada, 2018	37
Viscosity	Viscosity of the oil (cP @ 25°C)	Stout, 2015	8
Pour point	Temperature (degrees C) above which oil is fluid (liquid)	Stout, 2015	-28
Interfacial tension	Oil-seawater interfacial tension (untreated oil; mN/m)	Stout, 2015	19.6
Mousse water content	Maximum percentage of water in mousse (water-in-oil emulsion)	French-McCay et al. (2018) – typical for light crude oil	64
Saturated hydrocarbon content	Based on SARA analysis (weight %)	Environment Canada, 2018	62.6
Aromatic hydrocarbon content	Based on SARA analysis (weight %)	Environment Canada, 2018	3
Asphaltene content	Based on SARA analysis (weight %)	Environment Canada, 2018	0.3
Resin content	Based on SARA analysis (weight %)	Environment Canada, 2018	10.1
Total volatile and semi-volatile fraction	Percentage of oil with boiling points <380°C, which will volatilize (aromatics + aliphatics)	Environment Canada, 2018	63

Table B-2. Fractional composition of crude oil by pseudo-component group of soluble and semi-soluble components. Measured concentrations were summed by pseudo-component group.

Code	Hydrocarbon Pseudo-component	Fraction in Oil (g/g oil)	Molecular Weight (g/mol)	Vapor Pressure (atm, 25°C)	Solubility (mg/L)	log(K_{ow})* (Unitless)
AR1	BTEX, substituted benzenes	0.0293	108	1.78E-02	275	3.24
AR2	2-ring PAHs	0.0050	144	8.46E-04	13	4.29
AR3	3-ring PAHs	0.0103	197	2.07E-06	1	5.25

* K_{ow} = Octanol-water partition coefficient

Table B-3. Fractional composition of crude oil by pseudo-component group of insoluble components. Measured concentrations of soluble components were subtracted from total volatiles in the same boiling curve cuts to calculate the AL component concentrations.

Code	Hydrocarbon Pseudo-component	Fraction in Oil (g/g oil)	Molecular Weight (g/mol)	Vapor Pressure (atm, 25°C)	log(K_{ow})* (Unitless)
AL1	Aliphatics: BP < 180	0.2407	99	9.73E-02	3.46
AL2	Aliphatics: BP 180-280	0.1550	169	1.68E-03	6.47
AL3	Aliphatics: BP 280-380	0.2097	262	7.22E-07	9.91

* K_{ow} = Octanol-water partition coefficient

B.3 References

Environment Canada, 2018. Properties of Crude Oils and Oil Products, Environment Canada, Emergency Science and Technology Division. http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html (Downloaded October 2018).

French-McCay, D., D. Crowley, J. Rowe, M. Bock, H. Robinson, R. Wenning, A. H. Walker, J. Joeckel, and T. Parkerton. 2018. Comparative Risk Assessment of Spill Response Options for a Deepwater Oil Well Blowout: Part I. Oil Spill Modeling. Mar. Pollut. Bull. 133:1001–1015.

Stout, S.A., 2015. Bulk chemical and physical properties of fresh and weathered Macondo crude oil. NewFields Technical Report to the Trustees in support of the pDARP, Available on-line at www.doi.gov/deepwaterhorizon/adminrecord, Report DWH-AR0038585, 11p and Attachment DWH-AR0038567, 18p.