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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
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EXECUTIVE SUMMARY

Since 2005, the Bureau of Ocean Energy Management (BOEM) has been charged with issuing leases on the Outer Continental Shelf for potential renewable energy projects including wind energy. BOEM recognizes that renewable energy development should be managed responsibly. As part of this management responsibility BOEM uses the best available science in their environmental assessments of proposed leases, so that precautions are taken to mitigate potential environmental impacts. The main goal of this study was to assess the environmental risks, fates, and effects of chemical releases, including oils, associated with routine operations and maintenance of offshore wind turbines, as well as catastrophic events (e.g., toppling of one, multiple or all wind turbines, and topple of the electrical service platform). This study does not address spills from vessels transiting through wind facility areas (e.g., spills resulting from the collision of a vessel with wind turbines), nor does it address spills arising from the construction of these facilities. The ultimate goals of this study were to use the best available science to address public concerns on the potential environmental consequences of the release of hazardous material from wind facilities, and to generate information to support future Alternative Energy Programmatic Environmental Impact Statements.

Three specific tasks were addressed in this study. Task 1–Identification of the volumes and types of chemicals (including oil) commonly present in wind turbines designed for offshore use. This task included an evaluation of the environmental fate and partitioning behavior of chemicals of interest, and selection of relevant and catastrophic spill scenarios, with their associated probability of occurrence. Task 2–Identification and evaluation of the models available to predict the fate, transport, behavior, and environmental concentrations of chemicals of interest. Task 3–Assessment of the potential consequences to ecological and socioeconomic resources arising from each spill scenario at three representative offshore wind facilities using the best available models. This tasked included the development of thresholds of concern and the evaluation of currently existing thresholds.

A survey of currently available information indicated that petroleum and mineral oils, as well as a selected number of chemicals (glycols and sulfuric acid), are used in electric service platforms and wind turbine generators. Representative volumes of these oils and chemicals were used to define a series of spill scenarios ranging from spills associated with regular maintenance to catastrophic spills at three areas: a Call Area in North Carolina, and two Wind Energy Areas (WEAs) in Maryland and Rhode Island/Massachusetts. Using a fault tree approach, the combined probabilities of events leading to a release were used to determine the spill probability of each scenario. The highest release probabilities (1 time per month) were in the North Carolina Call Area, resulting from vessel allisions causing small releases of up to several hundred gallons, while at all Call Area/WEAs the probability of catastrophic spills (all oils totaling 129,000 gallons and all chemicals totaling 29,000 gallons) would be very low (1 time in ≥1,000 years).

A thorough review and evaluation of seven models determined that Spill Impact Model Application Package (SIMAP) and Chemical Discharge Model System (CHEMMAP) provide the most comprehensive capabilities of spill impact assessment and, as a result, these two models were used for this study. Model inputs included habitat and depth mapping, winds, currents, chemical composition and properties of the oils and chemicals of interest, and specifications of the release (amount, location, etc.). As part of the consequence analysis, toxic thresholds of concern were derived from existing toxicological information, and SIMAP and CHEMMAP outputs for each spill scenario were integrated into this analysis. This consequence analysis assessed the potential risks to ecological and socioeconomic resources as a function of the probability that an event would occur (spill risk), the probability that a resource would be exposed to the spilled material (exposure risk), and the impacts that the event would have on such resources (impact risk). The most likely types of releases (e.g., up to a few thousand gallons of oils) would cause minimal environmental consequences, which would be limited spatially and temporally to the vicinity of the point of release. By contrast, a catastrophic oil release (128,600 gallons of all oils) would cause, based on realistic and worst case model outputs, moderate environmental consequences to ecological and socioeconomic resources at all locations. However, the probabilities of occurrence of these types of catastrophic releases are extremely small. Furthermore, these consequence analyses used a conservative approach biased towards overestimation of risks, suggesting that conclusions arising from this study are conservative.

Future studies may be refined if additional information on the types and volumes of chemicals used in wind energy facilities becomes publically available or change over time. Also, the results of this study could be used in future environmental assessments to more accurately and quantitatively address the potential environmental consequences of a spill.

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ABBREVIATIONS AND ACRONYMS

AIS	Automatic Identification System
atm	atmosphere
BOEM	Bureau of Ocean Energy Management
BP	boiling point
BTEX	benzene, toluene, ethylbenzene, and xylenes
CEDRE	Center of Documentation, Research, and Experimentation on Accidental Water Pollution
CHARM	Chemical Hazard Assessment and Risk Management
CHEMMAP	Chemical Discharge Model System
CI	confidence interval
CLARA	calculations related to accidental releases in seawater
cm	centimeter
COSIM	Chemical Oil Spill Impact Model
ECCO	Estimating the Circulation and Climate of the Ocean
EcoRARs	ecological resources at risk
EIS	Environmental Impact Statement
EL_{50}	medial effective level concentration
ESI	Environmental Sensitivity Index
ESP	electric service platform
ft	feet
FE	federal endangered
FT	federal threatened
g/cm^3	grams per cubic meter
g/m^2	grams per square meter
HC_5	5th percentile concentration
HQ	hazard quotient
ICE	interspecies correlation estimation
IDLH	immediately dangerous to life or health
ISO	International Standard Organization
km	kilometer
K_{OW}	octanol-water partitioning coefficient
kg/L	kilograms per liter
LC_{50}	median lethal concentration
LL_{50}	medial lethal level concentration
m	meter
MAH	mono-aromatic hydrocarbons
MD WEA	Maryland Wind Energy Area
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter
mi	miles
mm	millimeters
mm^2/s	square millimeters per second
mol/L	moles per liter

mph	miles per hour
MW	megawatt
NAIS	Nationwide AIS
NC	North Carolina
NGDC	National Geographic Data Center
nm	nautical mile
NBDC	National Data Buoy Center
NOAA	National Oceanic and Atmospheric Administration
NRDA	Natural Resource Damage Assessment
NRDAM/CME	NRDA Models for Coastal and Marine Environments
NWS	National Wildlife Refuge
OCS	outer continental shelf
OilToxEx	Oil Toxicity and Exposure Model
OSRAM	Oil Spill Risk Analysis Model
PAH	polycyclic aromatic hydrocarbons
PDMS	polydimethylsiloxane
PEC	predicted environmental concentration
PET	polyethylene terephthalate
PNEC	predicted no effect concentration
POM	Princeton Ocean Model
ppb	parts per billion
ppb-h	parts per billion-hours
ppm	parts per million
ppt	parts per thousand
psu	practical salinity units
RI-MA WEA	Rhode Island and Massachusetts Wind Energy Area
RQ	risk quotient
RY	return years
SAR	structure activity relationship
SE	state endangered
SIMAP	Spill Impact Model Application Package
SRARs	socio-economic resources at risk
SSD	species sensitivity distribution
ST	state endangered
SWS	State Wildlife Sanctuary
µg/g	micrograms per gram
µg/L	micrograms per liters or part per billion
USCG	United States Coast Guard
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VTS	vessel traffic services
WAF	water-accommodated fraction
WCD	worst case discharge
WEA	Wind Energy Area
WEA/AOI	Wind Energy Area/Area of Interest
WTG	wind turbine generators

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Since 2005, the Bureau of Ocean Energy Management (BOEM) has been charged by the Department of the Interior with establishing the regulations for carrying out the responsibilities and authority granted under the Energy Policy Act of 2005 (Public Law 109-58) Section 388, including the implementation of the Outer Continental Shelf Lands Act (43 USC 1337) Section 8(p) provisions. Under this authority, BOEM may issue leases on the Outer Continental Shelf (OCS) for potential renewable energy projects including wind energy. BOEM recognizes that renewable energy development should be managed in a deliberate and responsible manner, keeping both the nation's energy needs and concerns for the marine environment in mind.

The US Department of Energy estimates that more than 900,000 megawatts (MW) of potential wind energy exist off the coasts of the United States (beyond 5 nautical miles [nm]), with more than half of the country's offshore wind potential located off New England and the Mid-Atlantic (Michel et al. 2007). As the use of renewable energy technology, and in particular wind energy, increases on the OCS, there is a need for assessing any potential environmental consequences from routine and catastrophic spills of chemicals, including oils, used in wind facility operations. It is important that BOEM uses the best available science in their environmental assessments of proposed projects, so that all necessary and effective precautions are taken to reduce potential impacts during wind facilities operation.

Individual turbines may contain internal equipment that uses various oils and hydraulic fluids (at volumes ranging from 500 to 1,000 gallons), while wind facilities with a central electric service platform (ESP) for transmission to a land-based substation may house transformers that contain large reservoirs of oil (insulating oil, diesel fuel, and lubricating oil) (Minerals Management Service (MMS) 2009). In the event of a rupture of one or more of the large transformers on the ESP, there is potential for a spill involving hundreds of gallons of electrical insulating oil (~40,000 gallons ESP total) (MMS 2009). For instance, the Cape Wind Energy Project, located on Horseshoe Shoal in Nantucket Sound, has the potential to spill ~67,000 gallons (190 gallons per turbine; 130 turbines) of dielectric fluids (e.g., MIDEL 7131) and oils into the adjacent marine environment (Louisiana State University (LSU) 2011). Detailed analyses of the environmental risks, fates, and effects of chemical spills associated with offshore wind turbines are needed to address public concerns on the environmental consequences of releases from offshore wind facilities. To date, only the Cape Wind Project has detailed analyses of a potential spill (MMS 2009).

As interest for renewable energy (particularly wind energy) projects increases, BOEM will be faced with increased scrutiny to ensure that accidental releases from ESP and wind turbine generators (WTG) do not pose unnecessary risks to aquatic resources, including nearby coastal habitats. It is critical that BOEM uses the best available science and current state of knowledge to address all outstanding concerns regarding chemicals and oils used in offshore wind energy related structures. Consequently, the purpose of this current project is clear:

To review the literature and modeling options available for assessment of the environmental risks, fates, and effects of chemicals, including oils, associated with offshore wind turbines. The results of this study could be used in future environmental assessments to more accurately and quantitatively address the potential effects of a possible spill.

This report provides a detailed consequence analysis of the impacts associated with oil and chemical releases from the ESP and WTGs using a wide range of release scenarios, from realistic to catastrophic.

1.2 STUDY OBJECTIVES

The objectives of this study, by Task, were as follows:

Task 1

- Identify the types of chemicals and volumes commonly present in different types of commercial wind turbines designed for offshore use, including ESPs and WTGs;
- Determine the environmental fate (solubility, volatilization) and partitioning behavior of chemicals of interest;
- Develop realistic exposure scenarios based on environmental models and chemical-specific partitioning behavior;
- Identify relevant and catastrophic spills scenarios, as well as likelihood of spill occurrence associated with the different scenarios, and
- Determine the probability that each of these potential scenarios would occur.

Task 2

- Identify and evaluate the types of models available that, with some certainty, predict the fate, transport, behavior, and environmental concentrations of chemicals of interest.

Task 3

- Assess the acute and sublethal toxicity to various aquatic resources across taxa to chemicals of interest;
- Compare estimated environmental concentrations to taxa-specific thresholds of concern;
- Evaluate the potential environmental consequences through a combination of reviewed literature and available models;
- Identify representative wind facility locations offshore used as test locations for consequence analyses; and
- Assess the temporal and spatial scale of impacts based on wind facility site-specific environmental settings.

A final objective also included a summary of the state of current knowledge and an identification of data gaps.

1.3 STUDY METHODS

1.3.1 Literature Search

In Task 1 of this project, a thorough literature review was undertaken to identify a list of oils and chemicals present in offshore wind facility WTGs and ESP. The team created a catalog of references (information and data) collected during the study. The literature review consisted of the following steps:

- Surveying literature by search engines (Scirus; Google Scholar; Web of Science)
- Surveying environmental and industrial journals (e.g., *Fuel and Energy*, *Renewable Energy, Sustainability*, and *Environmental Science and Technology*)
- Visiting University of Rhode Island Pell Marine Science Library
- Visiting world wide websites of professional societies and associations (e.g., American Wind Energy Association, European Wind Energy Association, American Chemical Society, and American Chemical Council)

Additionally, experts were contacted to gain additional information on the types of chemicals or oils, and their respective quantities. This list of contacts included the following:

- Renewable UK (2012)
- M&I Materials (2012)
- Vestas Wind Systems (2012)
- Pelastar, a division of Glosten Associates (2012)

However, this survey proved unsuccessful because either the candidates did not respond or they were unable to provide information due to privacy issues. As a result, much of the chemical and oil information used for this project was derived from the Cape Wind Energy Project Environmental Impact Statement (EIS) project (MMS 2009) proposed for off the coast of Massachusetts. For the Cape Wind Energy Project, the data on chemical and oil quantities and types were provided by the developers of wind facilities, rather than from manufacturers of the components. All of the information was thoroughly reviewed by stakeholders and environmental risk assessors, including the former Minerals Management Service (MMS). Thus, the Cape Wind project was determined to be the best representative case study on which to obtain this information.

A similar search scheme was used for Task 3. Briefly, toxicological information was gathered via GEOBASE, CSA Environmental Pollution and Management Database, PubMed, WebOfScience, Google Scholar, and other databases with online search capabilities. Search strategies included a combination of keywords by topics of interest (by chemical and/or marine resources). Information sources included selected peer-reviewed articles, gray literature, reports, unpublished data, and ongoing studies. These were acquired from online sources, requested from peers, State and Federal agencies, or acquired through library loans. Additional information acquisition was conducted through personal/telephone contacts and library visits. The subject matter experts exercised their professional judgment to determine the appropriateness of each article, and efforts were made to specifically narrow the scope of the literature review to information sources that would provide a high value to this particular task.

1.3.2 Annotated Bibliography

Of the extensive literature reviewed, only those documents that were considered to be of value and cited in the report were compiled in an electronic annotated bibliography using

EndNote® software. Each record in the database contains the complete citation. EndNote® can be queried by searching on: name, title, authors, date, publisher, journal/periodical, keywords, or any combination thereof. The database contains 193 records.

1.3.3 Study Areas

To assess the impact of potential spills of oils and chemicals, spill risk, exposure risk, and degree of impact were assessed at three representative wind facility locations offshore the Atlantic Outer Continental Shelf. In consultation with BOEM, three locations were chosen as shown in Figure 1.1, including:

(1) Rhode Island-Massachusetts (RI-MA) Wind Energy Area/Area of Interest (WEA/AOI),
(2) Maryland (MD) WEA, and
(3) North Carolina Kitty Hawk Call Area, North Carolina (NC Call Area).

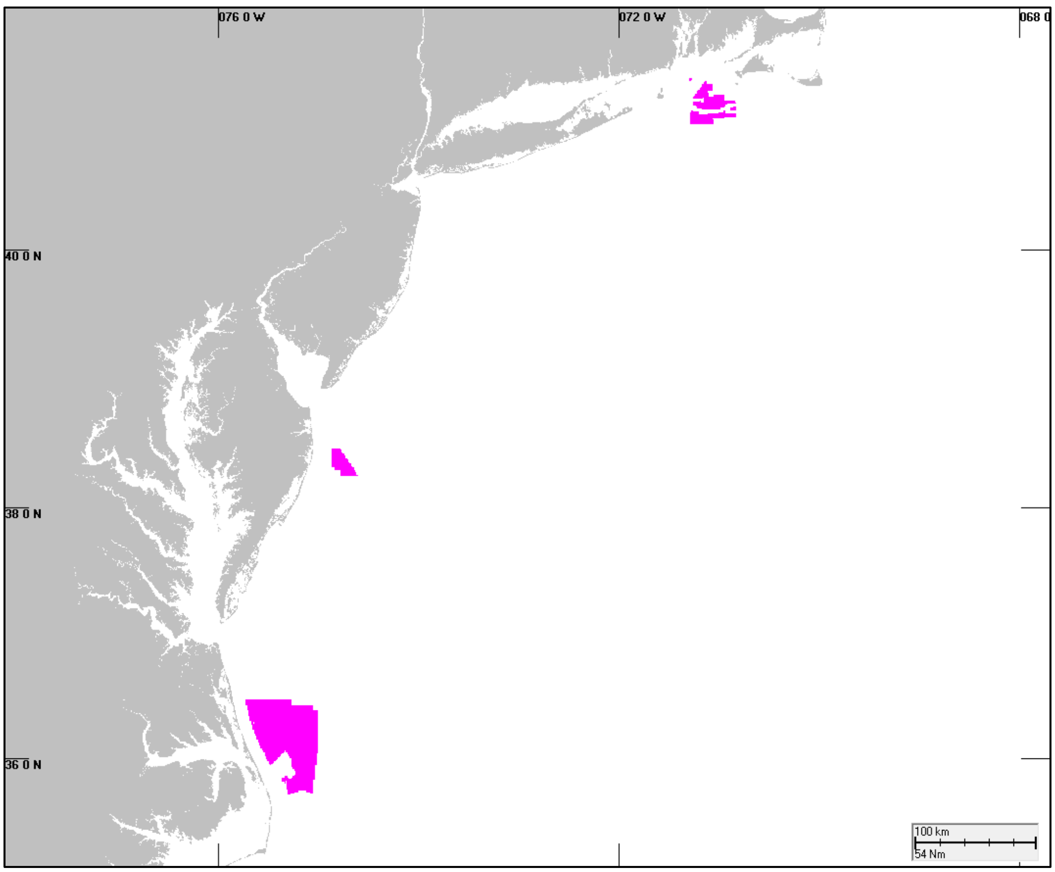

Figure 1.1 Three BOEM Call Area/Wind Energy Area locations used in spill modeling scenarios.

1.4 STRUCTURE OF THE REPORT

This report is divided into seven chapters. Chapter 1 is an Introduction. Chapter 2 is a review of the chemicals, including oils, used in offshore wind facilities in national and international wind facilities. Chapter 3 presents the probability analysis of spill events. Chapter 4 is a review of models that are available for evaluating environmental consequences in case of a hypothetical spill of wind facility chemicals or oils, including spill likelihood risk assessment models, transport and fate models, and biological effects models. Chapter 5 is an assessment of the toxicity data available for selected oils and chemicals associated with offshore wind facilities. Chapter 6 describes the spill modeling approach, spill scenarios and model inputs used for assessing potential spills that could occur at a number of sites along the Atlantic OCS. Chapter 7 presents simulation results and data interpretation of different hypothetical spill scenarios as described in Chapter 5. Chapter 8 summarizes the key points to draw conclusions of the literature review and syntheses results, and offers recommendation for future direction of continued studies. All the references cited are listed in Chapter 9.

2. CHEMICALS AND OILS AND THEIR QUANTITIES USED IN OFFSHORE CALL AND WIND ENERGY AREAS

Different chemicals, including oils may be present in various quantities in offshore wind facilities including WTGs and ESPs or substations. Offshore wind turbine transformers use mineral oils or alternative fluids (such as synthetic ester, natural ester, or silicone fluid) to provide electric insulation and offer a cooling medium that conducts away the heat generated by the transformer (Al-Amin et al. 2013). In a typical offshore wind facility, electricity is generated at a low voltage within the WTG, which is then "stepped up" via a turbine specific transformer and further "stepped up" via a power transformer located on the offshore ESP (MMS 2009). The offshore ESP may house multiple power transformers and carry different types and quantities of dielectrics (MMS 2009). The risks, fates, and effects of the chemicals and oils spilled from offshore WTGs and ESPs are dependent on the types and quantities that are present in different facilities (LSU 2011).

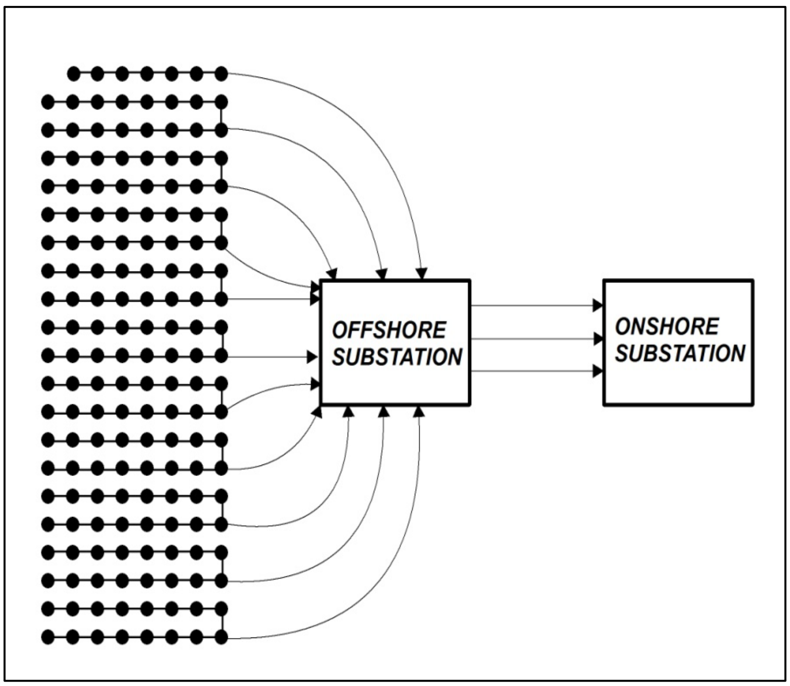

Figure 2.1 500 MW wind facility layout with 3 MW wind turbines (based on Green et al. 2007b).

2.1 OFFSHORE WIND FACILITY TRANSFORMERS

Two types of transformers are typically available including cast-resin transformers and fluid-filled transformers (Al-Amin et al. 2013). Cast-resin transformers use a solid epoxy resin to encapsulate the windings. The use of these transformers is restricted because they are unable to dissipate heat as effectively as fluid. Liquid-filled transformers can be filled with mineral oil or synthetic ester, natural ester, or silicone fluid.

The fundamental difference between the dry-type (e.g., solid epoxy resin) and liquid-filled transformer is the electrical insulation medium that is used. Air/resin is relied on in the dry-type transformer, while paper/liquid insulation is used in the liquid-filled transformer. Until recently, dry-type transformers had been installed in the vast majority of wind turbines due to their good fire behavior and compact dimensions. However, liquid-filled transformers with fire-retardant fluid have also been developed for the multi-megawatt turbines as their performance and reliability makes them well suited to such applications. Conversely, cast-resin transformers are unsuitable for use as high voltage offshore substation transformers. Offshore turbine transformers are located either within the turbine nacelle, turbine tower, or inside a specifically constructed housing unit below the nacelle. In any case, the external transformer cooling medium would be located outside in the marine air, which is humid, salty and variable in temperature.

The use of natural ester fluids as dielectric coolant is less desirable than mineral oil due to inferior oxidation stability and higher values for pour point, permeability and viscosity. Until recently, liquid-filled transformers primarily use mineral oils as the insulating fluid. Mineral oil with high insulating performance and cooling capacity is currently used for liquid-immersed transformers. However, mineral oil is derived from petroleum and has a lower flash point than silicone fluid or ester-based oil.

Table 2.1 provides a list of the top 25 offshore wind facilities that are currently operational, ranked by nameplate capacity. All 25 offshore wind facilities have become operational within the last ten years. Of the total 25 wind facilities, 22 are located in Europe (13 of which are in the UK) and the remaining three were built in China. As shown in Table 2.1, the major offshore facility turbine manufacturers are *Siemens*, *Vestas*, *Repower*, *Goldwind*, and *Sinovel*. The nameplate capacities range from 1.5 to 6 MW, and the majority of the turbines have 3 to 5 MW capacity. In comparison, the Cape Wind Energy Project has a designed maximum power generation capacity of 454 MW with 130 Siemens turbines with a generating capacity of 3.6 MW per turbine (Cape Wind Associates 2013).

Table 2.1
List of top 25 operational offshore wind facilities, ranked by total nameplate capacity (Wikipedia Foundation Inc 2013).

Wind facility	Total (MW)	Country	Turbines and model	Official Start
Greater Gabbard	504	United Kingdom	140 ×Siemens 3.6-107	2012
Walney (phases 1 and 2)	367.2	United Kingdom	102 ×Siemens SWT-3.6-107	2011 (phase 1) 2012 (phase 2)
Sheringham Shoal	315	United Kingdom	88 × Siemens 3.6-107	2012
Thanet	300	United Kingdom	100 × Vestas V90-3MW	2010
Thornton bank (phases 1 and 2)	215	Belgium	6 x REpower 5M, 30 x 6M	2012
Horns Rev II	209	Denmark	91 × Siemens 2.3-93	2009
Rødsand II	207	Denmark	90 × Siemens 2.3-93	2010
Chenjiagang (Jiangsu) Xiangshui	201	China	134 × 1.5MW	2010

Table 2.1 continued

Wind facility	Total (MW)	Country	Turbines and model	Official Start
Lynn and Inner Dowsing	194	United Kingdom	54 × Siemens 3.6-107	2008
Robin Rigg (Solway Firth)	180	United Kingdom	60 × Vestas V90-3MW	2010
Gunfleet Sands	172	United Kingdom	48 × Siemens 3.6-107	2010
Nysted (Rødsand I)	166	Denmark	72 × Siemens 2.3	2003
Bligh Bank (Belwind)	165	Belgium	55 × Vestas V90-3MW	2010
Horns Rev I	160	Denmark	80 × Vestas V80-2MW	2002
Ormonde	150	United Kingdom	30 × REpower 5M	2012
Longyuan Rudong Intertidal Demonstration	150	China	21 × Siemens 2.3-93; 20 ×Goldwind 2.5MW 17 × Sinovel 3W	2011 (phase 1) 2012 (phase 2)
Princess Amalia	120	Netherlands	60 × Vestas V80-2MW	2008
Donghai Bridge	110.6	China	34 × Sinovel SL3000/90 1 × Sinovel SL 5000 1 × Shanghai Electric W3600/116	2010
Lillgrund	110	Sweden	48 × Siemens 2.3-93	2007
Egmond aan Zee	108	Netherlands	36 × Vestas V90-3MW	2006
Kentish Flats	90	United Kingdom	30 × Vestas V90-3MW	2005
Barrow	90	United Kingdom	30 × Vestas V90-3MW	2006
Burbo Bank	90	United Kingdom	25 × Siemens 3.6-107	2007
Rhyl Flats	90	United Kingdom	25 × Siemens 3.6-107	2009
North Hoyle	60	United Kingdom	30 × Vestas V80-2MW	2003

2.2 Types and Quantities of Chemicals and Oils Used on Wind Turbine Generators and Electric Service Platforms

For the Cape Wind Energy Project (Etkin 2006a) it was estimated that 40,000 gallons of electric insulating oil and 1,000 gallons of diesel and other oils would be stored and utilized on the ESP, and up to 200 gallons of turbine and other lubricating oils would be contained in the gearboxes of each of the 130 WTGs. Unlike many other electricity-transmitting cables, there is no oil in the cables that connect the turbines to the ESP or the ESP to the land-based facility. Hence, under an extremely unlikely spill scenario, a total of 68,000 gallons of oil in the entire complex could be release into the environment. Tables 2.2 and 2.3 provide a detailed list of materials that could be present in an ESP and WTG, respectively, as provided in the Cape Wind Energy Project Final EIS (MMS 2009). In addition to the materials listed in Table 2.3, BOEM provided a list of chemicals of concern to the public that may be contained in each WTG (Table 2.4). In total, up to 220 gallons of ethylene and/or propylene glycol, 214 gallons of diesel oil, 370 gallons of biodegradable ester oil, 90 gallons of hydraulic oil, and 220 gallons of gear oil may be present in each WTG (Table 2.4). Note that the dielectric insulating fluid used in the ESPs and WTGs is typically a mineral oil, but natural vegetable oil-based (e.g., soybean oil-based) ester oil (or synthetic ester MIDEL 7131) may also be used (LSU 2011).

Table 2.2
Electric Service Platform (ESP) materials list (MMS 2009).

Component	Fluid Medium Function	Fluid Type	Approximate Quantity
Oil storage (Total volume = 41,210 gallons)			
Four 115 kV power transformers	Insulation/heat transfer	Naphthenic mineral oil	10,000 gallons each 40,000 gallons total
Two diesel engines	Internal component lubrication	Motor oil	5 gallons each 10 gallons total
Two diesel engine day tanks	Emergency generation fuel	Diesel oil	100 gallons each 200 gallons total
One fuel oil storage tank	Emergency generation fuel supply	Diesel oil	1,000 gallons total
Non-oil storage			
Two diesel engine radiators	Heat transfer	Water/glycol	15 gallons each 30 gallons total
Uninterruptible power supply (direct current battery system)	Electrolyte	Sulfuric acid	335 gallons total

Table 2.3
Wind Turbine Generator (WTG) materials list (MMS 2009).

Component	Fluid Medium Function	Fluid Type	Approximate Quantity
Oil storage (total volume = 214.25 gallons):			
Drive train main bearing	Bearing lubrication	Mobil SCH 632	19 gallons
Drive train main bear box	Gear lubrication	Optimol Synthetic A320	140 gallons
Drive train cooling systems	Cooling and lubrication	Optimol Synthetic A320	21 gallons
Hydraulic system brake	Brake fluid	Mobil DTE 25	2 gallons
Hydraulic system rotor lock	Hydraulic fluid	Mobil DTE 25	19 gallons
Hydraulic crane cylinder	Transmission fluid	ATF 66	5 gallons
Yaw system (drive gear)	Gear lubrication	Mobil SHC 630	7 gallons
Pitch system (pitch gear)	Gear lubrication	Mobil SHC XMP 220	0.25 gallon
Pitch system (pitch gear)	Gear lubrication	Mobil SHC XMP 460	1 gallon
Non-oil storage			
Oil coolers	Heat dissipation	Water/glycol	20 gallons total

Table 2.4
Chemicals and oils associated with wind facilities identified as of public concern.

Component	Location	Fluid Medium Function	Fluid Type	Approximate Quantity
Sloshing dampers	Near a turbine's nacelle of wind turbine generator	To dampen motion in offshore wind energy turbines	Ethylene; Propylene glycol	Up to 220 gallons in sealed containers
Transition pieces, grouting	Prefabricated large diameter steel structure standardized for each wind turbine generator	Grouted into place to the foundation monopole of the turbine	Ducorit® D4 by Densit using Quarts sand or Bauxite	Limited in size
Oil	Wind Turbine Generator	Emergency generation fuel	Diesel oil	214 gallons
Transformer oil	WTG	Insulating liquid within each transformer	Biodegradable ester oil	370 gallons
Hydraulic oil	WTG turbine nacelle			90 gallons each
Gear oil	WTG turbine nacelle	Lubrication	Examples: Polyalphaolefin/ ester-based products (Emgard®) Polyalkylene glycol-based products (Plurasafe®) Flender-approved synthetics with bio-based content over 50% (e.g., Delta Oil)[1] (for extreme pressure)	220 gallons total

ESPs are equipped with a number of oil collection systems to prevent oil from being released into the environment in the event of a leak from oil-storing equipment. The entire ESP has sealed leak-proof decks that act as fluid containment. A secondary containment, with a capacity of at least 110% of the primary containment, is provided for the oil-storing equipment on the ESP, including the transformers, diesel engine storage tank, and diesel engines/day tanks. WTGs are equipped with a number of oil collection systems that prevent the release of oil into the environment in the event of a leak. Oil sumps or guide plates are be located underneath the main bearing and oil cooler of each WTG. The collected oil runs into a central oil sump that is integrated into the top tower platform and is collected and disposed of as necessary.

Based on a literature review, the compiled list of additional chemical components in wind turbine structures, not shown in Tables 2.2 through 2.4, is provided in Table 2.5. The substances in Table 2.5 are incorporated into the components of turbines, which are manufactured offsite (i.e., not at the wind facility location). It is not anticipated that any of these components would "leak" or potentially spill into surrounding marine waters as they are no longer in liquid form. For example, the adhesives in the turbine blades are composed of epoxy resins which form from co-reactions of phenol and acetone (each of which have a certain toxicity), but when combined create polyepoxide polymers that harden or "cure." Once the polymer has formed, it cannot

[1] Oil viscosity cSt mm^2/s @ 40°C = 222; mm^2/s @ 100°C = 17.3

easily be broken into phenol and acetone. The polyethylene terephthalate (PET) in the internal foam core structure is a thermoplastic polymer resin (plastic) used in the manufacture of beverage containers and other materials. PET degrades extremely slowly (i.e., the problem with plastics in refuse sites) and is unlikely to leach any components into marine waters unless it burns unexpectedly.

Table 2.5
Types of chemical components in wind turbine structures.

Component	Location	Fluid Medium Function	Fluid Type	Approximate Quantity
Adhesives	Turbine blades	Composition of blades	Phenol (as part of epoxy)	6.6 tonnes in standard 1.5 mW turbine[2]
Adhesives	Turbine blades	Composition of blades	Acetone (as part of epoxy)	2.2 tonnes in standard 1.5 mW turbine
Coatings	Turbine blades	Composition of blades	Not available	Unknown
Internal structure (foam)	Turbine blades	Composition of blades (adds stability)	Polyethylene terephthalate (PET)	Unknown
Concrete additives	Base	Improves stability	Not available	Unknown

2.3 CHARACTERISTICS OF OFFSHORE WIND FACILITY OILS AND CHEMICALS

2.3.1 Physical-chemical Characteristics of Oils

2.3.1.1 Hydrocarbons of Environmental Concern

For modeling purposes, oils are characterized by a number of physical-chemical properties, such as density, viscosity, surface tension, and water content of emulsions (mousse). The oil's content of volatile and semi-volatile aliphatics and aromatics are quantified, grouping volatile and semi-volatile aliphatics and aromatics into three boiling point ranges. The volatile aliphatics rapidly volatilize from surface waters; however, these do not dissolve in measurable amounts, and they have limited influence on the biological effects on water column organisms (French McCay 2002; Mackay et al. 1992a, b, c). The 1- to 4-ring aromatics, as well as cyclic hydrocarbons, that are soluble or semi-soluble compounds in oil, are grouped into three components delineated by vapor pressure and solubility (as measured by the octanol-water partition coefficient (K_{OW}), a measure of hydrophobicity; Table 2.6), so they may be tracked separately in the modeling in order to evaluate potential toxicity of these compounds to water column organisms.

[2] Each turbine's blades contain 10 tonnes of epoxy, which is made from 6.6 tonnes phenol and 2.2 tonnes acetone (Borealis Group 2012).

Table 2.6
Definition of four distillation cuts and the eight components of oils for modeling purposes.

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 (^oC)	< 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	3.9-5.6	> 5.6
Aliphatic components: Number of carbons	volatile aliphatics: $C_4 – C_{10}$	semi-volatile aliphatics: $C_{10} – C_{15}$	low-volatility aliphatics: $C_{15} – C_{20}$	non-volatile aliphatics: > C_{20}
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} < 5.6	≥ 4 ring aromatics: PAHs with Log K_{OW} > 5.6 (very low solubility)

MAH = monoaromatic hydrocarbons; BTEX = benzene + toluene + ethybenzene + xylenes; PAH = polycyclic aromatic hydrocarbons

2.3.1.2 Transformer Mineral Oils

Petroleum-based transformer fluids are normally divided in two categories: 1) paraffin-rich oils, and 2) naphthene-rich oils. Paraffin-rich oils are used primarily in Canada, Japan, and Sweden, whereas naphthene-rich oils are exclusively used in the United States and most other countries (Kaplan et al. 2010).

Based on the analysis of an electric insulating oil sample of Naphthenic Base Stock (Ergon Refining, Inc.; sample ID 08F1801), the initial boiling point (BP) at 50% and final BP corresponding to the Carbon numbers of 12, 18, and 28 were 269^{o}F, 607^{o}F, and 817^{o}F, respectively (Kaplan et al. 2010). Additionally, the analytes of polycyclic aromatic hydrocarbons (PAHs) were reported for each compound present in all samples analyzed (Kaplan et al. 2010). Using the Naphthenic Base Stock sample measured concentration, the estimated Aromatics 1(AR1), Aromatics 2 (AR2), and Aromatics 3 (AR3) fractions were 0, 56.2, and 234.6 mg/kg (or expressed as mass fraction as 0, 0.0000562, and 0.0002346), respectively.

2.3.1.3 Hydraulic Fluid

Three oil samples analyzed by Wang et al., (2002) are considered representative of hydraulic-fluid type oil. The hydrocarbons of the samples were determined mainly in the carbon range from C_{20} to C_{37}. Detailed chemical characterization by Wang et al., (2002) indicate that the samples only contained trace benzene, toluene, ethylene, and xylenes (BTEX) and other lighter C_3-benzene compounds. The concentrations of target PAHs in the samples were found to be very low. The total of the five target alkylated PAHs and other US Environmental Protection Agency (USEPA) priority PAHs were determined to be between 6.4 and 6.5 micrograms per gram (µg/g) of oil for the three oil samples. The 2-ring compound biphenyl was the most abundant, and no high-molecular-weight (4-to-6 ring) PAHs were detected. Based on these conclusions, the amounts of the three aromatic fractions of a typical hydraulic fluid are summarized in Table 2.7. Additional information about the composition of mineral oil and hydraulic fluid can be found in several other sources (e.g., Anderson et al. 2003; Kaplan et al. 2010; Wang et al. 2002). A complete list of properties of the oils used for modeling scenarios is provided in Appendix A.

Table 2.7

Summary of the three aromatic ring (AR*) fractions of a typical hydraulic fluid (Wang et al. 2002).

Component	AR1	AR2	AR3	Residual
Mass fraction	0	0.000005	0.0000015	1.0

*AR1: mono-ring aromatics; AR2: 2-ring polycyclic aromatics; AR3: 3-ring polycyclic aromatics; Residual: 4- and more-ring aromatics and high molecular weight aliphatics.

2.3.2 Physical-chemical Characteristics of Chemicals

The physical behavior of several classes of chemicals (listed in Tables 2.8 and 2.9) has been defined based on the chemical properties (density, water solubility, and vapor pressure) (French McCay et al. 2008), as these properties control the rates of weathering processes in the environment, and so are important for the transport and fate modeling of chemicals. For instance, for a chemical with moderate or low water solubility, its density relative to water determines whether it initially floats or sinks. If water solubility is high, the chemical quickly dissolves before floating or sinking and is diluted in the water column. Similarly, volatilization (a function of vapor pressure of the spilled chemical) strongly influences the resulting fate and concentration of the chemical because a volatile chemical can experience a significant loss from water after a spill within a short time frame.

Table 2.8

Definitions used to classify the physical behavior of chemicals.

Buoyancy in Water	Solubility Behavior	Volatility
Floater: Density < 1.0 g/cm^3	Highly soluble: Solubility > 1,000 µg/g	Highly volatile: vapor pressure > 10^{-3} atmospheres (atm)
Neutral: Density 1.01-1.03 g/cm^3	Soluble: Solubility 100 – 1,000 µg/g	Semi-volatile: vapor pressure 10^{-7} - 10^{-3} atm
Sinker: Density > 1.03 g/cm^3	Semi-soluble: Solubility 1 - 100 µg/g	Non-volatile: vapor pressure < 10^{-7} atm
	Insoluble: Solubility < 1 µg/g	Non-volatile: vapor pressure << 10^{-7} atm

Table 2.9

Classification of physical behavior of chemicals.

Class	Buoyancy in Water	Solubility Behavior	Volatility	Example Chemical(s) Modeled
1	Floater	Highly soluble	Highly volatile	Benzene, Methyl ethyl ketone (MEK)
2	Floater	Semi-soluble	Highly volatile	Styrene
3	Sinker	Highly soluble	Highly volatile	Trichloroethylene (TCE)
4	Sinker	Highly soluble	Semi-volatile	Ethylene glycol
5	Sinker	Soluble	Highly volatile	Carbon tetrachloride
6	Sinker	Semi-soluble	Semi-volatile	Naphthalene
7	Sinker	Highly soluble	Non-volatile	
8	Neutrally buoyant	(assumed soluble)	(assumed zero)	Conservative Chemical, 10% Aqueous Solution

Table 2.10 lists the three chemicals that are stored and used in an offshore wind facility, WTG or ESP. Glycols are used as coolant, anti-freezer and sloshing damper, while sulfuric acid is required as an electrolyte. All three chemicals belong to Class #4 following their physical properties; therefore, these are all sinking, highly soluble, and semi-volatile chemicals. A complete list of the properties of the chemicals used for the modeling scenarios are provided in Appendix A.

Table 2.10
Chemical properties of chemicals stored and used in offshore wind facilities.

Chemical Name	Molecular Formula	CAS Number	State at 25°C and 1 atm	Density of pure chemical (g/cm^3)	Solubility (in pure water, mg/L)	Vapor pressure (atm at 25°C)	Physical Behavior Class*
Ethylene Glycol	$HOCH_2CH_2OH$	107-21-1	Liquid	1.14	1,000,000	1.18E-04	4
Propylene Glycol	$CH_3CHOHCH_2OH$	57-55-6	Liquid	1.036	1,000,000	2.11E-04	4
Sulfuric Acid	H_2SO_4	7664-93-9	Liquid	1.84	1,000,000	1.32E-06	4

* See Table 2.9

2.4 SUMMARY OF OILS AND CHEMICALS USED IN WIND TURBINES

Given data presented in Tables 2.2 to 2.10, oils and hazardous materials that were assessed in the evaluation of potential consequences in this project are:

- Petroleum distillate oils (mineral oil, diesel, hydraulic fluids, lubricating oil, gear oils);
- Biodegradable ester oil (e.g., vegetable oil, biodiesel, and commercial product dielectric fluid MIDEL$^{@}$ 7131);
- Electrolytes (sulfuric acids); and
- Anti-freezers (ethylene or propylene glycol).

A summary of the types and quantities of oils and chemicals used in WTGs is provided in Table 2.11.

Table 2.11
Summary of oil and chemicals types used in offshore wind facilities.

Type	Oil or Chemical Component	Location	Fluid Medium Function	Fluid Type	Quantity (gallons, per unit)	Number of Units	Total Quantity (gallons)
Oil	Transformer oil	ESP	Insulation/heat transfer	Mineral oil or ester oil	10,000	4	40,000
Oil	Motor oil	ESP	Internal component lubrication	Motor oil	5	2	10

Table 2.11 continued

Type	Oil or Chemical Component	Location	Fluid Medium Function	Fluid Type	Quantity (gallons, per unit)	Number of Units	Total Quantity (gallons)
Oil	Diesel oil	ESP	Emergency generation fuel supply	Diesel oil	1,200	1	1200
Chemical	Glycol/water	ESP	Heat transfer	Glycol	15	2	30
Chemical	Sulfuric acid	ESP	Electrolyte	Battery	335	1	335
Oil	Diesel oil	WTG	Emergency generation fuel	Diesel oil	214	130	27,820
Oil	Transformer oil	WTG	Insulating liquid within each transformer	Ester oil	370	130	48,100
Oil	Hydraulic oil	WTG			90	130	11,700
Oil	Gear oil	WTG	Lubrication	Examples: Polyalphaolefin/ ester-based products (Emgard®) Polyalkylene glycol-based products (Plurasafe®) Flender-approved synthetics with bio-based content over 50% (e.g., Delta Oil)[3] (for extreme pressure)	220	130	28,600
Chemical	Glycol	WTG	Dampening	Ethylene/ propylene glycol	220	130	28,600

2.5 OIL AND CHEMICAL SPILL SCENARIO MATRICES

In consultation with BOEM, ten oil spill scenarios (Table 2.12) were selected for modeling at each of the three wind facility locations. Scenarios ESP-Nap-500 to ESP-Nap-40K were chosen to simulate impacts from a dielectric fluid spill from an ESP at different spill volumes. The spill volumes modeled ranged from a small volume (500 gallons) transformer maintenance and/or transfer release to a large-scale spill of the maximum amount of the dielectric fluid (40,000 gallons) stored within four transformers at an ESP. Scenario ESP-Diesel-2K was a 2,000 gallon release of diesel oil from an ESP as a result of an impact accident, maintenance, or transfer. This volume would be the maximum of a two-day tank's storage.

[3] Oil viscosity cSt mm^2/s @ 40°C = 222; mm^2/s @ 100°C = 17.3

Scenarios WTG-Hyd-90 to WTG-Lub-220 represents the spill of hydraulic oil (90 gallons), transformer oil (370 gallons), or gear oil (220 gallons), respectively, as a result of an offshore WTG nacelle impact accident from a single WTG unit. Impact accidents represented by these scenarios include allision from a vessel, toppling during a major storm, or toppling during a seismic event (earthquake). For WTG-Lub-220, examples of gear oil to be spilled include Polyalphaolefin/ ester-based products (Emgard®); Polyalkylene glycol-based products (Plurasafe®); Flender-approved synthetics with bio-based content over 50% (e.g., Delta Oil) (for extreme pressure).

Table 2.12

Potential volumes for modeling of impacts of wind turbine-related oil spills.

Scenario Name	Oil Type	Situation	Volume (gallons)
ESP-Nap-500	Naphthenic mineral oil	ESP transformer maintenance/transfer (small)	500
ESP-Nap-1K	Naphthenic mineral oil	ESP transformer maintenance/transfer (large)	1,000
ESP-Nap-10K	Naphthenic mineral oil	ESP transformer impact accident (one transformer)	10,000
ESP-Nap-40K	Naphthenic mineral oil	ESP transformer impact accident (four transformers)	40,000
ESP-Diesel-2K	Diesel	ESP transformer impact accident (two day tanks) during maintenance/transfer	2,000
WTG-Hyd-90	Hydraulic oil	WTG nacelle impact accident	90
WTG-Nap-370	Transformer oil	WTG nacelle impact accident	370
WTG-Lub-220	Gear oil	WTG nacelle impact accident	220
5WTG-Mix1-3400	WEA Perimeter Allision Worst case	5 WTGs	450: hydraulic oil 1,850: transformer oil 1,100: gear oil
All-Mix2-129K	Worst case (Catastrophic) Discharge	ESP + 130 WTGs, all oils (e.g., hurricane)	128,600

Scenario 5WTG-Mix1-3.4K represents the largest WEA perimeter allision[4], which would involve the release of all of the contents of five WTGs. This scenario would occur if a large tanker (or other large vessel) were to allide with five WTGs on the perimeter of the WEA. The larger tankers take about 8 km to come to a complete stop when going at full-speed. This could conceivably take out 15 WTGs if they are positioned about 630 m apart (as is the case for the planned Cape Wind Energy Project, MMS 2009). However, it is assumed that tankers would be able to do some corrective steering to avoid hitting 15 WTGs, hitting approximately 5 of them, or that vessels would have been slowed down before reaching the first WTG with some visual or radar detection of the upcoming obstacles.

[4] An allision occurs when a moving object strikes a stationary object (e.g., a vessel strikes a pier). This is distinct from a collision, which occurs when two moving objects hit each other.

Scenario All-Mix2-129K represents a catastrophic release[5] of all available oils (128,600 gallons) from the entire wind facility (WTGs and ESP), including dielectric fluids and other oils.

In addition, four chemical spill scenarios were selected for modeling at each of the three wind facility locations (Table 2.13). Scenario WTG-Gly-440 simulates a release of glycol-based coolant (glycols, 440 gallons) from a WTG unit including the sloshing damper. Scenarios ESP-Gly-30 and ESP-Sulf-335 represents accidental releases of transformer coolant (glycols, 30 gallons) and electrolyte (sulfuric acid, 335 gallons) from an ESP transformer impact accident. WCD-Chems-29K represents the largest release scenario of multiple chemical spills from all 130 units of WTGs combined with those from the ESP; thus, the total amount of chemicals released would include 28,630 gallons of glycols and 335 gallons of sulfuric acid.

Table 2.13

Potential spill volumes for modeling of impacts of wind turbine-related chemical spills.

Scenario Name	Chemical Type	Situation	Volume (gallons)
WTG-Gly-440	Ethylene or propylene glycol	WTG nacelle impact accident (includes sloshing damper)	440
ESP-Gly-30	Ethylene glycol	ESP transformer impact accident	30
ESP-Sulf-335	Sulfuric acid	ESP transformer impact accident	335
WCD-Chems-29K	Worst case discharge	ESP + 130 WTGs, glycols (e.g., hurricane)	28,630: glycols + 335: sulfuric acid

[5] For the purpose of this analysis, a catastrophic release is conceptually different from a *worst case* model simulation. The latter is defined in Section 7.2 as the model simulation for each release scenario that results in the maximum model output causing the maximum degree of impacts to ecological and socio-economic resources.

3. PROBABILITY ANALYSIS OF SPILL EVENTS

Risk is the product of the impacts of an event and the probability that that event will occur. In this study, the "event" is a spill that occurs as a result of one of a number of potential occurrences. There are two main types of occurrences:

- Impact events, including allisions[6] from a vessel (i.e., a vessel hitting the structure), earthquakes, tsunamis (strong waves), or storms (e.g., hurricanes); and
- Maintenance and transfer accidents.

3.1 PROBABILITY ANALYSIS APPROACH

For the wind facility components (WTGs and ESPs) in each of the study locations, the potential spill scenarios that were analyzed are summarized in Table 3.1. For each of these events, there is a probability of occurrence, *P(wfcv)*, defined as the likelihood that the event will occur in a given year. This probability is described by the variable *P(wfcv)*, where *w* = wind energy area (RI-MA (*r*), MD (*m*), NC (*n*)), *f* = fluid type (*f* = naphthenic oil (*n*); diesel (*d*); hydraulic oil (*h*); lubricating oil (*l*); oil mixture 1 (*m1*); oil mixture 2 (*m2*); glycol (*g*); sulfuric acid (*s*); chemical mix (*mc*)), *c* = event type (cause) (ESP maintenance/transfer (*mt*); ESP impact (*ei*); WTG impact (*wi*); WEA perimeter allision (*pa*); worst case discharge (*wcd*)[7], and *v* = total spill volume (in gallons) (*k* = 1,000).

Table 3.1
Scenarios for oil and chemical spills from wind turbines.

Scenario Name	WEA/ Call Area (*w*)	Fluid Type (*f*)	Event Type (Cause) (*c*)	Volume (*v*, gallons)	P Variable
RI-MA-ESP-Nap-500	RI-MA	Naphthenic Oil 12-260	ESP maintenance/ transfer (small)	500	$P(w_r f_n c_{mt} v_{500})$
RI-MA-ESP-Nap-1K	RI-MA	Naphthenic Oil 12-260	ESP maintenance/ transfer (large)	1,000	$P(w_r f_n c_{mt} v_{1k})$
RI-MA-ESP-Nap-10K	RI-MA	Naphthenic Oil 12-260	ESP impact[8] (one transformer)	10,000	$P(w_r f_n c_{ei} v_{1k})$
RI-MA-ESP-Nap-40K	RI-MA	Naphthenic Oil 12-260	ESP impact (four transformers)	40,000	$P(w_r f_n c_{mt} v_{40k})$
RI-MA-ESP-Diesel-2K	RI-MA	Diesel 2002 12-260	ESP impact (2 day tanks) or maintenance/transfer	2,000	$P(w_r f_d c_{ei} v_{2k})$
RI-MA-WTG-Hyd-90	RI-MA	Hydraulic Oil 12-260	WTG impact	90	$P(w_r f_h c_{wi} v_{90})$

[6] An allision differs from a collision in that one of the two objects is stationary. In this case, the vessel is moving and the wind farm component (WTG or ESP) is stationary.
[7] Used here in a different context than *worst case* model simulations described in Section 7.2
[8] Impact accidents can also occur by allision from a vessel (i.e., a vessel hitting the structure), an earthquake, a tsunami, or a strong storm event (hurricane).

Table 3.1 continued

Scenario Name	WEA/ Call Area (*w*)	Fluid Type (*f*)	Event Type (Cause) (*c*)	Volume (*v*, gallons)	P Variable
RI-MA-WTG-Nap-370	RI-MA	Naphthenic Oil 12-260	WTG impact; oil case	370	$P(w_r f_n c_{wi} v_{370})$
RI-MA-WTG-Lub-220	RI-MA	Lubricating Oil 2 -12-260	WTG impact; gear oil case	220	$P(w_r f_l c_{wi} v_{220})$
RI-MA-5WTG-MIX1-3400	RI-MA	Oil Mixture 1 12-260	WEA perimeter allision WCD: 5 WTGs	3,400	$P(w_r f_{m1} c_{pa} v_{3400})$
RI-MA-All-Mix2-129K	RI-MA	Oil Mixture 2 12-260	WCD: ESP + 130 WTGs, all oils	128,600	$P(w_r f_{m2} c_{wcd} v_{128.6k})$
MD-ESP-Nap-500	MD	Naphthenic Oil 12-260	ESP maintenance/ transfer (small)	500	$P(w_m f_n c_{mt} v_{500})$
MD-ESP-Nap-1K	MD	Naphthenic Oil 12-260	ESP maintenance/transfer (large)	1,000	$P(w_m f_n c_{mt} v_{1k})$
MD-ESP-Nap-10K	MD	Naphthenic Oil 12-260	ESP impact (one transformer)	10,000	$P(w_m f_n c_{ei} v_{1k})$
MD-ESP-Nap-40K	MD	Naphthenic Oil 12-260	ESP impact (four transformers)	40,000	$P(w_m f_n c_{mt} v_{40k})$
MD-ESP-Diesel-2K	MD	Diesel 2002 12-260	ESP impact (2 day tanks) maintenance/transfer	2,000	$P(w_m f_d c_{ei} v_{2k})$
MD-WTG-Hyd-90	MD	Hydraulic Oil 12-260	WTG impact	90	$P(w_m f_h c_{wi} v_{90})$
MD-WTG-Nap-370	MD	Naphthenic Oil 12-260	WTG impact; oil case	370	$P(w_m f_n c_{wi} v_{370})$
MD-WTG-Lub-220	MD	Lubricating Oil 2 -12-260	WTG impact; gear oil case	220	$P(w_m f_l c_{wi} v_{220})$
MD-5WTG-MIX1-3400	MD	Oil Mixture 1 12-260	WEA perimeter allision WCD: 5 WTGs	3,400	$P(w_m f_{m1} c_{pa} v_{3400})$
MD-All-Mix2-129K	MD	Oil Mixture 2 12-260	WCD: ESP + 130 WTGs, all oils	128,600	$P(w_m f_{m2} c_{wcd} v_{128.6k})$
NC-ESP-Nap-500	NC	Naphthenic Oil 12-260	ESP maintenance/ transfer (small)	500	$P(w_n f_n c_{mt} v_{500})$
NC-ESP-Nap-1K	NC	Naphthenic Oil 12-260	ESP maintenance/ transfer (large)	1,000	$P(w_n f_n c_{mt} v_{1k})$
NC-ESP-Nap-10K	NC	Naphthenic Oil 12-260	ESP impact (one transformer)	10,000	$P(w_n f_n c_{ei} v_{1k})$
NC-ESP-Nap-40K	NC	Naphthenic Oil 12-260	ESP impact (four transformers)	40,000	$P(w_n f_n c_{mt} v_{40k})$
NC-ESP-Diesel-2K	NC	Diesel 2002 12-260	ESP impact (2 day tanks) maintenance/transfer	2,000	$P(w_n f_d c_{ei} v_{2k})$
NC-WTG-Hyd-90	NC	Hydraulic Oil 12-260	WTG impact	90	$P(w_n f_h c_{wi} v_{90})$
NC-WTG-Nap-370	NC	Naphthenic Oil 12-260	WTG impact; oil case	370	$P(w_n f_n c_{wi} v_{370})$

Table 3.1 continued

Scenario Name	WEA/ Call Area (w)	Fluid Type (f)	Event Type (Cause) (c)	Volume (v, gallons)	P Variable
NC-WTG-Lub-220	NC	Lubricating Oil 2 -12-260	WTG impact; gear oil case	220	$P(w_n f_l c_{wi} v_{220})$
NC-Perim-Mix1-3400	NC	Oil Mixture 1 12-260	WEA perimeter allision WCD: 5 WTGs	3,400	$P(w_n f_{m1} c_{pa} v_{3400})$
NC-All-Mix2-129K	NC	Oil Mixture 2 12-260	WCD: ESP + 130 WTGs, all oils	128,600	$P(w_n f_{m2} c_{wcd} v_{128.6k})$
RI-MA-WTG-Gly-440	RI-MA	Glycol[9]	WTG impact	440	$P(w_r f_g c_{wi} v_{440})$
RI-MA-ESP-Gly-30	RI-MA	Glycol	ESP impact	30	$P(w_r f_g c_{ei} v_{30})$
RI-MA-ESP-Sulf-335	RI-MA	Sulfuric acid	ESP impact	335	$P(w_r f_h c_{ei} v_{335})$
RI-MA-WCD-Chems-29K	RI-MA	Chemical mix[10]	WCD: ESP + 130 WTGs, all chemicals[11]	28,695	$P(w_r f_{mc} c_{wcd} v_{28.7k})$
MD-WTG-Gly-440	MD	Glycol	WTG impact	440	$P(w_m f_g c_{wi} v_{440})$
MD-ESP-Gly-30	MD	Glycol	ESP impact	30	$P(w_m f_g c_{ei} v_{30})$
MD-ESP-Sulf-335	MD	Sulfuric acid	ESP impact	335	$P(w_m f_h c_{ei} v_{335})$
MD-WCD-Chems-29K	MD	Chemical mix	WCD: ESP + 130 WTGs, all chemicals	28,695	$P(w_m f_{mc} c_{wcd} v_{28.7k})$
NC-WTG-Gly-440	NC	Glycol	WTG impact	440	$P(w_n f_g c_{wi} v_{440})$
NC-ESP-Gly-30	NC	Glycol	ESP impact	30	$P(w_n f_g c_{ei} v_{30})$
NC-ESP-Sulf-335	NC	Sulfuric acid	ESP impact	335	$P(w_n f_h c_{ei} v_{335})$
NC-WCD-Chems-29K	NC	Chemical mix	WCD: ESP + 130 WTGs, all chemicals	28,695	$P(w_n f_{mc} c_{wcd} v_{28.7k})$

3.1.1 Basic Approach to Probability Analysis

The probability that a spill of any of the oils or chemicals of concern will occur is dependent on a series of event probabilities. Each fluid type and spill cause combination (e.g., dielectric fluid spill due to hurricane impact) needs to be analyzed with regard to the probability that the incident would occur (i.e., the probability that there would be a catastrophic event, such as a hurricane, that would be of sufficient magnitude to cause a turbine to topple), that the incident would result in a spill, and that the spill would be of a particular type of fluid, as shown in the simplified example for hurricanes in Figure 3.1.

The probability that a spill of fluid *i* would occur due to a hurricane is the product of the probabilities of all of the events leading to a spill as in Equation 3.1:

$$P(hts_v f_i) = P(h) \cdot P(t) \cdot P(\mathrm{s}_v) \cdot P(f_i) \tag{3.1}$$

[9] Ethylene or propylene glycol

[10] Glycol + sulfuric acid

[11] 28,630 gallons glycol + 335 gallons sulfuric acid

Where, h = hurricane, t = toppling of wind turbines; s = spill; f_i = fluid of type i; and v = spill volume (vs = small spill; vl = large spill). The probability of a failure event is typically dependent on a constant failure rate, λ, and the exposure time, t, as in Equations 3.2 and 3.3:

(3.2) $$P = 1 - \exp(-\lambda t)$$

(3.3) $$P \approx \lambda t, \lambda t < 0.1$$

The probabilities can be calculated as the incident rate of the scenario on an annual basis. This can then be calculated as the probability of the scenario occurring over the course of a longer period of time, such as over the course of 20 to 30 years, as in Equation 3.4. The incident rates can also be expressed in "return years" (RY), which is the amount of time (in years) that it would generally take for the incident to occur once, as in Equation 3.5.

(3.4) $$P(event)_t = \frac{N_{event}}{t}$$

(3.5) $$RY = \frac{1}{N_{event}}, t = 1 year$$

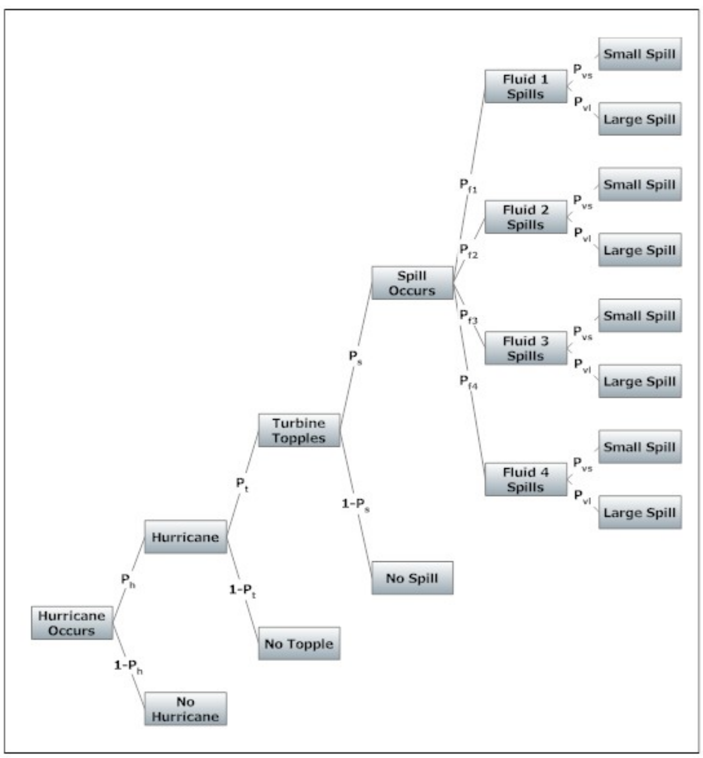

Figure 3.1 Event probabilities for hurricanes shown as a fault tree (P = probability; h = hurricane; t = toppling of wind turbine; s = spill; fi = fluid, i; v = spill volume; vs = small spill; vl = large spill).

3.1.2 Fault Tree Analysis

The series of event probabilities is analyzed by means of a "fault tree", which is based on Boolean logic, i.e., a statement (e.g., "There was an oil spill," or "A vessel allided with the wind turbine generator.") is either true or false, except that there are also probabilities associated with the "true" and "false" determinations. The fault tree combines a series of lower-level failure events to determine the likelihood of a "system failure". In this study, the system failure is the spill of oil or chemicals from one or more of the wind facility components.

With the wind facility, the system functions properly when there is no spill. That is, there are no hurricanes, earthquakes, or vessel allisions causing impacts to the wind facility, and there are no errors that occur during maintenance and oil transfer operations. If one of the components of the system "fails", there is the possibility of oil spillage.

In a simple fault tree, there are events that have probabilities of occurrence, e.g., the probability that a vessel will allide with a wind turbine generator within a particular time frame. The probabilities of a series of events occurring are characterized by "gates" that represent whether two or more events are all required for the failure to occur ("AND" gate), or if the events independently can cause the failure to occur ("OR" gate). The probability that both events occur is the product of the probabilities of the two events, as in Equation 3.6. For example, the probability that a tanker allides with a WTG *and* the impact is strong enough to cause a spill, is the probability of the allision times the probability of the degree of impact.

(3.6) $$P(AandB) = P(A \cap B) = P(A) \cdot P(\mathrm{B})$$

The probability that two independent events occur to cause a failure ("OR" gate) is represented by Equations 3.7 and 3.8:

(3.7) $$P(AorB) = P(A \bigcup B) = P(A) + P(B) - P(A \bigcap B)$$

(3.8) $$P(AorB) = P(A) + P(B), \mathrm{P(A \bigcap B)} \approx 0$$

Fault trees are typically depicted as a form of flow chart, as shown in Figure 3.2.

The probabilities of the output event of the OR- and AND-gates are calculated according to the equations below, where P_i is the probability of the input events (i) to the gates, as in Equations 3.9 and 3.10.

(3.9) $$P_{occurrenceOR} = 1 - \prod_i (1 - P_i)$$

(3.10) $$P_{occurrenceAND} = \prod_i P_i$$

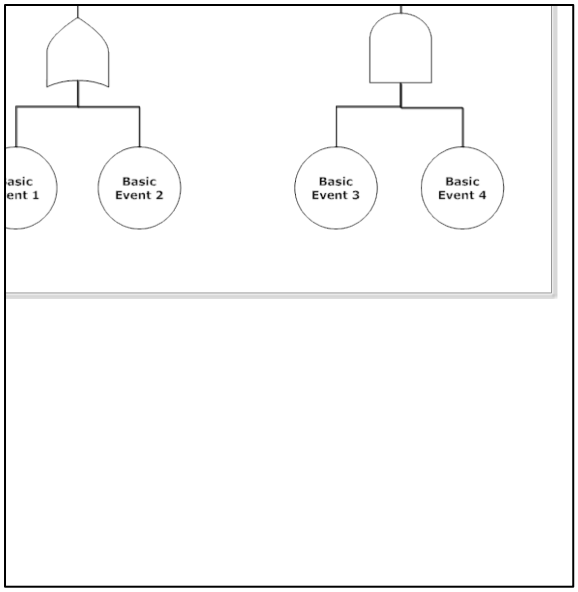

Figure 3.2 Basic fault tree design.

3.1.3 Incorporation of Monte Carlo Simulation

Given that there is some uncertainty and variability in the probabilities that are incorporated into the fault tree analysis, an additional step of Bayesian statistical approach needs to be added. Bayesian statistical methodologies take into account the variability and distributions of inputs as opposed to point values for probabilities. A Monte Carlo simulation[12] can be used to incorporate variable inputs into a basic fault tree analysis, as in Figure 3.3.

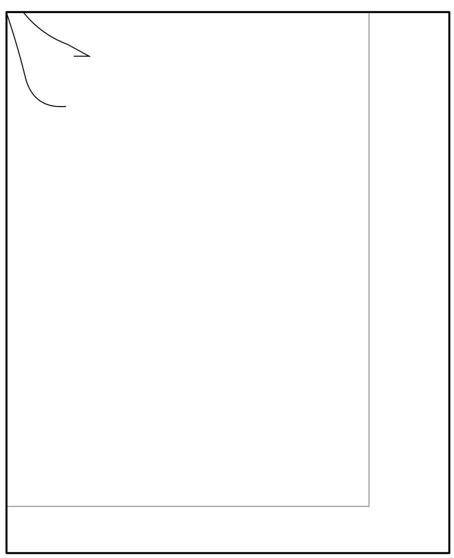

Figure 3.3 Monte Carlo simulation basis. Uncertainties of input variables are included in the result, which is a function of v_1 and v_2.

[12] Monte Carlo simulation is a problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs, called simulations, using random variables.

The Monte Carlo simulation was applied using Decisioneering Oracle® Crystal Ball software. This allowed for incorporation of variable probabilities for each of the series of events to determine the overall probability of each of the spill scenarios described in Table 3.1.

3.1.4 Potential Spill-Causing Events – Maintenance and Transfer

There are a number of ways in which there could conceivably be oil and/or chemical spills from wind facility components due to maintenance and transfer events, including structural failures that are not detected during routine maintenance, damage during maintenance and repairs, and errors that occur during fluid transfer operations. Allision of an offshore service vessel with a WTG or ESP causing a spill is considered as part of maintenance activities rather than under impact events. Structural failure can be considered a maintenance issue since inspection and correction or repair of any structural problems (e.g., corrosion) would be considered part of the general maintenance of the wind facility components. The failure to detect and correct any structural (or equipment) failures could lead to a spill.

3.1.5 Potential Spill-Causing Events – Impact Incidents

The various external impact events that could conceivably cause the various oil and/or chemical spill scenarios in each of the Call Area/WEAs include earthquakes, tsunamis or other ocean events, hurricanes or strong wind events, and allisions from vessels. Note that for impact-related events, the following assumptions are applied:

- Large vessels would not be able to maneuver through the 130 WTGs to allide with the central ESP;
- Small vessels would not be likely to maneuver through the 130 WTGs to allide with the central ESP unless it was a deliberate act of vandalism or terrorism; and
- Acts of vandalism or terrorism on a wind facility would be highly unlikely, and, in any case, outside the scope of this analysis.

3.1.6 Probabilities of Vessel Spills

For impact-related events, spills of oil or other commodities from the vessels involved in allisions with wind facility components or vessel-vessel collisions because of the presence of the wind facility are outside the scope of this analysis. A brief description of this phenomenon is presented herein.

In the event of an allision, it is highly possible that the *vessel*, as opposed to the wind facility component, could spill its own cargo and/or bunker fuels, depending on the vessel type, size, and construction (e.g., double-hulled cargo and/or bunker tanks), as well as its velocity and angle of approach at the time of impact. In addition to spills due to accidental allisions of vessels with wind facility components, there is also the remote possibility that the presence of the wind facility could cause additional collisions between vessels as a result of visual or radar interferences.

An analysis on the spills of oil from vessels due to both allisions with wind facility components and collisions between vessels as a result of the presence of a wind facility was conducted on the proposed Cape Wind Energy Project in Nantucket Sound (Etkin 2006b; Etkin 2008). The wind facility and potential allision and collision locations are shown in Figure 3.4.

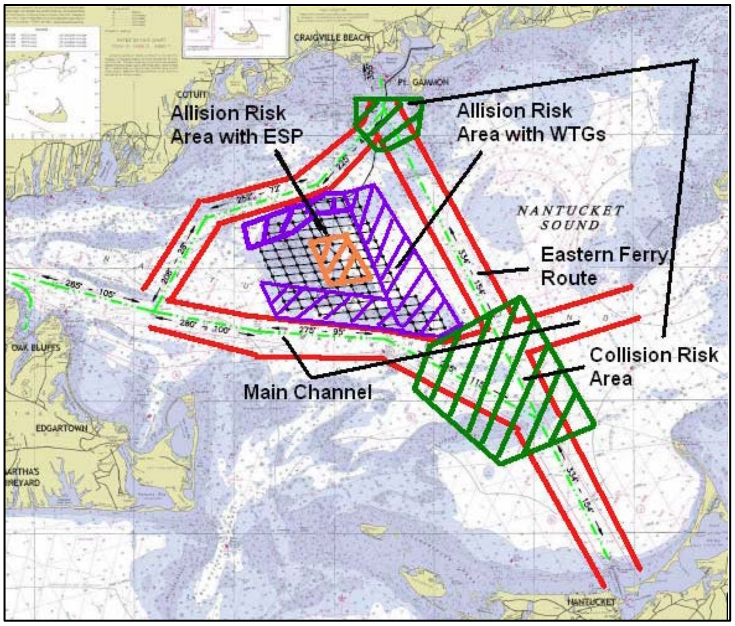

Figure 3.4 Approximate locations of vessel traffic lanes and allision/ collision zones for the Cape Wind Energy Project (Etkin 2006b).

These studies help to inform the overall environmental impact analysis of the potential wind facility projects along the Atlantic coast, but are not directly applicable to the Rhode Island-Massachusetts, Maryland, and North Carolina locations. The rates of incidents are directly related to the degree and nature of vessel traffic (numbers of vessels, patterns of transits, and types and sizes of vessels), as well as the proximity of general vessel traffic lanes in relation to the wind facility components. The vessel types and numbers of vessel transits for the Call Area/WEAs in the current study are shown in Table 3.2.

Table 3.2
Vessel traffic types and number of annual transits for the Atlantic Call Area/WEAs.

Vessel Type	Annual Vessel Transits		
	RI-MA WEA	MD WEA	NC Call Area
Cruise	45	3	188
Cargo	146	1,235	3,655
Tanker	162	195	148
Tow/Tug	22	646	680
Tank Barge	0	0	0
Dry Cargo Barge	0	0	0
Other	502	470	758
Total	877	2,549	5,429

Vessel allision incidents are covered in the portions of this study related to spills from WTGs, though the modeling of impacts is only related to the spills from the wind facility components and not the vessels. The rate of incidents can, however, be used to estimate the potential numbers of vessel spills caused by vessel allisions with WTGs.

While it would be necessary to conduct a more comprehensive vessel collision study to determine the risk of vessel collision-related spills, a rough estimate of differences between the Cape Wind Energy Project study results and those for the other Call Area/WEAs can be developed by applying general principles of collision rates as functions of potential vessel encounters. Generally, the vessel collision rate is based on the density of vessels. In a study conducted on fishing vessel collisions in the Strait of Juan de Fuca, Washington, Judson (1992) calculated that vessel collisions could be represented by the regression formula shown in Equation 3.11 (see Figure 3.5):

$$c = 0.00003d^{1.1898}$$
$$R^2 = 0.99 \qquad (3.11)$$

Where c = number of collisions per vessel transit
d = number of vessels per square mile

As density increases, the number of vessel encounters increases exponentially. If the vessel density doubles, for example, the collision rate increases 2.3 times. If the vessel traffic increases eight-fold, the vessel collision rates increases 12.4 times.

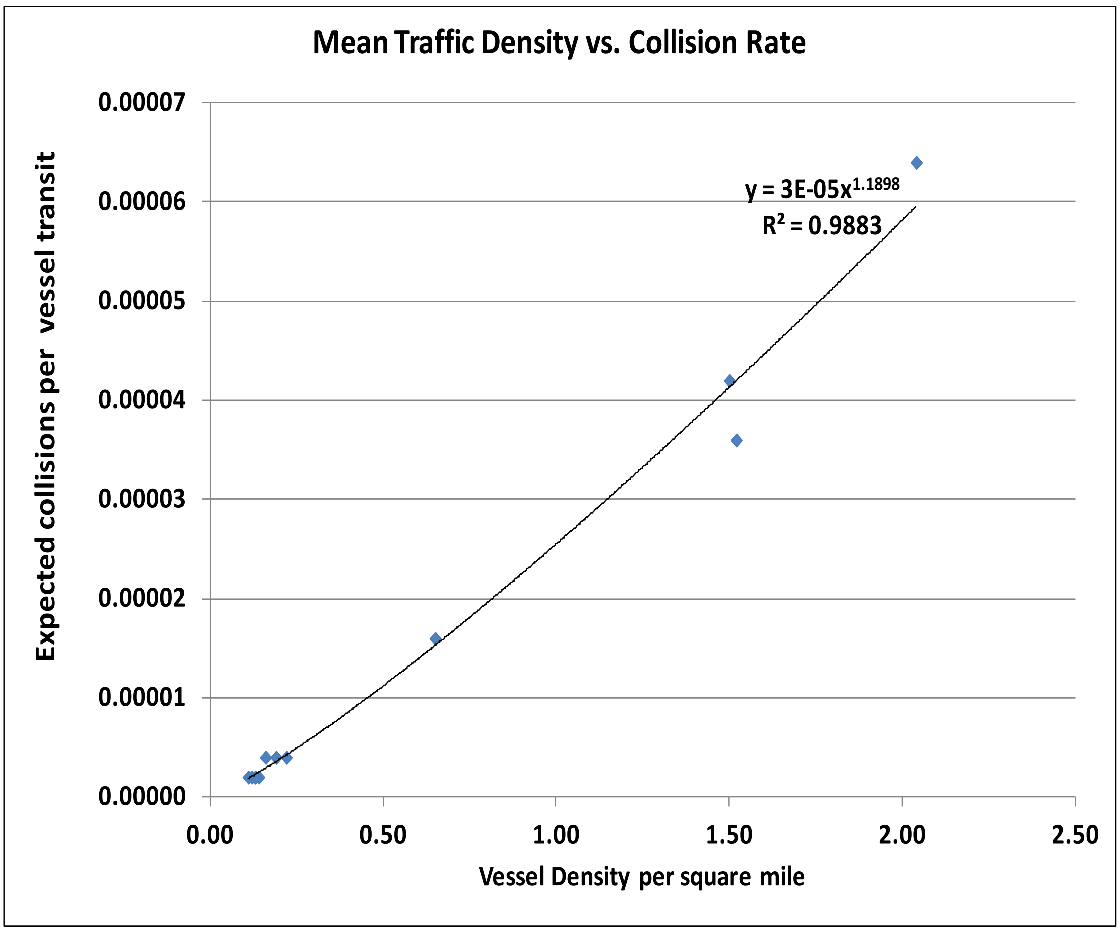

Figure 3.5 Mean traffic density vs. collision rate (based on Judson 1992).

3.1.7 Overall Probability Model Approach

For each of the Call Area/WEAs (RI-MA, MD, and NC), the probabilities for maintenance- or transfer-related spills and impact-related spills were calculated using the general fault tree design. Figure 3.6 shows the spill scenario for the spill of 500 gallons of naphthenic oil. The fault tree designs for the other spill scenarios are included in Appendix B.

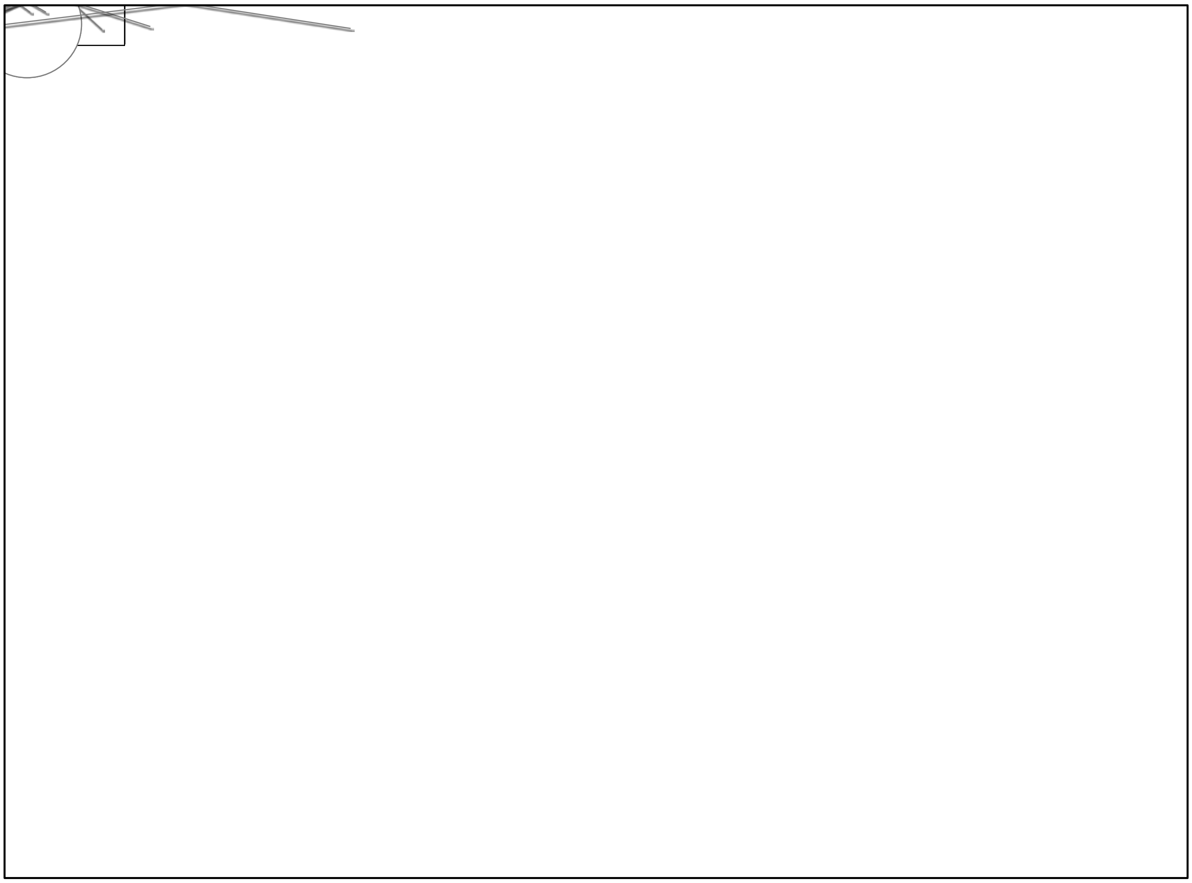

Figure 3.6 Fault tree design for 500-gallon naphthenic oil spill scenario**.**

3.1.8 Methodology for Seismic Event Analysis

Seismic events (earthquakes and tremors) could conceivably cause external impact incidents for the wind facility components in one of two ways – directly by quakes and tremors, or by creating tsunamis. Between 1990 and 2001, there were 284 earthquakes recorded in the northeastern United States and eastern Canada. The distribution of magnitudes[13] of these earthquakes is shown in Figure 3.7.

[13] Richter magnitudes and effects: Less than 3.5: generally not felt, but recorded; 3.5-5.4: often felt, but rarely causes damage; under 6.0: at most slight damage to well-designed buildings, can cause major damage to poorly constructed buildings over small regions; 6.1-6.9: can be destructive in areas up to about 100 kilometers across where people live; 7.0-7.9: major earthquake, can cause serious damage over larger areas; 8 or greater: great earthquake, can cause serious damage in areas several hundred kilometers across. Because of the logarithmic basis of the Richter scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value (USGS 2009).

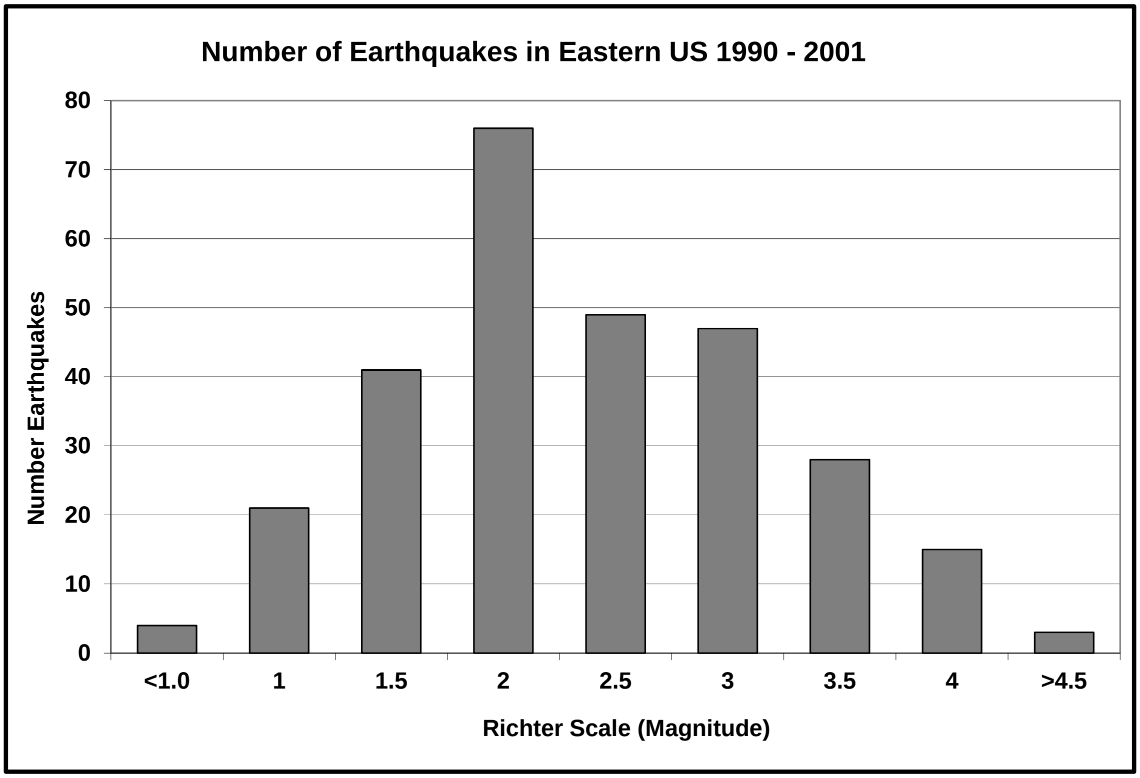

Figure 3.7 Earthquakes in the eastern US during 1990 – 2001 (Lamont Seismic Network, Columbia University).

Nearly 94% of the earthquakes were below 3.5 in magnitude, a level that is generally inconsequential with regard to structural damage. The probabilities of earthquakes in the Call Area and two WEAs locations were computed using the US Geological Survey (USGS) National Seismic Hazard Mapping Project (USGS 2009) for each of the WEA locations over the next 100 years, as shown in Table 3.3 and Figures 3.8 through 3.10 for the next 100 years.

Table 3.3
Major earthquake incident rates by Call Area/WEA location (2008 USGS-National Seismic Hazard Mapping Project).

Earthquake Intensity Richter	Annual Incident Rates		
	RI-MA WEA	MD WEA	NC Call Area
7.65	0.000003	0.000002	0.000001
7.55	0.000002	0.000001	0.000001
7.45	0.000015	0.000011	0.000006
7.35	0.000028	0.000021	0.000011
7.25	0.000015	0.000011	0.000006
7.15	0.000029	0.000021	0.000011
7.05	0.000059	0.000044	0.000023
6.95	0.000027	0.000019	0.000010
6.85	0.000047	0.000035	0.000018

Table 3.3 continued

Earthquake Intensity Richter	Annual Incident Rates		
	RI-MA WEA	MD WEA	NC Call Area
6.75	0.000094	0.000066	0.000034
6.65	0.000041	0.000028	0.000014
6.55	0.000079	0.000053	0.000027
6.45	0.000147	0.000100	0.000051
6.35	0.000063	0.000042	0.000022
6.25	0.000197	0.000133	0.000068
6.15	0.000148	0.000099	0.000051
6.05	0.000281	0.000188	0.000096
5.95	0.000117	0.000077	0.000040
5.85	0.000371	0.000246	0.000127
5.75	0.000280	0.000186	0.000096
5.65	0.000530	0.000351	0.000181
5.55	0.000225	0.000149	0.000077
5.45	0.000714	0.000473	0.000244
5.35	0.000889	0.000589	0.000304
5.25	0.001106	0.000733	0.000378
5.15	0.000000	0.000000	0.000000
5.05	0.001377	0.000912	0.000470

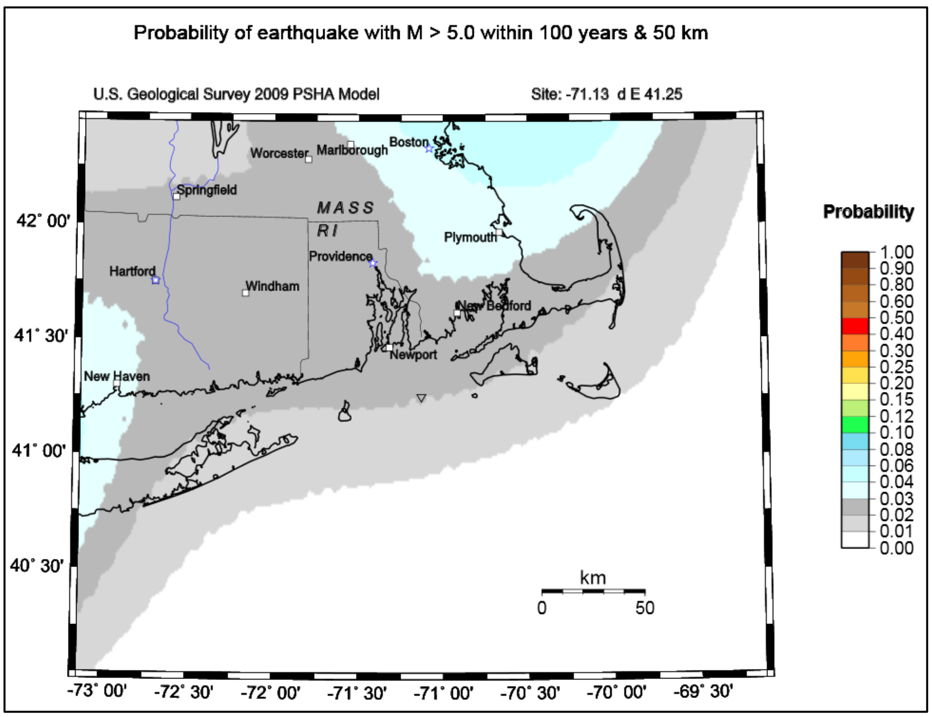

Figure 3.8 Earthquake probabilities in the RI-MA WEA (100 years).

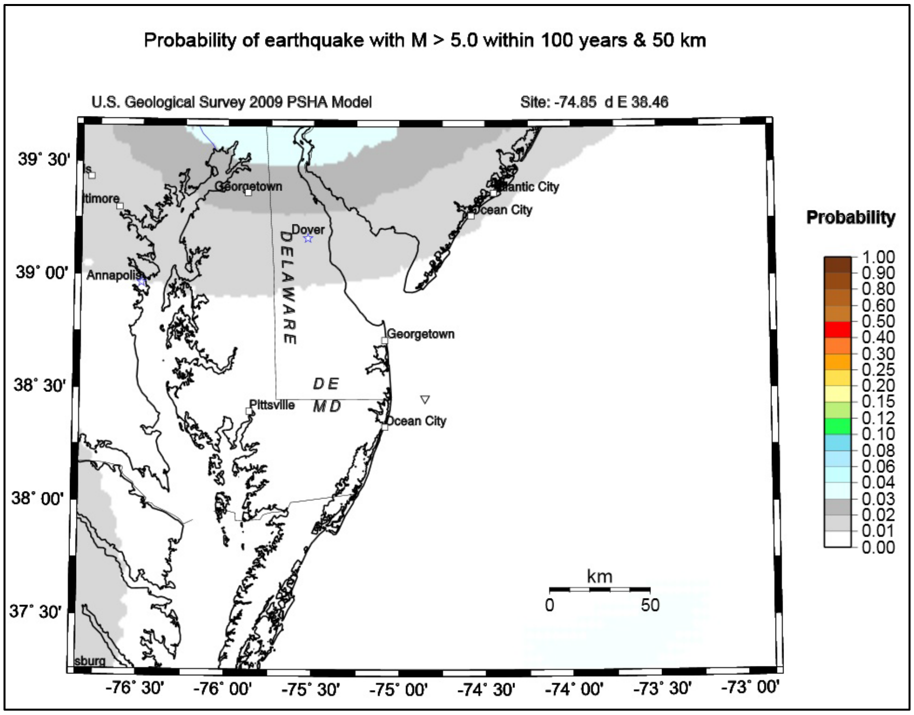

Figure 3.9 Earthquake probabilities in the MD WEA (100 years).

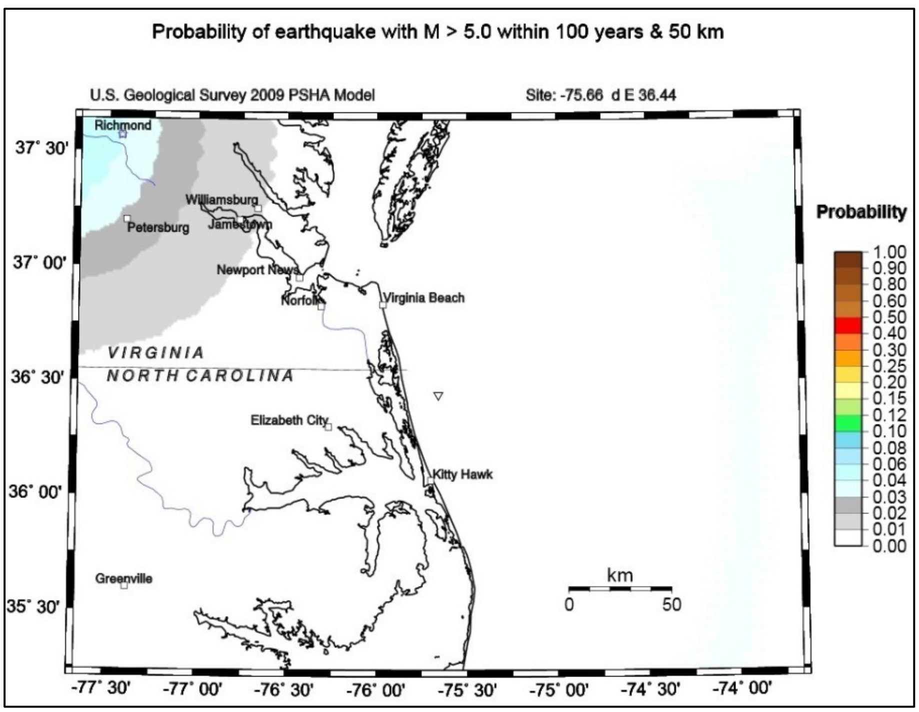

Figure 3.10 Earthquake probabilities in the NC Call Area (100 years).

Tsunamis (also called "seismic sea waves") occur when there are undersea earthquakes of at least 7.5 on the Richter scale[14]. Given the probabilities of earthquakes exceeding 7 on the Richter scale, the predicted incident rates of earthquake-induced tsunamis are shown in Table 3.4. Note that not all earthquakes of this magnitude cause tsunamis, so these figures are most likely over-estimates.

Table 3.4

Tsunami incident rates for Call Area/WEA locations (2008 USGS-National Seismic Hazard Mapping Project).

Earthquake Intensity Richter	Annual Incident Rates		
	RI-MA WEA	MD WEA	NC Call Area
7.65	0.000003	0.000002	0.000001
7.55	0.000002	0.000001	0.000001
7.45	0.000015	0.000011	0.000006
7.35	0.000028	0.000021	0.000011
7.25	0.000015	0.000011	0.000006
7.15	0.000029	0.000021	0.000011
7.05	0.000059	0.000044	0.000023

The massively destructive tsunami that occurred in Southern Asia in December 2004 followed a 9.3-Richter scale earthquake. Tsunamis are most common in the Pacific Ocean, but have occurred in the North Atlantic Ocean, including one that followed the 1775 Lisbon earthquake. This tsunami was 23 ft high in the Caribbean Sea. The probability that there would be an earthquake of a magnitude severe enough to cause a tsunami along the Atlantic coast over the course of 30 years is, for all practical purposes, zero. Tsunamis also rarely occur after extraterrestrial collisions from asteroids or meteors, or as a result of massive underwater landslides, which are often related to or caused by earthquakes. The probability of this occurring along the Atlantic coast over the next 30 years is also exceedingly small[15]. The particularly wide and shallow continental shelf off the US east coast would considerably dampen the power of any tsunami arriving from the open ocean through bottom friction. The fact that wind facilities are planned for the inner shelf area would mean that these potential tsunamis would arrive there after having lost significant amounts of energy (about 20% according to Kusky 2008) during their travel over most of the continental shelf width. An additionally protective factor is the fact that wind facilities would be placed away from the shore, thus reducing the chance of explosive energy release by a potential tsunami, i.e., tsunamis break as they approach the shoreline, just like other surface gravity waves.

[14] Tsunamis can also rarely occur after volcanic eruptions, landslides, or extraterrestrial collisions (e.g., meteors). On the US east coast, a massive underwater landslide on the continental shelf could cause a tsunami. To estimate the probability of this type of event occurring would require a geological analysis beyond the scope of this study.

[15] In over 300 years, there has been one report of a possible tsunami that affected the waters off Nantucket, Massachusetts (41.28N; 70.08W) based on information from the National Geophysical Data Center (NGDC). The *New York Times* (1924) published an account (letter to the editor) of a sailing party traveling between Nantucket and Tuckernuck Islands. The men witnessed "a vast, huge wave stretching shore to shore approaching the vessel. This huge wave was topped by a white foaming crest which curled and threw off white froth, and yet did not curl over frontward." Lockridge et al. (2002) surmised that an earthquake on Oct 24, [1879], and an aftershock Oct 26, [1879] may have disturbed sediments causing a landslide tsunami. This earthquake information is not verified as of 2006. NGDC classifies this tsunami report as a "very doubtful tsunami".

3.1.9 Methodology for Hurricane Analysis

Hurricanes of sufficient magnitude could conceivably topple one or more of the components of a wind facility causing oil spillage due to wind force or storm surge. There are five categories of hurricanes on the Saffir-Simpson Hurricane Scale, as described in Table 3.5, based on the hurricane's present intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline, in the landfall region. Note that all winds are using the US one-minute average.

Table 3.5
Saffir-Simpson hurricane scale.

Saffir-Simpson Category	Description		
	Winds (mph)	Storm Surge (ft)	Damage Potential
One	74 – 95	4 – 5	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.
Two	96 – 110	6 – 8	Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings.
Three	111 – 130	9 – 12	Some structural damage to small residences and utility buildings with a minor amount of curtain-wall failures. Damage to shrubbery and trees with foliage blown off trees and large trees blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Flooding near the coast destroys smaller structures with larger structures damaged by battering from floating debris. Terrain continuously lower than 5 ft above mean sea level may be flooded inland 8 miles or more.
Four	131 – 155	13 – 18	More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded.
Five	> 155	> 18	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline. Only 3 Category Five hurricanes have made landfall in the United States since records began.

Because the wind facility components would generally be constructed to withstand a "100 year storm"[16] and a Category Three hurricane (Etkin 2006a), only a Category Four or Five hurricane would have sufficient force to cause a spill. Hurricane data were derived from Blake et al. (2005). Data for the Call Area/WEA locations are shown in Table 3.6. Because categories One to Three hurricanes are not strong enough to topple and break WTGs and/or ESPs, hurricane data for the Call Area and the two WEA locations were analyzed with regard to the likelihood of a Category Four or Five hurricane toppling and breaking these structures.

Table 3.6
Historical data on hurricanes in Call Area/WEA locations 1851 – 2004 (Blake et al. 2005).

Saffir-Simpson Category	Number of Hurricanes in 1851 – 2004		
	RI-MA WEA	MD WEA	NC Call Area
Category One	8	1	21
Category Two	4	1	13
Category Three	7	0	11
Category Four	0	0	1
Category Five	0	0	0
All Categories	19	2	46

3.1.10 Methodology for Allision Analysis

An allision with one or more WTGs could conceivably occur if a vessel were off-course and the vessel operator did not take sufficient evasive or corrective actions to avoid an allision, or if there were some other form of failure (human error, propulsion failure, or steering failure) in an off-course vessel. It is assumed that the off-course vessels would take corrective actions in most cases unless there was also a storm event or heavy fog that may interfere with proper navigational procedures or the other errors were occurring.

The general approach to determining the likelihood of vessel allisions (by large or small vessels) with WTGs is as follows:

- Determine the number of vessel transits that occur in the vicinity of each WEA;
- Determine the percentage of vessel transits that may potentially allide with one or more WTGs based on the distribution of vessels across the typical transit lanes (allision candidates);
- Determine the length of time that the allision-candidate vessels spend in the vicinity of the WTGs based on vessel speed and length of the sides of the Call Area/WEAs;
- Determine the probability that a vessel operator would not take corrective action due to the presence of a storm or fog; and
- Determine the probability of an error based on previously established per-unit time error rates.

[16] A "100-year storm" is an event that statistically has a one percent chance of occurring in any one given year. Over the course of 30 years, there would be a one percent chance in any one year that such a storm would occur. The fact that a severe storm occurred in one year has no impact on whether it might occur in the following year. Thus, there is the possibility of having two "100 year storms" two years in a row.

3.1.11 Vessel Traffic Analysis – Larger Vessels

Vessel traffic data were analyzed to determine the likelihood of a vessel allision incident occurring in any of the Call Area/WEAs. Automatic Identification System (AIS) data were used for this purpose. The AIS is an automatic tracking system used on ships and by Vessel Traffic Services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships and AIS Base stations. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport. AIS technology and communication protocol has been adopted by the International Maritime Organization as an international standard for ship-to-ship, ship-to-shore, and shore-to-ship communication of navigation information. AIS users operating in proximity to each other automatically create a virtual network. Shore stations can join these virtual networks and receive shipboard AIS signals, perform network and frequency management, and send additional broadcast or individual informational messages to AIS equipped vessels.

The Nationwide AIS (NAIS) enables the US Coast Guard to identify, track, and communicate with marine vessels using the AIS. NAIS is currently receiving 64 million AIS messages *per day* from approximately 6,000 vessels in 58 ports and 11 coastal areas. Over the course of a year, there are over 23 billion AIS messages handled by the NAIS.

While the purpose of these communications is primarily for vessel traffic control, collision avoidance, and other maritime safety and security applications, the aggregate data of vessel traffic also provides an extremely detailed history of vessel traffic that can be used in determining patterns of vessel movement and establishing numbers of vessels in traffic lanes, port areas, and regions by vessel type. These data also provide a means of conducting a comprehensive vessel traffic study, including estimating vessel accidents and impacts associated with the construction and presence of offshore wind facilities.

The AIS data archives are very large and complex. To make the full use of the data in the AIS archives, RPS ASA's AIS Data Handler for ESRI®'s ArcGIS 10 was used for the 2009-2011 AIS data archives in the region of the Call Area/WEAs. An example of AIS data for the Maryland WEA is shown in Figures 3.11 and 3.12.

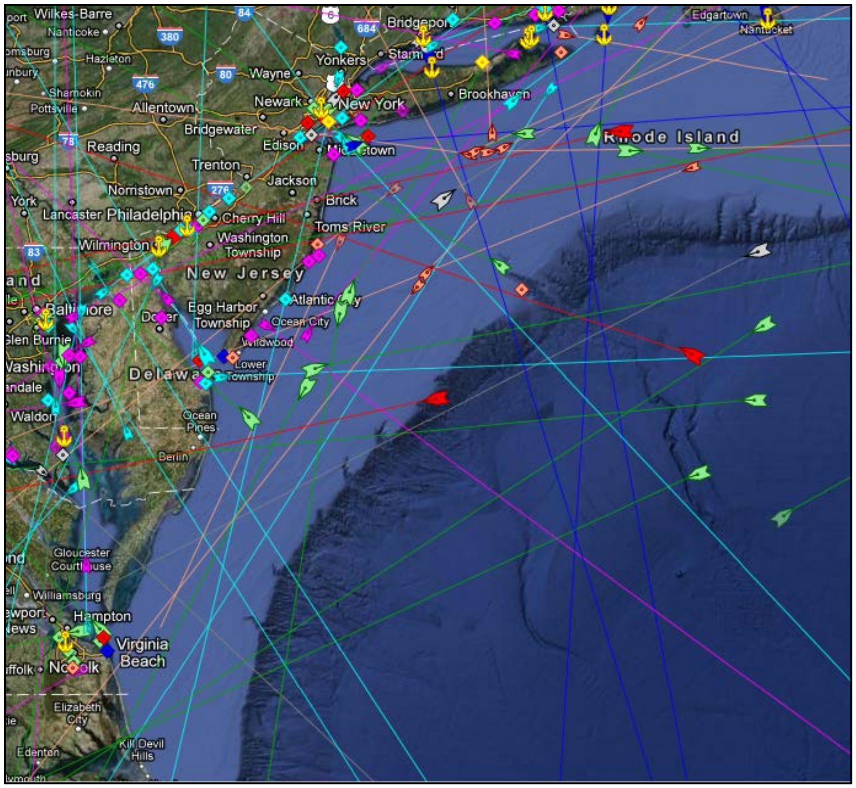

Figure 3.11 Snapshot of AIS data for a 72-hour period in MD WEA region.

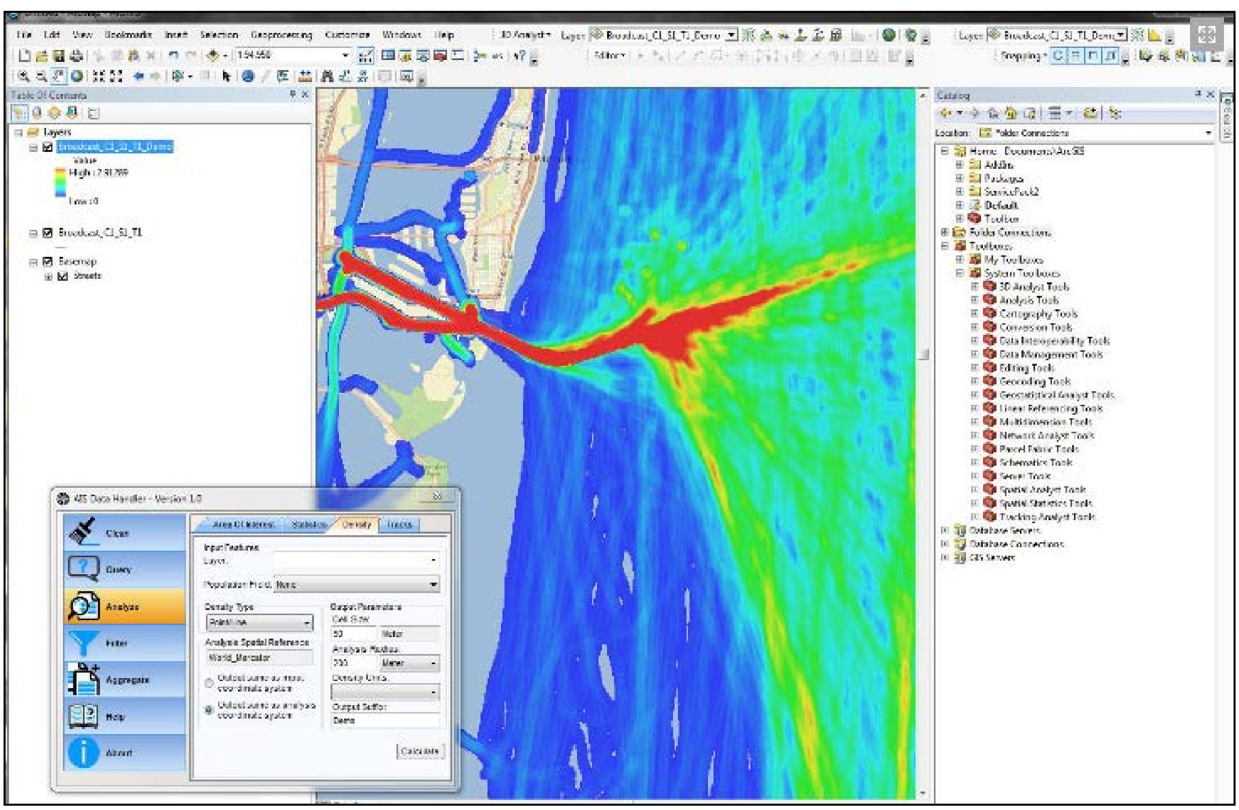

Figure 3.12 Sample of AIS data showing vessel traffic over a longer period of time.

Vessel trip data for the Call Area/WEAs as derived from 2011 AIS data[17] are shown in Table 3.7. The AIS data was used to determine the number of large vessels (tankers, cargo vessels, passenger vessels, tugs, and towing vessels) that transit the area in the vicinities of the three WEA sites, as well as to determine the routes of the most frequently used shipping lanes and areas of the greatest numbers of vessels. AIS or similar data have been used for calculations of oil spill and vessel casualty risk (from collisions, allisions, and groundings) for several studies, including Jürgensen et al. (2013) and Bruce et al. (2013).

Table 3.7
Vessel trips by Call Area/WEA location and vessel type (2011).

Region		Area (mi^2)	Cargo	Pass.	Tug Tow	Tanker	Other*	Total
RI-MA	WEA	257	146	45	22	162	502	877
	50-km buffer	5,833	1,443	4,382	3,762	1,129	11,861	22,577
	Total	6,090	1,589	4,427	3,784	1,291	12,363	23,454
MD	WEA	125	1,235	3	646	195	470	2,549
	50-km buffer	4,559	4,671	2,620	2,625	1,813	4,151	15,880
	Total	4,683	5,906	2,623	3,271	2,008	4,621	18,429
NC	Call Area	1,372	3,655	188	680	148	758	5,429
	50-km buffer	8,218	9,560	407	1,933	892	4,102	16,894
	Total	9,590	13,215	595	2,613	1,040	4,860	22,323

* Other includes military vessels, military ships, pilot boats, search and rescue vessels, and miscellaneous vessels over 300 gross tonnes.

The vessel trip data were then analyzed to determine the percentages of vessels that would have the potential for allisions with the outer WTGs in each Call Area/WEA based on the patterns of vessel traffic and the potential distribution of vessels across the main vessel transit lanes and routes.

3.1.12 Methodology for Vessel Traffic Analysis – Smaller Vessels

The most common smaller vessels in the Call Area/WEA locations are likely to be commercial fishing vessels. The three Call Area/WEA areas are active commercial fishing grounds, as shown in Figure 3.13.

[17] 2011 AIS data were used because these were the most recent data available and included a larger number of vessels.

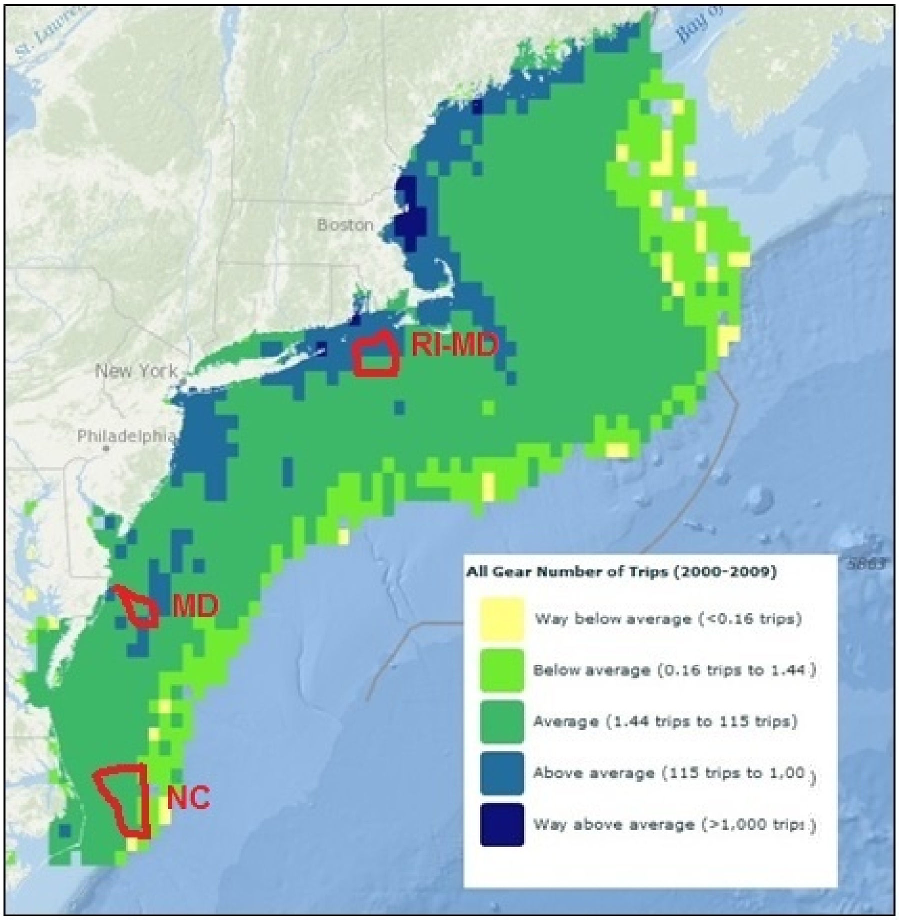

Figure 3.13 Average annual fishing trips in Call Area/WEA locations (Nature Conservancy and NOAA National Marine Fisheries, 2010). Approximate location of Call Area/WEAs is shown in red as a reference.

Determining the probability of allisions of smaller commercial fishing vessels with the wind facility structures required data on the numbers of vessel transits in the regions. Data on fishing vessel trips for the general area surrounding and including Call Area/WEAs are shown in Table 3.8. Note that not all of these vessel trips would occur in or near the Call Area/WEAs themselves. The estimated number of vessel trips in the actual Call Area/WEA was calculated by taking the percentage of area that the Call Area/WEA encompasses relative to the general fishing area of the states for which the fishing trip data were provided. As with the larger vessels, the percentage of fishing vessels and other smaller vessels likely to be off-course was calculated for potential allisions. Because vessel transit data for small recreational vessels (small craft) with outboard motors (e.g., jet skis, small motor boats or powerboats), or small sailboats were not available, an analysis of a small craft allisions with wind facility components was not possible. However, the results from such an analysis, if possible, would not likely change any outcomes. Small craft generally transit in areas closer to shore and would be unlikely to transit in the area with heavy traffic with larger vessels. If they do go into the vessel traffic lanes with large merchant ships, tankers, barges, etc., they risk collisions with these larger vessels. In the small chance that small craft would be in the wind facility area, one can reasonably assume that there would be no damages sufficient to topple the wind turbines, though there may be oil releases from the vessels themselves, most likely only a few gallons. Based on anecdotal evidence only for other small craft ramming accidents, since there have been no known studies on small craft alliding with wind turbines or other structures, it is reasonable to assume that if a small motor boat crashed into a wind turbine base the boat would break up. One example of a ramming incident is a powerboat that struck a construction barge head-on in the Hudson River in July 2013. Two of the four occupants were killed and two were seriously injured and the powerboat was a total loss, but the stationary barge had no damages. A wind turbine structure is very unlikely to be toppled by being hit by a powerboat, thus these smaller vessels were not included in the analysis.

Table 3.8
Estimated annual commercial fishing vessel trips in general Call Area/WEA locations (sources: NOAA National Marine Fisheries Atlantic Coastal Cooperative Statistics Program (data request)).

WEA/Call Area	States Included	Regional Fishing Vessel Trips (Average 2007 – 2012)	Estimated % Area	WEA/Call Area Fishing Annual Vessel Trips
RI-MA	RI, MA	231,376	1.25%	2,900
MD	MD, DE, NJ	227,928	3.5%	8,000
NC	NC, VA	363,410	1.25%	4,500

3.2 Calculation of Probabilities for Event Trees

The probabilities of each of the components of the fault trees were calculated as discrete values or as distributions of values. Annual incident rates were used as proxies for probabilities of occurrence within a single year. Probabilities of occurrence over future years were calculated based on annual incident rates for the following events for each Call Area/WEA region:

- Corrosion of wind facility structures
- Cracking or other structural failure of wind facility structures
- Failure to detect structural failures during maintenance
- Damage during maintenance or other operations errors
- Transfer errors during refueling and transfer of oil
- Earthquakes
- Tsunamis
- Hurricanes
- Small (fishing) vessel allision with individual WTG
- Large vessel allision with individual WTG
- Large vessel allision with five WTGs
- Failure of evasive action from small vessel
- Failure of evasive action from large vessel

3.2.1 Probability of Structural Failure

Structural failure has been the primary cause of oil spills in 3,400 incidents involving USEPA-regulated facilities, representing nearly 13% of spill incidents that occurred during 1980 and 2003. Off these incidents, 220 involved electric-generating stations and/or transformers. Of 2,638 electric facilities in the US, 8% had spills related to structural failures over the 24-year period (Etkin 2004 and ERC spill databases).

Structural failure of a wind facility can occur due to corrosion or cracking of the WTG or ESP components. While there are no definitive data on structural failures of wind facility components due to cracking per se, there is considerable literature on corrosion in these structures.[18] Most of this research has been conducted in Europe where offshore wind technology has been a vital part of energy production since the first offshore wind facility was built in Vindeby, Denmark in 1991.

According to Black and Nielsen (2011), offshore locations of wind facilities expose the structure to heavy stresses and a severely corrosive environment due to humidity with high salinity, UV light, and tidal and wave action. The design life of wind turbine structures is typically 20-25 years (Hilbert et al. 2011). The design anticipates a low, uniform corrosion rate of about 0.1 mm/year and a localized corrosion rate of 0.7 mm/year in a closed compartment over that time period, but corrosion has been detected in structures of 2 to 10 years.

There are typically two strategies that are used to mitigate corrosion, generally in conjunction with each other – coating to prevent corrosion and regular inspection to detect corrosion. The International Standard Organization (ISO) has developed standards for anti-corrosive coatings, EN ISO 12944, ISO 20340, and NORSOK M 501. Regular inspections conducted during maintenance or through remote sensing can help to prevent extensive damage that would lead to leakage of oil and chemicals from the wind turbines (Black and Nielsen 2011).

Based on the structural failure rate in USEPA-regulated facilities, the general structural failure rate is estimated to be 0.003 incidents per year (Etkin 2006c). Fires and explosions, which occur on occasion in transformers at electrical facilities, are assumed to occur at a rate of 0.001 per year. Based on the rate of corrosion noted in existing offshore wind energy facilities, the corrosion rate is assumed to be 0.04 (once in 24 years). It is assumed that structural and corrosion failures would be detected during annual maintenance. Equipment failure is estimated to be 0.004 incidents annually based on analyses of electrical utility facilities under USEPA jurisdiction (Etkin 2004 and ERC spill databases). The probability of missing the damage is assumed to be 0.05 per year.

3.2.2 Probability of Maintenance Damage and Operations Errors

Damage to one of the WTGs or the ESP could theoretically occur if the offshore supply (service) vessel carrying the maintenance workers and equipment allides with one of the WTGs or ESP or if an error occurs during maintenance procedures (other than spills during oil or chemical transfers, which are discussed in Section 1.2.3). Such errors might include damage to or breakage of one of the components or subcomponents. Spills could also occur due to various other operations errors.

The expected incidence rate of damage during maintenance is likely to be very small and is estimated to be about 0.003 incidents per year (Etkin 2006b). Other operations errors are estimated to be 0.004 incidents per year. Equipment failure is estimated to be 0.004 incidents

[18] Literature on "failures" of wind farms generally relate to the malfunctions in the technology that cause the facilities to fail to reliably deliver energy output rather than to cause leakage of oil and/or chemicals. (e.g., Watson 2010).

annually. These incident rates are based on analyses of electrical utility facilities under USEPA jurisdiction (Etkin 2004 and ERC spill databases).

3.2.3 Probability of Transfer Error

It is assumed that oil and chemical transfer operations would likely occur after the first year of operation and then every two years after that. Transfer errors are one of the most common causes for oil spills. Estimates of oil spills due to errors during transfer operations as determined in various studies are shown in Table 3.9. The variations in spill rates per transfer operation are attributable to differences in operational procedures. After the implementation of preventive transfer safety regulations, spill rates in California dropped by 34%, for example. Note that there are no studies that directly address spills due to transfers of chemicals, but it is assumed that since analogous procedures are implemented during transfer operations, the spill rates per transfer would likely be similar.

Table 3.9

Transfer error-related spill rates (Etkin 2006c).

Location (Time Period)	Spill Rate (Spills/Transfer Operation)
California (1992 – 2004)	0.0046 – 0.0134
Washington (1992 – 2004)	0.00026 – 0.00035

Because there are 130 WTGs and one ESP projected to be in a WEA, the number of transfer operations is assumed to be 131 for each WEA location. The spill rate is assumed to be 0.0067 (the midpoint between the highest and lowest rates in Table 3.9.) times 131, or 0.878 incidents per year. Because spill volumes for transfer error-related incidents tend to be very small and the likelihood of the release of the entire volume of the transferred oil is small, the incident rates were adjusted by the percentage of incidents of that volume likely to occur (Etkin 2006b). For spills of 500 gallons, the incident rate was multiplied by 5%, for spills of 1,000 gallons, the incident rate was multiplied by 1%, and for spills of 2,000 gallons, the incident rate was multiplied by 0.5%. The incident rates applied for transfer errors is 0.044 for 500 gallon spills, 0.0088 for 1,000 gallon spills, and 0.0044 for 2,000 gallon spills.

3.2.4 Probability of Earthquakes and Tsunamis

For each of the Call Area/WEAs, the probabilities of earthquakes exceeding a 5.0 or 7.0 on the Richter scale were applied for earthquake and tsunami damage, respectively, based on the data in Tables 3.4 and 3.5. For the RI-MA WEA, the annual incident rate of a seismic event of greater than 5.0 is estimated at 0.0014, for the MD WEA, the rate is estimated at 0.0009, and for the NC Call Area, the rate is estimated at 0.0005. For the incident rates for tsunamis (i.e., seismic events of 7.0 or higher) is estimated at 0.00006 for the RI-MA WEA, 0.000044 for the MD WEA, and 0.000023 for the NC Call Area.

3.2.5 Probability of Hurricanes

The probabilities of hurricanes at or exceeding Category 3 were applied for each of the Call Area/WEAs based on the data in Table 3.6. Since there were no hurricanes exceeding Category 2 in the MD WEA area, the incident rate was estimated to be zero. For the RI-MA WEA and NC Call Area, the incident rates were estimated to be 0.045 and 0.805 annually, respectively.

3.2.6 Probabilities of Allisions and Evasive Actions

Allisions of vessels with wind facility structures would occur due to human error,[19] steering failure,[20] or propulsion failure[21] provided the vessels are in the vicinity of the wind energy facility structures. These three causes are generally considered in vessel allision analyses, including those for offshore wind energy facilities (e.g., Christensen et al. 2001; Glosten et al. 2004; Fujii 1983; Macduff 1974; Pedersen 1996; Karlsson et al. 1998). The estimated incident rate values for these types of events are outlined in Table 3.10.

Table 3.10
Potential vessel failure scenarios.

Failure	Parameter	Estimated Values	
		Christensen et al. (2001)	Glosten et al. (2004)
Human Error	Probability human error	2 X 10^{-4} per passage	Not estimated
	Duration of error	20 minutes	Not estimated
Steering Failure	Probability steering failure	6.3 X 10^{-5} per hour	2.9 X 10^{-5} per hour
	Sail radius	2.5 X ship length	Not estimated
Propulsion Failure	Probability drifting ship	1.5 X 10^{-4} per hour	6.5 X 10^{-5} per hour
	Anchoring probability	0.7	Not estimated

The probabilities of vessel failure were converted into *per-trip* values, as shown in Table 3.12 based on the average transit times spent in the WEA vicinity, as calculated in Table 3.11. For steering failure and propulsion failure, the averages of the values between the two studies in Table 3.10 were applied. For propulsion failure, the anchoring probability, which would prevent the vessel from moving further, was applied to the higher value from the Christensen et al. (2001) study. Anchoring had already been taken into account in the Glosten et al. (2004) figure. Human error was estimated to occur 0.0002 times for each passage (trip) for the duration of 20 minutes, or 0.01584 times daily. Steering failure was assumed to occur 0.0011 times per day of vessel transit. Propulsion failure was assumed to occur 0.001325 times per hour of vessel travel or 0.0318 times daily (based on methodology in Etkin 2006c).

The probabilities needed to be converted to a per-vessel trip rate for each of the Call Area/WEAs based on the length of the vessel traffic lanes alongside the edges of the WEA that would likely be traveled. The maps of the Call Area/WEAs, as shown in Figure 3.14, were used to determine the distances covered at the edge of the Call Area/WEAs closest to the vessel traffic lanes.

[19] For a human error to result in a ship allision with a wind park structure, two things must happen: the ship has to be in an allision course (i.e., have direction towards wind facility) and no actions are taken to correct this course. Reason (1997) classifies human errors into three broad categories: decision errors, skill-based errors, and perceptual errors.

[20] When a steering failure occurs on a vessel, the rudder is locked and the ship starts sailing into a circular path, the diameter of which depends on the locked position of the rudder and the under-keel clearance. According to general experience, a full deflection of the rudder is the most typical result of a steering system failure (based on Christensen et al. 2001).

[21] A failure in propulsion machinery will cause a vessel to drift. The drift could occur in any direction, but will depend on the wind and current directions (based on Christensen et al. 2001).

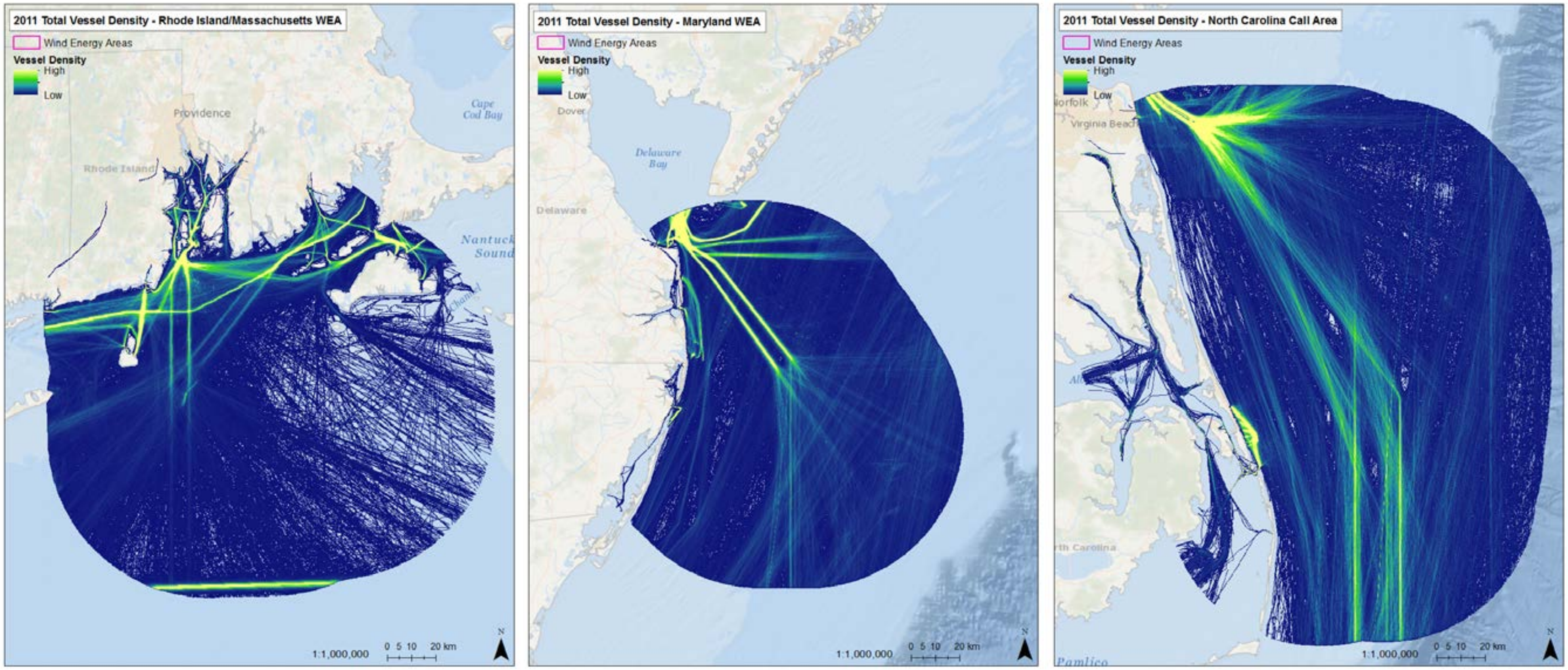

Figure 3.14 Total vessel density for RI-MA WEA (left), MD WEA (center) and NC Call Area (right) (2011 AIS data).

It was assumed that vessel traffic lanes would generally be routed around and away from the Call Area/WEAs once the facilities were in place, but that there would be a small percentage of vessels that would be outside the general traffic lanes, as per Figure 3.15.

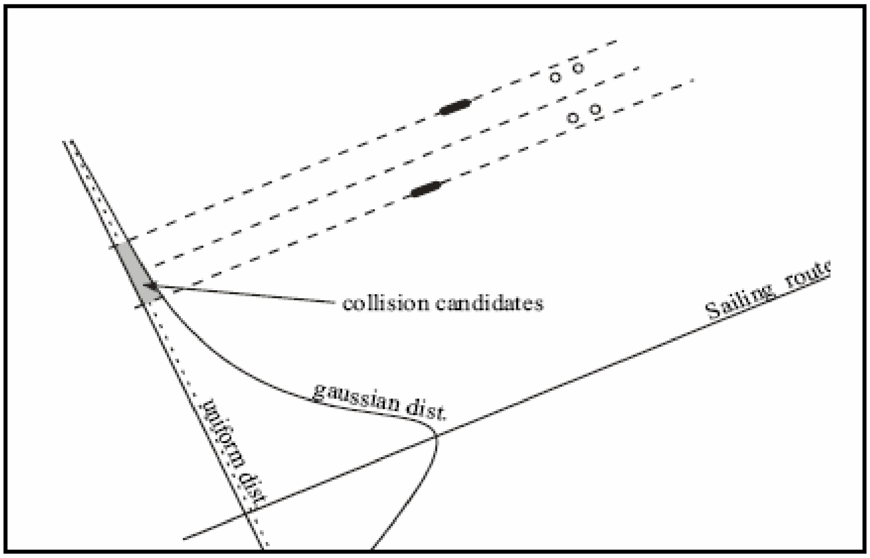

Figure 3.15 Geometrical ship distribution (based on Christensen et al. 2001).

Based on this assumption, approximately 2% of the vessels would be assumed to be outside the general vessel traffic lane on the side closest to the WTGs and be candidates for potential allisions with the structures.

The vessel types and length of time transiting each WEA area are shown in Table 3.11. The lengths of the Call Area/WEAs with potentially exposed WTGs (i.e., those WTGs that may potentially be hit by vessels because of their proximity to the vessel transit lanes) are: RI-MA = 30 miles; MD = 20 miles; and NC = 55 miles. The total transit times are calculated based on 5% of the total trips (allision candidates). The corresponding failure rates are shown in Table 3.12.

Table 3.11
Vessel trips and transit times in Call Area/WEAs (Based on Etkin 2006c).

Vessel Type	Avg. Speed (kts)	RI-MA WEA			MD WEA			NC Call Area		
		Total Annual Trips	2% Trips	Annual Transit Time (days)	Total Annual Trips	2% Trips	Annual Transit Time (days)	Total Annual Trips	2% Trips	Annual Transit Time (days)
Cargo	18	146	2.9	0.15	1,235	24.7	0.99	3,655	73.1	8.13
Tanker	12.8	162	3.2	0.24	195	3.9	0.22	148	3.0	0.46
Tow/Tug	12.8	22	0.4	0.03	646	12.9	0.74	680	13.6	2.14
Passenger	12	45	0.9	0.07	3	0.1	0.00	188	3.8	0.62
Other	12	502	10.0	0.78	470	9.4	0.56	758	15.2	2.52
Fishing	12	2,900	58.0	4.52	8,000	160.0	9.60	4,500	90.0	14.94
Total	-	3,777	75.5	5.88	10,549	211.0	12.61	9,929	198.6	32.82

Table 3.12
Estimated annual vessel operation failure rates by Call Area/WEA.

Failure Type	RI-MA WEA	MD WEA	NC Call Area
Human Error	0.2328	0.4994	1.2997
Steering Failure	0.0162	0.0347	0.0903
Propulsion Failure	0.4675	1.0027	2.6092
Total	0.7165	1.5368	3.9992

Visibility problems associated with fog or darkness when radar is not functioning properly could also potentially cause allisions. Typical fog (visibility less than 3,250 ft) and heavy fog (visibility less than 650 ft) occur in the areas around the Call Area/WEAs at the frequencies shown in Table 3.13.[22]

Table 3.13
Daily incidence of fog by Call Area/WEA (Based on National Weather Service Global Historical Climatological data).

WEA/Call Area	Daily Incidence of Fog
RI-MA	0.076
MD	0.091
NC	0.083

The probability that a vessel allision impact with a WTG would result in a spill is based on the analyses in a study conducted for Cape Wind Energy Project.[23] The allision analysis relies on the following key *conservative* assumptions:

- Any vessel that is 4,000 ft off-center from mid-course would hit a WTG if there is also a vessel failure (human error, steering failure, and/or propulsion failure) or an environmental event (storm, hurricane, earthquake, or tsunami).
- The vessel operator took no corrective or evasive action to avoid an allision with the WTG.

In actuality, a vessel that is off-course (in the direction of a WTG) is more likely to *miss* a WTG than to impact it based on the fact that the WTGs are likely to be spaced so that there is approximately 0.63 km (2,067 ft) between WTGs in the northwest-southeast direction and 1.0 km (3,281 ft) between them in the east-west direction (if the configurations are similar to those of Cape Wind Energy Project). If the vessel were off-course and running at an angle to the idealized vessel traffic lane, it would likely go between two of the WTGs. Since each WTG is at most 18 ft wide at its base, the WTGs themselves take up only 0.86%[24] of the space in the outermost line of WTGs. Since each vessel is *at most* 300 ft in width at an angle (again, the most conservative assumption that would *increase* the probability of allision), even broad-side, there would only be a 14.5% probability that the vessel would hit the WTG rather than fit *between* two

[22] Data for RI-MA are based on Kingston, RI; for MD on Salisbury, MD; and for NC on Elizabeth City, NC.
[23] The study by Kothnur et al. (2006), which appears as an appendix to the *Draft Revised Navigational Risk Assessment* (Cape Wind Associates and ESS Group Inc. 2007), utilizes an elasto-plastic finite element model of the tower-monopile-soil configuration with the maximum load computed from the kinetic energy of the vessel.
[24] This is derived by dividing 18 ft by the minimum distance between WTGs (2,067 ft).

WTGs[25]. This would suggest that the probability of an allision with the largest vessels is more likely to be only 14.5% of the calculated allision probability.

The assumption that the vessel operator would take no corrective or evasive action to avoid an allision with a WTG is also highly conservative. A vessel's risk of allision with a WTG can be further minimized by adhering to the COLREGS[26] (the basis for USCG Navigation Rules), which provide specific guidance on safe vessel operation and avoiding allisions. While marine casualties occur in spite of the safeguards in COLREGS, the proper use and application of these safeguards provides a means of reducing the potential for vessels to allide with a WTG. The vessel's captain is responsible for properly assessing the risk of a collision/allision, operating at safe speeds, and taking necessary action to avoid impact. The mariner must remain cognizant of the presence of the WTGs, and adjust operation of the vessel accordingly in compliance with the COLREGS.[27]

A vessel operator that realizes that the vessel is on a "collision-course" or an "allision-course" with a stationary navigation hazard (e.g., a WTG) is likely to take some kind of evasive action to correct the vessel's course, to decrease speed, or otherwise avoid an impact for the safety of the vessel's crew and passengers.

The only known study that predicts the probability that the vessel owner in such a situation would take corrective action[28] is that used in the Christensen et al. (2001) study, which concluded:

> If a human failure shall result in a ship collision [allision], the following two restrictions must be fulfilled. The ship has to be on a collision course, *i.e.*, have direction towards the wind facility or the trafo module[29], and the ship will have to maintain this course until collision [allision], thus no actions are taken in order to prevent the collision. The probability that the collision course is maintained is denoted "the probability of human failure".

Christensen et al. (2001) set the probability of human failure as 0.0002 per vessel trip. If one were to assume that human failure to take evasive or corrective action in the face of a potential allision with a WTG is 0.0002, the probability that the vessel operator would take evasive or corrective action would be 0.9998 (or 99.98%).

Even if the probability of taking evasive or corrective action is very high, there is still the possibility that the action would be unsuccessful, that is, the vessel operator attempts to steer out

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[25] This is derived by dividing the maximized length of the vessel (300 ft) by the minimum distance between WTGs (2,067 ft).
[26] Based on the international convention IMO (International Maritime Organization) International Convention for the Prevention of Collisions at Sea, 1992. The US Coast Guard regulations related to this convention are in *USCG Commandant Instruction M16672.2D Navigation Rules, International-Inland* and 33 *Code of Federal Regulations – CFR* 83; 33 *CFR* 84-90; 33 *CFR* 26.
[27] Detailed in ESS Group, Inc. (2006).
[28] A number of studies on vessel casualty risk were reviewed, including: Grabowski (Grabowski 2005); Merrick et al. (Merrick et al. 2000); Paté-Cornell and Murphy (1996); Harrald et al. (1998); van Dorp et al. (2001); McCallum et al. (2000); Miller et al. (1998).
[29] The "trafo module" is the equivalent of the ESP in the Cape Wind Energy Project Wind Farm.

of the way of the WTG but there is still an impact. Combining the probabilities of corrective maneuvering and hitting a WTG is calculated as in Equations 3.12 through 3.15.

(3.12)
$$P_{aa} = P_{ta} \cdot k_a$$

Where P_{aa} = probability of actual allision course
P_{ta} = probability of theoretical allision[30]
k_a = allision adjustment factor

(3.13)
$$k_a = P_{hf} + \left(P_{ca} \cdot P_{cf}\right)$$

Where P_{hf} = probability of human failure to take corrective action once on allision course (= 0.0002)
P_{ca} = probability of taking corrective action (= 0.09998)
P_{cf} = probability of failure of corrective action

(3.14)
$$P_{cf} = \frac{L_v}{D_{WTG}}$$

(3.15)
$$P_{cfc} = \frac{L_{lv}}{L_{lv} + L_{sv}}$$

Where: L_v = length of vessel by vessel type
D_{WTG} = distance between WTGs

The probability of failure in the corrective action is dependent upon the vessel length, which is related to the overall ability of the vessel to be maneuvered successfully off the allision course. The larger the vessel, the less likely the corrective maneuver will be successful. The probabilities of corrective maneuvers being unsuccessful by vessel type are shown in Table 3.14. It is conservatively estimated that if one of the largest vessels (tankers or cargo ship) allides with a WTG, there is a 0.40 probability that there will be a spill from the WTG. For other large vessels (commercial fishing, passenger, tow/tug), the probability of a spill will be conservatively assumed to be 0.20, i.e., one fifth of allisions will result in a spill from the WTG. For small commercial fishing vessels and the "other vessels" in the large category, which are generally smaller than the various vessels in the large category, the percentage is assumed to be 0.10.

[30] Based on conservative-based, fault tree analysis in which it is assumed that all vessels that are allision candidates do actually allide with the structure.

Table 3.14
Probability of corrective maneuver (evasive) failure by vessel type.

Vessel Type	Vessel Length (ft)	Probability of Corrective Maneuver (Evasive) Failure
Cargo	990	0.48
Passenger	330	0.16
Tanker	990	0.48
Tow/Tug[31]	330	0.16
Other	40	0.02
Comm. Fishing	150	0.07

The percentages of vessel types by size were applied to calculate a weighted average of likelihood of a spill due to allision, as shown in Table 3.15.[32]

Table 3.15
Calculation of probabilities of allision-related spills and evasive maneuvering failure.

WEA/Call Area	Size Group	Vessel Type	Number	% Total	Prob. Spill	Prob. Evasive Failure	Weighted Average Probability	
							Allision Spills	Evasive Failure
RI-MA WEA	Large	Cargo	146	16.65%	0.4	0.48	0.23 (Large)	0.19 (Large)
		Passenger	45	5.13%	0.2	0.16		
		Tanker	162	18.47%	0.4	0.48		
		Tow/Tug	22	2.51%	0.2	0.16		
		Other	502	57.24%	0.1	0.02		
	Small	Comm. Fish	2,900	100.00%	0.1	0.07	0.10 (Small)	0.07 (Small)
MD WEA	Large	Cargo	1,235	48.45%	0.4	0.48	0.30 (Large)	0.31 (Large)
		Passenger	3	0.12%	0.2	0.16		
		Tanker	195	7.65%	0.4	0.48		
		Tow/Tug	646	25.34%	0.2	0.16		
		Other	470	18.44%	0.1	0.02		
	Small	Comm. Fish	8,000	100.00%	0.1	0.07	0.10 (Small)	0.07 (Small)
NC Call Area	Large	Cargo	3,655	67.32%	0.5	0.48	0.33 (Large)	0.36 (Large)
		Passenger	188	3.46%	0.2	0.16		
		Tanker	148	2.73%	0.4	0.48		
		Tow/Tug	680	12.53%	0.2	0.16		
		Other	758	13.96%	0.1	0.02		
	Small	Comm. Fish	4,500	100.00%	0.1	0.07	0.10(Small)	0.07 (Small)

The fault tree that describes the approach for determining the incident rate of allisions is shown in Figure 3.16. Vessel operation failures or environmental events that interfere with navigation could lead to a potential vessel casualty. If the vessel is also in the vicinity of the WTGs by being outside the vessel traffic lane and the evasive maneuvers are ineffective, an

[31] Towboats or tugboats may tow a single barge up to 195 ft in length. Sea-going tugboats are rarely pushing a large tow with multiple barges as are seen on inland waterways. The length shown is for a tugboat with one barge.
[32] Current offshore turbine standards (e.g., API RP 2A-WSD; DNV OS J101; IEC 61400-3) require turbines to be designed to withstand allision impacts, indicating that the probability of spills from this type of incident is possibly lower than estimated.

allision may occur.[33] Note that this calculation only determined the likelihood of an allision occurring, not whether the allision results in a spill.

Figure 3.16 Fault tree design for allision analysis.

The fault tree calculation is represented by Equations 3.16 through 3.18:

(3.16) $$P_{vof} = P_{he} + P_{sf} + P_{pf}$$

(3.17) $$P_{ee} = P_{f} + P_{h} + P_{t}$$

(3.18) $$P_{a} = (\mathrm{P}_{vof} + P_{ee}) \cdot P_{oc} \cdot P_{fem}$$

[33] For the purposes of storm/hurricane-related interferences with navigation and transit, Category 1 and above hurricanes are included.

Where: P_{vof} = probability of vessel operation failure
P_{he} = probability of human error
P_{sf} = probability of steering failure
P_{pf} = probability of propulsion failure
P_{ee} = probability of environmental event
P_f = probability of fog
P_h = probability of hurricane
P_t = probability of tsunami
P_{oc} = probability of vessel being off-course
P_{fem} = probability of failure of evasive maneuver

For the scenario in which a large vessel allides with several WTGs, the additional probability of not only one WTG but five WTGs needed to be considered, as well as the probability that all five of the WTGs would spill. It was conservatively assumed that the probability of hitting more than one WTG, let alone five in a row, would be one-fifth that of hitting a single one. The actual probability would be related to the exact angle at which the vessel would be approaching the WTGs and would likely be lower than 0.20. With regard to the probability of a spill, it was also conservatively assumed that if a large vessel did allide with five WTGs, they would spill their contents.

The annual incident rates of vessel allisions in the Call Area/WEAs are shown in Table 3.16. These estimated rates are based on the fault tree design in Figure 3.16.

Table 3.16
Estimated annual incident rate of vessel allision with WTGs.

WEA/Call Area	Small Vessel Allision	Large Vessel Allision	Large Vessel Multiple WTG Allision
RI-MA	0.29	0.22	0.04
MD	1.10	1.47	0.29
NC	4.58	28.2	5.64

3.2.7 Probability of Total Release with Spillage

The spill scenarios analyzed in this study assume that there is a total release of the contents of the vesicle (container or tank) holding the oil or chemical. In reality, in the event of a breach of the vesicle, whether through vessel impact, corrosion or structural failure, seismic event, or storm, the entire contents may not flow out. The degree and rate of outflow will depend on the nature of the impact, degree of damage to the vesicle, the size of the hole, the length of time before the breach is noticed and repaired, the configuration and compartmentalization of the vesicle, and the nature of the fluid, particularly viscosity in relation to the ambient temperature.

Numerous studies have been conducted on oil outflow from tankers (National Research Council (NRC) 2001; Tikka 1998; Simsonsen 1998; International Maritime Organization (IMO) 1992 and 1996; and Rawson et al. 1998) and bunker tanks in cargo vessels (Michel and Winslow 1999; Yip et al. 2011a,b). These studies and developed models indicate that the probability of a total release of the contents of contained oil is unlikely. The models, however, are not directly applicable to the WTG and ESP components, and there are no other specific models on which to base an estimate of the degree of outflow from these components. Historical data on spills of storage tanks and other facility components indicate that the degrees of outflow and spill volumes are generally distributed in a log-normal fashion. This means that smaller spills are more common than larger ones. Worst case discharges generally represent a minority of spill events, often less than 1% of cases (Etkin 2002, 2003, 2004, 2010).

Conservatively, it was assumed that the probability of a worst case discharge (complete release of all the oil and chemical fluids in the largest spill scenarios) is 0.1. It is assumed that for the smaller incidents of 500 gallons or less (e.g., the outflow of 90 gallons of hydraulic oil from a WTG nacelle), the entire contents of the vesicle would spill. For incidents involving more than 500 gallons, the probability of 0.1 would be applied. For incidents involving seismic events or hurricanes exceeding Category 3, it is assumed that there would be a worst case discharge.

3.3 Expected Values for Spill Incident Probabilities

3.3.1 Results of Fault Tree Analysis

The fault tree analyses were applied to all the spill scenarios based on the probabilities relevant to each of the Call Area/WEAs to derive annual rates (and return-year values). The probabilities derived from the fault tree analyses are summarized in Tables 3.17 for each of the Call Area/WEAs. The probabilities are incident rates per year. The incident rates are summarized in Table 3.18.

Table 3.17
Probabilities for incidents based on fault tree analyses for each of the Call Area/WEAs. See Table 2.12 and 2.13 for detailed descriptions of spill scenarios.

Scenario Name	Spill Causal Event	Annual Rate		
		RI-MA WEA	MD WEA	NC Call Area
ESP-Nap-500	Structural failure/corrosion and failure to detect	0.00240	0.00240	0.00240
	Maintenance damage or operations errors	0.01100	0.01100	0.01100
	Transfer error	0.01000	0.01000	0.01000
	Total annual incidents	**0.02340**	**0.02340**	**0.02340**
ESP-Nap-1K	Structural failure/corrosion and failure to detect	0.00024	0.00024	0.00024
	Maintenance damage or operations errors	0.00110	0.00110	0.00110
	Transfer error	0.00100	0.00100	0.00100
	Total annual incidents	**0.00234**	**0.00234**	**0.00234**
ESP-Diesel-2K	Structural failure/corrosion and failure to detect	0.00024	0.00024	0.00024
	Maintenance damage or operations errors	0.00110	0.00110	0.00110
	Transfer error	0.00100	0.00100	0.00100
	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Total annual incidents	**0.04925**	**0.00328**	**0.08078**
ESP-Nap-10K	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Total annual incidents	**0.04691**	**0.00094**	**0.07844**

Table 3.17 continued

Scenario Name	Spill Causal Event	Annual Rate		
		RI-MA WEA	MD WEA	NC Call Area
ESP-Nap-40K	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Probability that all four tanks breached	0.25000	0.25000	0.25000
	Total annual incidents	**0.01173**	**0.00024**	**0.01961**
ESP-Ethyl-30	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Transfer error	0.01000	0.01000	0.01000
	Total annual incidents	**0.05691**	**0.01094**	**0.08844**
ESP-Sulf-335	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Transfer error	0.01000	0.01000	0.01000
	Total annual incidents	**0.05691**	**0.01094**	**0.08844**
WTG-Hyd-90	Small vessel allision	0.02900	0.11000	0.45800
	Large vessel allision	0.02070	0.14700	3.10200
	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Transfer error	0.01000	0.01000	0.01000
	Total annual incidents	**0.10661**	**0.26794**	**3.64844**
WTG-Gly-440	Small vessel allision	0.02900	0.11000	0.45800
	Large vessel allision	0.022000	0.14700	2.82000
	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Transfer error	0.01000	0.01000	0.01000
	Total annual incidents	**0.10791**	**0.26794**	**3.29502**
WTG-Nap-370	Small vessel allision	0.02900	0.11000	0.45800
	Large vessel allision	0.022000	0.14700	2.82000
	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.01000	0.00000	0.07792
	Transfer error	0.04545	0.01000	0.01000
	Total annual incidents	**0.10791**	**0.26794**	**3.29502**
WTG-Lub-220	Small vessel allision	0.02900	0.11000	0.45800
	Large vessel allision	0.022000	0.14700	2.82000
	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.01000	0.00000	0.07792
	Transfer error	0.04545	0.01000	0.01000
	Total annual incidents	**0.10791**	**0.26794**	**3.29502**
5WTG-Mix1-3400	Large vessel allision to 5 WTGs	0.00400	0.02900	0.56400
	Total annual incidents	**0.00400**	**0.02900**	**0.56400**

Table 3.17 continued

Scenario Name	Spill Causal Event	Annual Rate		
		RI-MA WEA	MD WEA	NC Call Area
All-Mix2-129K	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Probability that all structures breached	0.01000	0.01000	0.01000
	Total annual incidents	**0.00047**	**0.00001**	**0.00078**
WCD-Chems-29K	Seismic event exceeding 5.0	0.00140	0.00090	0.00050
	Seismic event exceeding 7.0 to cause tsunami	0.00006	0.00004	0.00002
	Hurricane/storm event exceeding Category 3	0.04545	0.00000	0.07792
	Probability that all structures breached	0.01000	0.01000	0.01000
	Total annual incidents	**0.00047**	**0.00001**	**0.00078**

Table 3.18
Spill scenario incident rate summary.

Spill Scenario	Annual Incident Rate/ Return Years							
	RI-MA WEA		MD WEA		NC Call Area		Total	
	Annual	Return Years	Annual	Return Years	Annual	Return Years	Annual	Return Years
ESP-Nap-500	0.02340	42.7	0.02340	42.7	0.02340	42.7	0.07020	14.2
ESP-Nap-1K	0.00234	427.4	0.00234	427.4	0.00234	427.4	0.00702	142.5
ESP-Diesel-2K	0.04925	20.3	0.00328	304.9	0.08078	12.4	0.13331	7.5
ESP-Nap-10K	0.04691	21.3	0.00094	1,063.8	0.07844	12.7	0.12629	7.9
ESP-Nap-40K	0.01173	85.3	0.00024	4,166.7	0.01961	51.0	0.03158	31.7
ESP-Ethyl-30	0.05691	17.6	0.01094	91.4	0.08844	11.3	0.15629	6.4
ESP-Sulf-335	0.05691	17.6	0.01094	91.4	0.08844	11.3	0.15629	6.4
WTG-Hyd-90	0.10791	9.3	0.26794	3.7	3.29502	0.3	3.67087	0.3
WTG-Gly-440	0.10791	9.3	0.26794	3.7	3.29502	0.3		0.3
WTG-Nap-370	0.10791	9.3	0.26794	3.7	3.29502	0.3		0.3
WTG-Lub-220	0.10791	9.3	0.26794	3.7	3.29502	0.3		0.3
All-Mix2-129K	0.00047	2,131.7	0.00001	100,000.0	0.00078	1,282.1	0.00126	793.7
WCD-Chems-29K	0.00047	2,131.7	0.00001	100,000	0.00078	1,282.1	0.00126	793.7
5WTG-Mix1-3400	0.00400	250.0	0.01000	100.0	0.564	1.77		1.6
Total	0.68403	1.5	0.86591	1.2	14.12709	0.07		0.06

The most likely incidents are 90-gallon hydraulic oil spills (WTG-Hyd-90), 370-gallon naphthenic oil spills (WTG-Nap-370), 220-gallon lubricating oil spills (WTG-Lub-220) and 440-gallon ethylene glycol chemical spills (WTG-Gly-440) from a WTG in the NC Call Area. It is important to note that the probabilities of these incidents would be significantly reduced by the presence of well-enforced vessel exclusion zones and changes in vessel traffic lanes. These spills would each be expected to occur 3.6 times per year based on the probabilities and assumptions inherent in the fault tree analysis. The next four most likely scenarios are the same spill types occurring in the MD WEA, though these incidents would be expected at less than $1/10^{th}$ the rate.

3.3.2 Application of Monte Carlo Simulation for Sensitivity Analysis

The fault tree analysis is based on static (set) probabilities that are estimated from actual data, and in some cases, estimated based on best professional judgment. There is a certain degree of error inherent in these probability estimates. A Monte Carlo simulation approach in which the probabilities in the fault tree analysis are varied allows for a sensitivity analysis to determine the degree of uncertainty and potential variability in the calculated incident rates, as well as to determine the degree to which different variables in the fault tree analysis contribute to the overall variability.

The probabilities and incident rates used in the fault tree analysis are shown as potential ranges in Table 3.19 for each of the Call Area/WEAs. The ranges are the values above and below the estimate incident rate that are applied to allow for an estimation of error and sensitivity analysis as part of the Monte Carlo simulation. For the potential ranges, an assumed distribution is suggested.[34]

Table 3.19

Ranges and distributions for probabilities applied in fault tree analyses.

Variable	Set Values			Likely Value Ranges			Range Logic	Dist. Type
	RI-MA	MD	NC	RI-MA	MD	NC		
Seismic event > 5.0	0.00140	0.00090	0.00050	0.001275 -0.014	0.000874 - 0.009	0.00045 - 0.005	Damage at 4.0; no damage until 6.0	Log-normal
Seismic event > 7.0	0.00006	0.00004	0.00002	0.000002 - 0.0013	0.000001 -0.0009	0.000001 -0.0005	Damage at 6.0; no damage until 7.5	Log-normal
Hurricane > 3 event	0.04500	0.00000	0.07792	0.0 – 0.0714	0.0 – 0.0065	0.0065 – 0.1623	Damage with 2; no damage until 4	Log-normal
Struc fail + 500-gal spill + detect fail	0.00240	0.00240	0.00240	0.00024 – 0.024	0.00024 – 0.024	0.00024 – 0.024	1/10 to 10 X structural failure rate	Weibull
Struc fail + 1,000-gal spill + detect fail	0.00024	0.00024	0.00024	0.000024 – 0.0024	0.000024 – 0.0024	0.000024 – 0.0024	1/10 to 10 X structural failure rate	Weibull
Maintenance damage or operation error	0.00700	0.00700	0.00700	0.0007 – 0.07	0.0007 – 0.07	0.0007 – 0.07	1/10 to 10 X estimated rate	Log-normal
Breakage with 1,000-gal+ release	0.00100	0.00100	0.00100	0.0001 – 0.01	0.0001 – 0.01	0.0001 – 0.01	1/10 to 10 X estimated rate	Log-normal
All four tanks breached	0.25000	0.25000	0.25000	0.0625 – 1.0	0.0625 – 1.0	0.0625 – 1.0	1/4 to 4 times estimated rate	Log-normal
All structures breached	0.10000	0.10000	0.10000	0.01 – 1.0	0.01 – 1.0	0.01 – 1.0	1/10 to 10 X estimated rate	Log-normal
Small vessel allision	0.02900	0.11000	0.45800	0.0029 – 0.29	0.011 – 1.1	0.0458 – 4.58	1/10 to 10 X estimated rate	Log-normal

[34] A normal distribution is one in which the mean value is the most likely. The distribution is symmetrical around the mean. A value is more likely to be closer to the mean than further away from it. A log-normal distribution is one in which the upper value is unlimited but values cannot fall below zero. The natural logarithm of the distribution is a normal distribution. The distribution is positively skewed with most values near the lower limit. An extreme value distribution describes the largest value of a response over time. This is typically used to describe earthquake and flooding events. A Weibull distribution is a slightly positively skewed normal distribution. This type of distribution is often applied for failure time in a reliability study (e.g., corrosion). A uniform distribution has equal likelihood for all values in the designated range.

Table 3.19 continued

Variable	Set Values			Likely Value Ranges			Range Logic	Dist. Type
	RI-MA	MD	NC	RI-MA	MD	NC		
Large vessel allision	0.02200	0.14700	2.8200	0.0022 – 0.22	0.0147 – 1.47	0.2802 - 28.2	1/10 to 10 X estimated rate	Log-normal
5 WTG-breach in allision	0.00400	0.02900	0.56400	0.0004 – 0.04	0.0029 – 0.29	0.0564 – 5.64	1/10 to 10 X estimated rate	Log-normal
Transfer error < 500 gal	0.01000	0.01000	0.01000	0.00026 – 0.0134	0.00026 – 0.0134	0.00026 – 0.0134	Table 3.9	Log-normal
Transfer error > 500 gal	0.00100	0.00100	0.00100	0.00003 – 0.0013	0.00003 – 0.0013	0.00003 – 0.0013	Table 3.9	Log-normal

To account for possible errors in engineering analyses concluding that the wind facility structures would withstand a Category 3 hurricane, the possibility of the damage from a Category 3 (and above) hurricane was included in the range of possible annual incident rates. Note that no category 3 or higher hurricane occurred in the MD WEA during the 153-year time period 1851-2004.

Table 3.20 shows the ranges of annual incident rates based on the Monte Carlo simulation using 1,000 runs. In some cases, the calculations from the "static variables", i.e., those in Table 3.17, differ from the mean and median calculated in the Monte Carlo simulation. This is attributable to the differences in the ranges and probabilities of values in the distributions applied. The 10th percentile and 90th percentile values in the simulations are shown in Table 3.21.

Table 3.20
Relative spill incident rates and estimated ranges based on Monte Carlo simulation.

Spill Scenario	WEA/Call Area	Annual Incident Rate (Incidents per Year)					
		Calculated with Static Variables	Monte Carlo Simulation Results				
			Mean	Median	Standard Deviation	10th percentile	90th percentile
ESP-Nap-500	RI-MA	0.02340	0.02340	0.02365	0.00494	0.01701	0.02997
	MD	0.02340	0.02340	0.02365	0.00494	0.01701	0.02997
	NC	0.02340	0.02340	0.02365	0.00494	0.01701	0.02997
ESP-Nap-1K	RI-MA	0.00234	0.01281	0.01196	0.00616	0.00525	0.02152
	MD	0.00234	0.01281	0.01196	0.00616	0.00525	0.02152
	NC	0.00234	0.01281	0.01196	0.00616	0.00525	0.02152
ESP-Diesel-2K	RI-MA	0.04925	0.05037	0.05098	0.01492	0.02928	0.06959
	MD	0.00328	0.01119	0.01098	0.00341	0.00682	0.01560
	NC	0.08078	0.06601	0.06007	0.03679	0.02224	0.12118
ESP-Nap-10K	RI-MA	0.04691	0.04512	0.04622	0.01489	0.02460	0.06397
	MD	0.00094	0.00610	0.00591	0.00242	0.00300	0.00940
	NC	0.07844	0.08283	0.08114	0.03248	0.04053	0.12940
ESP-Nap-40K	RI-MA	0.01173	0.01114	0.01147	0.00379	0.00585	0.01588
	MD	0.00024	0.00151	0.00144	0.00062	0.00072	0.00233
	NC	0.00884	0.02071	0.02062	0.00784	0.01022	0.03191
ESP-Gly-30	RI-MA	0.05691	0.05348	0.05551	0.01532	0.03191	0.07241
	MD	0.01094	0.01414	0.01430	0.00358	0.00922	0.01875
	NC	0.08844	0.09201	0.09173	0.03225	0.04926	0.13578

Table 3.20 continued

Spill Scenario	WEA/Call Area	Annual Incident Rate (Incidents per Year)					
		Calculated with Static Variables	Monte Carlo Simulation Results				
			Mean	Median	Standard Deviation	10th percentile	90th percentile
ESP-Sulf-335	RI-MA	0.05691	0.05348	0.05551	0.01532	0.03191	0.07241
	MD	0.01094	0.01414	0.01430	0.00358	0.00922	0.01875
	NC	0.08844	0.09201	0.09173	0.03225	0.04926	0.13578
WTG-Hyd-90	RI-MA	0.10791	0.25911	0.24958	0.08823	0.15391	0.37960
	MD-DE	0.26794	0.96751	0.93203	0.40180	0.46391	1.52684
	NC	3.29502	11.97414	10.79370	6.22347	4.41942	20.99746
WTG-Gly-440	RIMA	0.10791	0.25911	0.24958	0.08823	0.15391	0.37960
	MD	0.26794	0.96751	0.93203	0.40180	0.46391	1.52684
	NC	3.29502	11.97414	10.79370	6.22347	4.41942	20.99746
WTG-Nap-370	RI-MA	0.10791	0.25911	0.24958	0.08823	0.15391	0.37960
	MD-DE	0.26794	0.96751	0.93203	0.40180	0.46391	1.52684
	NC	3.29502	11.97414	10.79370	6.22347	4.41942	20.99746
WTG-Lub-220	RI-MA	0.10791	0.25911	0.24958	0.08823	0.15391	0.37960
	MD-DE	0.26794	0.96751	0.93203	0.40180	0.46391	1.52684
	NC	3.29502	11.97414	10.79370	6.22347	4.41942	20.99746
All-Mix2-129K	RI-MA	0.00047	0.00045	0.00046	0.00015	0.00025	0.00065
	MD-DE	0.00001	0.00006	0.00006	0.00002	0.00003	0.00010
	NC	0.00078	0.00040	0.00040	0.00020	0.00020	0.00070
WCD-Chems-29K	RI-MA	0.00047	0.00045	0.00046	0.00015	0.00025	0.00065
	MD	0.00001	0.00006	0.00006	0.00002	0.00003	0.00010
	NC	0.00078	0.00040	0.00040	0.00020	0.00020	0.00070
5WTG-Mix1-3400	RI-MA	0.00400	0.002010	0.01398	0.00453	0.00402	0.02796
	MD-DE	0.02900	0.01099	0.07101	0.02195	0.03187	0.20593
	NC	0.56400	0.20157	1.31696	0.42812	0.60471	3.95088

The Monte Carlo simulations show that some incident rates were potentially over- or under-estimated based on the particular values chosen for the variable inputs. These differences can be seen by comparing the calculated values from the set variables to the mean and median of the Monte Carlo simulation results. The range of values in the Monte Carlo simulation (10th and 90th percentiles) also demonstrates the potential variability in the incident rate calculations. Taking the most precautionary approach, the higher median (50th percentile) or calculated values should be considered in determining potential risk. The 10th and 90th percentiles provide a sense of the range of the probabilities of incident occurrence. Taking this approach, the results are summarized in Table 3.21. These results tend to potentially over-estimate the probability of these spill scenarios.

Table 3.21

Spill incident rate results applying precautionary approach.

Spill Scenario	WEA/Call Area	Annual Incident Rate			30-Year Incident Rate		
		Max. Median	10th Percentile	90th Percentile	Max. Median	10th Percentile	90th Percentile
ESP-Nap-500	RI-MA	0.024	0.017	0.030	0.710	0.510	0.899
	MD	0.024	0.017	0.030	0.710	0.510	0.899
	NC	0.024	0.017	0.030	0.710	0.510	0.899

Table 3.21 continued

Spill Scenario	WEA/Call Area	Annual Incident Rate	30-Year Incident Rate	Spill Scenario	WEA/Call Area	Annual Incident Rate	30-Year Incident Rate
Table ESP-Nap-1K	RI-MA	0.012	0.005	0.022	0.359	0.158	0.646
	MD	0.012	0.005	0.022	0.359	0.158	0.646
	NC	0.012	0.005	0.022	0.359	0.158	0.646
ESP-Diesel-2K	RI-MA	0.051	0.029	0.070	1.529	0.878	2.088
	MD	0.011	0.007	0.016	0.329	0.205	0.468
	NC	0.081	0.022	0.121	2.423	0.667	3.635
ESP-Nap-10K	RI-MA	0.047	0.025	0.064	1.407	0.738	1.919
	MD	0.006	0.003	0.009	0.177	0.090	0.282
	NC	0.081	0.041	0.129	2.434	1.216	3.882
ESP-Nap-40K	RI-MA	0.012	0.006	0.016	0.352	0.176	0.476
	MD	0.001	0.001	0.002	0.043	0.022	0.070
	NC	0.021	0.010	0.032	0.619	0.307	0.957
ESP-Gly-30	RI-MA	0.057	0.032	0.072	1.707	0.957	2.172
	MD	0.014	0.009	0.019	0.429	0.277	0.563
	NC	0.092	0.049	0.136	2.752	1.478	4.073
ESP-Sulf-335	RI-MA	0.057	0.032	0.072	1.707	0.957	2.172
	MD	0.014	0.009	0.019	0.429	0.277	0.563
	NC	0.092	0.049	0.136	2.752	1.478	4.073
WTG-Hyd-90	RI-MA	0.250	0.154	0.380	7.500	4.620	11.400
	MD-DE	0.932	0.464	1.527	27.961	13.917	45.805
	NC	10.794	4.420	20.997	323.820	132.600	629.91
WTG-Gly-440	RIMA	0.250	0.154	0.380	7.500	4.620	11.400
	MD	0.932	0.464	1.527	27.961	13.917	45.805
	NC	10.794	4.420	20.997	323.820	132.600	629.91
WTG-Nap-370	RI-MA	0.250	0.154	0.380	7.500	4.620	11.400
	MD-DE	0.932	0.464	1.527	27.961	13.917	45.805
	NC	10.794	4.420	20.997	323.820	132.600	629.91
WTG-Lub-220	RI-MA	0.250	0.154	0.380	7.500	4.620	11.400
	MD-DE	0.932	0.464	1.527	27.961	13.917	45.805
	NC	10.794	4.420	20.997	323.820	132.600	629.91
All-Mix2-129K	RI-MA	0.00047	0.00025	0.00065	0.014	0.008	0.020
	MD-DE	0.00006	0.00003	0.00010	0.002	0.001	0.003
	NC	0.00078	0.00020	0.00080	0.023	0.006	0.024
WCD-Chems-29K	RIMA	0.00047	0.00025	0.00065	0.014	0.008	0.020
	MD	0.00006	0.00003	0.00010	0.002	0.001	0.003
	NC	0.00078	0.00020	0.00080	0.023	0.006	0.024
	RI-MA	0.014	0.004	0.028	0.420	0.030	0.840
	MD-DE	0.071	0.032	0.206	2.130	0.960	6.180
5WTG-Mix1-3400	NC	1.317	0.428	3.951	39.510	12.84	118.53

Based on the results in Table 3.21, the median annual rates were arranged in decreasing order of probability, as in Table 3.22. Once again, the highest rates are for incidents in the NC Call Area. The reason for this high rate is the potential relative frequency of vessel allisions causing small spills. If vessel traffic is adequately re-routed around the NC Call Area, this incident rate will drop precipitously. Risk mitigation measures for these and other spills are described in Section 1.5.

The incident rates can be roughly grouped into five categories of probability – very high, high, medium, low, and very low, as indicated by the colors red, yellow, and green in Table 3.22.

Table 3.22

Incident rates for spill scenarios in decreasing order based on maximized median rates.

Spill Scenario	WEA/Call Area	Annual Incident Rate	Return Years	Probability Group
WTG-Hyd-90	NC	10.794	0.1	**VERY HIGH 1 time per month**
WTG-Gly-440	NC	10.794	0.1	
WTG-Nap-370	NC	10.794	0.1	
WTG-Lub-220	NC	10.794	0.1	
WTG-Hyd-90	MD	0.932	1.1	HIGH 1 time in 1 to 5 years
WTG-Gly-440	MD	0.932	1.1	
WTG-Nap-370	MD	0.932	1.1	
WTG-Lub-220	MD	0.932	1.1	
5WTG-Mix1-3400	NC	0.639	1.6	
WTG-Hyd-90	RIMA	0.227	4.4	
WTG-Gly-440	RIMA	0.227	4.4	
WTG-Nap-370	RIMA	0.227	4.4	
WTG-Lub-220	RIMA	0.227	4.4	
ESP-Gly-30	NC	0.092	11	**MEDIUM 1 time in 10 to 50 years**
ESP-Sulf-335	NC	0.092	11	
ESP-Diesel-2K	NC	0.081	12	
ESP-Nap-10K	NC	0.081	12	
5WTG-Mix1-3400	MD	0.071	14	
ESP-Gly-30	RIMA	0.057	18	
ESP-Sulf-335	RIMA	0.057	18	
ESP-Diesel-2K	RIMA	0.051	20	
ESP-Nap-10K	RIMA	0.047	21	
5WTG-Mix1-3400	MD	0.034	29	
ESP-Nap-500	RIMA	0.024	42	
ESP-Nap-500	MD	0.024	42	
ESP-Nap-500	NC	0.024	42	
ESP-Nap-40K	NC	0.021	48	**LOW 1 time in 50 – 100 years**
ESP-Gly-30	MD	0.014	71	
ESP-Sulf-335	MD	0.014	71	
ESP-Nap-1K	RIMA	0.012	83	
ESP-Nap-1K	MD	0.012	83	
ESP-Nap-1K	NC	0.012	83	
ESP-Nap-40K	RIMA	0.012	83	
ESP-Diesel-2K	MD	0.011	91	
ESP-Nap-10K	MD	0.006	167	
5WTG-Mix1-3400	RIMA	0.006	167	
ESP-Nap-40K	MD	0.001	1,000	**VERY LOW 1 time in 1,000 or more years**
All-Mix2-129K	NC	0.0008	1,250	
All-Mix2-129K	RIMA	0.0005	2,000	
All-Mix2-129K	MD	0.00006	16,667	
WCD-Chems-29K	NC	0.0008	1,250	
WCD-Chems-29K	RIMA	0.0005	2,000	
WCD-Chems-29K	MD	0.00006	16,667	

3.4 SPILLS FROM VESSELS

This project specifically addresses only oil or chemicals spill scenarios originating from the wind energy facility components (WTGs and ESPs) themselves. While this includes incidents that might occur when a vessel allides with one or more wind facility components, it excludes any spill that might occur from the vessels (bunker fuel and/or oil or other cargo) involved in either allisions with WTGs and ESPs or from vessels colliding with each other for reasons attributable to the presence of the wind energy facility (e.g., blocking of radar).

While the data for the RI-MA, MD, and NC Call Areas have not specifically been analyzed for this with respect to probability of vessel spills, a brief review of the results of the analyses conducted herein, as well as those conducted specifically for the Cape Wind Energy project (Etkin 2006a, c; Cape Wind Associates and ESS Group Inc. 2007), provides some insight into the likelihood and magnitude of these types of spills.

3.4.1 Vessel Allision-Related Spills

The analyses in this report include estimations of incident rates for vessels alliding with WTGs. This same incident rate can be applied to estimate the probability of spills on the vessel-side of these casualty incidents, though the probabilities that there will be a vessel spill associated with an allision and the associated spill volumes are different than for the WTG spill. The probability of a spill due to a vessel impact (collision or allision) is about 0.005 spills per casualty for most vessels (Etkin 2006a, c; Cape Wind Associates and ESS Group Inc. 2007) with the exception of tankers, for which the incident rate is higher (0.40 for single-hulled tankers and 0.14 for double-hulled tankers).[35] In this study, it is assumed that all tankers are double-hulled. The implementation date of the double-hull provisions of the Oil Pollution Act of 1990 is 2015. The vast majority of tankers operating in US waters are already double-hulled.

Annual vessel allision incident rates[36] for small and large vessels are shown in Tables 3.23 and 3.24. The probabilities of spills and spill volume scenarios from the vessels are also included. Spill volume and spill probabilities are weight-averaged on the basis of the types of vessels transiting each Call Area/WEA region. The WCD is the full contents of a fully laden tanker corrected for the expected outflow due to the double hull.

Table 3.23

Estimated annual incident rate of small vessel allision with WTGs and vessel-related spills.

WEA/Call Area	Allision Annual Rate	Spill Probability	Annual Spills	Return Years	Spill Volume (gallons)			
					10th Percentile	50th Percentile	90th Percentile	WCD
RI-MA	0.29	0.005	0.00145	690	< 1	6	60	1,200
MD	1.10	0.005	0.00550	182	< 1	6	60	1,200
NC	4.58	0.005	0.02290	44	< 1	6	60	1,200

[35] Based on the probability of zero outflow in the International Maritime Organization methodology refers to the likelihood of no spill when the outer shell (hull) of a tanker has been ruptured (IMO 1992, 1996; National Academies Marine Board/Transportation Research Board 2001).

[36] For the large vessel allisions, allisions with single and multiple WTGs are combined into one incident rate.

Table 3.24
Estimated annual incident rate of large vessel allision with WTGs and vessel-related spills.

WEA/Call Area	Allision Annual Rate	Spill Probability	Annual Spills	Return Years	Spill Volume (gallons)			
					10th Percentile	50th Percentile	90th Percentile	WCD
RI-MA	0.22	0.0070	0.00154	649	3	62	3,340	40,000,000
MD-DE	1.47	0.0037	0.00544	184	2	41	1,550	40,000,000
NC	28.20	0.0047	0.13254	8	2	37	830	40,000,000

The incident rate of vessel spills due to allisions is very small. The most likely vessel spill due to a vessel allision would occur in the NC WEA, where an incident is expected once every 8 years. Again, as with the spills from the Call Area/WTGs or ESPs, the vast majority of spills, if they occur in the first place, involve relatively small amounts of oil. A very small percentage of incidents involves a large volume of oil, let alone a worst case discharge (Etkin 2002, 2003, 2004, 2010).

3.4.2 Vessel Collision-Related Spills

The analysis of vessel collision-related spill incidents is more complex. This type of analysis was conducted for the Cape Wind project (Etkin 2006a, c; ESS Group Inc. 2006; Cape Wind Associates and ESS Group Inc. 2007). The general approach to that project, which was followed in the analysis for the Call Area/WEAs, was to:

- Analyze local vessel traffic data and patterns of transit around the facility perimeters;
- Determine the probability that a vessel would be off-track on the side of the WTGs (as in Figure 3.15;
- Apply the probabilities of vessel and human failures (as in Table 3.12);
- Apply the probabilities of evasive maneuver failures (as in Table 3.14);
- Account for the probability of visibility issues (e.g., fog and darkness) and extreme weather events (tsunamis, hurricanes, storms);
- Analyze the probability of radar interference for vessels in the vicinity of WTGs;
- Analyze the angles of encounter between the vessels and their respective velocities;
- Analyze the forces of encounter between the vessels;[37] and
- Analyze outflow models for estimation of likelihood of a spill and spill volume probability distributions based on vessel type and hull type.

The incident rates for the Call Area/WEAs are shown in Table 3.2.

As discussed in Section 3.1.6, vessel collisions increase with the probability of encounters. As the density of vessels increases, the number of vessel encounters and potential collisions increases exponentially. The large vessel densities in the Call Area/WEAs are shown in Table 3.25. The estimated collision rate was calculated for the Call Area/WEAs based on the rate in the Cape Wind area adjusted by Equation 3.11. The expected incident rate for vessel collisions related to the presence of the wind energy facilities in the Call Area/WEAs would be extremely low.

[37] Based on: $E = 0.5mv^2$, where: v = velocity (in m/s), and m = (displacement x 1.1), to take into account the added mass of water acting within the vessel. Velocity and displacement are maximized in all vessel categories.

Table 3.25
Estimated vessel collision-related spills for Call Area/WEAs.

WEA/Call Area	Vessel Density (number vessels/year/sq. mile)	Estimated Collision-Related Spills			
		No Evasive Maneuvers		With Evasive Maneuvers	
		Annual Rate	Return Years	Annual Rate	Return Years
RI-MA	15	0.0016	625	0.00002	50,000
MD	28	0.0033	303	0.00005	20,000
NC	45	0.0057	175	0.00008	12,500

3.5 RISK MITIGATION

An examination of Table 3.20 and the underlying probabilities in Table 3.18 indicates that there is a particularly high probability of vessel allision-related events in the NC Call Area, as well as in the MD WEA, though to a lower extent. These elevated incident rates are driven primarily by the relatively high number of large vessels transiting in the areas in and around the Call Area/WEAs. In the NC Call Area, there are 3,655 cargo vessels in transit annually, and in the MD WEA, there are 1,235 cargo vessels in the vicinity. While the various assumptions applied in the fault tree analysis are conservative, i.e., tending to over-estimate the probability of incidents occurring, to afford a general precautionary approach, there does remain a high likelihood of incidents of this nature.

Risk mitigation measures aimed at reducing the likelihood of spill incidents should focus primarily on vessel traffic in these locations. It should be noted that the fault tree analysis assumed that the vessel traffic currently in the Call Area/WEA areas would continue to be in that vicinity after the Call Area/WEA facilities were in place. Clearly, vessel traffic would need to be generally re-routed around the structures during the construction and when the facility structures were in place. Assuming that vessel traffic would be appropriately re-routed to vessel traffic lanes that avoid the WEA and that adequate measures would be taken to include these structures on navigational charts and include appropriate warning lighting and other deterrents, the vast majority of these allision incidents should be avoided.

While natural phenomenon (seismic events, hurricanes, tsunamis, fog) cannot be avoided, measures can be taken to reduce the likelihood of a spill attributable directly or indirectly to these events by such measures as:

- Engineering of WTG and ESP components to adequately withstand impacts from seismic, wind, and wave impacts to the extent feasible;
- Properly including the WEA structures on navigational charts to avoid allisions during low visibility of fog (or darkness);
- Properly installing warning lighting and other deterrents;
- Inspection of WTGs and ESPs after significant seismic events or storms to detect damage; and
- Maintenance and repair of damaged or compromised components as appropriate.

Oil and chemical transfer operations, as well as maintenance procedures, are other circumstances that can lead to spills. Implementation of best-practices protocols[38] for these operations can be extremely effective in reducing the incidents of spills, as evidenced by implementation of these types of measures in oil transfer operations between vessels and between vessels and facilities (Etkin 2006b; Washington Department of Ecology 2005).

3.6 FUTURE SPILL PROBABILITIES

Since the probability of a spill is driven by the following factors, any variation in these factors will either increase or decrease the probabilities for spill incidents:

- Magnitude of vessel traffic (changes in shipping patterns, changes in oil energy transport);
- Changes in the proportions of vessel types (e.g., numbers of tankers relative to cargo vessels);
- Re-routing of vessel traffic around Call Area/WEAs;
- Changing weather patterns (e.g., increases in storm events due to climate change or periodic weather cycles);
- Effectiveness of safety measures taken by vessel operators; and
- Safety measures taken by wind energy operators (e.g., changes in maintenance patterns, implementation of oil/chemical transfer spill prevention measures).

The increased reliance on wind energy, as well as other changes in energy consumption and generation in the US, may decrease reliance on foreign petroleum transports. This will reduce the number of tanker trips and the potential incidence of vessel allisions (as well as collisions) and related spills.

Increases in vessel traffic will tend to increase the likelihood of allision- and collision-related spills, though this may be offset by better vessel traffic management, re-routing of vessels around Call Area/WEAs, and increased safety regulations and voluntary best practices to reduce casualties and spills. There has been a general reduction in the spills from tankers and other vessels after implementation of the Oil Pollution Act of 90 spill prevention measures (e.g., double hulls) despite documented increases in vessel traffic in the US (Etkin 2002, 2003, 2004, 2010). Similar measures in other nations have also decreased spill rates (GESAMP 2007). These types of reductions might be expected to offset any potential increases in vessel traffic-related incidents in the Call Area/WEAs.

Increasing age of the infrastructure of the Call Area/WEAs (i.e., ESPs and WTGs) will generally increase the likelihood of leakage due to corrosion and general structural failure. Increased vigilance in maintenance and inspection may offset these increases. Changes in the frequency of hurricanes and storms may occur due to climate change and periodic weather cycles.

[38] For example: WAC chapters 173-184-100, 173-180-215, and 173-180-210

4. REVIEW AND EVALUATION OF MODELS FOR ANALYSIS OF ENVIRONMENTAL CONSEQUENCES

Modeling can be a powerful tool for oil-spill impact quantification as part of environmental risk assessments, contingency planning, hindcast impact analyses, and natural resource damage assessments. Models use knowledge of physical, chemical, and biological relationships along with environmental data to simulate pollutant transport, fate, and effects associated with a release of oil. Spill-related impacts are typically evaluated based on three main factors: water surface oiling (e.g., area oiled, mass of oil on the surface), shoreline oiling (e.g., length/area oiled, shore types affected, mass of oil on shorelines), and water column contamination (e.g., volume of water exposed above effects threshold, dose). Sediment oiling is also a concern in some situations.

Models that might be used to analyze the transport and fate of chemicals and oils associated with typical wind energy projects were reviewed and evaluated for their applicability to this analysis. Examples and a short description of the available models are provided below.

4.1 OSRAM (Oil Spill Risk Analysis Model)

The Oil Spill Risk Analysis Model (OSRAM) calculates the probability of spill occurrence, as well as the probability of the 2-dimensional (2D, i.e., at the water surface) trajectory and fate of spilled oil based on historical environmental conditions (OSRAM 2004). The model operates using a stochastic approach by simulating hundreds to thousands of individual spill events and calculating the probabilities for surface and shoreline oiling for oil spills greater than 1,000 barrels originating from a specified location. OSRAM generates the individual oil spill trajectories using either historical and/or model-generated environmental data as input. Model results include predictions of the area of surface oiling and the probability that oil contacts a certain section of coastline. The probability that oil will contact a specific target of interest is calculated by tracking the location of the oil slick at every time step and by counting the number of contacts, taking the variability of various environmental parameters (i.e., wind, currents, tides, etc.) into consideration.

OSRAM does not account for transport and re-suspension due to tides, oil weathering processes, simulation of the 3-dimensional (3D) fate and transport (i.e., subsurface in the water column), or exposure and toxicity of oil. On the other hand, it uses estimates by other chemical models to assist in the determination of the appropriate simulation time periods for oil floating on water (Guillen et al. 2004). OSRAM is used by BOEM to support preparation of documents for National Environmental Policy Act and other environmental analyses for offshore energy development activities. This model is designed to evaluate floating oil transport, but not chemicals or oil components that might disperse in the water column and cause toxicity to aquatic biota.

4.2 COSIM (Chemical Oil Spill Impact Model)

COSIM is a transport, fate, and effects model developed by Cardno Entrix that is sometimes used under contract to Responsible Parties to conduct “cooperative” (i.e., while in discussion with government trustees) and/or parallel Natural Resource Damage Assessments (NRDA)

(Kubitz et al. 2011). The model tracks the fate of released oils and chemicals in various phases and forms including surface slick, product stranded on shoreline, evaporated into the atmosphere, dissolved and/or entrained in the water column, and deposited on sediments. Potential toxicological effects can be evaluated using a suite of methods that range from a conservative screening (comparison of modeled concentrations to potential effects thresholds) to a fully specified toxicological assessment that simulates in-situ conditions. For NRDA, the offsetting effects of spill-related closures are extrapolated from human-use evaluations typically conducted in association with chemical releases and third-party commercial claims. COSIM requires an environmental data characterization of the system (i.e., winds, tides, temperature, suspended solid concentrations, and shoreline substrates), a characterization of the chemical properties of the oil, a "release scenario," and a hydrodynamic grid. The model incorporates processes such as spreading, advection, dispersion, evaporation, volatilization, entrainment and resurfacing, dissolution, emulsification, photo-oxidation, biodegradation, partitioning, sinking and sedimentation, cleanup operations, and shoreline deposition and removal.

RPS ASA has evaluated this model to the degree that it is publically documented. However, COSIM is not publically available, and it has not been validated in publications or reports (only compared to results of other model evaluations for a few cases). It was developed to evaluate RPS ASA’s Spill Impact Model Application Package (SIMAP) and Chemical Discharge Model System (CHEMMAP) models as part of NRDA case work (as noted in their website brochure). Therefore, it was determined that the model would not offer as much to this BOEM project as the well-vetted, documented, and published models SIMAP and CHEMMAP.

4.3 OSCAR (OIL SPILL CONTINGENCY AND RESPONSE)

The OSCAR model system has been developed for objective analysis of alternative spill response strategies (Aamo et al. 1995; Aamo et al. 1997a; Reed et al. 1995a). The key components of the model include SINTEF’s oil weathering model (Aamo et al. 1993; Daling et al. 1990), a three-dimensional oil trajectory and chemical fates model (Reed et al. 1995b), an oil spill combat model (Aamo et al. 1995; Aamo et al. 1996), as well as biological exposure models (Downing and Reed 1996; Reed et al. 1995b). The oil and chemical database supplies data to the model, and results of the model simulations are stored at discrete time-steps, which can then be used as input to the biological exposure models (Aamo et al. 1997b). OSCAR uses environmental data, together with its oil weathering and fates algorithms, to calculate the distribution of oil on the water surface, on shorelines, in the water column, and in the sediments. Processes simulated within the model include spreading, dispersion, entrainment, emulsification, adsorption, dissolution, sedimentation, and degradation.

The OSCAR model can be used in either stochastic mode or deterministic (trajectory) mode. The stochastic mode is used to estimate the probability of particular trajectories occurring based on historic wind data. The stochastic model runs a series of trajectories under various historic wind conditions and combines the individual results to illustrate the probability of where oil may travel. The deterministic model is used to predict the trajectory of an oil slick over time and estimate the oil weathering based on meteorological conditions.

RPS ASA has evaluated OSCAR model to the degree that it is publically documented and has compared it to the SIMAP model (described in Section 4.4). OSCAR and SIMAP have similar model structure and capabilities. Both models include oil transport through wind effect and currents, buoyancy of the entrained oil droplets, and the random-walk turbulence diffusion. However, there are significant differences between the two models in terms of the specific details of the fate algorithms and their implementations. Furthermore, while OSCAR has an exposure modeling component and proclaims to assess the behavioral categories similar to SIMAP, the toxicity model that OSCAR uses is simpler than the oil toxicity and biological exposure model (OilToxEx) developed in SIMAP. Given the fact that OSCAR was developed mainly for emergency contingency response purposes, OSCAR is typically not used to evaluate toxicity beyond the point of comparing hydrocarbon concentrations to the risk threshold. Likewise, because OSCAR lacks a biological injury model (such as the one used in the SIMAP), no direct injury calculation can be made using this model.

4.4 SIMAP (Spill Impact Model Application Package)

SIMAP, developed by RPS ASA, is a fully three-dimensional and time-varying model. It uses wind data, current data, and transport and weathering algorithms to calculate the mass of oil components in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, etc.), oil pathway over time (trajectory), surface oil distribution, and concentrations of the oil components in water and sediments as a result of a spill (French McCay 2003; French McCay 2009; French McCay 2011; French McCay et al. 2004; French McCay 2002, 2004). Processes simulated within the model include spreading, shoreline stranding, dispersion, evaporation, entrainment, emulsification, adsorption, dissolution, sedimentation, and degradation. SIMAP was derived from the physical fates and biological effects sub-models in the NRDA Models for Coastal and Marine Environments (NRDAM/CME), which were developed by RPS ASA for the US Department of the Interior as the basis of Comprehensive Environmental Response, Compensation and Liability Act of 1980 NRDA regulations for Type A assessments (French McCay et al. 1996; Reed et al. 1995b). SIMAP contains physical fate and biological effects models, which estimate exposure and impact on each habitat and species (or species group) in the area of a spill. Environmental, geographical, physical-chemical, and biological databases supply required information to the model for computation of fates and effects. The model algorithms in SIMAP (French McCay 2002, 2003, 2004) have been developed over the past three decades to simulate fate and effects of oil spills under a variety of environmental conditions. Additions and modifications have been made to SIMAP to increase model resolution, allow for modification and site-specificity of input data, incorporate temporally varying current data, evaluate subsurface releases and movements of subsurface oil, track multiple chemical components of the oil, and enable stochastic modeling and analysis of results. The SIMAP transport model has been validated with more than 20 case histories, including the T/V *Exxon Valdez* and other large spills (French McCay 2003, 2004; French McCay and Rowe 2004), as well as test spills designed to verify the model's transport algorithms (French McCay et al. 1997; French McCay et al. 2007).

The three-dimensional physical fates model in SIMAP estimates distribution (as mass, areas and thicknesses of oil, and concentrations) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments. Processes simulated include spreading, evaporation, slick transport, mixing, emulsification, entrainment of oil as droplets into the water, dissolution of soluble components, volatilization, adherence of oil droplets to suspended sediments, adsorption of soluble and semi-soluble aromatics to suspended sediments, sedimentation, stranding on shorelines, and degradation.

"Whole" oil (containing non-volatiles and volatile components not yet volatilized or dissolved from the oil) is simulated as floating slicks, emulsions and/or tar balls, or as dispersed oil droplets of varying diameter (some of which may resurface). Spreading (gravitational and by transport processes), emulsification, weathering (volatilization and dissolution loss), entrainment, resurfacing, and transport processes determine the thickness, dimensions, and locations of floating oil over time.

Surface slicks interact with shorelines, depositing and releasing material according to shoreline type. In the water column, horizontal and vertical transport by currents and turbulent (random) dispersion are simulated. A contaminant in the water column is partially adsorbed to particles and partially dissolved. Contaminants at the bottom are mixed by benthic animals into underlying sediments according to a simple bioturbation algorithm. Degradation of water column and sediment contaminant is estimated assuming a constant rate of "decay" in each environment.

Oil is a mixture of hydrocarbons of varying physical, chemical, and toxicological characteristics. Therefore, oil hydrocarbons have varying fates and impacts on organisms. The most toxic components of oil to water-column and benthic organisms are lower-molecular-weight compounds, which are both volatile and soluble in water, especially the aromatic compounds (French McCay et al. 1996; French McCay 2001, 2002). These include the monoaromatic hydrocarbons (MAH) and polycyclic aromatic hydrocarbons (PAH). It has been shown that toxicity of narcotic organic compounds, such as these lower-molecular-weight aromatics in oil (MAHs and PAHs), is related to the octanol-water partition coefficient (K_{OW}), a measure of hydrophobicity (French McCay et al. 1996; French 1998; French McCay 2001, 2002; Mackay et al. 1992a, b, c; Di Toro and Mcgrath 2000; Di Toro et al. 2000). The more hydrophobic the compound, the more toxic it is. However, the more hydrophobic the compound, the less soluble it is in water, hence the less exposure there is to aquatic organisms. Thus, impact is the result of a balance between bioavailability and toxicity once exposed.

The Oil Toxicity and Exposure Model (OilToxEx) was developed for use in SIMAP to estimate the median lethal concentration (LC_{50}; the concentration that kills 50% of the exposed organisms) for acute exposures to dissolved hydrocarbons from oil. The biological effects model uses the calculated sum of PAHs (or sum of benzene, toluene, ethybenzene, and xylenes (BTEX) and PAHs, if BTEX is significant in the oil) and the estimated $LC50_{mix}$, corrected for time and temperature of exposure, to estimate mortality to aquatic biota. Typically, the appropriate LC_{50mix} is for average sensitivity for most species, as specific data are not available for all species. However, for certain sensitive or insensitive species the 2.5th or 97.5th percentile LC_{50mix}, respectively, is more appropriate. Categorization of species as sensitive, average, or insensitive is based on bioassay data reviewed in French McCay (2001, 2002). For a risk assessment, the range of potential sensitivities is typically examined, or a threshold for potential effects is based on the effects levels for sensitive species.

The SIMAP toxicity model takes into account the time and temperature of exposure for biota in or moving through an ephemeral and moving plume of pollutant. Time of exposure is evaluated by tracking concentrations experienced by organisms as the concentrations change in space and time. Stationary or moving Lagrangian tracers that represent organisms record the concentrations of exposure over time. Exposure time is the total time concentration that exceeds LC_1 (lethal concentration to 1% of exposed individuals). The concentration is the average over that time. The percent mortality is then calculated using the log-normal function centered on LC_{50} that is standard in aquatic toxicology.

For risk assessments, such as in this study, conservative thresholds for potential effects have been developed based on expected acute effects of long (days to weeks) exposures to concentrations in water. The 2.5th percentile (LC_{50mix}) for sensitive species is often used as an acute threshold for potential effects of any exposure duration. This acute criterion may be multiplied by a ratio of sublethal to lethal effects concentrations to develop a sublethal effects threshold (French McCay 2009; see next section).

In addition to addressing the effects of oil on water column biota, SIMAP is designed to be run in stochastic mode, where hundreds of simulations are made varying inputs within a set of probability distributions, as well as run as individual cases to examine representative or catastrophic scenarios of interest for examining impacts to particular resources. Thus, it is a powerful tool for performing oil spill consequence analyses; such is involved in this project.

4.5 CHARM (Chemical Hazard Assessment and Risk Management)

CHARM is an environmental risk model used to calculate the ratios of predicted environmental concentration (PEC) to the predicted no effect concentration (PNEC) for organic chemicals released during offshore oil exploration and production (Thatcher et al. 2005). The PEC is an estimate of the expected concentration of a chemical to which the environment will be exposed during and after the discharge of that chemical. The exposure depends on the intrinsic properties of the chemical, the concentration of the waste stream, and the dilution in the receiving environmental compartment. The PNEC is an estimate of the highest concentration of a chemical in a particular environmental compartment at which no adverse effects are expected. It is an estimate of the sensitivity of the ecosystem to a certain chemical, thus representing a toxicity threshold.

The PEC:PNEC ratios, referred to as hazard quotients (HQ), are calculated for the water and sediment phase of the environment, and are used to identify chemicals with the lowest environmental impact. The CHARM model enables the following stepwise environmental evaluation for chemicals: (1) Applicability Check - used prior to the use of the model to identify chemicals that cannot be assessed using a PEC:PNEC comparison; (2) Hazard Assessment - used to select chemicals with the lowest adverse effects to environmental compartments of concern (i.e., water and sediments); (3) Risk Analysis - used to evaluate the environmental impact of the discharge of a chemical under actual, site specific conditions and select chemicals according to the potential environmental impacts at the specific site; and (4) Risk Management - used to compare risk reducing measures based on cost/benefit analyses (Thatcher et al. 2005).

The environmental Hazard Assessment, Risk Analysis and Risk Management components within CHARM are all based on hazard and risk quotients (HQ and RQ), which are calculated using the PEC:PNEC method, which is internationally accepted (Thatcher et al. 2005; Bascietto et al. 1990).

The traditional PEC:PNEC analysis assesses the potential for a substance to have an acute toxic effect on the environment; however, it does not account for properties such as persistence and accumulation. Therefore, this model should not be used for accumulative substances which exhibit < 20% biodegradation in 28 days or for persistent substances with a molecular weight lower than 600 and a Log K_{OW} greater than or equal to 5 (Thatcher et al. 2005). The chemicals that are suitable for analysis using CHARM include production chemicals, water-based drilling muds, cementing chemicals, and other work-over and completion chemicals. A list of the different chemical products and their hazard quotient categories is maintained and distributed by the Center for Environment, Fisheries and Aquaculture Science.

Other limitations of the CHARM model are that it cannot be used to evaluate chemicals with surface active properties (i.e., surfactants) and that the model is only applicable to single substance chemicals, unless several additional assumptions are made (Thatcher et al. 2005). Within the CHARM model, several of the calculation rules assume equilibrium partitioning between the water and organic phase; however, surfactants do not partition between phases, instead likely form a layer at their interface. Additionally, CHARM cannot be used for inorganic substances because they are not biodegradable nor do they partition between water and an organic phase.

The end products of the CHARM model are the Risk Analysis module, which ranks individual chemicals according to their predicted environmental impact to assist in the selection of the least environmentally harmful alternative, and the Risk Management module, which enables comparison between risk reducing measures in regards to their costs (Thatcher et al. 2005). Therefore, this model is useful for the evaluation of concentration threshold for risk, and for preliminary and localized estimates of concentrations near a release site. However, it cannot be used to determine spill probability or 2D or 3D trajectory and fate of chemicals spilled. One of the main reasons it is not adequate to assess the 2D or 3D trajectory and fates of the chemical spilled is that it is unable to use spatially and temporarily 3D tidal or ocean currents; rather, it is a calculation for an equilibrium state near a chronic release point.

4.6 EUROPEAN CHEMICAL SPILL MODELS (CLARA)

Many, if not all, European countries have their own “national” chemical spill model. For instance, CEDRE (the Center of Documentation, Research, and Experimentation on Accidental Water Pollution) is the French national responder for marine pollution; approximately five years ago, they implemented the operational chemical modeling system CLARA (“Calculations related to accidental releases in seawater”). This model includes the use of a physicochemical, eco-toxicological, and toxicological database and relates the modeling of hydrodynamic mechanisms, the behavior of chemicals in seawater, and the atmospheric dispersion of volatile products (Gouriou et al. 2008). Once the hydrodynamic simulations are complete, a physicochemical simulation is run in association with the hydrodynamics to assess the environmental and human health risks. In the case of an evaporating product, when the physicochemical simulation is complete, the atmospheric dispersion module runs and provides all of the concentrations in the atmosphere at four different levels (10, 20, 50 and 100 meters). CLARA also provides information on the toxicity of the substance spilled by providing three potential effects thresholds: PNEC, for short-term and long-term exposures, and immediately dangerous to life or health (IDLH).

The software was designed for crisis management and setting up appropriate exclusion zones in the English Channel, Atlantic coast of Europe and Mediterranean coasts (Gouriou et al. 2008). Regardless of the development of CLARA, several years ago, CEDRE purchased licensing to RPS ASA's CHEMMAP to effectively respond to emergencies and to compare the output with that produced using CLARA. European Maritime Safety Agency (EMSA 2011) provides an example in which CEDRE used CHEMMAP during an emergency for an actual spill in European Union waters.

4.7 CHEMMAP (Chemical Discharge Model System)

CHEMMAP, developed by RPS ASA over the past 30 years (originating in the "type A" model included in the CERCLA regulations for performing NRDAs, under which it underwent extensive reviews), estimates the distribution of chemical (as mass and concentrations) on the water surface, on shorelines, in the water column, and in the sediments. CHEMMAP is unique in being able to: 1) evaluate biological impacts; 2) run in a stochastic implementation; 3) interconnect with hydrodynamic models; 4) provide atmospheric concentration predictions using a connected air model; 5) use Geographic Information System; and 6) use its own Graphic User Interface. The model is three-dimensional, separately tracking surface floating chemical, entrained droplets or suspended particles of pure chemical, chemical adsorbed to suspended particulates, and dissolved chemical. Unlike CHARM (Section 4.5), CHEMMAP has the advantage of being able to use spatial and time-varying environmental data (wind, currents, temperature/salinity) to aid in the transport and fate of the spilled chemicals. Processes simulated within CHEMMAP are spreading (floating liquids), dispersion, evaporation, entrainment (liquids), dissolution, partitioning, sedimentation, and degradation. The physical-chemical properties required by the model to simulate the transport and fate of the spilled material include density, vapor pressure, water solubility, environmental degradation rates, adsorbed/dissolved partitioning coefficients, viscosity, and surface tension. The spilled chemical is modeled using the Lagrangian approach where multiple sublots, called spillets, of the entire mass (or volume) spilled are tracked as they move in 3D space over time (by addition of the transport vectors due to wind, currents, and buoyancy). At each time step, phase transfer rates are calculated and a proportionate percentage of the spillets are transferred to a new phase. Concentrations are then calculated using a 3D Gaussian distribution. Additionally, CHEMMAP has the ability to calculate PEC/PNEC values, similar to CHARM (Section 4.5). However, CHEMMAP has the added ability to calculate time-weighted average concentrations for air and water.

The detailed technical documentation for CHEMMAP is described in a series of published reports and papers (French McCay et al. 1996; French McCay 2002; French McCay and Isaji 2004; French McCay et al. 2008; French McCay et al. 2006). Similar to SIMAP, CHEMMAP may be run in stochastic mode (varying inputs according to defined probability density functions) or as individual scenarios to examine representative events.

4.8 MODEL EVALUATION SUMMARY

The capacities of the models reviewed herein to provide an ecological risk assessment of the risks, fate, and effects of potential oil or chemical spills related to offshore wind energy development are summarized in Table 4.1. While the OSRAM model is capable of determining spill probability, the spill probability and spill volume probability analysis approach performed by ERC (as described in detail in Section 3) has a good track record of being used in spill incident risk evaluations for several recent offshore wind energy development projects (Etkin 2006b; Etkin 2008). Of the seven candidate models reviewed, SIMAP and CHEMMAP modeling packages provide the most comprehensive capability of spill impact assessment in terms of 3D trajectory, fate, and transport modeling, as well as biological exposure and toxicity modeling. These models are also well-documented in published papers and reports. They have been used in numerous risk assessment analyses (e.g., French McCay 2001; French McCay 2002, 2003; 2005a; 2005b; 2005c; 2006; 2008; 2011; 2012; French McCay and Isaji 2004). Therefore, SIMAP and CHEMMAP provide the most robust packages for a defensible environmental and ecological risk assessment. Furthermore, SIMAP and CHEMMAP's model algorithms have been tested and validated to ensure accuracy in predicted oil and chemical fate and transport (French McCay 2003, 2004; French McCay and Rowe 2004; French McCay et al. 2006).

Table 4.1
Modeling capabilities of the identified oil spill models.

Model	References	Spill Probability	Trajectory (2D)	Fate and Transport (3D)	Exposure and Toxicity (3D)	Environ-mental Risk
ERC	Etkin 2006a, b, 2008	X				
OSRAM	OSRAM et al. 2004	X	X			
OSCAR	Reed et al. 2005, Aamo et al. 1997a; Aamo et al. 1997b		X	X	X	X
SIMAP	French et al. 1996; French McCay 2002, 2003, 2004, 2009, 2011		X	X	X	X
CHEMMAP	French et al. 1996; French McCay 2002; French McCay and Isaji 2004; French McCay et al. 2006a, 2008		X	X	X	X
CHARM	Thatcher et al. 2004					X
COSIM	Kubitz et al. 2011		X	X	X	X
CLARA	Gouriou et al. 2008			X	X	

5. TOXICITY OF OILS AND CHEMICALS USED IN OFFSHORE CALL AND WIND ENERGY AREAS

5.1 LITERATURE REVIEW

An evaluation of the potential environmental effects to selected marine resources (birds, marine mammals, sea turtles, fish, and invertebrates) from accidental exposure to chemicals used in offshore wind facilities (identified in Section 2.0) relies on information available in the scientific literature. This section summarizes relevant toxicity data (lethal and sublethal) for chemicals of interest identified in Section 2.0. Model(s) and toxicity assessment assumptions, and data limitations and knowledge gaps are noted, and sources of uncertainty are clearly identified.

5.1.1 Petroleum and Non-Petroleum Oils

5.1.1.1 Diesel

Diesel fuel is a petroleum-based fuel comprised of a mixture of hydrocarbons obtained by distillation of crude oil. Although the chemical composition of fresh diesel varies depending on the crude oil source and distillation processes, its composition is generally as follows: 40% n-alkanes, 40% iso- and cycloalkanes, 10-20% aromatic hydrocarbons (monocyclic and polycyclic), and traces of resins, waxes, isoprenoids, sulfur, nitrogen, and oxygenated compounds (Mackay et al. 1985; Wang et al. 2003). Relevant properties of diesel that influence its environmental fate and behavior include its volatility, density, and viscosity.

The acute toxicity of diesel is the result of its high content of monoaromatic hydrocarbons (benzene, toluene, ethylbenzene, and xylenes; BTEX) and low molecular weight polycyclic aromatic hydrocarbons (e.g., naphthalenes). Its low viscosity makes it easily entrained into the water, increasing the likelihood of exposure of aquatic organisms to the toxic fractions of diesel. A report by the America Petroleum Institute (API 2011) concluded that water-accommodated fractions (WAF) of commercial distillate fuels (e.g., No. 2 fuel oil and diesel fuel) had a moderate toxicity to aquatic life. Lethality levels (medial lethal level concentration, LL_{50}; mostly 96h-LL_{50}) for fish ranged between 3.2 and 65 milligrams per liter (mg/L; based on nominal oil loading rates, which is the amount of oil added to the media and not the actual exposure concentrations experienced by organisms), immobilization levels (medial effective level concentration EL_{50}; mostly 48h-EL_{50}) for invertebrates ranged between 2.0 and 210 mg/L, and growth and biomass inhibition levels for algae ranged between 1.9 and 78 mg/L (all based on nominal oil loadings; API 2011). These values were generally within those reported by other sources (Table 5.1). Note that toxicity values expressed as total hydrocarbons are highly variable due to the broad range in sensitivity of species and life stages, and the various potential mixtures in the exposure regimes and methods for their measurement or estimation. A study that compared the toxicity of several fresh and weathered oil types found that WAFs of diesel fuel were as toxic to several aquatic species (silverside minnows, mysids, shrimp, and sand dollar larvae) as WAFs of light crude oils (Neff et al. 2000). Given the moderate toxicity of diesel and its great potential for natural dispersion and entrainment into the water column, drifting pelagic organisms (e.g., eggs and larvae of many species, plankton) may be at high risk of exposure as these organisms may not be able to avoid contact with oil droplets. However, for most instantaneous spills, water mixing and dilution would likely limit their exposure to a maximum of one day (National Oceanic and Atmospheric Administration [NOAA], ADIOS2, Seattle, WA). One of the greatest limitations regarding the currently available toxicological information is that many studies do not report the concentrations associated with a toxic response in terms of measured concentrations. Because oils are a mixture of compounds with varying solubilities, nominal concentrations do not adequately represent the toxicity of the exposure media. This limitation likely applies to other lethal concentrations presented here.

Table 5.1

Acute toxicity of diesel to aquatic species. F and U refer to exposures with filtered and unfiltered water accommodated fractions, respectively. Note that concentrations based on nominal loadings are highly variable and uncertain.

Diesel Type	Test Species	Endpoint; Effects Concentration; Exposure Media(citation)
Diesel	Juvenile water flea (*Daphnia magna*)	Mortality; 24-h LC_{50} 1.78 mg/L; U[1]
	Rainbow trout fry (*Oncorhynchus mykiss*)	Mortality; 24-h LC_{50} 578 mg/L; U[1]
Ultralow sulfur diesel	Fingerling rainbow trout (*O. mykiss*)	Mortality; 96-h LC_{50} 270 mg/L; U[6]
	Juvenile water flea (*D. magna*)	Immobilization; 48-h IC_{50} 15 mg/L; U; 3,300 mg/L; F[2]
Low sulfur diesel	Fingerling rainbow trout (*O. mykiss*)	Mortality; 96-h LC_{50} 160 mg/L; U[6]
	Juvenile water flea (*D. magna*)	Immobilization; 48-h IC_{50} 17 mg/L; U; > 25,000 mg/L; F[2]
Diesel fuel	Rainbow trout (*O. mykiss*)	Mortality; 96-h LL_{50} 21 mg/L[3]
	Water flea (*D. magna*)	Immobilization; 48-h IC_{50} 13 mg/L[3]
	Algae (*Raphidocellus subcapitata*)	Growth inhibition; 72-h EL_{50} 10 mg/L[3]
Diesel fuel, No. 2	Fathead minnow (*Pimephales promelas*)	Mortality; 96-h LC_{50} 35 mg/L[4]
Diesel fuel	Bluegill (*Lepomis macrochirus*)	Mortality; 96-h LC_{50} 31 mg/L[4]
	Algae (*Skeletonema costatum*)	Growth inhibition; 72-h EL_{50} 0.4 mg/L[4]
	Water flea (*D. magna*)	Immobilization; 48-h IC_{50} 1.09-3.4 mg/L[4]

[1]Khan et al. 2007, nominal concentrations; [2]Hollebone et al. 2007, measured concentrations; [3]Chevron Phillips MSDS, nominal concentrations; [4]Hess MSDS, nominal concentrations; Median lethal loading, LL_{50}; Median lethal concentration based on oil loading rate, LC_{50}; Median immobilization concentration, IC_{50}; Median effective level, EL_{50}

An accidental release of diesel fuel has the potential to impact marine mammals, birds, and sea turtles through direct contact, inhalation of volatile fractions, and ingestion of contaminated/fouled prey. However, the magnitude of the effects associated with each of these pathways depends on the scale of the release and the density of these animals in the impacted area. Although quantitative studies have not directly characterized the impacts of diesel fuels on these biological resources, small releases (500-5,000 gallons) in open water may not result in large kills or life-threatening impacts. However, marine mammals, and particularly sea turtles surfacing to breathe in areas with high concentration of volatile compounds, may experience irritation of the respiratory track, although high concentrations of volatile compounds would be likely localized and limited mostly to areas with large quantities of surface slicks. Birds would be at high risk of feather fouling, which would lead to the loss of thermal insulation and buoyancy. Furthermore, accidental ingestion of oil through preening can cause kidney damage at high concentrations, and transfer of diesel from oiled birds to eggs in breeding colonies can lead to significant reductions in egg hatchability (see Szaro 1977).

Spills of diesel have the following general behaviors, fates, and effects in open waters (NOAA fact sheet; Wauquier 1995):

- Diesel fuel is a relatively non-persistent oil that quickly evaporates, and forms oil slicks that spread fast and are easily physically dispersible;
- The light compounds of diesel fuel readily evaporate from the water surface or dissolve naturally in the water from slicks or dispersed droplets within a short amount of time (few days);
- Diesel has a low viscosity (2.0-4.5 square millimeters per second [mm^2/s] @ 40°C) and is readily dispersed into the water column in the form of droplets. Water dispersion occurs with high winds (~12 knots) and breaking waves (> 2 ft);
- Diesel is much lighter than water (specific gravity of diesel = 0.82-0.86 kilograms per liter (kg/L) vs. seawater = 1.03 kg/L) and does not sink or accumulate on the seafloor unless it adheres to fine-grained suspended sediments in the water column;
- Chemical constituents in diesel are not likely to bioaccumulate in the food web, unless oil residues are absorbed into sediments;
- Most compounds in diesel are biodegraded by naturally occurring microbes under timeframes of up to two months;
- Diesel is one of the oil types most likely to result in acute toxicity, and aquatic resource (fish, invertebrates, and seaweed) kills may occur when directly exposed to the spilled material. However, small spills in open water dilute rapidly, reducing the likelihood of massive kills;
- Small diesel spills can affect birds by direct contact, though the number of affected birds is usually small because of the short time the oil is on the water surface; and
- Bird mortality may be caused by ingestion during preening as well as to hypothermia from matted feathers. Greater risks to birds may result from large aggregations in the proximity of the spill location.

Summary of risk of adverse effects from spills of diesel from offshore wind facilities:

Marine Resources	Comments	Risk of Adverse Effects
Invertebrates	Acutely toxic when directly exposed to the spilled material. Small spills in open water dilute rapidly reducing the likelihood of massive kills	Low
Fish		Low
Sea turtles	Direct exposure of sensitive tissues (e.g., eyes, mucous membranes) and inhalation of fumes can lead to temporary irritation and inflammation. Large mortalities are unlikely because of the short time the oil is on the water surface	Low
Marine mammals		Low
Birds	Direct contact can cause negative effects, but large mortalities are unlikely because of the short time the oil is on the water surface. Could be higher if large congregations coincide spatially with large diesel spills	Low

5.1.1.2 Biodiesel

Biodiesel commonly refers to oil extracted from renewable resources and converted from triglycerides (natural esters) into long-chain alkyl (methyl, propyl, or ethyl) esters via transesterification (see Gerpen 2005 for details). The most commonly produced biodiesel comes from vegetable oils, which are derived from the fatty oil material contained in plant seeds and other plant material (canola, corn, soybean, safflower, and sunflower).

The environmental effects of biodiesel have not been as extensively studied as those of petroleum diesel, and most of the currently available information has been generated from studies with freshwater species (Goodband 2005; Vryenhoef 2005; Goodband 2006; Hollebone et al. 2007; Khan et al. 2007; AstraZeneca 2010). However, from the available literature, the most common effects associated with biodiesel spills include depletion of dissolved oxygen, smothering of benthic habitats, and fouling of aquatic biota and fur/feathers of wildlife (Crump-Wiesner and Jennings 1975; Mckelvey et al. 1980; Smith and Herunter 1989; Calanog et al. 1999; Mudge 1995). Although vegetable oils are generally perceived as non-acutely toxic, these oils have a greater potential for fouling than petroleum oils. While both petroleum and non-petroleum oils can coat bird feathers causing loss of thermal insulation and buoyancy (Crump-Wiesner and Jennings 1975; Mudge 1995; Smith and Herunter 1989), the likelihood of smothering by non-petroleum oils may be greater because of their lack of strong odor and coloration, thus preventing animal avoidance of the impacted area. In fact, the loss of birds from three small spills of rapeseed oil in Vancouver Harbor were greater (500 birds) than the combined losses from 176 spills of petroleum oils between 1974 and 1978 (50 birds) (Mckelvey et al. 1980). Furthermore, because of their chemical composition, biodiesels are relatively more viscous (neat biodiesels: 4.1-5.02 mm^2/s @ 40°C; biodiesels blends: 3.11-4.41 mm^2/s @ 40°C) than petroleum diesel (No. 2 diesel: 2.56-2.7 mm^2/s @ 40°C; No. 2 low sulfur diesel: 2.51-2.54 mm^2/s @ 40°C) (Yuan et al. 2005; Dunn 2011), thus indicating some smothering potential.

In one study, sets of chicken eggs exposed to biodiesel (castor, corn, linseed, safflower, soybean oil) during early and late incubation had 100% suppression in hatchability (Pochop et al. 1998a). Similarly, 99% of ring-billed gull eggs sprayed with canola oil (2 milliliters/egg; 1-15 days into incubation) while in their nests failed to hatch leading to a 97% failure in the hatching success of the exposed nests (Pochop et al. 1998b). It is important to note that the exposed eggs in both of these studies were entirely covered with test oils.

A clear distinction between biodiesel and petroleum diesel is their chemical composition. Compared to petroleum diesel, WAF of neat biodiesels lacks the acutely toxic aromatic components and volatiles, and it has higher levels of normal alkanes (C_{26}-C_{36}), which comprise the bulk of fatty acid esters in these oils (Hollebone et al. 2007). Consequently, neat biodiesels are generally perceived as substantially less toxic than petroleum diesel. Several researchers have studied the acute toxicity to aquatic species of neat and blended biodiesels relative to those of petroleum diesel (Table 5.2) (Khan et al. 2007; Goodband 2005; Vryenhoef 2005; Goodband 2006; Hollebone et al. 2007; AstraZeneca 2010). Khan et al. (2007) tested the toxicity of neat biodiesel (B100), biodiesel blends with petroleum-diesel (B50, B20, and B5), and petroleum diesel, and found that petroleum diesel (on a per gram of oil basis) was more toxic to the water flea and rainbow trout fry than the biodiesels B100 and B20, and slightly more toxic than the biodiesel blends B50 and B5. A related study (Hollebone et al. 2007) also found that, although neat biodiesels were 5 to 10 times less acutely toxic to aquatic organisms than petroleum diesels (on a per-gram basis), these oils have a great potential to cause mortality by physical smothering. In fact, greater sensitivity of juvenile water fleas than early life stages of rainbow trout exposed to unfiltered WAF of biodiesels suggested that physical smothering is likely an important exposure pathway for small organisms (Hollebone et al. 2007; Khan et al. 2007). Other studies involving exposures of fish, water flea, and green algae to filtered WAF of neat NExBTL renewable diesel found no mortalities at the prescribed dosages (Goodband 2005; Vryenhoef 2005; Goodband 2006; AstraZeneca 2010). As indicated by Hollebone and Yang (2009), the acute toxicity of biodiesels depends on blends and formulations, such that biodiesel blends with up to 20% diesel have similar toxicities to rainbow trout as petroleum diesel.

Table 5.2

Acute toxicity of biodiesel to aquatic species. F and U refer to exposures with filtered and unfiltered water accommodated fractions, respectively.

Biodiesel Name	Test Species	Endpoint; Effects Concentration; Exposure Media(citation)
NExBTL	Juvenile rainbow trout (*Oncorhynchus mykiss*)	Mortality; 96-h LL_{50} > 1,000 mg/L; 96-h NOEL 1,000 mg/L; F[1]
	Water flea (*Daphnia magna*)	Immobilization; 48-h EL_{50} > 100 mg/L; 48-h NOEL 100 mg/L; F[2]
	Algae (*Scenedesmus subspicatus*)	Growth inhibition; 72-h EL_{50} > 100 mg/L (WAF); 72-h; NOEL 100 mg/L[3]
	Adult mud shrimp (*Corophium volutator*)	Mortality; 10-d LC_{50} > 1,200 mg/kg dw sediment; 10-d 373 mg/kg dw sediment[4]
B100 (neat)	Juvenile water flea (*D. magna*)	Mortality; 24-h LC_{50} 4.65 mg/L; U[5]
	Rainbow trout fry (*O. mykiss*)	Mortality; 96-h LC_{50} 455 mg/L; U[5]
B50 (blend)	Juvenile water flea (*D. magna*)	Mortality; 24-h LC_{50} 3.29 mg/L; U[5]
	Rainbow trout fry (*O. mykiss*)	Mortality; 96-h LC_{50} 498 mg/L; U[5]
B20 (blend)	Juvenile water flea (*D. magna*)	Mortality; 24-h LC_{50} 4.54 mg/L; U[5]
	Rainbow trout fry (*O. mykiss*)	Mortality; 96-h LC_{50} 277 mg/L; U[5]
B5 (blend)	Juvenile water flea (*D. magna*)	Mortality; 24-h LC_{50} 1.98 mg/L; U[5]
	Rainbow trout fry (*O. mykiss*)	Mortality; 96-h LC_{50} 129 mg/L; U[5]
B100 (neat; animal)	Fingerling rainbow trout (*O. mykiss*)	Mortality; 96-h LC_{50} 660 mg/L; U[6]
	Juvenile water flea (*D. magna*)	Immobilization; 48-h IC_{50} 582 mg/L; U; 7,500 mg/L; F[6]
B100 (neat; soy)	Fingerling rainbow trout (*O. mykiss*)	Mortality; 96-h LC_{50} 390 mg/L; U[6]
	Juvenile water flea (*D. magna*)	Immobilization; 48-h IC_{50} 38 mg/L; U; 7,500 mg/L; F[6]
B100 (neat; canola)	Fingerling rainbow trout (*O. mykiss*)	Mortality; 96-h LC_{50} 707 mg/L; U[6]
	Juvenile water flea (*D. magna*)	Immobilization; 48-h IC_{50} 280 mg/L; U; 24,650 mg/L; F[6]

[1]Goodband 2006, measured concentrations; [2]Goodband 2005, measured concentrations; [3]Vryenhoef 2005, measured concentrations; [4]AstraZeneca 2010, measured concentrations; [5]Khan et al. 2007; nominal concentrations; [6]Hollebone et al. 2007, measured concentrations. LL_{50} lethal loading concentration

Aside from their chemical composition, another property that may further decrease the effects of biodiesels is their relatively high biodegradation potential (see for example Campo et al. 2012; Demello et al. 2007; Lisiecki et al. 2013; Pasqualino et al. 2006; Peterson and Möller 2005; Salam et al. 2012; Yassine et al. 2012, 2013; Zhang et al. 1998). Under optimum oxygen and nutrient conditions, unpolymerized vegetable oil undergoes 80-90% complete biodegradation in 28 days (Hollebone and Yang 2009; Khan et al. 2007); thus, vegetable oil biodegrades 2-2.5 times faster than petroleum diesel, resulting in a low potential for chronic toxicity and food chain bioaccumulation. Moreover, neat biodiesels and biodiesel-rich blends are also more dispersible in high energy environments than petroleum diesel (Hollebone et al. 2007), reducing the likelihood of exposures to elevated concentrations of accommodated fractions.

Vegetable oil can persist for several years in the sedimentary bed, particularly if oil polymerization occurs (Mudge et al. 1993; Mudge et al. 1995), as this process causes the formation of concrete-like aggregates with sediment particles reducing its permeability to water and oxygen. However, this is not likely the case for surface spills of biodiesel in open waters.

Based on the available information, biodiesel spills may have the following characteristics in open waters:

- Biodiesel does not readily evaporate but is dispersible in high energy environments;
- Biodiesel is much lighter than water and does not sink or accumulate on the seafloor unless it adheres to fine-grained suspended sediments suspended in the water column;
- Biodiesel biodegrades at a faster rate than petroleum diesel, resulting in a low potential for chronic toxicity and food chain bioaccumulation;
- Neat biodiesels lack the acutely toxic aromatic components and volatiles and consequently are not generally acutely toxic. Therefore, mortality of aquatic resources (fish, invertebrates, and seaweed) are unlikely, unless the spill involves biodiesel blends;
- Biodiesels are more viscous and have a greater potential for fouling than refined light oils. Because these lack strong odor and coloration, there is a greater risk that small biodiesel spills can affect marine birds by direct contact; and
- Bird mortality may be caused by hypothermia from matted feathers. Greater risks to birds may result from large aggregations in the proximity of the spill location.

Although it is reasonable to assume that an oil spill of biodiesels would cause less environmental damages than a spill of petroleum diesel (see for example Campo et al. 2012), the current state of knowledge on the fate and effects of neat biodiesels and biodiesel blends is insufficient to fully evaluate their risks (Hollebone et al. 2007). The available scientific evidence indicates a potential risk of smothering of birds and fur-bearing marine mammals.

Summary of risk of adverse effects from spills of biodiesel from offshore wind facilities:

Marine Resources	Comments	Risk of Adverse Effects
Invertebrates	Based on the currently available information, not acutely toxic, and low likelihood of large kills	Low
Fish		Low
Sea turtles		Low
Marine mammals	Based on the currently available information, not acutely toxic, and low likelihood of large kills. There is considerable risk of smothering of fur-marine mammals	Moderate
Birds	Based on the currently available information, not acutely toxic, but there is considerable risk of smothering	Moderate

5.1.1.3 Dielectric Insulating Fluids

Mineral oils, silicone fluids, and synthetic esters are commonly used as dielectric fluids in ESP wind facilities. Mineral oils are petroleum distillates that contain a complex mixture of petroleum hydrocarbons (primarily aromatic and aliphatic hydrocarbons) that varies depending on the oil source and distillation processes. One of the mineral oils used in wind ESP is naphthenic oil. These mineral oils are naphthene-rich distillate oils characterized by saturated-ring hydrocarbon compounds (C_{15}-C_{50}). Recently, USEPA (2012) reported that no adequate acute and chronic toxicity data for naphthenic oils are available for aquatic organisms. However, based on the physical-chemical properties of their carbon range (octanol-water partitioning coefficient, Log K_{OW}[39], 4.4-19.6) and low water solubility (< $1x10^{-6}$-0.07 mg/L), acute and chronic aquatic toxicity to aquatic organisms is not expected, particularly for the heavier naphthenic oils (USEPA 2012).

Silicone fluids (e.g., polydimethylsiloxane, PDMS) are insoluble fluids characterized by high viscosity (range: 10-> 100,000 mm^2/s @ 25°C depending on the degree of polymerization and molecular weight) (Wacker 2002 cited in ECTOC 2011) and low volatility. Because of their chemical structure, silicone fluids are virtually non-toxic and are not likely to bioconcentrate, although they have high affinity for soil and sediment where their biodegradation is slow (ECETOC 2011). Although these chemicals show little to no aquatic toxicity, they have the potential to smother organisms when in contact with spilled fluids. ECETOC (2011) also indicated that an accidental spill of PDMS on water will quickly spread into a thin oil sheen that is easily naturally dispersed into fluid droplets. Studies reported in ECETOC (2011), such as Aubert et al. (1985) and Guillemaut et al. (1987) found no evidence of bioaccumulation in an experimental marine food chain that included phytoplankton, mollusks, annelids, and fish.

Synthetic esters (e.g., Midel 7131) are made through the esterification of natural fats and oils, and are compounds with low water solubility (<< 1 mg/L), and low to very low aquatic toxicity (LC_{50} values in the 1,000-10,000 mg/L range) (Willing 1999). Because of their relatively simple chemical structure, synthetic esters are, in most cases, readily biodegradable under both aerobic and anaerobic conditions, and they have a greater biodegradation potential than mineral oil (Willing 1999; Battersby 2000). The maker of Midel 7131, for example, reports that this dielectric fluid has an acute toxicity to *Salmo gairdneri* (96h-LC_{50}) and *Daphnia magna* (48h-EC_{50}) of > 1,000 mg/L, and that under optimum conditions this fluid is readily biodegradable (89% after 28 days) (Midel M&I Materials Ltd. 2013).

Despite their low toxicity, dielectric insulating fluids have a low to moderate viscosity (Mineral oil 12 mm^2/s @ 40°C; silicone fluids: 35-39 mm^2/s @ 40°C; Midel 7131: 28 mm^2/s @ 40°C; see also Section 6), which may pose a risk of physical smothering after a spill, particularly to birds and fur-bearing mammals. However, studies were not identified confirming such effects.

Based on the available information, dielectric insulating fluid spills may have the following characteristics in open waters:

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[39] The octanol-water partitioning coefficient, Log K_{OW}, is a chemical parameter that describes the partitioning of a chemical between equal volumes of two non-miscible solvents, *n*-octanol and water. A chemical's affinity for *n*-octanol, a surrogate for lipids, indicates a greater potential for bioconcentration in tissues of aquatic organisms.

- Dielectric insulating fluids spread quickly to a thin sheen and are easily dispersible;
- Dielectric insulating fluids have a low to very low water solubility and aquatic toxicity; therefore, mortality of aquatic resources (fish, invertebrates and seaweed) is unlikely;
- Dielectric insulating fluids are moderately viscous and have a greater potential for fouling, posing greater risk to marine birds by direct contact;
- Dielectric insulating fluids may cause mortality by hypothermia from matted feathers. Greater risks to birds may result from large aggregations in the proximity of the spill;
- Because of their high Log K_{OW} dielectric insulating fluids have limited bioaccumulation potential, especially those with Log $K_{OW} > 10$; and
- There is little environmental and toxicological information regarding spills of these fluids in marine environments.

Summary of risk of adverse effects from spills of dielectric insulating fluids from offshore wind facilities:

Marine Resources	Comments	Risk of Adverse Effects
Invertebrates	Based on the currently available information, not acutely toxic, and low likelihood of massive kills	Low
Fish		Low
Sea turtles		Low
Marine mammals	Based on the currently available information, not acutely toxic, and low likelihood of massive kills. There is considerable risk of smothering of fur-marine mammals	Low
Birds	Based on the currently available information, not acutely toxic, but there is considerable risk of smothering	Moderate

5.1.2 Other Chemicals of Interest

5.1.2.1 Sulfuric Acid

Sulfuric acid (CAS# 7664-93-9) is a strong acid that dissociates in water to sulfate ions and hydrated protons. Spills of this and similar acids in seawater cause a strong exothermic reaction raising the temperature of the water abruptly (Cabon et al. 2010). However, temperature changes are less of a concern in open waters where water column mixing quickly dilutes the high concentration of acids into the water column. Acid spills have the potential to abruptly change the pH of the receiving waters; however, given the high buffering capacity of seawater, changes in pH (below 6.5) are less of a concern at least for small spills.

The toxicity of sulfuric acid in seawater has seldom been studied. The available toxicity data for this chemical (Portmann and Wilson 1971) indicates that the toxicity of sulfuric acid varies between 42.5 and 350 mg/L (Table 5.3). Although unlikely, severe effects can occur if wildlife is directly exposed to the spilled acid prior to its dissolution in seawater.

Table 5.3
Acute toxicity of sulfuric acid to aquatic species.

Test species	Endpoint; Effects Concentration(citation)
Green Crab (*Carcinus maenas*)	Mortality; 48-h LC_{50} 75 mg/L[1]
Sand Shrimp (*Crangon crangon*)	Mortality; 48-h LC_{50} 75 mg/L[1]
Aesop Shrimp (*Pandalus montagui*)	Mortality; 48-h LC_{50} 42.5 mg/L[1]
Hooknose (*Agonus cataphractus*)	Mortality; 48-h LC_{50} 85 mg/L[1]
European Flounder (*Platichthys flesus*)	Mortality; 48-h LC_{50} 215 mg/L[1]
Cockle (*Cerastoderma edule*)	Mortality; 48-h LC_{50} 350 mg/L[1]

[1]Portmann and Wilson 1971

A study in the 1990s evaluated the toxicity of acidic seawater on oceanic zooplankton species and reported an average pH value of 5.46 (24-h LC_{50}) across 10 species with a minimum 24-h LC_{50} pH of 4.74 (Yamada and Ikeda 1999). These 24-h LC_{50} pH values were generally below the ranges known to cause adverse effects on several marine and estuarine species (Locke 2008), except for a number of bony fish species, one of which had a 24-h LC_{50} pH value as low as 4.48 (Brownell 1980 in Locke 2008). However, these lethal pH values are assumed to remain relatively constant for 24 hours, which is clearly not the case when sulfuric acid spills occur in open waters where, within minutes to a few hours, water-column mixing quickly dilutes the spilled acid.

Based on the available information, sulfuric acid spills may have the following characteristics in open waters:

- Sulfuric acid readily dissociates upon contact with water and is likely dispersible in moderate to high energy environments;
- Sulfuric acid may not accumulate on the seafloor unless shallow depths prevent its dissociation in water;
- Sulfuric acid dissipates quickly into the water column and poses no chronic risks to marine organisms;
- The acute toxicity of sulfuric acid spills is a function of pH. Because of dilution and the buffering capacity of seawater, aquatic resource (fish, invertebrates, and seaweed) kills from sulfuric acid spills in open water are unlikely; and
- Acute impacts (irritation) may result from direct contact with the spill material; however, the likelihood of direct contact is relatively low for most aquatic organisms.

Summary of risk of adverse effects from spills of sulfuric acid from offshore wind facilities:

Marine Resources	Comments	Risk of Adverse Effects
Invertebrates	Acutely toxic when directly exposed to the spilled material. Small spills in open water dilute rapidly reducing the likelihood of large kills	Low
Fish		Low
Sea turtles	Direct exposure of sensitive tissues (e.g., eyes, mucous membranes) to low pH in the water column can lead to temporary irritation and inflammation.	Low
Marine mammals		Low
Birds		Low

5.1.2.2 Ethylene and Propylene Glycol

Ethylene glycol (CAS# 107-21-1) and propylene glycol (CAS# 57-55-6) are organic compounds commonly used in cooling systems (antifreeze solutions). These chemicals have low viscosity (ethylene glycol: 6.5 mm^2/s @ 50°C) and moderate water solubility (> 10,000 mg/L) and are not expected to volatilize from the water surface (CAFE 2013, NOAA ERD, Seattle, WA). Given their high specific gravity relative to water (ethylene glycol: 1.14 kg/L; propylene glycol: 1.04 kg/L), these chemicals are expected to mix into the water column following an accidental release. Given their relatively simple structure, these chemicals are biodegraded in aquatic environments, with half-lives for surface water estimated to range between 2 and 12 days (Howard et al. 1991).

There is relatively little information on the acute toxicity of these chemicals, and the available information suggests relatively low toxicity. The reported 24h-LC_{50} value for formulated ethylene glycol averages 100,000 mg/L for marine crustaceans, with the lowest reported value of > 100 mg/L (48h-LC_{50}) for the common shrimp (*Crangon crangon*). By comparison, the acute toxicity (LC_{50}) of formulated propylene glycol on marine crustaceans has been reported to be > 1,000 mg/L for exposures of 24 to 96 hours (USEPA 2013a). As demonstrated by Pillard (1995), formulated mixtures containing glycol materials were substantially more toxic than either of the pure glycol compounds.

Based on the available information, ethylene and propylene glycol spills may have the following characteristics in open waters:

- Glycols do not readily evaporate but are water soluble and are expected to be dispersed into the water column particularly in high-energy environments;
- Glycols are slightly heavier than water and are expected to mix into the water column;
- These compounds are expected to biodegrade in the water column within a relatively short time frame (< 2 weeks), resulting in a low potential for chronic toxicity;
- Even though there is limited toxicity data, these compounds are not expected to cause acute toxicity, although antifreeze solutions containing additives may be slightly more toxic. Therefore, aquatic resource (fish, invertebrates, and seaweed) kills are unlikely;
- Glycols have low viscosity and their high water solubility make animal encounters with concentrations that might cause effects unlikely; and
- There is little environmental and toxicological information regarding spills of these fluids in marine environments.

Summary of risk of adverse effects from spills of ethylene glycol and propylene glycol from offshore wind facilities:

Marine Resources	Comments	Risk of Adverse Effects
Invertebrates	Acutely toxic when directly exposed to the spilled material. Small spills in open water dilute rapidly reducing the likelihood of large kills	Low
Fish		Low
Sea turtles	Direct exposure of sensitive tissues (e.g., eyes, mucous membranes) can lead to temporary irritation and inflammation.	Low
Marine mammals		Low
Birds		Low

5.2 TOXICITY ASSESSMENTS

5.2.1 Petroleum and Non-Petroleum Oils

Indices of potential water-column impacts for both ecological and socio-economic (e.g., seafood) resources were quantified as the volume of water that had dissolved aromatic concentrations exceeding 1 µg/L at some time after a spill based on the toxicity evaluations of French McCay (2002). As outlined in further detail in French McCay (2002), PAHs cause the majority of toxicity to water-column biota; the median expected dissolved PAH LC_{50} for marine species is about 45±3 µg/L, whereas that for the 2.5th percentile (sensitive) species is 6 µg/L. Assuming the Final Acute-Chronic Ratio for toxicity endpoints of about 4 for PAHs (USEPA 2003), and rounded to nearest whole µg/L, the threshold for sublethal effects would be approximately 1 µg/L of dissolved PAHs.

The contamination in the water column changes rapidly in space and time, such that a dosage measure (i.e., the product of concentration and time) may be a more appropriate index of impacts than simply comparing the peak concentration to a threshold such as 1 µg/L. Toxicity to aquatic organisms increases with time of exposure, such that organisms may be unaffected by brief exposures to the same concentration that is lethal at long times of exposure. Thus, the 1 µg/L threshold used here is a very conservative low estimate of an effects threshold, appropriate for use in a risk assessment such as this.

Because the spills from the wind turbines and associated structures are modeled to be from the surface, impacts to water column resources would primarily be limited to the surface mixed layer, which is conservatively assumed to be 10 meters deep in the model runs.

Based on the available information, the same threshold used for diesel will be used for dissolved aromatic concentrations resulting from spills of biodiesels and dielectric insulating fluids. This threshold is assumed to be conservative because: 1) biodiesels and dielectric insulating fluids are inherently less toxic than diesel, and 2) exposures are likely short (i.e., infinite exposure times are unlikely). As noted in Section 5.1.1, biodiesels and dielectric insulating fluids have very low contents of soluble aromatics, so the concentrations of dissolved aromatics following spills of these oils and fluids are expected to be much lower than for diesel spills of similar volume.

5.2.2 Other Chemicals of Interest

5.2.2.1 Sulfuric Acid

Empirical toxicity data (24-h LC_{50} pH) for seawater species from Yamada and Ikeda (1999) and Brownell (1980) (in Locke 2008) were used to construct an aquatic species sensitivity distribution (SSD) (Posthuma et al. 2002) for pH. A SSD was constructed using the cumulative plot of effects concentrations (pH) versus the rank assigned percentiles for each species for which acute toxicity data were available. Using the methodology described elsewhere (Bejarano and Farr 2013), a probabilistic bootstrap approach was used to derive an effects concentration that can be used as a threshold for acute toxicity of pH. Specifically, the 5th percentile concentration (HC_5; and its associated 95% confidence interval, 95%CI) of the SSD, or the concentration assumed to be protective of 95% of the exposed species, was used as a surrogate threshold level of concern for sulfuric acid. This approach (Figure 5.1) produced a pH HC_5 threshold of 4.71 (95%CI = 4.36-5.06) for a spill of sulfuric acid. This threshold is assumed to be extremely conservative, as exposures to an accidental spill of sulfuric acid in open waters are not likely to last 24 hours. This threshold is further corrected for effects of salinity and the buffering capacity of seawater, which would reduce the impacts of acid spills in aquatic environments.

Based on the analysis of the buffering capacity of seawater by French McCay et al. (2003), addition of sulfuric acid to full seawater (assumed 32 practical salinity units [psu]) would bring the pH to 4.71 at a concentration of 265,041 milligrams per cubic meter (mg/m^3), which is ~265,041 µg/L. Calculated concentrations are converted from pH, accounting for the buffering capacity of seawater and background pH using a linearization of the polynomial regression described in Appendix C of French McCay et al. (2003), applicable to the range of pH from 4.5 to 8.0. The buffering capacity for acid is calculated using a linear regression based on alkalinity (in moles per liter, mol/L) (Eq. 5.1) and salinity (psu) data (Eq. 5.2) collected from around the world (Poisson et al. 1990) as follows:

(5.1) Buffering Capacity for Acid (mol/L) = (63.871 * (salinity) + 18.066) / 1000000

Background pH, as function of salinity (psu), was developed by French McCay et al. (2003) using data from Poisson et al. (Poisson et al. 1990), as follows:

(5.2) Background pH = 0.0102 * salinity + 7.698

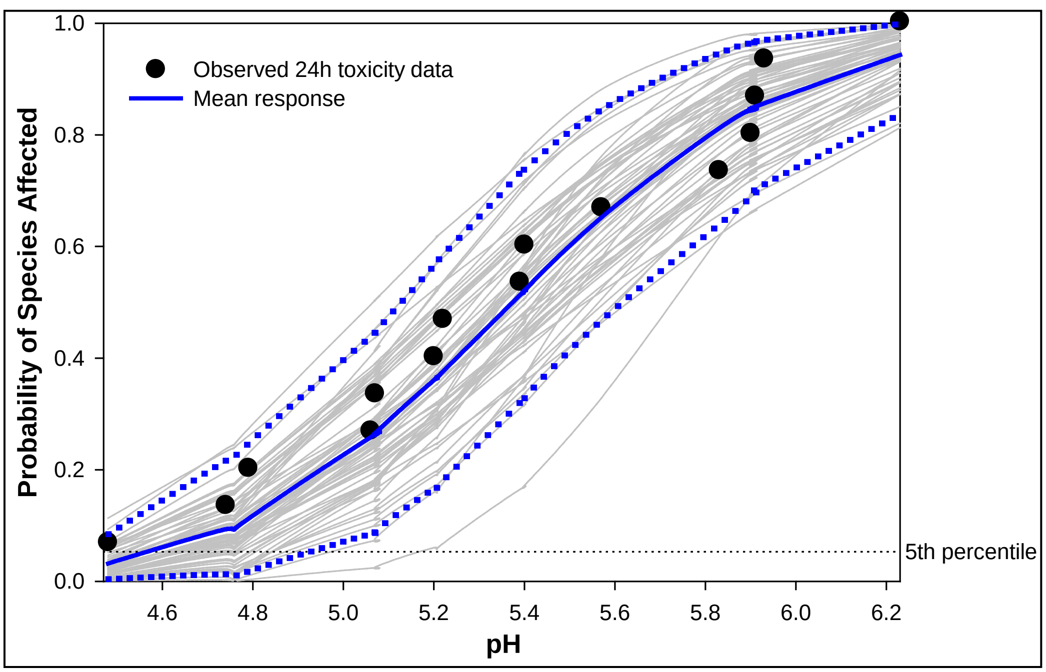


Figure 5.1 Species sensitivity distribution (SSD) for pH using all available acute toxicity information for aquatic species for exposures lasting 24 hours. The black dots represent the known aquatic toxicity of pH for individual species, while the blue lines represent the mean response and the 95%CI of the SSD. The HC_5 threshold is represented by the dotted horizontal line.

5.2.2.2 Ethylene and Propylene Glycol

Limited information is currently available for pure and formulated ethylene glycol and propylene glycol. Therefore, a structure activity relationship (SAR)[40], or the relationship between acute toxicity and ethylene and propylene glycol's octanol water partitioning coefficients (-1.2 and -0.78 Log K_{OW}, respectively), were used as surrogates for empirical acute toxicity data. This SAR (USEPA 2013b) is represented by the Eq. 5.3:

$$\text{Log 48-h } EC_{50} \text{ (mmol/L)} = -0.3226 \text{ (Log } K_{OW}) - 0.773 \text{ (Daphnid 48-h } EC_{50}) \quad (5.3)$$

which produced 48-h EC_{50} concentrations for ethylene and propylene glycol of 10,987 mg/L and 6,148 mg/L, respectively, for a daphnid species (assumed *Daphnia magna*).

These estimates of acute toxicity for a surrogate species (*D. magna*) where used to estimate 48-h EC_{50} for several other aquatic species using interspecies correlation estimation models (ICE; Asfaw et al. 2003; Dyer et al. 2006; Raimondo et al. 2007). These models use least square regressions facilitating the prediction of acute toxicity (LC_{50}) to one or several species based on estimates of relative sensitivity between the target species and the surrogate species (in this case *D. magna*) (Raimondo et al. 2007). Using data from SAR and ICE models, SSDs were generated following the approach outlined earlier, producing 48-h EC_{50} thresholds for ethylene and propylene glycol of 2,939 mg/L (95%CI = 829-11,388 mg/L) and 1,820 mg/L (95%CI = 526-6,705 mg/L), respectively (Figure 5.2). Because of large data uncertainties, a safety factor of 100 was applied to these thresholds (ethylene and propylene glycol of 29.39 mg/L, and 18.20 mg/L, respectively) to adequately address concerns regarding sensitive life stages. For the purpose of modeling exercises, and because of the similarities between these two chemicals, the average of the two final values, 48-h EC_{50} = 23.8 mg/L, was used as the threshold value. This threshold is extremely conservative, as exposures to an accidental spill of these chemicals in open waters are not likely to last 48 hours and the safety factor is included as well.

[40] Structure Activity Relationships (SARs) predict the biological activity (including toxicity) of a chemical based on its chemical structure. These relationships are developed using toxicity data from structurally similar chemicals.

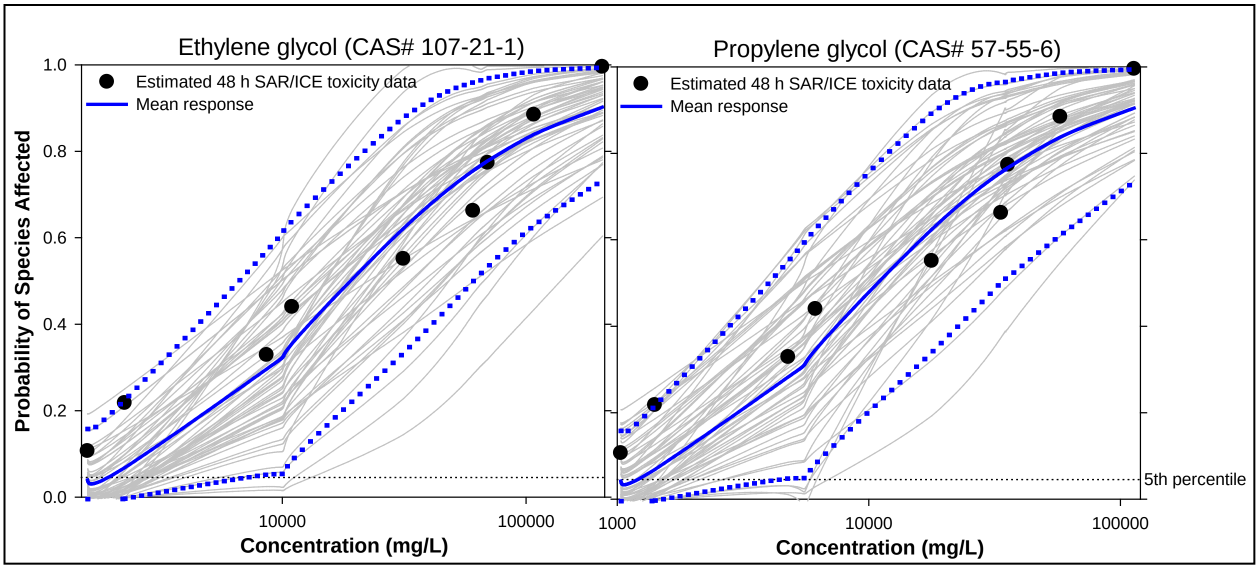


Figure 5.2 Species sensitivity distribution (SSD) for ethylene glycol (left) and propylene glycol (right) using estimated aquatic toxicity data derived from SAR and ICE models. The black dots represent the estimated aquatic toxicity concentrations for individual species, while the blue lines represent the mean response and the 95%CI of the SSD. The HC_5 threshold is represented by the dotted horizontal line.

6. SPILL SCENARIOS AND MODELING PARAMETERS

6.1 SPILL MODELING APPROACH

The evaluation of potential environmental consequences to marine species including avian species, fish marine mammals, sea turtles, and invertebrates was performed through modeling using the SIMAP and CHEMMAP models because these are the most suitable, vetted, and documented models to meet the goals of this project, as illustrated in Section 4.0. The approach used for this project is similar to that used for previously performed risk assessments, such as for on-going oil spill risk assessment analyses for deepwater spills in the Gulf of Mexico under a BOEM contract to RPS ASA and the prior modeling analysis performed by RPS ASA for the Minerals Management Service evaluating the spill consequences of hazardous materials used in deepwater oil and gas operations in the Gulf of Mexico (Boehm et al. 2001; French McCay and Isaji 2004).

6.1.1 Oil Spills

Oil behavior, fate, and effects assessment was conducted using SIMAP's stochastic model to determine the range of distances and directions hypothetical oil spills are likely to travel from a spill site within representative Call Area/WEAs, given historical wind and current speed and direction data for the area. Long-term wind and current records at and around the spill site of interest were sampled at random and model runs performed for each of 200 selected spill dates and times. This set of random dates/times represents the potential environmental conditions that could occur during a release.

The stochastic modeling outputs provide a statistical description of the potential likelihoods and magnitudes of oil-spill related impacts that would be expected from a given Call Area/WEA. These results can be summarized by statistics such as mean and standard deviation. Using these results, we estimated the areas of water surface, lengths of shoreline, and volumes of water exposed to oil above effects thresholds presented in Section 5.2.1 (oil thickness or concentrations).

To address both coastal and offshore concerns in areas in which there is currently interest to develop offshore energy, modeling was performed for a matrix of oil spill scenarios described in Section 2.5. This matrix encompasses a range of potential spill volumes, as well as oil types with varying physical-chemical properties and potential toxicity.

6.1.2 Chemical Spills

Because all the chemicals used in wind turbines are sinking, highly soluble, and semi-volatile; are stored in relatively small volumes (Section 2.3.2), and have relatively high-concentration effects thresholds (i.e., they have relatively low toxicity, see Section 5.2.2), in order to model the environmental consequences from a chemical spill, the focus needed to be directly near the potential spill site within a Call Area/WEA. The stochastic approach performed on a broad scale for the oil spill modeling was not appropriate for these chemical spill cases because the expected effects would only be felt locally, so the broad scale gridding diluted the resulting chemical concentrations to the point of showing no effects at any location. Therefore, for each scenario outlined in Section 2.5, an example 3D fates scenario was run in the immediate vicinity of the spill site using a fine resolution (400 m^2) fixed concentration grid, a constant depth of 20 m (the approximate depth of the pycnocline), wind data from a nearby buoy, and currents of a constant speed and direction typically observed in the area of the spill site. The release date used for each scenario was chosen by observing the currents in the immediate vicinity of the spill site and determining when they were at a constant speed and direction over one day. The concentrations only needed to be tracked for a period of one day, as the thresholds of concern (Section 5.2.2) were only exceeded for the first few hours after release. A description of the model inputs used is provided in Section 6.2. The outputs of this chemical spill modeling approach include summaries of the volume greater than the threshold of effects (Section 5.2.2) for each scenario; the peak concentration per scenario, the distance that concentration occurred from the spill site, and plots of concentration above the threshold of concern over time.

6.2 MODEL INPUTS

Modeling inputs include habitat and depth mapping, winds, currents, other environmental conditions, chemical composition and properties of the oils and chemicals likely to be spilled, and specifications of the release (amount, location, etc.). The input data for modeling impacts are available from government-run websites (e.g., winds, temperatures), government reports, published literature, and data libraries that RPS ASA has compiled over many years of performing similar modeling. General modeling inputs are discussed in the following sections. Additional detail regarding model inputs for each location modeled can be found in Appendix A.

6.2.1 Spill Locations

To assess the impact of spills of the oils and chemicals identified in Section 2, potential spills of oils and chemicals were modeled at three representative wind facility locations offshore the Atlantic Outer Continental Shelf. In consultation with BOEM, three locations were chosen as shown in Figure 1.1, including: RI-MA, MD, and NC. Within each Call Area/WEA, representative locations were derived for spills initiated at a WTG, ESP, and series of WTGs and the entire wind facility (Appendix A). In general, the locations for the WTGs were assumed to be farther offshore than those for the ESPs (Green et al. 2007a). A detailed description of the spill locations is provided in Appendix A.

6.2.2 Geographic and Model Grid

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

The intertidal habitats are assigned based on the shore types in digital Environmental Sensitivity Index (ESI) maps distributed by the Office of Response and Restoration, National Oceanic and Atmospheric Administration. These data were gridded using the ESRI® Arc/Info compatible Spatial Analyst program. Open water areas were defaulted to sand bottom, as open water bottom type has no influence on the model results. Depth data are typically obtained from bathymetric contours within the GEBCO Digital Atlas (GEBCO et al. 2003).

6.2.3 Environmental Data

The model uses hourly wind speed and direction for the time of the spill and simulation. A long term wind record is sampled at random to develop a probability distribution of environmental conditions that might occur at the time of a spill. The model can use multiple wind files, spatially interpolating between them to determine local wind speed and direction.

Surface water temperature in the model varies by month, based on data from French et al. (1996). The air immediately above the water is assumed to have the same temperature as the water surface, this being the best estimate of air temperature in contact with floating oil. Salinity is assumed to be the mean value for the location of the spill site, based on data compiled in French et al. (1996). The salinity value assumed in the model runs has little influence on the fate of the oil, as salinity is used to calculate water density (along with temperature), which is used to calculate buoyancy, and none of the oils evaluated have densities near that of the water.

Suspended sediment in the water column is assumed to be 10 mg/L, a typical value for coastal waters (Kullenberg 1982). The settling velocity of an individual sediment particle is set at 1 m/day. These default values have no significant effect on the model trajectory. Sedimentation of oil and PAHs becomes significant at about 100 mg/L suspended sediment concentration.

The horizontal diffusion (randomized mixing) coefficient is assumed as 1-5 m^2/sec for floating oil and the water column. The vertical diffusion (randomized mixing) coefficient is assumed as 0.0001 m^2/sec. These are reasonable values for coastal waters based on empirical data (Okubo and Ozmidov 1970; Okubo 1971) and modeling experience.

6.2.4 Currents

Currents have significant influence on the trajectory and oil fate, and are critical data inputs. Dependent upon geographic location, wind-driven, tidal and background currents are included in the modeling analysis. The tidal currents and background (other than tidal) currents are input to model from a current file that is prepared for this purpose (see Appendix A for a detailed description of currents for each location).

6.2.5 Oil and Chemical Properties and Toxicity

The spilled oil and chemicals used in modeling for this project consisted of a variety of types, as outlined in Section 2.3. Physical and chemical data on these oils and chemicals are summarized in Appendix A.

The oil’s content of volatile and semi-volatile aliphatics and aromatics (which are also soluble and cause toxicity in the water column) is defined and input to the model. The volatile aliphatics rapidly volatilize from surface water, and their mass is accounted for in the overall mass balance. However, as they do not dissolve in significant amounts, they have limited influence on the biological effects on water column and benthic organisms.

For oil spills at/near the water surface, mono-aromatic hydrocarbons (MAH) do not have a significant impact on aquatic organisms for the following reasons: MAH concentrations are less than 3% in fresh fuel oils; MAHs are water soluble and volatilize faster than they dissolve, such that toxic concentrations (500 µg/L for sensitive species) (French McCay 2002) are not reached;

The small concentrations of MAHs in the water will quickly be diluted to levels well below toxic thresholds immediately after a spill.

Thus, the toxicity of dissolved aromatics used to develop the threshold of concern for the modeling is that of the 2-ring and 3-ring PAH mixture typically found in surface waters after oil spills. The toxicity of these compounds is described in more detail in Section 5.0.

6.2.6 Shoreline Oil Retention

Retention of oil on a shoreline depends on the shoreline type, width and angle of the shoreline, viscosity of the oil, the tidal amplitude, and the wave energy. In the NRDAM/CME (French McCay et al. 1996), shore holding capacity was based on observations from the *Amoco Cadiz* spill in France and the *Exxon Valdez* spill in Alaska (based on Gundlach 1987) and later work summarized in French et al. (1996). This approach and data were used in the present study.

6.3 Oil and Chemical Spill Scenarios

Each of ten model scenarios (Table 2.12) for the three proposed wind facility locations was modeled for a total duration of 20 days with an instantaneous release of oil for scenarios at the ESP and WTG locations (ESP-Nap-500 to WTG-Lub-220) and a one-hour release of oil for the WCD scenarios (5WTG-Mix1-3400 and All-Mix2-129K).

Transformer oils that could be spilled in Scenarios WTG-Nap-370, 5WTG-Mix1-3400 and All-Mix2-129K include either naphthenic mineral oil or biodegradable synthetic ester oil. The physical-chemical properties of these oils are quite similar (Table 6.1); however, the petroleum-based naphthenic mineral oil would contain more hydrocarbon components toxic to water column biota and have slower degradation rates than the synthetic ester-based oil. Consequently, spills of mineral oil were modeled based on their potential for higher impacts to water column organisms.

Table 6.1

Oil physical-chemical properties of naphthenic mineral oil and synthetic ester oil.

	Naphthenic mineral oil	Synthetic ester oil
Physical state	Liquid	Organic liquid
Odor	Odorless	Faintly sweet
Melting Point/Freezing Point	-50°C	-57°C
Boiling Point:	310°C	> 300°C
Flash Point	~ 170°C	260°C
Flammability	Flammable	Non flammable
Vapor Pressure at 20°C (atm)	< 1.32E-5	< 0.01 Pa
Density at 20°C (kg/m^3)	880-890	970
Water Solubility (mg/L)	negligible	< 1
Log K_{OW}	> 6.8	> 6.74
Viscosity at 40°C: (cSt)	9.4-12	28

The four chemical spill scenarios (Table 2.13) were simulated using RPS ASA's CHEMMAP at each of the three proposed wind facility locations as instantaneous releases.

7. POTENTIAL ENVIRONMENTAL CONSEQUENCES OF ACCIDENTAL RELEASES OF OIL AND CHEMICALS FROM OFFSHORE CALL AND WIND ENERGY AREAS

7.1 ANALYSIS OF MODELING RESULTS

The modeling approach involves estimating the areas of water surface, lengths of shoreline, and volumes of water exposed above consequence thresholds for a series of oil spill scenarios from each Call Area/WEA. All of the impact thresholds are summarized in Table 7.1 and described below.

For water surface impacts, a threshold degree of oiling of 0.01 g/m^2 (0.01 grams of floating oil per square meter of water surface or the amount of oil averaged over a modeled grid cell resolution ranging from 0.9 to 1.3 km^2, depending on location) was used as the threshold for impacts on socio-economic resources because fishing may be prohibited in areas with any visible oil to prevent contamination of fishing gear and catch. This amount of oiling would appear as a barely visible sheen, oil patches of various amounts of oil, and/or scattered tarballs. A threshold of 10 g/m^2 was used as the threshold for ecological impacts to the water surface, as this level of oiling has been observed to be enough to mortally impact birds and other wildlife associated with the water surface (French McCay et al. 1996; French McCay 2009).

For shoreline impacts, an average loading of 1 g/m^2 was used as the threshold for impacts on socio-economic resources because that amount of oil would conservatively trigger the need for shoreline cleanup on amenity beaches. A concentration of 100 g/m^2 was used as the threshold for ecological impacts to shoreline habitats based on a synthesis of the literature showing that shoreline life has been affected by this degree of oiling (French McCay et al. 1996; French McCay 2009).

Table 7.1
Impact thresholds used to estimate consequences.

Consequence	Impact Measure	Impact Threshold	Oil Appearance*	No. of 1 inch Tarballs	Rationale
Impact to ecological resources - water surface	Water surface area exposed to floating oil	10 g/m^2	Dark brown sheen	~5,000-6,000 tarballs per acre	This level of oiling has been observed to mortally impact birds and other wildlife
Impact to socio-economic resources - water surface	Water surface area exposed to floating oil	0.01 g/m^2	Colorless and silver sheen	~5-6 tarballs per acre	Fishing may be prohibited in areas with any visible oil to prevent contamination of fishing gear and catch
Impact to ecological resources - shoreline	Shore length exposed	100 g/m^2	Black oil	~12-14 tarballs/m^2	Based on a literature synthesis, this level of oiling affects shoreline life
Impact to socio-economic resources - shoreline	Shore length exposed	1 g/m^2	Dull brown sheen	~0.12-0.14 tarballs/m^2	This amount of oil would conservatively trigger the need for shoreline cleanup on amenity beaches

Table 7.1 continued

Consequence	Impact Measure	Impact Threshold	Oil Appearance*	No. of 1 inch Tarballs	Rationale
Water column impact	Water volume exposed to dissolved aromatic concentrations	1 µg/L	N/A	N/A	Screening threshold for potential sublethal impacts on the most sensitive marine organisms

* Oil appearance listed in the table is for a continuous area of oil of the same thickness. In reality, the degree of oiling in the model is based on the amount of oil averaged over a large area (dependent on the resolution of the model). For example, 0.01 g/m^2 of oil on the water surface could appear as a barely visible sheen, oil patches of various amounts of oil, and/or scattered tarballs.

Water column impacts for both ecological and socio-economic (e.g., commercial fishing) resources were quantified as the volume of water that had dissolved aromatic concentrations exceeding 1 µg/L. At 1 µg/L, there are likely to be sublethal impacts to the most sensitive organisms in the water column and potential tainting of seafood, so this concentration is used as a screening threshold for both the ecological and socio-economic risk factors for water column resource impacts. Contamination in the water column changes rapidly in space and time, such that a dosage measure (i.e., the product of concentration and time) is a more appropriate index of impacts than simply peak concentration. Toxicity to aquatic organisms increases with time of exposure, such that organisms may be unaffected by brief exposures to the same concentration that is lethal at long times of exposure. Determining the dose to water column organisms was beyond the scope of this project, so a threshold of 1 µg/L was used as a screening threshold for potential impacts on sensitive organisms.

7.2 RISK SCORING AND RANKING

Assessing the potential risks associated with each release scenario requires the evaluation of the probability that an event would occur, the probability that a resources of interest would be exposed to the spilled material, and the impacts that the event would have on such resources. Consequently, three analyses are needed to characterize potential risks:

- **Spill Risk:** Analysis of the probability that there will be an oil or chemical release;
- **Exposure Risk:** Analysis of the probability of oil or chemical exposures to water column, water surface, and shorelines when concentrations exceed thresholds known to affect individual ecological and/or socioeconomic resources (Table 7.1). Each scenario outlined in Table 2.12 is modeled twice varying thresholds for impacts to ecological and socioeconomic resources.
- **Impact Risk:** Analysis of the probability of oil or chemical impacts to water column, water surface, and shoreline when the area or volume of impacts exceed thresholds that may negatively impact (at the population or ecosystem level) ecological resources at risk (EcoRARs) and socio-economic resources at risk (SRARs).

Ultimately, the overall risk assessment is aimed at determining whether there is a consequential impact to EcoRARs and SRARs. This requires addressing three main questions, assuming that a spill occurs:

- What is the magnitude of exposure to the water column, water surface, and shoreline and to what degree does this exposure exceed thresholds known to cause impacts to ecological and/or socioeconomic resources? (Exposure Risk)
- Are there ecological and socio-economic resources in the area that are potentially at risk of exposure to oil above thresholds known to cause adverse impacts? (Impact Risk)
- What is the degree of adverse impact to these resources resulting from oil exposures above the threshold levels effects? (Impact Risk)

The EcoRAR and SRAR risk assessment process involves evaluating spill risk to three categories:

- **Water Column:** Impacts to ecological and socio-economic resources in the water column;
- **Water Surface:** Impacts to ecological and socio-economic resources on the water surface, and
- **Shoreline:** Impacts to the shoreline and ecological and socio-economic resources on the shoreline.

For each of these three categories, in turn, risk is classified with regard to:

- The **probability of oiling** over a certain threshold (i.e., the likelihood that there will be exposure to specific resources over a certain minimal amount known to cause impacts); and
- The **degree of oiling** (the magnitude or amount of that exposure over the threshold known to cause impacts).

Thus, the potential *risk* associated with each release scenario is defined in Eq. 7.1 as follows:

(7.1) **Risk = Probability (spill) x Probability (impact) x Consequence**

In this equation, the "probability" term includes spill risk probability and the probability of an impact risk threshold exceedance. Note that there first needs to be an exceedance of the exposure risk thresholds (Table 7.1) for there to be an areal or volumetric exceedance of thresholds that may negatively impact EcoRARs and SRARs (or impact risk). The "consequence" term refers to the magnitude or amount of exposure over the threshold known to cause impacts, or degree of oiling.

The EcoRAR and SRAR risk scoring involves the following process:

- Predetermined release volumes based on results from Section 2.0;
- Analysis of modeling output data to determine *oiling probability risk scores* and *degree of oiling risk scores* for water column, water surface, and shoreline oiling; and
- Final EcoRAR and SRAR risk scoring combining the modeling data scoring and the RAR evaluations.

For each risk scoring variable a three-point scale of Low, Medium, and High (color-coded as green, yellow, and red, respectively) was used to distinguish levels of magnitude, probability, and impact (Table 7.2). Specific risk criteria are further defined as follows:

- **Spill Risk:**
  - Spill probability: The probability that a specific release scenario would occur. Because these probabilities are a function of annual incident rate and return years (see Table 3.22), these probabilities are summarized categorically and not numerically. By definition, the spill probability that a specific release scenario would occur at each location would be the same for each iteration of a particular simulation, such as when varying the thresholds for impacts to EcoRARs and SRARs.

- **Exposure Risk:** Defined as the percent probability of exceeding the threshold at any given time during a model simulation.
  - Water Column Exposure:
    - The threshold for petroleum and non-petroleum oils exposure for the water column is **1 µg/L**. At this concentration and above, impacts to ecological (e.g., lethal or sublethal toxicity) and socio-economic resources (e.g., tainting of fish and shellfish), EcoRARs and SRARs respectively, in the water column may occur.
    - Thresholds for sulfuric acid and glycols are **265,041 mg/m^3** and **23,800 mg/m^3**, respectively. For these chemicals, Exposure Risk will only be assessed based on the ratio of the peak modeled environmental concentrations to the threshold, and not on their probability.
  - Water Surface Exposure:
    - The threshold for petroleum and non-petroleum oils exposure for the water surface is **10 g/m^2** (French McCay et al. 1996; French McCay 2009). At this concentration and above, impacts to birds and other animals (EcoRARs) that spend time on the water surface may occur. A lower threshold, **0.01 g/m^2** is assumed for impacts to socio-economic resources (e.g., closure of fisheries in the presence of sheens), or SRARs.
    - Water Surface Exposures are not specifically evaluated for sulfuric acid and glycols, as these chemicals are not expected to impact surface water due to their rapid dissolution and mixing into the water column.
  - Shoreline Exposure:
    - The threshold for petroleum and non-petroleum oils exposure for the shoreline is **100 g/m^2** of shoreline. At this concentration and above, the shoreline would be coated with enough oil to cause impacts to shoreline organisms (French McCay et al. 1996; French McCay 2009), or EcoRARs. A lower threshold, **1 g/m^2**, is assumed for impacts to socio-economic resources (SRARs).
    - Shoreline Exposures are not specifically evaluated for sulfuric acid and glycols, as these chemicals are not expected to reach the shoreline due to their rapid dissolution and mixing into the water column.

- **Impact Risk:** Defined as the areal or volumetric impact with exposure concentrations at or above the proposed impact threshold. For the purpose of this project, the oil spill impact risk probability is expressed as the percent of the 200 total simulations per scenario (Table 2.12) that exceed the proposed threshold for potential impacts over a specified volume or area. Each scenario of 200 simulations, as outlined in Table 2.12, has a ***realistic*** and ***worst case***[41] model simulation. The *realistic* model simulation represents the mean model output of each of the three spill risk categories (water column, water surface and shoreline impacts), while the *worst case* model simulation represents the maximum model output of the three impacts. By definition, the percent probability of exceeding the threshold for each release scenario by location (Table 2.12) would be the same for the *realistic* and *worst case* model simulations. Note that a different approach is used for chemical exposure risks.

- Water Column Impacts:
  - The threshold for volumetric impacts to the water column is set at 0.5 km^2 of the upper 10 m of the water column, or ~**5.18 million m^3**. The water column risk factor reflects the probability that this volume of the water column would be contaminated with a high enough concentration of oil to cause socio-economic impacts. As discussed above, the threshold for water column impacts to socio-economic resources at risk is an oil concentration of 1µg/L. This concentration and water volume is used as a screening threshold for both the ecological and socio-economic risk factors.
- Water Surface Impacts:
  - The threshold for areal impacts to the water surface for petroleum and non-petroleum oils is set at **2,590 km^2** (or 1,000 mi^2) of the water surface. The threshold level for water surface impacts to EcoRARs is 10 g/m^2 (10 grams of floating oil per square meter of water surface). For SRARs, the threshold is lower at 0.01 g/m^2 (i.e., 0.01 grams of floating oil per square meter of water surface). The thresholds for EcoRAR and SRAR impacts differ; therefore, there might be impacts to SRARs while there might not be any impacts or lower impacts to EcoRARs.
  - Water Surface Impacts are not specifically evaluated for sulfuric acid and glycols, as these chemicals are not expected to impact surface water due to their rapid dissolution and mixing into the water column.
- Shoreline Impacts:
  - The threshold for areal impacts to the shoreline for petroleum and non-petroleum oils is set at **16 km** (or 10 miles) of shoreline. For the EcoRAR risk analysis for shoreline impact, shoreline sensitivity was factored into the modeling results and analysis. Impacts to shoreline types were weighted by their degree of sensitivity to oiling by multiplying by a factor of 3 (most sensitive) to 1 (least sensitive). Multipliers were as follows: wetlands “3”, mudflats “3”, rocky and gravel shores “2”, sand beaches “1”, and artificial intertidal “0”. The impacts to different types of shorelines also vary based on economic value. Therefore, for the SRAR risk analysis for shoreline impact, shoreline type was also factored into the modeling

[41] For the purpose of this analysis, the worst case model simulation is defined as the model simulation for each release scenario that results in the maximum model output causing the maximum degree of impacts to ecological and socio-economic resources. Consequently, the worst case model simulation is conceptually different from the catastrophic release of 128,600 gallons of all oils (All-Mix2-129K).

results and analysis. Impacts to shoreline types were weighted based on their degree of economic value by multiplying by a factor of 3 (most valuable) to 1 (least valuable). Sand beaches are the most economically valued shorelines (weighted as “3” in the impact analysis), rocky and gravel shores are moderately valued (weighted as “2”), and wetlands, mudflats and artificial intertidal are the least economically valued shorelines (weighted as “1”). Note that the values used in the SRAR risk analysis differ from those used in the EcoRAR risk analysis.

- For EcoRARs, the shoreline impact risk factor reflects the probability that the shoreline would be coated by enough oil to cause impacts to shoreline organisms. The threshold for shoreline oiling impacts to ecological resources at risk is 100 g/m^2 (i.e., 100 grams of oil per square meter of shoreline). For SRARs, the shoreline impact risk factor reflects the probability that the shoreline would be coated by enough oil to cause impacts to shoreline users. The threshold for impacts to shoreline SRAR is 1 g/m^2. Note that this is lower than the threshold for EcoRARs. This means that there might be impacts to SRARs while there might not be any impacts or lower impacts to EcoRARs.
- Shoreline Impacts are not specifically evaluated for sulfuric acid and glycols, as these chemicals are not expected to reach the shoreline due to their rapid dissolution and mixing into the water column.

Table 7.2

Three-point color coded scale associated with the categories considered in the Risk Scoring for each release scenario in Table 2.12. Note that for some scale categories, values are for both petroleum and non-petroleum oils and wind turbine-related chemicals (oils | chemicals).

Scale Categories	Low	Medium	High
Spill Risk			
Categorical spill probability	1 time in > 50 years	1 time in 10-50 years	1 time in < 10 years
Percent Probability of Impact Risk Threshold Exceedance[1]			
Water Column Impacts	< 30% | ratio peak:threshold < 1	30-65% | ratio peak:threshold 1-10	> 65% | ratio peak:threshold >10
Water Surface Impacts	< 30% | NA	30-65% | NA	> 65% | NA
Shoreline Impacts	< 30% | NA	30-65% | NA	> 65% | NA
Consequence: Degree of Oiling			
Water Column Impacts	< 5.18 million m^3	5.18-518 million m^3	> 518 million m^3
Water Surface Impacts	< 2,590 km^2 | NA	2,590-25,900 km^2 | NA	> 25,900 km^2 | NA
Shoreline Impacts	< 16 km | NA	16-160 km | NA	> 160 km | NA

[1] Percent of model simulations (out of 200 total) that exceed the proposed threshold for impacts

7.3 MODEL RESULT INTERPRETATION AND SPILL SCENARIO EVALUATION

7.3.1 SIMAP for Petroleum and Non-Petroleum Oils

The SIMAP modeling approach estimates areas of water surface, lengths of shoreline, and volumes of water exposed above consequence thresholds for the spill scenarios (Table 2.12).

Because of the varying environmental conditions, each of the 200 individual simulations per modeling scenario (Table 2.12) has the potential to follow a different trajectory. Figure 7.1 shows examples of surface oil trajectories from the simulation of a 40,000 gallon spill of naphthenic mineral oil from the assumed ESP location (ESP-Nap-40K in Table 2.12) within the NC Call Area. To generate a map of the probability of surface oil reaching a given location (Figure 7.2), all 200 individual simulations are overlaid and the number of simulations reaching a given location is used to calculate the oiling probability at that location. Probability maps of shoreline oiling are generated in the same manner. For the analyses presented here, model scenarios are summarized based on a *realistic* model simulation with the mean results for degree of oiling and a *worst case* model simulation with the maximum results for degree of oiling.

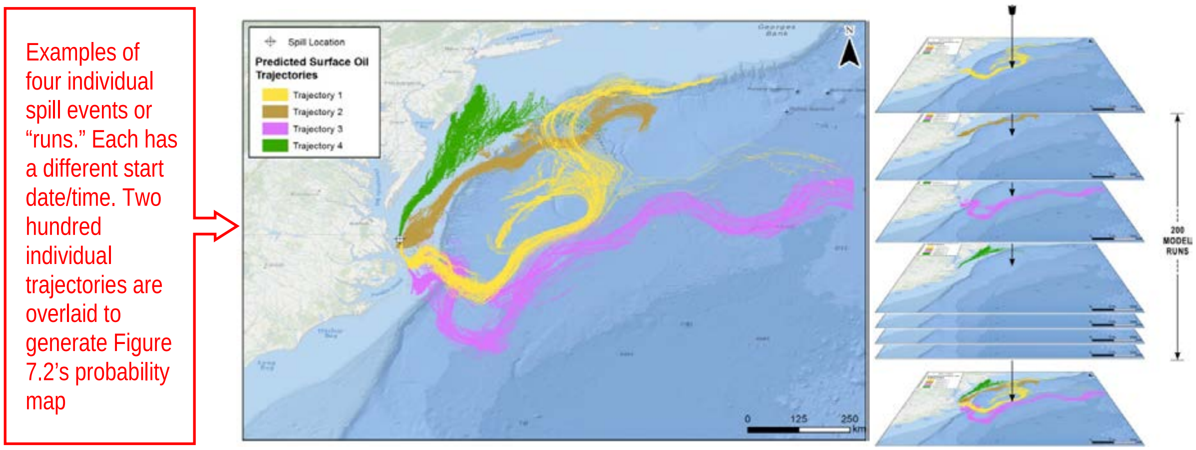


Figure 7.1 Examples of four individual spill trajectories predicted by SIMAP for a spill of 40,000 gallons of naphthenic mineral oil from the NC Call Area. The frequency of contact with given locations is used to calculate the probability of impacts during a spill. Essentially, all 200 model simulations are overlain (shown as the stacked runs on the right) and the number of times that a trajectory reaches a given location is used to calculate the oiling probability above the exposure risk threshold for that location.

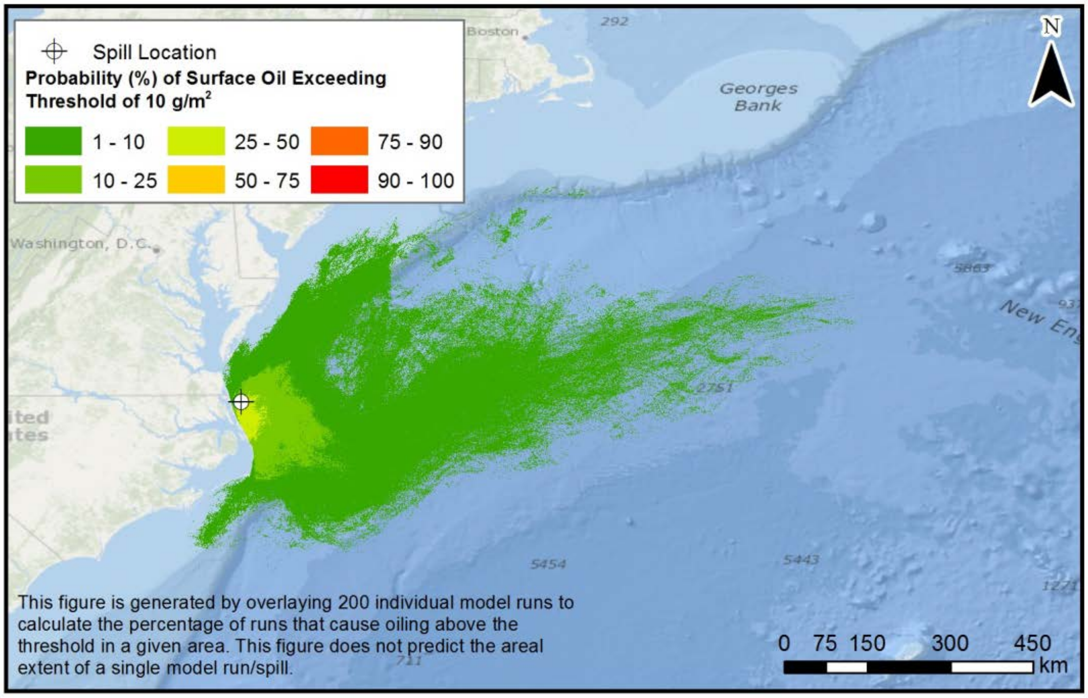


Figure 7.2 Probability of surface oil exceeding 10 g/m^2 for a spill of 40,000 gallons of naphthenic mineral oil from the NC Call Area. This figure is generated by overlaying 200 individual model simulations to calculate the percentage of runs that caused oiling above the threshold in a given area, where warmer colors depict the extent with greater probability of threshold exceedance. This figure does not depict the areal extent of a single model simulation.

7.3.2 CHEMMAP for Other Chemicals of Interest

The CHEMMAP modeling approach estimates the extent of concentrations above consequence thresholds for the spill scenarios (refer to the scenarios in Table 2.13). Figure 7.3 shows an example of the CHEMMAP model output from the simulation of a catastrophic chemical release (WCD-Chems-29K[42], Table 2.13) in the immediate vicinity of the RI-MA WEA.

[42] Model as 28,630 gallons of ethylene glycol as the additive impacts associated with 335 gallons of sulfuric acid did not result in exceedances of the threshold for sulfuric acid at the 3 Call Area/WEA locations.

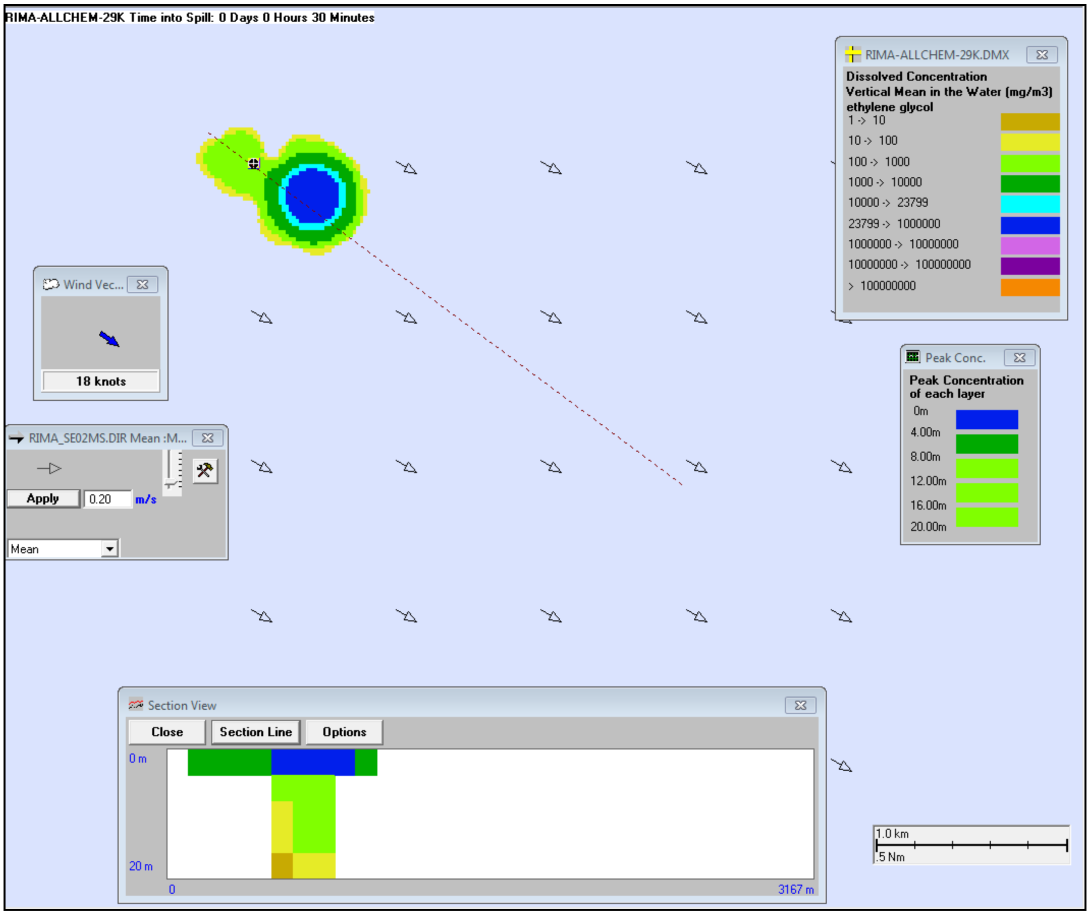


Figure 7.3 CHEMMAP model output in plain view and cross section. This example shows the first 30 minutes of dissolved chemical concentrations (and peak concentration vertically) following a catastrophic chemical release (28,630 gallons of ethylene glycol) in the immediate vicinity of the RI-MA WEA. The lowest chemical threshold (23,800 for mg/m^3 glycols) falls within the dark blue concentration range of estimated environmental concentrations.

7.4 RHODE ISLAND-MASSACHUSETTS WIND ENERGY AREA OIL SPILL MODELING RESULTS

Using the information presented in Table 7.1, model outputs (see details of each model scenario at each location of interest in Table 2.12, Section 6.0 and Appendix A) were used to characterize potential risks for each of the release scenarios in the three geographic locations. EcoRAR and SRAR risk analysis of *realistic* and *worst case* model outputs for the three modeled areas are shown in the following sections for petroleum and non-petroleum oils.

7.4.1 Ecological and Socioeconomic Resources at Risk

The Rhode Island-Massachusetts Wind Energy Area (RI-MA WEA), between Block Island and Martha's Vineyard, is located about 9.2 nautical miles south of the Rhode Island coastline, and it covers approximately 257 mi^2 (Figure 7.4).

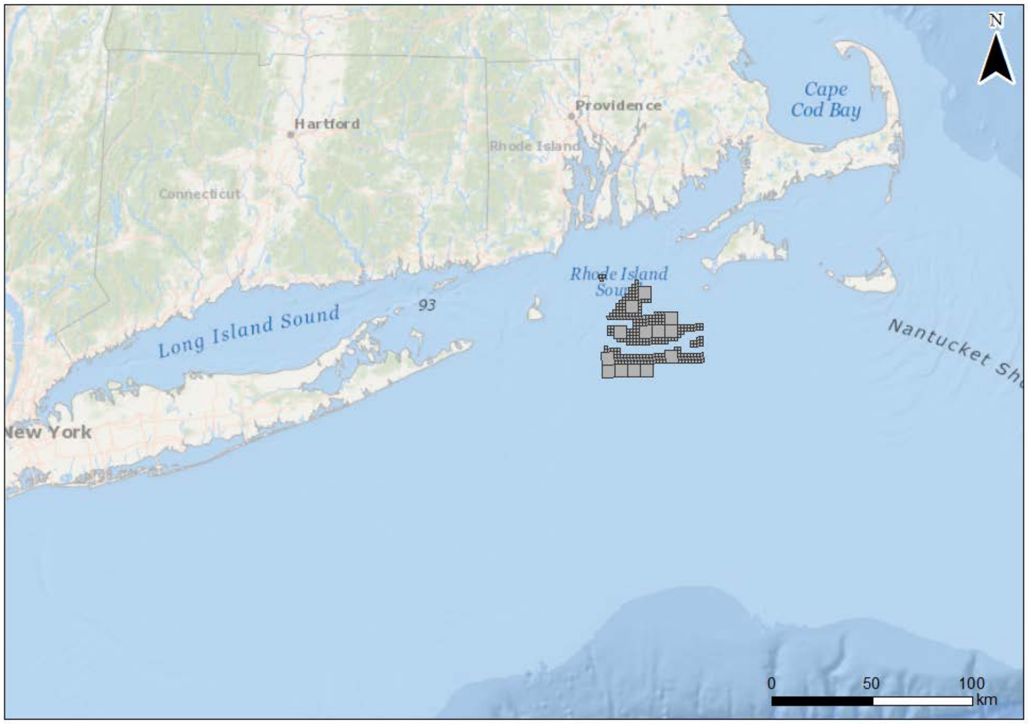


Figure 7.4 Location of the RI-MA WEA.

Ecological resources at risk from a release of oil from RI-MA WEA (Table 7.3) include numerous guilds of birds present in nearshore/offshore waters, particularly those sensitive to surface oiling while rafting or plunge diving to feed. In addition, this region is important for migrating marine mammals and commercially important fish and invertebrates.

Table 7.3

Ecological Resources at Risk from oil and chemical releases from the RI-MA WEA. FT = Federal threatened; FE = Federal endangered; ST = State threatened; SE = State endangered.

Species Group	Species Subgroup and Geography	Seasonal Presence
Pelagic Birds and Sea Birds	• Offshore waters support 1,000s of loons, grebes, petrels, shearwaters, pelicans, cormorants, phalaropes, and terns • Northern gannet are abundant fall-spring throughout the coastal zone (often > 3 km from shore) • Pelagic/water bird use most diverse and abundant fall through spring, but 10,000s of birds have been observed feeding some summers; RI is critical wintering habitat for a significant number of loons	Terns, gulls, cormorants present spring/summer; Loons and pelicans present in spring/fall; Shearwaters in summer; Grebes, phalaropes in fall/winter
Sea Ducks	• Cape Cod and Nantucket Shoals are most important offshore wintering areas on the Atlantic Coast for long-tailed ducks; also are concentration areas for scoters • Benthic community composition and water depth important for determining preferred foraging sites (not well known, some studies have been conducted	Migration from fall to spring (Oct-Apr)

Table 7.3 continued

Species Group	Species Subgroup and Geography	Seasonal Presence
Shorebirds, Waterfowl, and Colonial Nesting Birds	Shorebirds, colonial nesting birds (colonial waterbirds, shorebirds, and waterfowl are abundant on small islands, beaches, and marshes throughout the region) • RI: Numerous important sites for beach and salt marsh habitats, including NWRs that support breeding (e.g., least tern and piping plover) and migratory stopover points • Important wintering areas for harlequin duck • Important habitat for 1,000s of migratory waterfowl including declining populations of American black duck and northern pintail	Beach nesters peak Apr-Aug Migration typically spring/fall, but varies by species and location and ranges from Feb-Jun/Aug-Dec. Nesting Apr-Jun
Sea Turtles	Summer foraging grounds for adult and juvenile green (FE), loggerhead (FT), Kemp's ridley (FE) and Leatherback (FE) sea turtles	Adults and juveniles present spring/ summer
Marine Mammals	*Baleen whales*: North Atlantic right whale (FE), humpback whale (FE), fin whale (FE), and minke whale are more common offshore but can move inshore to feed on forage fish and zooplankton. • Right whales are critically endangered (300-400 individuals remaining) and use this area as a migratory pathway *Inshore cetaceans:* Atlantic white-sided dolphin, bottlenose dolphin, harbor porpoise, common dolphin, and killer whale use coastal waters to the shelf break *Pinnipeds*: 100s of gray seals and harbor seals are common during the winter, with Block Island, Plum Island, Fishers Island, and Great Gull Island serving as important haul out locations. Hooded and harp seals can occur but are less common	Baleen whales migrate through in spring and fall, males and juveniles may stay year round; Dolphins more common in southern area, during summer; Harbor porpoises calve May-Aug; Seals common Nov-Jun
Fish and Invertebrates	Coastal ocean waters support many valuable fisheries and/or species of concern in the region: • Benthic: Sea scallop, scup, summer flounder, winter flounder, black sea bass, Atlantic rock crab, Atlantic surf clam • Midwater: Atlantic mackerel, Atlantic herring, longfin squid, shortfin squid, striped bass, bluefish, menhaden, spiny dogfish shark, spot, weakfish • Pelagic: Bluefin tuna, yellowfin tuna, dolphinfish, and longbill spearfish • Diadromous: Alewife, blueback and Atlantic herring, American shad, hickory shad, American eel, Atlantic sturgeon (Fed. species of concern), shortnose sturgeon (FE) Important concentration/conservation areas: • Essential Fish Habitat (EFH) for highly migratory species occurs in the area, including swordfish, bluefin tuna, yellowfin tuna, and many shark species • Juvenile and adult bluefin tuna aggregate in the area in the winter	Generally spawn during the warmer months (except winter flounder); Many coastal fish migrate seasonally either across the shelf or east-west (winter flounder); Juveniles of many species use estuaries, seagrass, hard bottom habitats as nursery areas

In addition to natural resource impacts, spills from the RI-MA WEA have the potential to cause social and economic impacts. Socio-economic resources potentially at risk from oiling are listed in Table 7.4. The potential economic impacts include disruption of coastal economic activities such as commercial and recreational fishing, boating, recreating, commercial shipping, and other activities that may become claims following a spill.

Table 7.4
Socio-economic resources at risk from oil and chemical releases from the RI-MA WEA.

Resource Type	Resource Name	Economic Activities
National Wildlife Refuge (NWR)/ State Wildlife Sanctuary (SWS)	Amagansett NWR, NY Block Island NWR, RI Ninigret NWR, RI Trustom Pond NWR, RI Sachuest NWR, RI Nomans Land NWR, MA Mashpee NWR, MA Monomoy NWR, MA Nantucket NWR, MA Penikese Island SWS, MA Tarpaulin Cove SWS, MA South Barrier Beach State Fish and Wildlife Area, MA	National wildlife refuges in three states may be impacted. These federally managed and protected lands provide refuges and conservation areas for sensitive species and habitats.
National Seashores	Fire Island National Seashore, NY Cape Cod National Seashore, MA	National seashores provide recreation for local and tourist populations as well as preserve and protect the nation's natural shoreline treasures. National seashores are coastal areas federally designated as being of natural and recreational significance as a preserved area.
Tourist Beaches	Montauk, NY Block Island, RI East Matunuck State Beach, RI Roger W. Wheeler State Beach, RI Scarborough State Beach, RI Fishers Island Horseneck Beach State Reservation, MA Edgartown Beach, MA South Beach, MA Many beaches along Nantucket Sound, MA Many beaches on Nantucket Island and Martha's Vineyard, MA	Potentially affected beach resorts and beach-front communities in Rhode Island and Massachusetts provide recreational activities (e.g., swimming, boating, recreational fishing, wildlife viewing, nature study, sports, dining, camping, and amusement parks) with substantial income for local communities and state tax income. Many of these recreational activities are limited to or concentrated into the late spring into early fall months.
State Parks	Montauk SP, NY Montauk Downs SP. NY Hither Hills SP, NY Misquamicut State Beach, RI Demarest Lloyd Memorial State Park, MA	Coastal state parks are significant recreational resources for the public (e.g., swimming, boating, recreational fishing, wildlife viewing, nature study, sports, dining, camping, and amusement parks). They provide income to the states. Many of these recreational activities are limited to or concentrated into the late spring into early fall months.
Tribal Lands	Narragansett Indian Reservation, RI	Narragansett Indian Reservation, Rhode Island, is home to 2,400 tribal members.
Commercial Fishing	Fishing fleets for commercial fishing include	
	Montauk, NY	Total Landings (2010): \$17.7M
	New London, CT	Total Landings (2010): \$10.6M
	Stonington, CT	Total Landings (2010): \$18.5M
	Point Judith, RI	Total Landings (2010): \$32.2M

7.4.2 EcoRAR Impact Risk Analysis Results for All Scenarios

EcoRAR impact risk analyses were conducted for all oil spill scenarios in the RI-MA WEA listed in Table 2.12, as summarized below.

- The *realistic* simulations of each scenario (Table 7.5) suggest that spill risks (probabilities) are generally high for small volume spills (WTG-Hyd-90, WTG-Nap-370, WTG-Lub-220), moderate for intermediate size spills (ESP-Nap-500, ESP-Nap-10K, ESP-Diesel-2K) and low for intermediate to high volume spills (ESP-Nap-1K, ESP-Nap-40K, 5WTG-Mix1-3400, All-Mix2-129K).
- Two of the spill scenarios, a 2,000 gallon spill of diesel (ESP-Diesel-2K) and a 128,600 gallon spill of an oil mixture (All-Mix2-129K), had the greatest probability of water column impacts (66% and 98.5%, respectively); thus, contaminating more than 5.18 million m^3 of water using the 1 µg/L threshold and leading to moderate to high impacts to the water column, respectively.
- While the 128,600 gallon spill of an oil mixture (All-Mix2-129K), and the 10,000 and 40,000 gallon spill of naphthenic mineral oil (ESP-Nap-10K and ESP-Nap-40K, respectively) had a moderate to high probability of shoreline threshold exceedances (56.5%, 72%, and 80%, respectively), only the two larger spills had the potential to moderately impact 18.8 and 31.2 km of shorelines.
- The overall risk of each scenario, which combines the relative contribution of spill and impact risk probability and consequence (or degree of oiling), is generally low for most scenarios except the 2,000 gallon spill of diesel (ESP-Diesel-2K) and the 128,600 gallon spill of an oil mixture (All-Mix2-129K).
- EcoRAR impact risk analyses for the *worst case* simulations for each scenario (Table 7.6) are similar to those of the *realistic* simulations, except that there is a greater potential water column volume and shoreline area than would be impacted under the worst case scenario. For example, while the *realistic* simulation of the 128,600 gallon scenario (All-Mix2-129K) could impact over 500 million m^3 of the water column, the extent of oiling for the *worst case* simulation of that scenario would be over twice that volume. Similarly, the results for the *realistic* simulation of that same scenario show potential impact of 31.2 km of shorelines (primarily gravel beaches), while the *worst case* simulation results in an extent of oiling of 187.3 km (primarily gravel beaches, followed by rocky shores).
- In general, the overall risk is generally low for most of the *worst case* simulations of the scenarios (Table 7.6) except for the 10,000 gallon spill of naphthenic mineral oil (ESP-Nap-10K), the 2,000 gallon spill of diesel (ESP-Diesel-2K), and the 128,600 gallon spill of an oil mixture (All-Mix2-129K).

Table 7.5

Risk Scoring for EcoRAR based on *realistic* model outputs for the oil spill scenarios in the RI-MA WEA. *Realistic* refers to the average degree of oiling across all model runs with oiling results. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling										Overall Risk
							Weighted Shoreline (km)								
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total		
ESP-Nap-500	1 time in 10-50 years	0	0	9	316	12.4	0	0	0.83	1.49	0	0	2.32	Low	
ESP-Nap-1K	1 time in >50 years	0	0	21	934	21.2	0	0	0.43	2.30	0	0	2.73	Low	
ESP-Nap-10K	1 time in >50 years	0	0	72	25,600	117	0	0.59	0.81	7.85	0.19	0	9.44	Low	
ESP-Nap-40K	1 time in >50 years	0	0	80	256,000	274	0	2.24	1.31	14.3	0.95	0	18.8	Low	
ESP-Diesel-2K	1 time in 10-50 years	66	0	17	10,400,000	11.5	0	0	0.59	2.08	0	0	2.67	Moderate	
WTG-Hyd-90	1 time in <10 years	0	0	0	0	3.95	0	0	0	0	0	0	0	Low	
WTG-Nap-370	1 time in <10 years	0	0	0	0	13.3	0	0	0	0	0	0	0	Low	
WTG-Lub-220	1 time in <10 years	0	0	0	0	17.4	0	0	0	0	0	0	0	Low	
5WTG-Mix1-3400	1 time in >50 years	0	0	19	0	197	0	0.15	0.31	3.86	0	0	4.32	Low	
All-Mix2-129K	1 time in >50 years	98.5	0	56.5	512,000,000	397	0	7.46	0.97	21.1	1.67	0	31.2	Moderate	

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (10 g/m^2 threshold); [3] Probability of Shoreline Impact (100 g/m^2 threshold).

Table 7.6
Risk Scoring for EcoRAR based on *worst case* model outputs for several spill scenarios in the RI-MA WEA. *Worst case* refers to the maximum degree of oiling. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	0	9	34,900	52.1	0	0	3.96	1.98	0	0	5.94	Low
ESP-Nap-1K	1 time in >50 years	0	0	21	68,300	89.6	0	0	3.96	3.96	0	0	7.92	Low
ESP-Nap-10K	1 time in 10-50 years	0	0	72	471,000	495	0	3.96	15.9	29.7	2.97	0	52.53	Moderate
ESP-Nap-40K	1 time in >50 years	0	0	80	2,880,000	1,130	0	11.9	41.6	43.6	14.9	0	112	Low
ESP-Diesel-2K	1 time in 10-50 years	66	0	17	47,300,000	47.9	0	0	3.96	3.96	0	0	7.92	Moderate
WTG-Hyd-90	1 time in <10 years	0	0	0	0	43.5	0	0	0	0	0	0	0	Low
WTG-Nap-370	1 time in <10 years	0	0	0	0	83.2	0	0	0	0	0	0	0	Low
WTG-Lub-220	1 time in <10 years	0	0	0	0	89.1	0	0	0	0	0	0	0	Low
5WTG-Mix1-3400	1 time in >50 years	0	0	19	0	830	0	1.98	5.94	9.91	0	0	17.83	Low
All-Mix2-129K	1 time in >50 years	98.5	0	56.5	1,300,000,000	2,460	0	29.7	47.6	89.2	20.8	0	187.3	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (10 g/m^2 threshold); [3] Probability of Shoreline Impact (100 g/m^2 threshold).

7.4.3 Modeling Results for Catastrophic Release of All Oils Using EcoRAR Impact Thresholds

This section provides a more detailed interpretation of the scenario of the catastrophic release of 128,600 gallons of all oils (All-Mix2-129K) spilled from an entire wind turbine facility in the RI-MA WEA using the EcoRAR thresholds of impacts, as presented in Figures 7.5 through 7.9 and summarized in Table 7.7.

Table 7.7
Summary of Exposure Risk and Impact Risk analysis results for catastrophic release of all oils (All-Mix2-129K) in RI-MA WEA using EcoRAR thresholds.

Modeling Parameter	Result	Reference
Probability of exceedance above surface oil exposure risk threshold (10 g/m^2)	Greatest in immediate proximity of release with 1-10% probability further from release point	Figure 7.5
Probability of exceedance above surface oil impact risk threshold (2,590 km^2 above 10 g/m^2)	0%	Tables 7.5 and 7.6
Minimum time (days) to exceed the exposure risk surface water threshold (10 g/m^2) for all simulations	< 2 days within approximately 150 km of spill site	Figure 7.6 (top)
Minimum time (days) to exceed the exposure risk surface water threshold (10 g/m^2) for *worst case* out of 200 simulations	< 2 days within approximately 150 km southwest of spill site	Figure 7.6 (bottom)
Probability of exceedance above shoreline exposure risk threshold (100 g/m^2)	Most shores with 0-10% and 25-50% within 50 km of spill site	Figure 7.7 (top)
Minimum time (days) to exceed the exposure risk shoreline threshold (100 g/m^2) for all simulations	< 2 days	Figure 7.7 (bottom)
Probability of exceedance above shoreline impact risk threshold (16 km above 100 g/m^2)	56.5% (113 out of 200 model simulations)	Tables 7.5 and 7.6
Maximum oil mass (g/m^2) on shorelines to exceed the exposure risk shoreline oiling threshold (100 g/m^2) for *worst case* out of 200 simulations	100 g/m^2 to > 1,000 g/m^2 with most oiling occurring north-east from the point of release	Figure 7.8
Water column volume affected by oil above the exposure threshold (1µg/L) at any instant in time	90% of simulations at < 1 km^3	Figure 7.9 (top)
Water surface area (km^2) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	91% of simulations at < 800 km^2; 75% of simulations at < 500 km^2	Figure 7.9 (middle)
Shoreline length (km) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	90% of simulations at < 40 km; ~70% at < 20 km; nearly 50% with negligible shoreline impacts	Figure 7.9 (bottom)

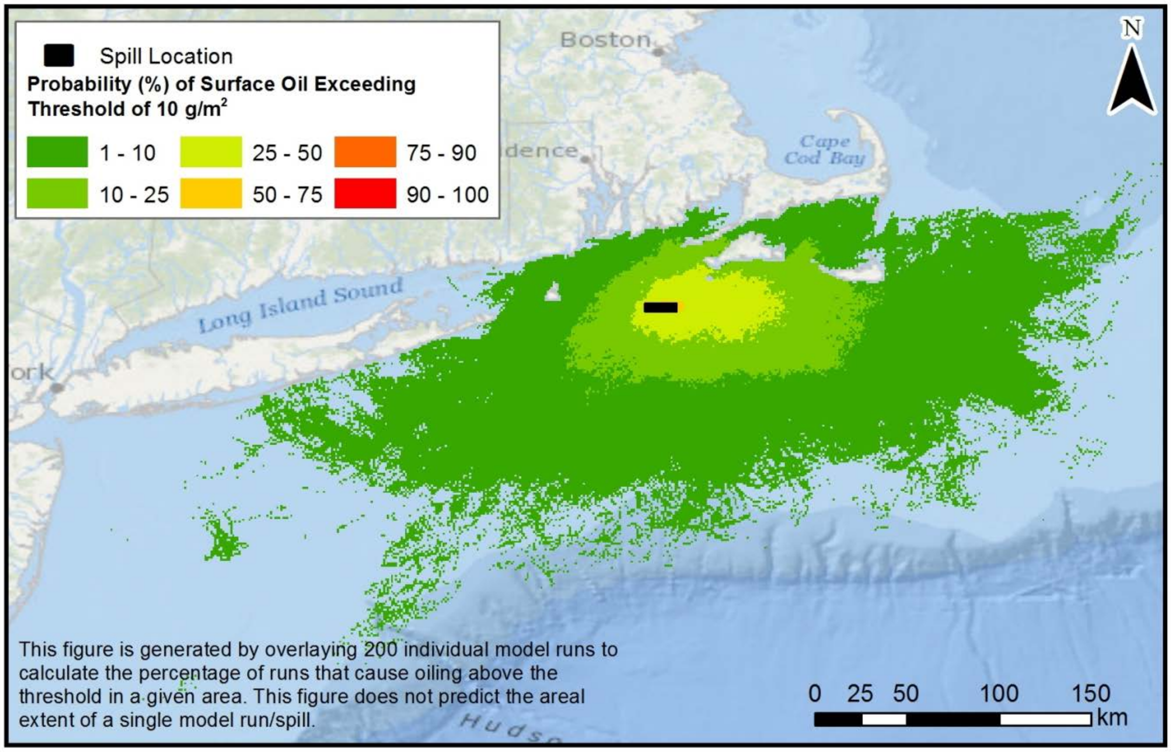


Figure 7.5 Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA*.* This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

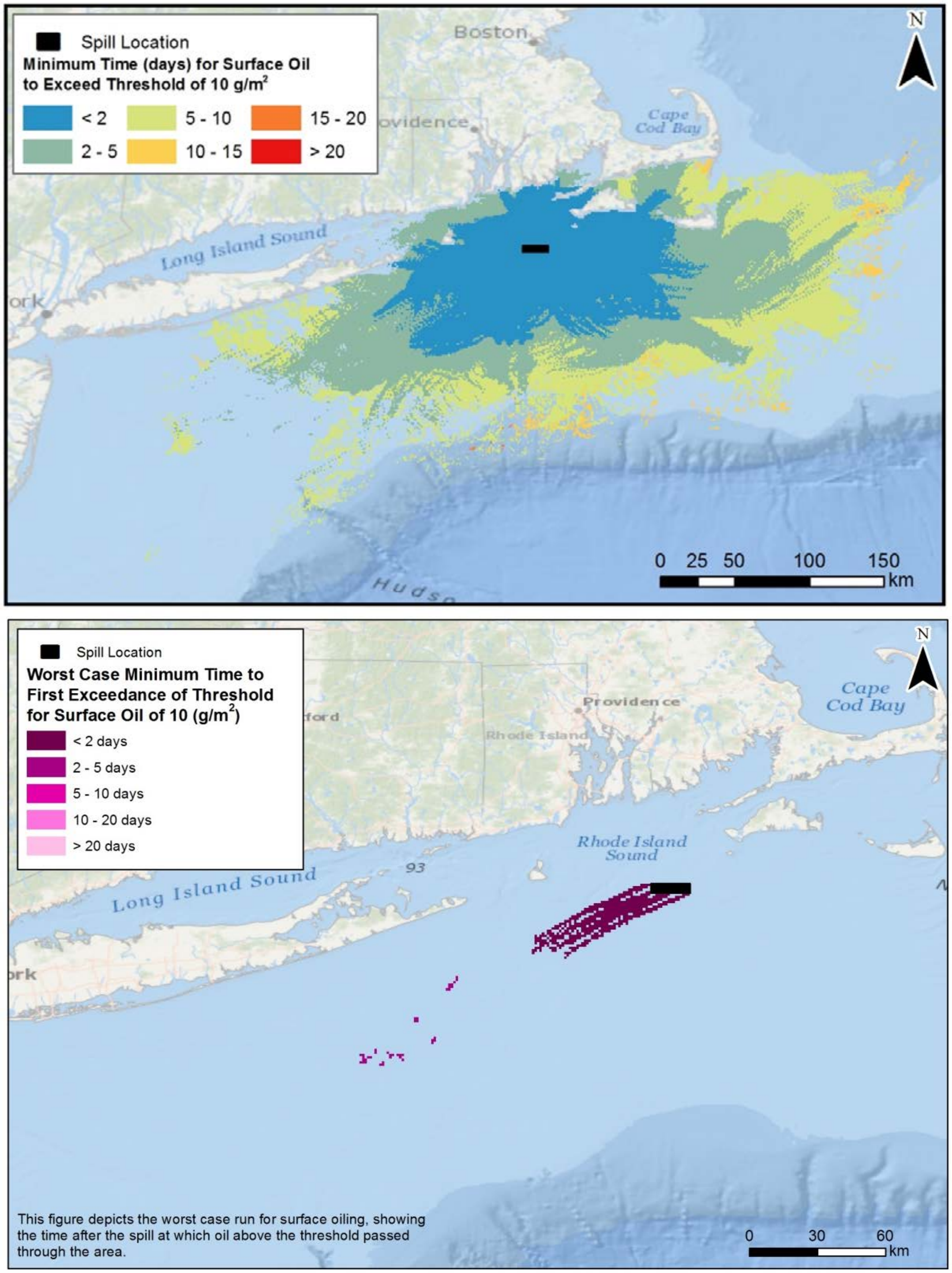
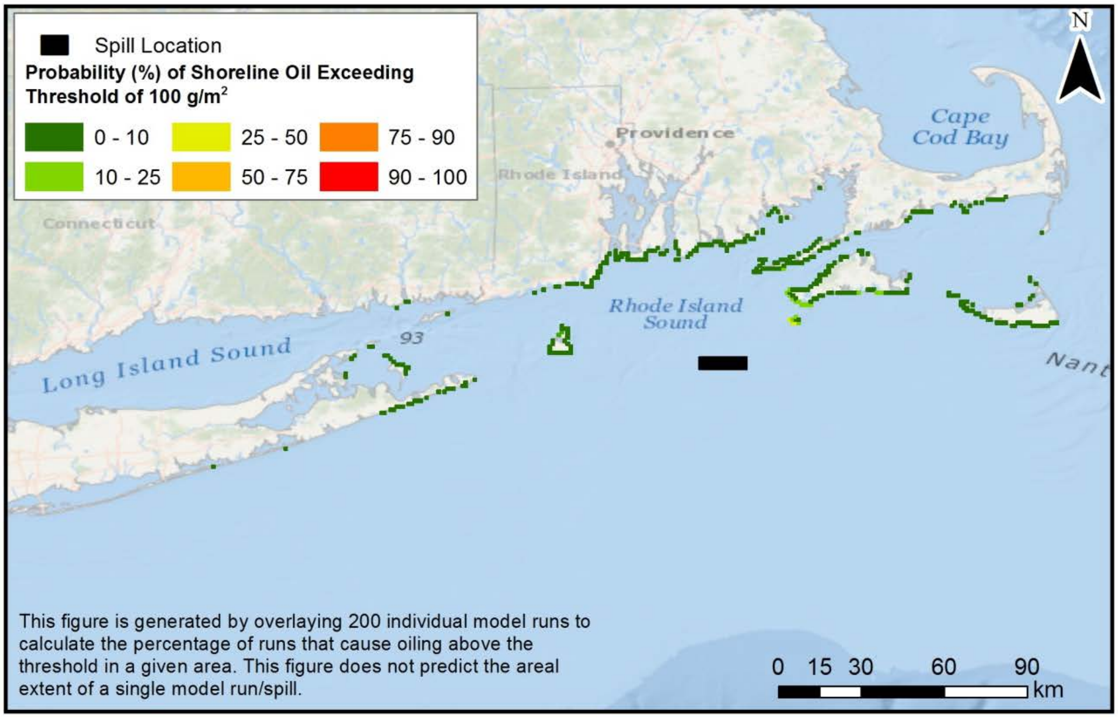


Figure 7.6 Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



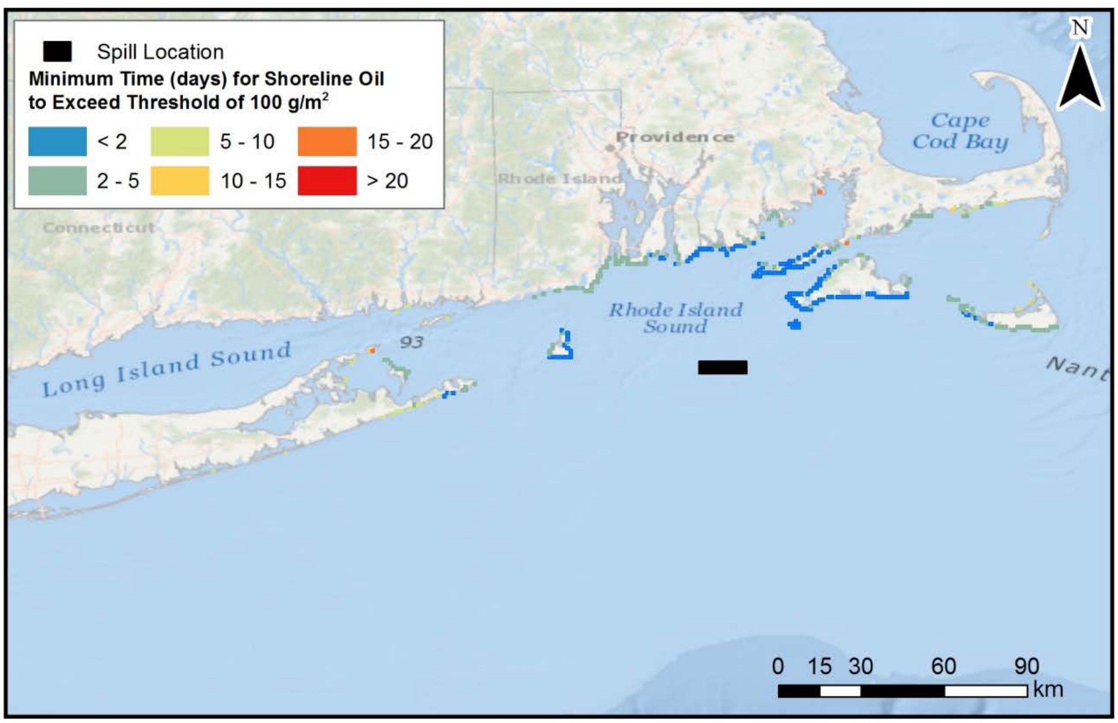


Figure 7.7 Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

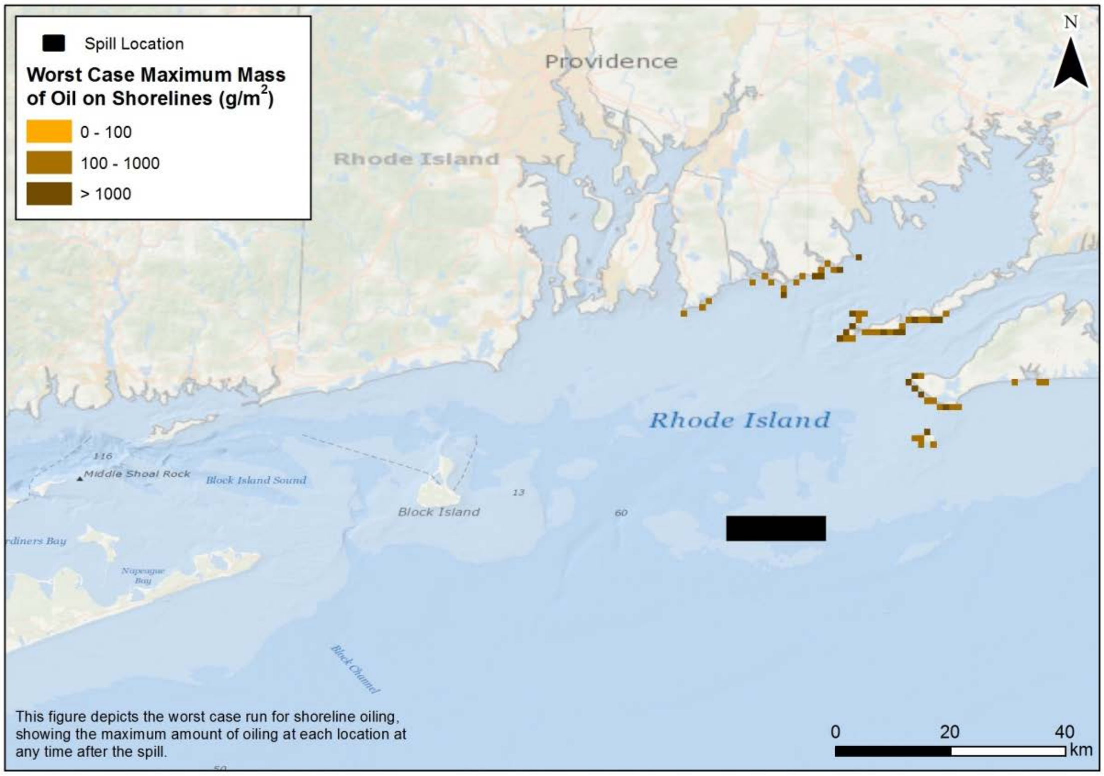


Figure 7.8 Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA. Map represents a single simulation.

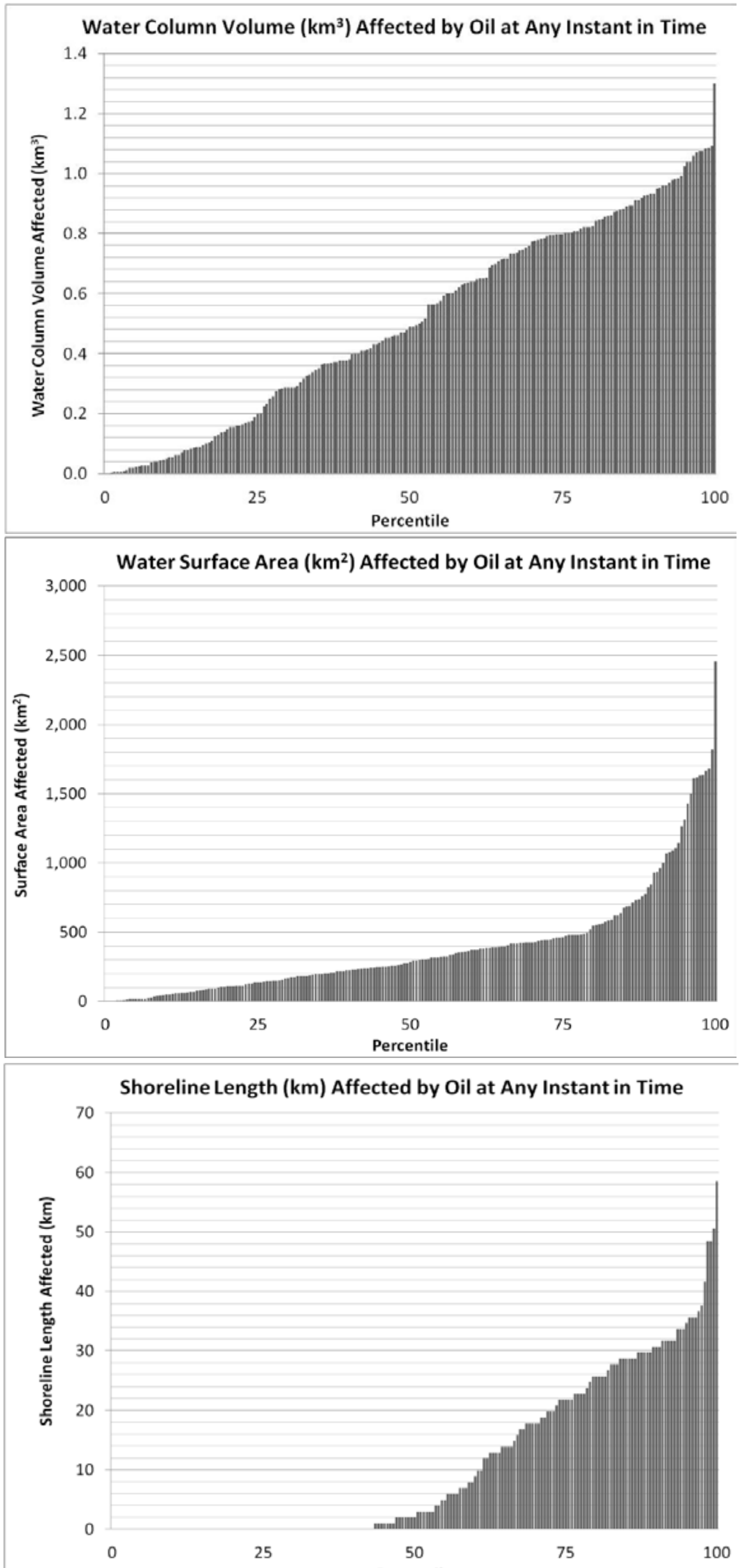


Figure 7.9 Summary of 200 model simulations of a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA showing the estimated water column volume (top), surface water area (middle), and shoreline length (bottom) impacted above the exposure risk EcoRAR thresholds.

7.4.4 SRAR Impact Risk Analysis Results for All Scenarios

SRAR impact risk analyses were conducted for all oil spill scenarios in the RI-MA WEA listed in Table 2.12, as summarized below.

- The *realistic* simulations of the modeling scenarios (Table 7.8) are similar to those of the EcoRAR (Table 7.5), except that there are more scenarios with moderate to high probability of exceeding the shoreline impact thresholds when applying the SRAR impact analyses. Consequently, the shoreline length impacted above SRAR thresholds would be greater than those of the EcoRAR scenarios. Additionally, when applying SRAR thresholds, the probability of exceeding the impact risk threshold for water surface increases from 0% in the EcoRAR analysis to 77.5%.
- The overall risk of impacts are low for the *realistic* simulations of most scenarios (Table 7.8), except the 10,000 gallon spill of naphthenic oil (ESP-Nap-10K), the 2,000 gallon spill of diesel (ESP-Diesel-2K), and the 128,600 gallon spill of an oil mixture (All-Mix2-129K).
- SRAR risk analyses for the *worst case* simulations (Table 7.9) are very similar to those of the *realistic* simulations (Table 7.8), except that there is a greater potential for oiling of a greater water column volume and shoreline area. For example, while the *realistic* simulation of the 128,600 gallon oil mixture scenario (All-Mix2-129K) could impact over 500 million m^3 of the water column, the *worst* case simulation for that scenario could result in an extent of oiling over twice that volume. Similarly, results for the *realistic* simulation of that same scenario show potential impact of 88.7 km of shorelines (primarily sand beaches followed by gravel beaches), while the *worst case* simulation results in an extent of oiling of 436 km (primarily sand beaches).
- The overall risk is generally low for the *worst case* simulations of most scenarios (Table 7.9), except for the 500, 10,000 and 40,000 gallon naphthenic mineral oil spills (ESP-Nap-500, ESP-Nap-10K, ESP-Nap-40K, respectively), the 2,000 gallon diesel spill (ESP-Diesel-2K), and the 128,600 gallon spill of an oil mixture (All-Mix2-129K).

Table 7.8
Risk Scoring for SRAR based on *realistic* model outputs for several spill scenarios in the RI-MA WEA. *Realistic* refers to the average degree of oiling across all model runs with oiling results. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	0	65.5	316	320	0.64	2.45	0.77	9.86	0.08	0	13.8	Low
ESP-Nap-1K	1 time in >50 years	0	0	77.5	934	367	0.84	4.81	1.01	12.7	0.21	0.02	19.6	Low
ESP-Nap-10K	1 time in 10-50 years	0	0.5	85	25,600	757	1.54	22.6	1.42	25.1	1.07	0.19	51.9	Moderate
ESP-Nap-40K	1 time in >50 years	0	26.5	85.5	256,000	1,750	2.20	39.6	2.54	34.2	2.58	0.56	81.7	Low
ESP-Diesel-2K	1 time in 10-50 years	66	0	46	10,400,000	40.4	0.25	1.00	0.57	4.73	0.03	0	6.57	Moderate
WTG-Hyd-90	1 time in <10 years	0	0	4	0	518	0.71	0.849	0	2.55	0.28	0	4.39	Low
WTG-Nap-370	1 time in <10 years	0	0	15.5	0	598	0.42	2.49	0.45	3.58	0.10	0	7.03	Low
WTG-Lub-220	1 time in <10 years	0	0	24.5	0	693	0.75	3.46	0.45	4.69	0.10	0	9.44	Low
5WTG-Mix1-3400	1 time in >50 years	0	0	45	0	447	0.98	27.8	1.43	15.8	0.84	0.09	46.9	Low
All-Mix2-129K	1 time in >50 years	98.5	77.5	65	512,000,000	4,320	2.12	47.6	1.71	33.7	2.58	0.97	88.7	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (0.01 g/m^2 threshold); [3] Probability of Shoreline Impact (1 g/m^2 threshold).

Table 7.9

Risk Scoring for SRAR based on *worst case* model outputs for several spill scenarios in the RI-MA WEA. *Worst case* refers to the maximum degree of oiling. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	0	65.5	34,900	1,150	3.96	14.9	21.8	29.7	1.98	0	72.3	Moderate
ESP-Nap-1K	1 time in >50 years	0	0	77.5	68,300	1,200	6.94	26.7	35.7	41.6	2.97	1.98	116	Low
ESP-Nap-10K	1 time in 10-50 years	0	0.5	85	471,000	3,270	11.9	113	29.7	93.1	8.92	3.96	261	Moderate
ESP-Nap-40K	1 time in >50 years	0	26.5	85.5	2,880,000	10,300	15.9	202	59.4	115	21.8	7.93	422	Moderate
ESP-Diesel-2K	1 time in 10-50 years	66	0	46	47,300,000	161	2.97	8.92	7.93	15.9	0.99	0	36.7	Moderate
WTG-Hyd-90	1 time in <10 years	0	0	4	0	1,500	1.98	5.94	0	9.91	0.99	0	18.8	Low
WTG-Nap-370	1 time in <10 years	0	0	15.5	0	1,690	1.98	11.9	13.9	15.9	0.99	0	44.7	Low
WTG-Lub-220	1 time in <10 years	0	0	24.5	0	2,400	6.94	32.7	17.8	23.8	0.99	0	82.2	Low
5WTG-Mix1-3400	1 time in >50 years	0	0	45	0	1,280	8.92	92.1	51.5	83.2	5.94	1.98	244	Low
All-Mix2-129K	1 time in >50 years	98.5	77.5	65	1,300,000,000	17,500	20.8	214	51.5	121	22.8	5.94	436	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (0.01 g/m^2 threshold); [3] Probability of Shoreline Impact (1 g/m^2 threshold).

7.4.5 Modeling Results for Catastrophic Release of All Oils Using SRAR Impact Thresholds

This section provides a more detailed interpretation of the scenario of the catastrophic release of 128,600 gallons of all oils (All-Mix2-129K) spilled from an entire wind turbine in the RI-MA WEA using the SRAR thresholds for impacts is presented in Figures 7.10 through 7.14 and summarized in Table 7.10.

Table 7.10

Summary of Exposure Risk and Impact Risk analysis results for catastrophic release of all oils (All-Mix2-129K) in RI-MA WEA using SRAR thresholds.

Modeling Parameter	Result	Reference
Probability of exceedance above surface oil exposure risk threshold (0.1 g/m^2)	Greatest in immediate proximity of release with 1-10% probability further from release point; larger area of 25-50% probability of exceedance than with EcoRAR thresholds (Fig. 7.5)	Figure 7.10
Probability of exceedance above surface oil impact risk threshold (2,590 km^2 above 0.1g/m^2)	77.5% (155 out of 200 model simulations)	Tables 7.9 and 7.10
Minimum time (days) to exceed the exposure risk surface water threshold (0.1 g/m^2) for all simulations	< 2 days within approximately 300 km of spill site	Figure 7.11 (top)
Minimum time (days) to exceed the exposure risk surface water threshold (0.1 g/m^2) for *worst case* out of 200 simulations	< 2 days within approximately 100 km southwest of spill site	Figure 7.11 (bottom)
Probability of exceedance above shoreline exposure risk threshold (1 g/m^2)	Most shores with 0-10% and 25-50% within 50 km of spill site	Figure 7.12 (top)
Minimum time (days) to exceed the exposure risk shoreline threshold (1 g/m^2) for all simulations	< 2 days	Figure 7.12 (bottom)
Probability of exceedance above shoreline impact risk threshold (16 km above 1 g/m^2)	65% (130 out of 200 model simulations)	Tables 7.9 and 7.10
Maximum oil mass (g/m^2) on shorelines to exceed the exposure risk shoreline oiling threshold (1 g/m^2) for *worst case* out of 200 simulations	0 to > 1,000 g/m^2 with most oiling occurring north-east from the point of release	Figure 7.13
Water column volume affected by oil above the exposure threshold (1µg/L) at any instant in time	90% of simulations at < 1 km^3 *	Figure 7.14 (top)
Water surface area (km^2) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	95% of simulations at < 10,000 km^2; 75% of simulations at < 6,000 km^2	Figure 7.14 (middle)
Shoreline length (km) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	90% of simulations at < 70 km; ~70% at < 40 km; nearly 50% with negligible shoreline impacts	Figure 7.14 (bottom)

* Note that the output for water column volume with concentrations exceeding the SRAR threshold is the same as that for the EcoRAR threshold (Figure 7.9, top) because both scenarios use 1µg/L as the threshold for impacts.

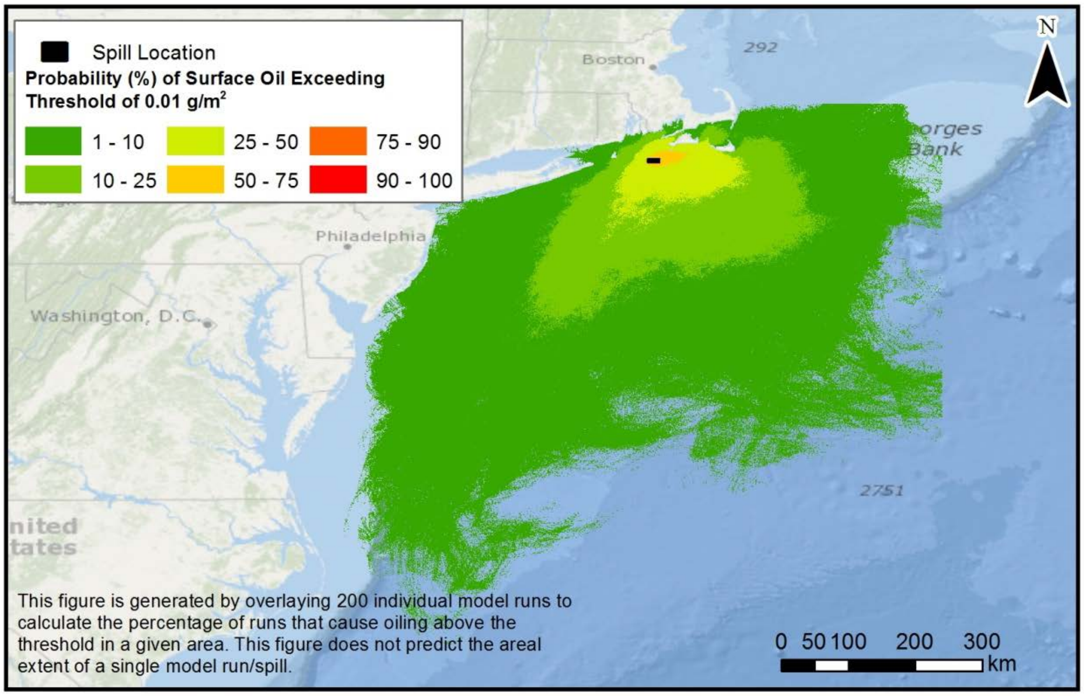


Figure 7.10 Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

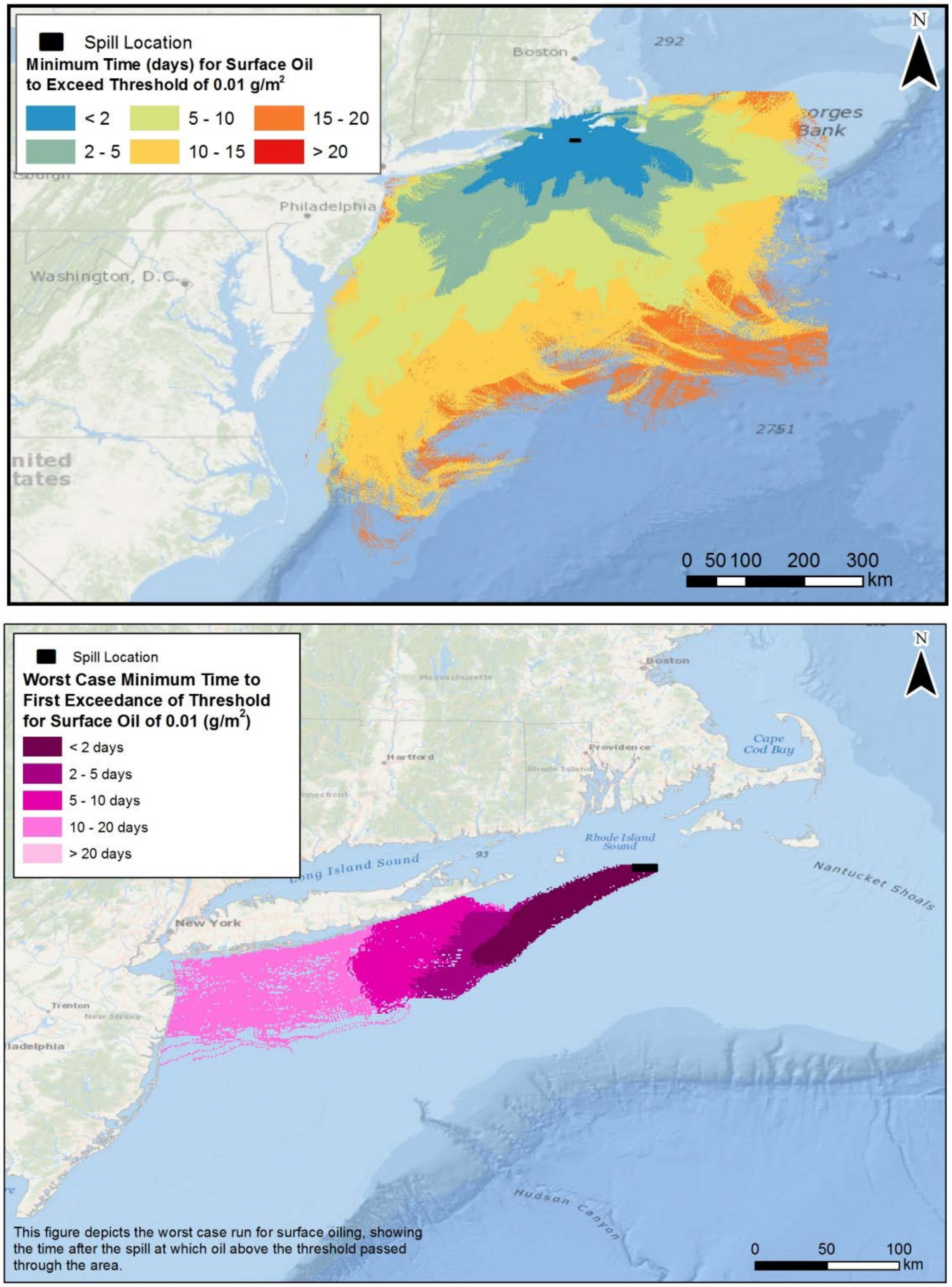


Figure 7.11 Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

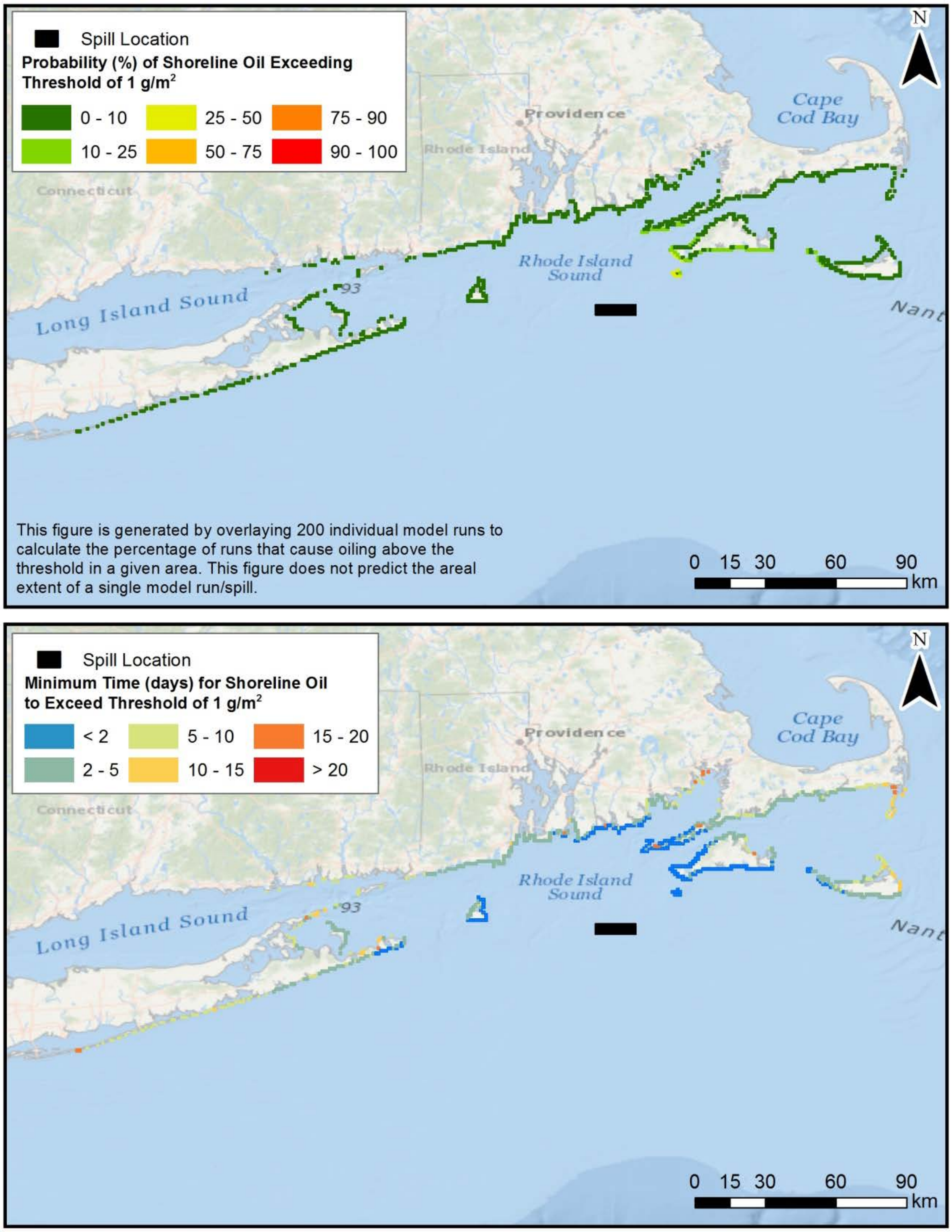


Figure 7.12 Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

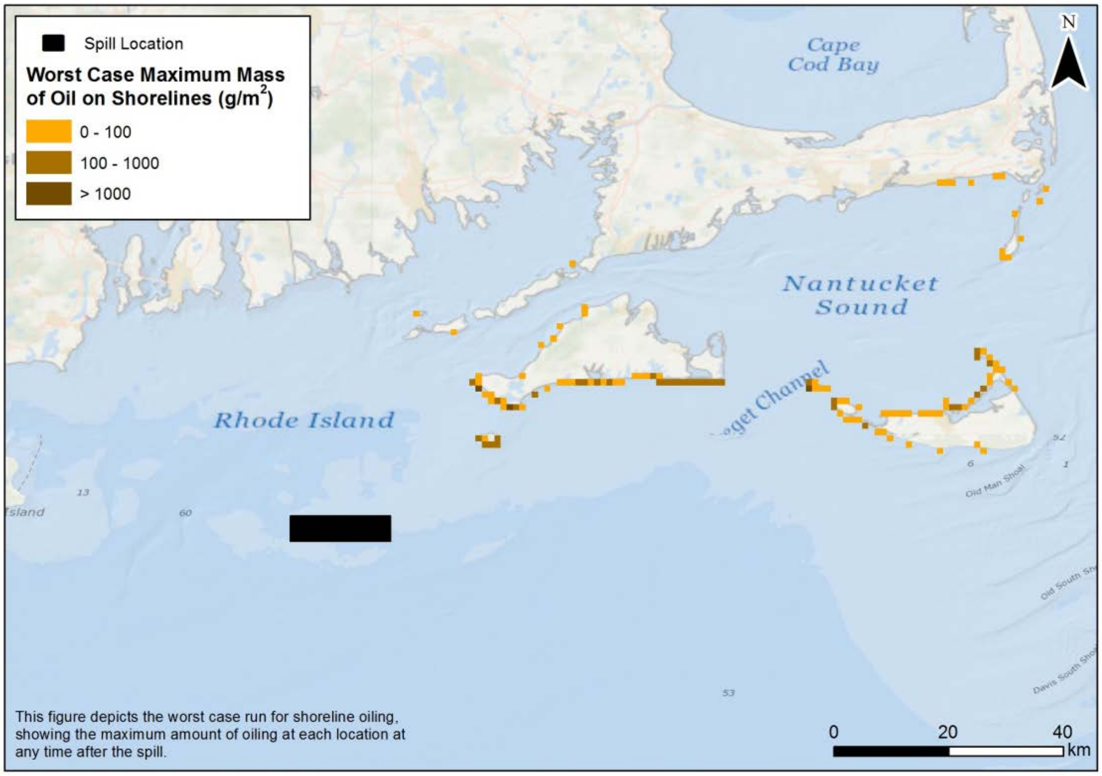


Figure 7.13 Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA. Map represents a single simulation.

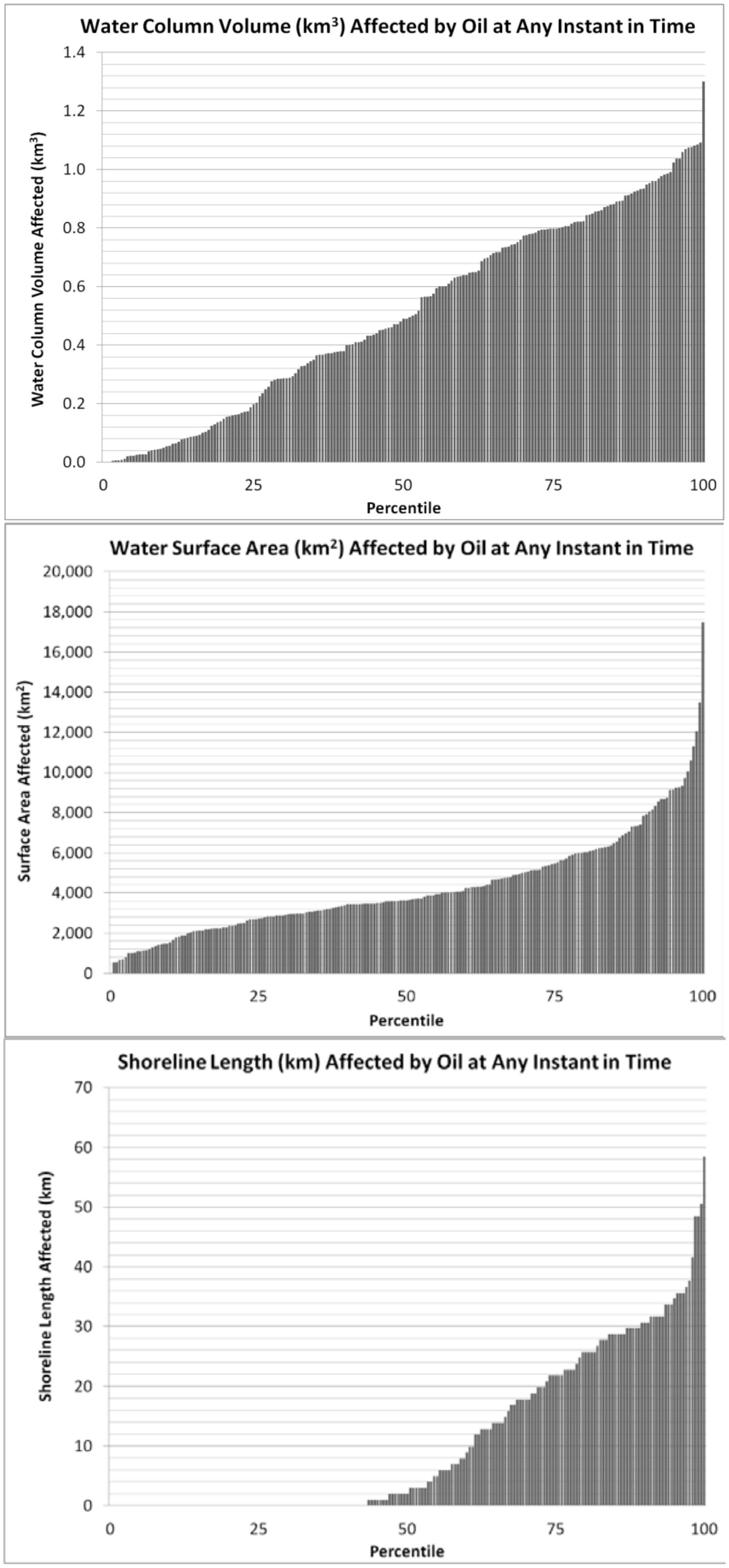


Figure 7.14 Summary of 200 model simulations of a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA showing the estimated water column volume (top), surface water area (middle), and shoreline length (bottom) impacted above the exposure risk SRAR thresholds.

7.5 Maryland Wind Energy Area Oil Spill Modeling Results

7.5.1 Ecological and Socioeconomic Resources at Risk

The Maryland Wind Energy Area (MD WEA) is located about 11 nautical miles off Ocean City along the MD border. It covers approximately 216 mi^2 (Figure 7.15).

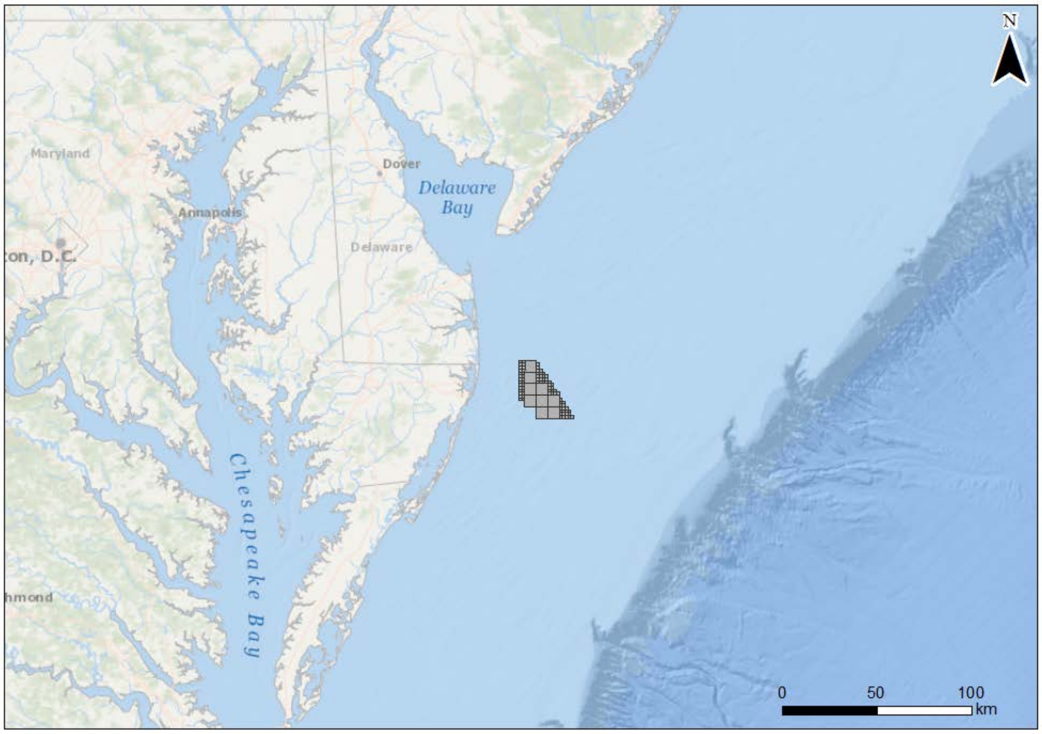


Figure 7.15 Location of the MD WEA.

Ecological resources at risk from a release of oil from MD WEA (Table 7.11) include numerous guilds of birds present in nearshore/offshore waters, particularly those sensitive to surface oiling while rafting or plunge diving to feed. In addition, this region is important to many shorebird and seabird species, which congregate in these areas during winter. This area is also important for commercially important fish and invertebrates.

Table 7.11
Ecological Resources at Risk from oil and chemical releases from the MD WEA. FT = Federal threatened; FE = Federal endangered; ST = State threatened; SE = State endangered.

Species Group	Species Subgroup and Geography	Seasonal Presence
Seabirds	• Seabird species groups using Mid-Atlantic US waters include: Boobies (~300K), alcids (tens of thousands), northern gannet,	Shearwaters off of NC/VA: late summer
Pelagic Birds, Waterfowl, and Diving Birds	• Mid-Atlantic inshore/offshore waters: 150K loons, 6K pelicans, 100s of thousands of cormorants and terns, millions of gulls • Mouth of Chesapeake: High concentrations of gannets and very high concentrations of red-breasted merganser Western Delmarva and Bay Islands: Supports significant American black duck populations	Terns, gulls in spring/summer; Loons, sea ducks in spring/fall Waterfowl, gannets and red-breasted mergansers in winter

Table 7.11 continued

<table>
<tr><th>Species Group</th><th>Species Subgroup and Geography</th><th>Seasonal Presence</th></tr>
<tr><td>Sea Ducks</td><td>Sea ducks (mean and max distance of flocks to shore, 2009-2010 data)
Surf scoter - 2 nm/8 nm/Black scoter – 2 nm/13 nm:
Chesapeake Bay: 19-58K surf scoter, 3-27K black scoter
Off MD/DE: 16-22K surf scoter, 3-61K black scoter
Long-tailed duck (2 nm/25 nm)
Chesapeake Bay: 17-31K
Off MD/DE: 2K
Bufflehead, mergansers, goldeneyes (< 1 nm/7-14 nm)
Chesapeake Bay: 14-35K
Off MD/DE: 3K
Mouths of DE Bay and Chesapeake Bay (especially) have high concentrations of species that are abundant over shoals (e.g., loons, pelicans, cormorants, sea ducks, gulls, terns, alcids); scoters are 10X more abundant than other species on shoals and large numbers concentrate off of VA/Chesapeake Bay</td><td>Sea ducks surveyed in winter (peak abundances). Migration from fall to spring (Oct-Apr)
Winter use of shoals (Dec-Mar); summer use of shoals likely farther north</td></tr>
<tr><td>Shorebirds and Colonial Nesting Birds</td><td>VA Barrier Island/Lagoon System: Most important bird area in VA and one of most along Atlantic coast of North America with piping plover (FT), Wilson's plover, American oystercatcher, gull-billed tern, least tern, black skimmer (many of these species are state listed or special concern in VA); Delaware beaches are also nesting habitat for these species; internationally significant stopover point for whimbrel, short-billed dowitcher, and red knot
Western Shore VA marshes: Extensive low marshes support significant populations of many marsh nesting species</td><td>Colonial and beach nesters peak Apr-Aug
Migration typically spring/fall, but varies by species and location and ranges from Feb.-June/Aug.-Dec.</td></tr>
<tr><td>Raptors and Passerines</td><td>Lower Delmarva (Cape Charles area of VA): 20-80 K raptors and over 10 million migrating passerines</td><td>Fall</td></tr>
<tr><td>Sea Turtles</td><td>Offshore hot spots not well known
Bays and sounds are foraging grounds for juvenile green (FT), loggerhead (FT), and Kemp's ridley (FE),
Leatherback juveniles (FE) are widely distributed and feed on jellyfish aggradations at the mouth of Chesapeake Bay</td><td>In water:
Year round with Apr-Dec peak</td></tr>
<tr><td>Marine Mammals</td><td>Baleen whales: North Atlantic right whale (FE), humpback whale (FE), fin whale (FE), sei whale (FE) and minke whale
Right whales are critically endangered (< 400 individuals left); Coastal waters are used as a migratory pathway and border the northern extent of calving grounds
Inshore cetaceans: Bottlenose dolphin, harbor porpoise use coastal waters out to the shelf break
Offshore cetaceans: Pilot whale, Risso's dolphin, striped dolphin, common dolphin, Atlantic spotted dolphin, spinner dolphin
Often associated with shelf edge features and convergence zones
Deep diving whales: Sperm whale (FE), pygmy sperm whale, beaked whales (5 species present) forage in deep waters along the shelf
Pinnipeds: Harbor seal can sometimes occur as far south as NC during the winter. Harp, hooded, and gray seals have also been observed but are rare</td><td>Baleen whales present fall-spring;
Juvenile humpbacks forage offshore during winter
Bottlenose dolphins present year round
Harbor seals present during the winter</td></tr>
</table>

Table 7.11 continued

Species Group	Species Subgroup and Geography	Seasonal Presence
Fish and Invertebrates	Coastal ocean waters support many valuable fisheries and/or species of concern in the region: • *Benthic or bottom associated*: Sea scallop, scup, black sea bass, butterfish, goosefish, scamp, horseshoe crab, tilefish • *Midwater*: Atlantic mackerel, Spanish mackerel, shortfin squid, bluefish, menhaden, spiny dogfish, smooth dogfish • *Pelagic*: Bluefin tuna, yellowfin tuna, wahoo, dolphinfish, bigeye tuna, swordfish • *Diadromous*: Alewife, blueback herring, American shad, hickory shad, Atlantic tomcod, American eel, Atlantic sturgeon (Fed. species of concern), shortnose sturgeon (FE), striped bass • *Estuarine dependent*: Southern flounder, spotted seatrout, blue crab, Atlantic croaker, spot, weakfish, shrimp Important concentration/conservation areas are: • Pelagic species can be more concentrated around the shelf break and at oceanographic fronts in the region	Estuarine dependent fish migrate offshore in the fall/winter to spawn; juveniles and adults use estuaries during the spring/summer Anadromous fish migrate inshore to spawn in fresh water in the spring American eel migrates offshore to spawn in the winter Bluefin tunas present fall-spring

In addition to natural resource impacts, spills from the MD WEA have the potential to cause social and economic impacts. Socio-economic resources potentially at risk from oiling are listed in Table 7.12. The potential economic impacts include disruption of coastal economic activities such as commercial and recreational fishing, boating, vacationing, commercial shipping, and other activities that may become claims following a spill. Specifically, recreational beaches are found in the area and highly utilized during summer. Shore fishing is also important particularly during spring and fall. Hotspots for chartered fishing vessels and recreational fishing party vessels are also common in the area, particularly off the mouth of Delaware Bay. Many areas along the entire potential spill zone are widely popular seaside resorts and support recreational activities such as boating, diving, sightseeing, sailing, fishing, and wildlife viewing.

Table 7.12

Socio-economic resources at risk from oil and chemical releases from the MD WEA.

Resource Type	Resource Name	Economic Activities
Tourist Beaches	Ocean City, MD Rehoboth Beach, DE Dewey Beach, DE Indian Beach, DE Bethany Beach, DE Middlesex Beach, DE Fenwick Island, DE Cape May, NJ Wildwood, NJ Avalon, NJ Atlantic City, NJ Ocean City, NJ	Potentially affected beach resorts and beachfront communities in New Jersey, Delaware, and Maryland provide recreational activities (e.g., swimming, boating, recreational fishing, wildlife viewing, nature study, sports, dining, camping, and amusement parks) with substantial income for local communities and state tax income. Many of these recreational activities are limited to or concentrated into the late spring into early fall months.
National Seashores	Assateague Island National Seashore, MD and VA	National seashores provide recreation for local and tourist populations as well as preserve and protect the nation's natural shoreline treasures. National seashores are coastal areas federally designated as being of natural and recreational significance as a preserved area.

Table 7.12 continued

Resource Type	Resource Name	Economic Activities
National Wildlife Refuges	Eastern Shore of Virginia NWR, VA Wallops Island NWR, VA Chincoteague NWR, VA Cape May NWR, NJ	These federally managed and protected lands provide refuges and conservation areas for sensitive species and habitats.
State Parks	Assateague State Park, MD Cape Henlopen State Park, DE Cape May Point State Park, NJ Corson's Inlet State Park, NJ	Coastal state parks are significant recreational resources for the public (e.g., swimming, boating, recreational fishing, wildlife viewing, nature study, sports, dining, camping, and amusement parks). Many of these recreational activities are limited to or concentrated in late spring to early fall months.
Commercial Fishing	A number of fishing fleets use potentially affected waters for commercial fishing, including	
	Atlantic City, NJ	Total Landings (2010): $17.3M
	Cape May-Wildwood, NJ	Total Landings (2010): $81M
	Chincoteague, VA	Total Landings (2010): $3.5M
	Ocean City, MD	Total Landings (2010): $8.8M

7.5.2 EcoRAR Impact Risk Analysis Results for All Scenarios

EcoRAR impact risk analyses were conducted for all oil spill scenarios in the MD WEA listed in Table 2.12, as summarized below.

- The *realistic* simulations of each scenario (Table 7.13) suggest that spill risks are generally high for small volume spills (WTG-Hyd-90, WTG-Nap-370, WTG-Lub-220), moderate for a small naphthenic oil spill (ESP-Nap-500) and the 3,400 gallon oil mixture (5WTG-Mix1-3400), and low for the highest volume spill (All-Mix2-129K).
- Two of the spill scenarios, a 2,000 gallon spill of diesel (ESP-Diesel-2K) and a 128,600 gallon spill of an oil mixture (All-Mix2-129K), had the greatest probability of water column impacts (52% and 100%, respectively); thus, contaminating more than 5.18 million m^3 of water using the 1 µg/L threshold and leading to moderate to high impacts to the water column. While the 40,000 gallon spill of naphthenic mineral oil (ESP-Nap-40K) had a moderate probability of shoreline threshold exceedances (49%), this spill would oil a relatively small segment of the overall shoreline.
- The overall risk, which combines the relative contribution of spill and impact risk probability and consequence (or degree of oiling), is low for the *realistic* simulations of most scenarios except the 128,600 gallon spill of an oil mixture (All-Mix2-129K).
- EcoRAR risk analyses for the *worst case* simulations (Table 7.14) are very similar to those of the *realistic* simulations (Table 7.13), except that there is a greater potential for oiling of water column volume and shoreline area. For example, while the *realistic* simulation of the 128,600 gallon scenario (All-Mix2-129K) could impact over 600 million m^3 of the water column, the extent of oiling for the *worst case* simulation would be nearly twice that volume. Similarly, the results for the *realistic* simulation of that same scenario show potential impact of 9.5 km of shorelines, while the *worst case* simulation results in an extent of oiling of 55 km (primarily sand beaches). In general, the overall risk is generally low for most of the *worst case* simulations of the scenarios (Table 7.14) except the 128,600 gallon spill of an oil mixture (All-Mix2-129K).

Table 7.13

Risk Scoring for EcoRAR based on *realistic* model outputs for several spill scenarios in the MD WEA. *Realistic* refers to the average degree of oiling across all model runs with oiling results. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Total	
ESP-Nap-500	1 time in 10-50 years	0	0	0	0	11.2	0	0	0	0	0	0	0	Low
ESP-Nap-1K	1 time in >50 years	0	0	0	0	21.8	0	0	0	0	0	0	0	Low
ESP-Nap-10K	1 time in >50 years	0	0	24	2,400	192	0	2.06	0.11	0.42	0.08	0	2.67	Low
ESP-Nap-40K	1 time in >50 years	0	0	48.5	34,400	489	0	5.10	0.30	0.62	0.22	0	6.24	Low
ESP-Diesel-2K	1 time in >50 years	51.5	0	0	9,010,000	8.87	0	0	0	0	0	0	0	Low
WTG-Hyd-90	1 time in <10 years	0	0	0	0	2.58	0	0	0	0	0	0	0	Low
WTG-Nap-370	1 time in <10 years	0	0	0	0	9.57	0	0	0	0	0	0	0	Low
WTG-Lub-220	1 time in <10 years	0	0	0	0	20.1	0	0	0	0	0	0	0	Low
5WTG-Mix1-3400	1 time in 10-50 years	0	0	2.5	0	217	0	1.43	0	0	0	0	1.43	Low
All-Mix2-129K	1 time in >50 years	99.5	0	29.5	634,000,000	318	0	8.22	0.04	0.41	0.62	0.18	9.47	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (10 g/m^2 threshold); [3] Probability of Shoreline Impact (100 g/m^2 threshold).

Table 7.14

Risk Scoring for EcoRAR based on *worst case* model outputs for several spill scenarios in the MD WEA. *Worst case* refers to the maximum degree of oiling. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	0	0	0	47.1	0	0	0	0	0	0	0	Low
ESP-Nap-1K	1 time in >50 years	0	0	0	0	95.0	0	0	0	0	0	0	0	Low
ESP-Nap-10K	1 time in >50 years	0	0	24	202,000	602	0	4.75	2.38	11.9	3.56	0	22.6	Low
ESP-Nap-40K	1 time in >50 years	0	0	48.5	1,570,000	1,710	0	15.4	7.13	16.6	3.56	0	42.7	Low
ESP-Diesel-2K	1 time in >50 years	51.5	0	0	48,600,000	35.9	0	0	0	0	0	0	0	Low
WTG-Hyd-90	1 time in <10 years	0	0	0	0	21.2	0	0	0	0	0	0	0	Low
WTG-Nap-370	1 time in <10 years	0	0	0	0	51.7	0	0	0	0	0	0	0	Low
WTG-Lub-220	1 time in <10 years	0	0	0	0	104	0	0	0	0	0	0	0	Low
5WTG-Mix1-3400	1 time in 10-50 years	0	0	2.5	0	867	0	2.38	0	0	0	0	2.38	Low
All-Mix2-129K	1 time in >50 years	99.5	0	29.5	1,220,000,000	2,330	0	28.5	2.38	9.51	7.13	7.13	54.7	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (10 g/m^2 threshold); [3] Probability of Shoreline Impact (100 g/m^2 threshold).

7.5.3 Modeling Results for Catastrophic Release of All Oils Using EcoRAR Impact Thresholds

This section provides a more detailed interpretation of the scenario of the catastrophic release of 128,600 gallons of all oils (All-Mix2-129K) spilled from an entire wind turbine in the MD WEA using the EcoRAR thresholds of impacts, as presented in Figures 7.16 through 7.20 and summarized in Table 7.15.

Table 7.15
Summary of Exposure Risk and Impact Risk analysis results for catastrophic release of all oils (All-Mix2-129K) in MD WEA using EcoRAR thresholds.

Modeling Parameter	Result	Reference
Probability of exceedance above surface oil exposure risk threshold (10 g/m^2)	Greatest in immediate proximity of release with 1-10% probability further from release point	Figure 7.16
Probability of exceedance above surface oil impact risk threshold (2,590 km^2 above 10 g/m^2)	0%	Tables 7.14 and 7.15
Minimum time (days) to exceed the exposure risk surface water threshold (10 g/m^2) for all simulations	< 2 days within approximately 200 km of spill site	Figure 7.17 (top)
Minimum time (days) to exceed the exposure risk surface water threshold (10 g/m^2) for *worst case* out of 200 simulations	< 2 days within approximately 75 km southeast of spill site, 2-5 days within approximately 150 km southwest of spill site	Figure 7.17 (bottom)
Probability of exceedance above shoreline exposure risk threshold (100 g/m^2)	0-10% within approximately 100 km of spill site	Figure 7.18 (top)
Minimum time (days) to exceed the exposure risk shoreline threshold (100 g/m^2) for all simulations	< 2 days within 60 km of spill site	Figure 7.18 (bottom)
Probability of exceedance above shoreline impact risk threshold (16 km above 100 g/m^2)	29.5% (59 out of 200 model simulations)	Tables 7.14 and 7.15
Maximum oil mass (g/m^2) on shorelines to exceed the exposure risk shoreline oiling threshold (100 g/m^2) for *worst case* out of 200 simulations	100 g/m^2 to 1,000 g/m^2 with most oiling within 80 km southwest of spill site	Figure 7.19
Water column volume affected by oil above the exposure threshold (1µg/L) at any instant in time	90% of simulations at < 1 km^3, 75% at < 0.8 km^3	Figure 7.20 (top)
Water surface area (km^2) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	90% of simulations at < 1,000 km^2; 75% of simulations at < 400 km^2	Figure 7.20 (middle)
Shoreline length (km) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	90% of simulations at < 20 km; ~70% at < 1km; over 50% with negligible shoreline impacts	Figure 7.20 (bottom)

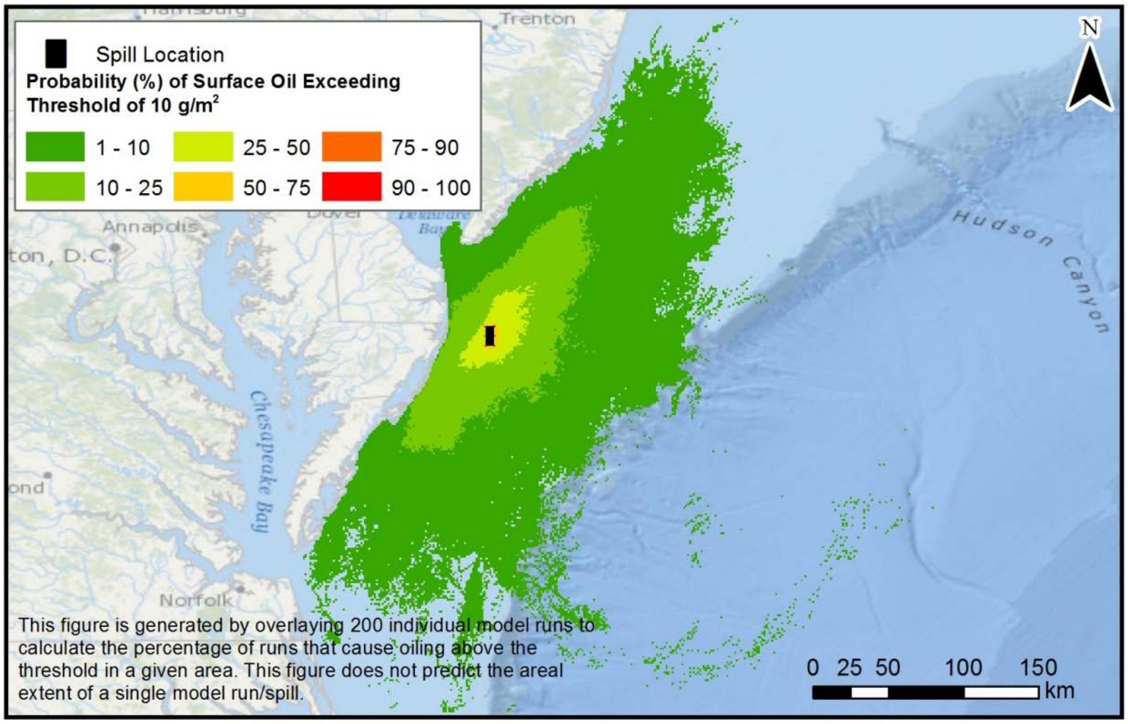


Figure 7.16 Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

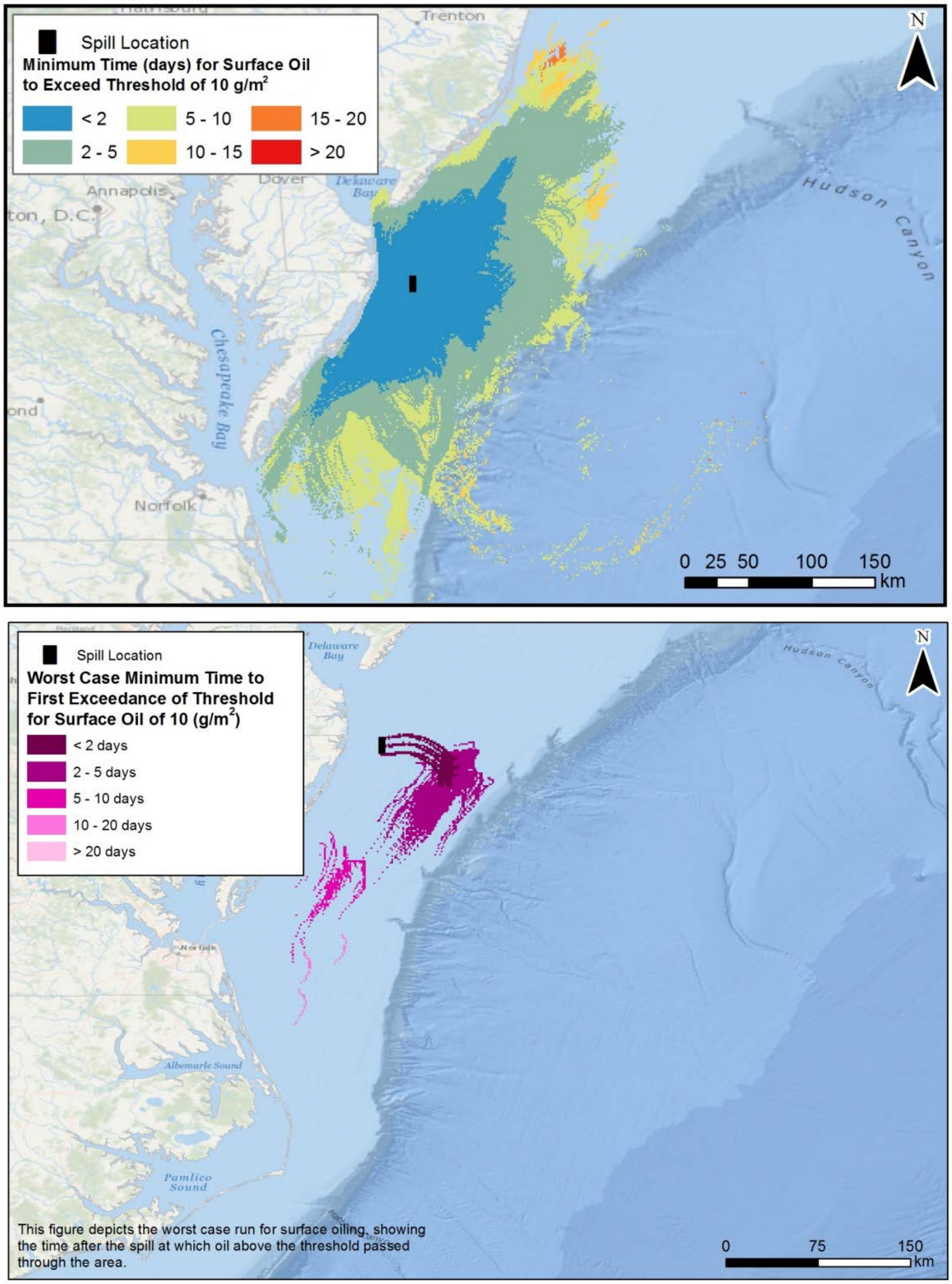


Figure 7.17 Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

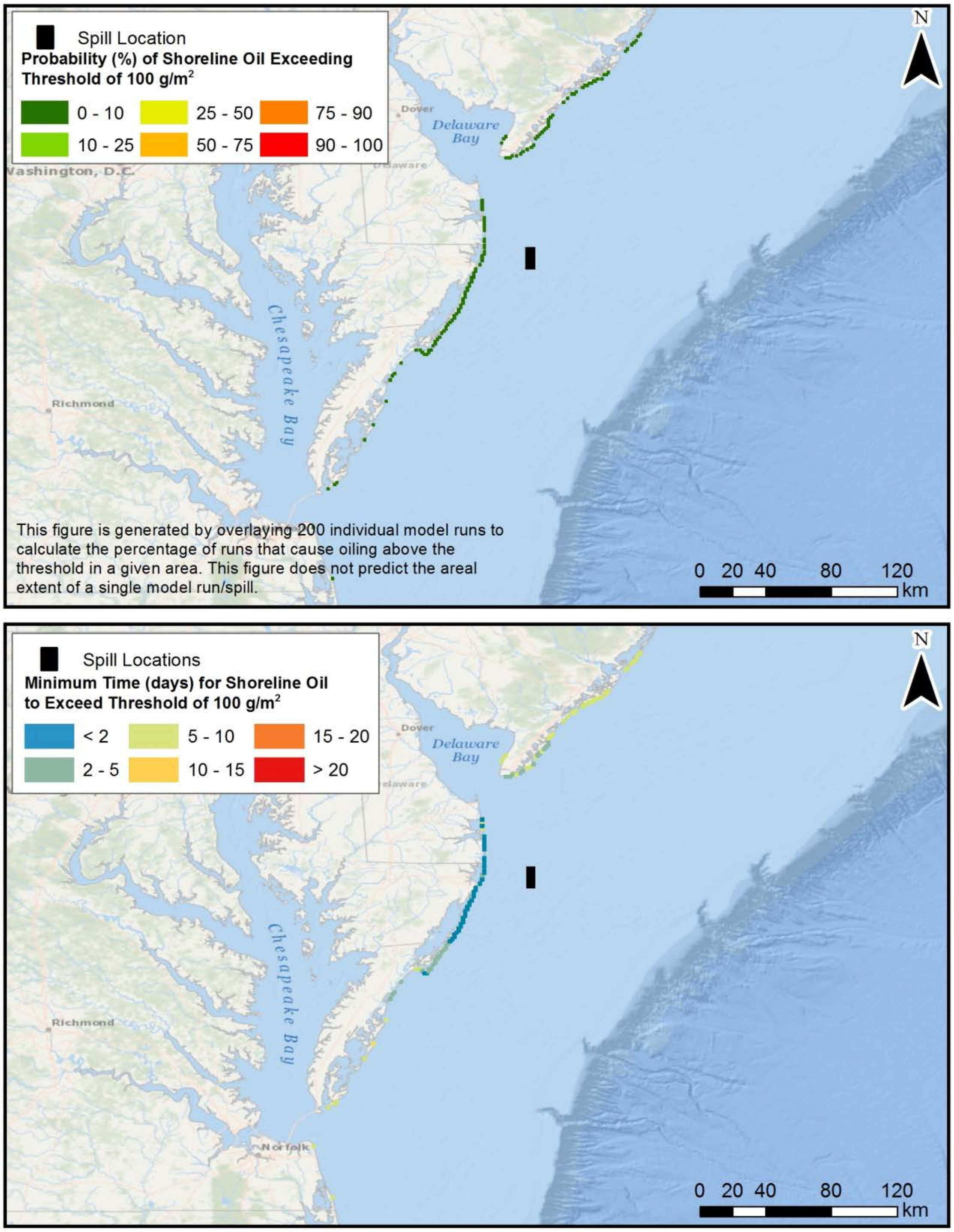


Figure 7.18 Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

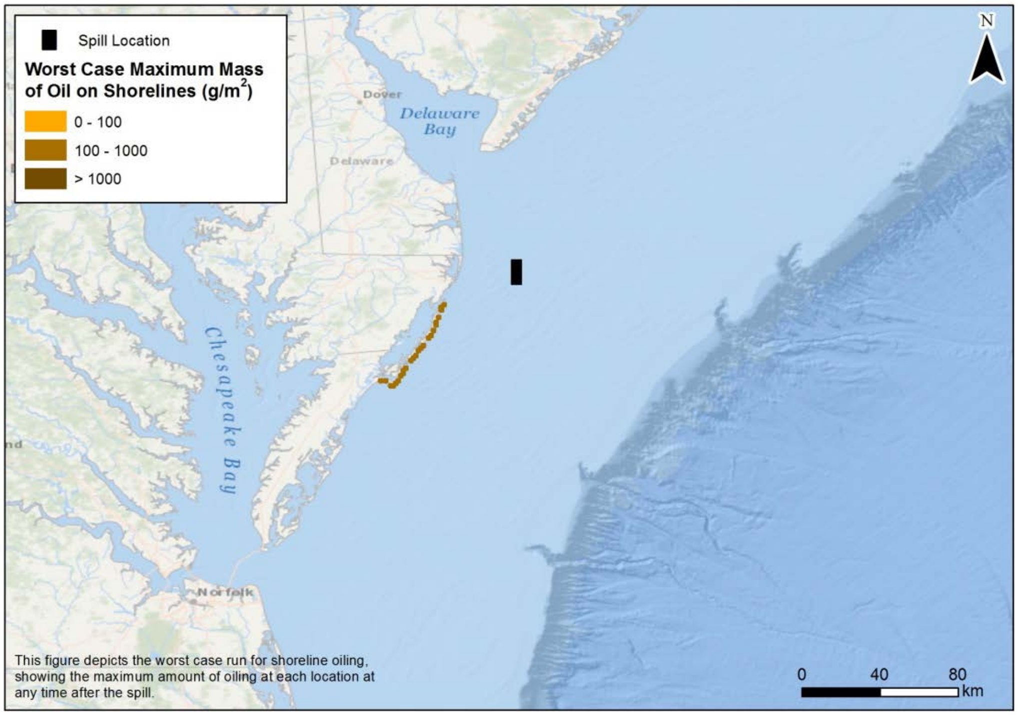


Figure 7.19 Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA. Map represents a single simulation.

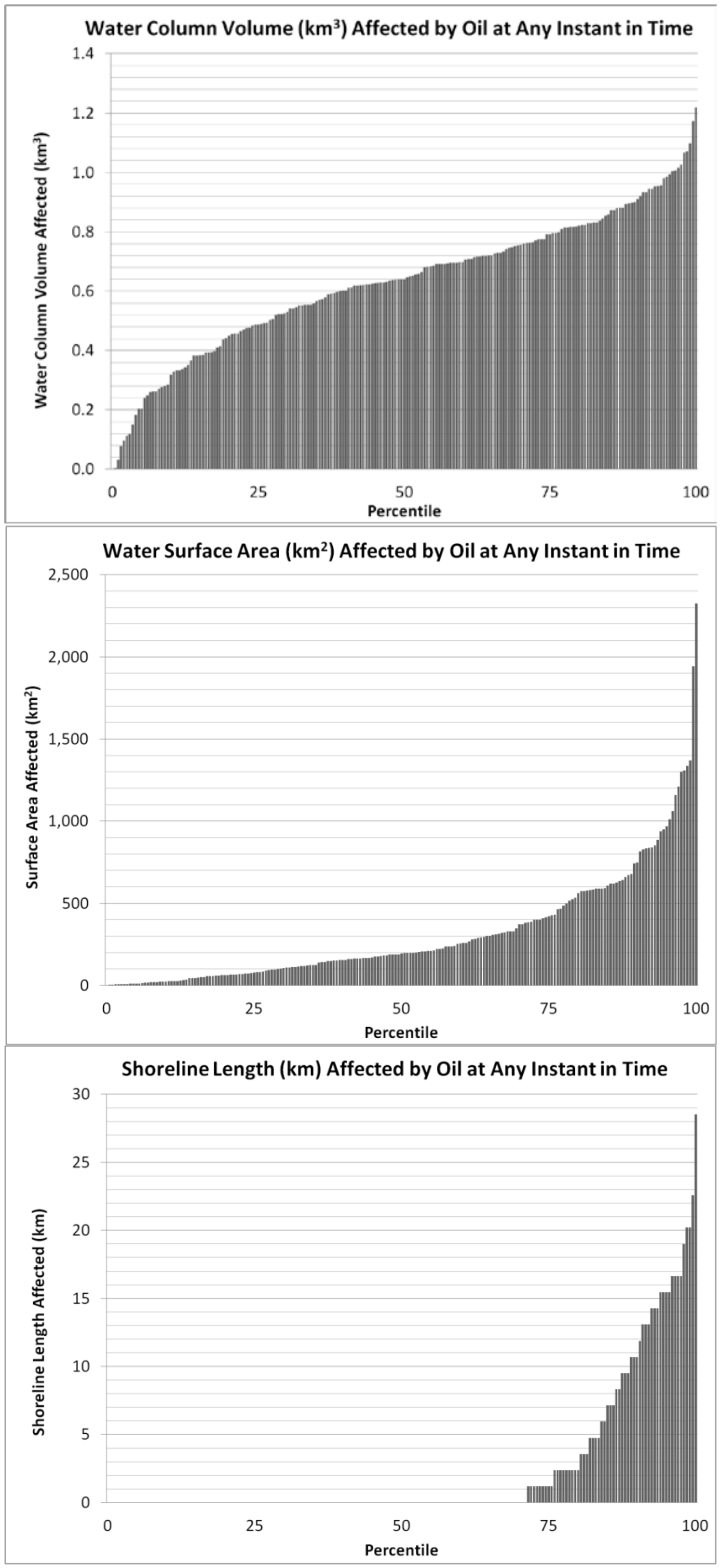


Figure 7.20 Summary of 200 model simulations of a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA showing the estimated water column volume (top), surface water area (middle), and shoreline length (bottom) impacted above exposure risk EcoRAR thresholds.

7.5.4 SRAR Impact Risk Analysis Results for All Scenarios

SRAR impact risk analyses were conducted for all oil spill scenarios in the MD WEA listed in Table 2.12, as summarized below.

- The *realistic* simulations of the modeling scenarios (Table 7.16) are similar to those of the EcoRAR (Table 7.13), except that there are more scenarios in which there is a moderate level of probability of exceeding shoreline impact risk thresholds for the SRAR. Consequently, the shoreline length impacted above thresholds would be greater than those of the EcoRAR scenarios.
- The overall risk of impacts would be low for the *realistic* simulations of most scenarios, except the 40,000 gallon spill of naphthenic mineral (ESP-Nap-40K) and the 128,600 gallon spill of an oil mixture (All-Mix2-129K).
- SRAR risk analyses for the *worst case* simulations (Table 7.17) are very similar to those for the *realistic* simulations (Table 7.16), except that there is a potential for oiling of a greater water column volume and shoreline area. For example, while the *realistic* simulation of the 128,600 gallon oil mixture scenario (All-Mix2-129K) could impact over 600 million m^3 of the water column, the *worst case* simulation for that scenario could result in an extent of oiling nearly twice that volume. Similarly, results for the *realistic* simulation of that same scenario show potential impact of 54.5 km of shoreline (primarily sand beaches), while the *worst case* simulation results in an extent of oiling of 242 km (primarily rocky shores followed by sand beaches).
- For the *worst case* simulations (Table 7.17), the overall risk is generally low for most scenarios, except for two of the smaller spills (WTG-Nap-370, WTG-Lub-220), the 10,000 and 40,000 gallon spill of naphthenic mineral oil (ESP-Nap-10K and ESP-Nap-40K, respectively), and the two highest volume spills (5WTG-Mix1-3400 and All-Mix2-129K).

Table 7.16
Risk Scoring for SRAR based on *realistic* model outputs for several spill scenarios in the MD WEA. *Realistic* refers to the average degree of oiling across all model runs with oiling results. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	1	28	0	717	1.92	6.51	0	0.13	0.21	0	8.77	Low
ESP-Nap-1K	1 time in >50 years	0	0.5	38	0	800	2.32	12.1	0.09	0.28	0.77	0	15.6	Low
ESP-Nap-10K	1 time in >50 years	0	7	57.5	2,400	1,330	3.39	50.8	0.35	1.18	0.35	0.36	56.4	Low
ESP-Nap-40K	1 time in >50 years	0	53.5	59.5	34,400	2,670	3.47	77.2	0.52	1.20	0.56	1.06	84.0	Moderate
ESP-Diesel-2K	1 time in >50 years	51.5	0	14	9,010,000	45.7	1.25	3.39	0	0	0	0	4.64	Low
WTG-Hyd-90	1 time in <10 years	0	1.5	1.5	0	849	1.19	1.19	0	0	0	0	2.38	Low
WTG-Nap-370	1 time in <10 years	0	1	10	0	902	2.38	4.94	0.24	0.06	0	0	7.62	Low
WTG-Lub-220	1 time in <10 years	0	0.5	19	0	558	1.60	2.85	0	0	0	0	4.45	Low
5WTG-Mix1-3400	1 time in 10-50 years	0	0	35	238	497	1.92	45.7	0.37	0.75	0.26	0.19	49.2	Low
All-Mix2-129K	1 time in >50 years	99.5	79	41.5	634,000,000	4,190	2.86	48.0	0.29	1.89	0.42	1.00	54.5	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (0.01 g/m^2 threshold); [3] Probability of Shoreline Impact (1 g/m^2 threshold).

Table 7.17

Risk Scoring for SRAR based on *worst case* model outputs for several spill scenarios in the MD WEA. *Worst case* refers to the maximum degree of oiling. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	1	28	0	5,510	8.32	11.9	35.6	0	0	0	55.8	Low
ESP-Nap-1K	1 time in >50 years	0	0.5	38	0	5,570	11.9	14.3	42.8	1.19	2.38	0	72.6	Low
ESP-Nap-10K	1 time in >50 years	0	7	57.5	202,000	4,360	19.0	42.8	128	3.57	7.13	3.57	204	Moderate
ESP-Nap-40K	1 time in >50 years	0	53.5	59.5	1,570,000	8,290	21.4	103	310	3.57	7.13	7.13	452	Moderate
ESP-Diesel-2K	1 time in >50 years	51.5	0	14	48,600,000	572	4.75	2.38	7.13	0	0	0	14.3	Low
WTG-Hyd-90	1 time in <10 years	0	1.5	1.5	0	4,410	2.38	1.19	3.56	0	0	0	7.13	Low
WTG-Nap-370	1 time in <10 years	0	1	10	0	5,850	11.9	17.8	53.5	3.57	7.13	0	93.9	Moderate
WTG-Lub-220	1 time in <10 years	0	0.5	19	0	2,700	8.32	7.13	21.4	0	0	0	36.9	Moderate
5WTG-Mix1-3400	1 time in 10-50 years	0	0	35	0	1,500	11.9	48.7	146	3.57	0	2.38	213	Moderate
All-Mix2-129K	1 time in >50 years	99.5	79	41.5	1,220,000,000	11,000	11.9	53.5	160	3.57	7.13	5.94	242	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (0.01 g/m^2 threshold); [3] Probability of Shoreline Impact (1 g/m^2 threshold).

7.5.5 Modeling Results for Catastrophic Release of All Oils Using SRAR Impact Thresholds

This section provides a more detailed interpretation of the scenario of the catastrophic release of 128,600 gallons of all oils (All-Mix2-129K) spilled from an entire wind turbine facility in the MD WEA using the SRAR thresholds for impacts, as presented in Figures 7.21 through 7.25 and summarized in Table 7.18.

Table 7.18

Summary of Exposure Risk and Impact Risk analysis results for catastrophic release of all oils (All-Mix2-129K) in MD WEA using SRAR thresholds.

Modeling Parameter	Result	Reference
Probability of exceedance above surface oil exposure risk threshold (0.1 g/m^2)	Greatest in immediate proximity of release with 1-10% probability further from release point; larger area of 25-50% probability of exceedance than with EcoRAR thresholds (Fig. 7.15)	Figure 7.21
Probability of exceedance above surface oil impact risk threshold (2,590 km^2 above 0.1 g/m^2)	79% (158 out of 200 model simulations)	Tables 7.17 and 7.18
Minimum time (days) to exceed the exposure risk surface water threshold (0.1 g/m^2) for all simulations	< 2 days within approximately 300km of spill site	Figure 7.22 (top)
Minimum time (days) to exceed the exposure risk surface water threshold (0.1 g/m^2) for *worst case* out of 200 simulations	< 2 days within approximately 100km southeast of spill site	Figure 7.22 (bottom)
Probability of exceedance above shoreline exposure risk threshold (1 g/m^2)	0-10% within 300 km of spill site	Figure 7.23 (top)
Minimum time (days) to exceed the exposure risk shoreline threshold (1 g/m^2) for all simulations	< 2 days	Figure 7.23 (bottom)
Probability of exceedance above shoreline impact risk threshold (16 km above 1 g/m^2)	41.5% (83 out of 200 model simulations)	Tables 7.17 and 7.18
Maximum oil mass (g/m^2) on shorelines to exceed the exposure risk shoreline oiling threshold (1 g/m^2) for *worst case* out of 200 simulations	0 g/m^2 to 1,000 g/m^2 with most oiling southwest of spill site	Figure 7.24
Water column volume affected by oil above the exposure threshold (1µg/L) at any instant in time	90% of simulations at < 1 km^3 *, 75% at 0.8 km^3	Figure 7.25 (top)
Water surface area (km^2) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	95% of simulations at < 9,000 km^2; 75% of simulations at < 5,000 km^2	Figure 7.25 (middle)
Shoreline length (km) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	90% of simulations at < 50 km; ~70% at < 10 km; over 50% with negligible shoreline impacts	Figure 7.25 (bottom)

* Note that the output for water column volume with concentrations exceeding the SRAR threshold is the same as that for the EcoRAR threshold (Figure 7.20, top) because both scenarios use 1µg/L as the threshold for impacts.

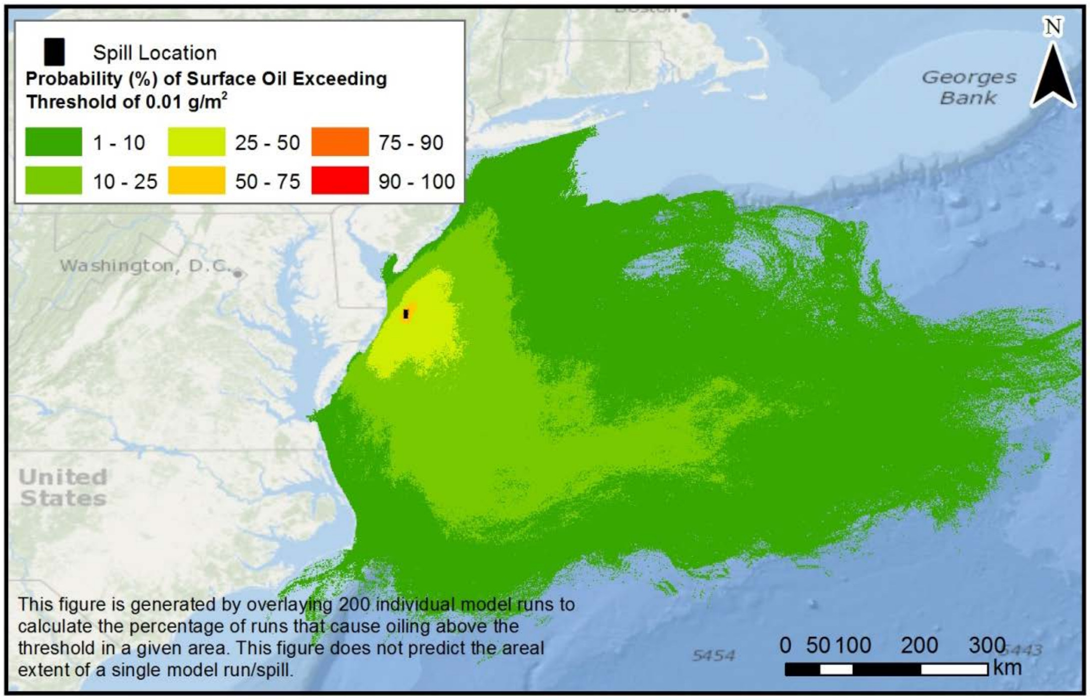
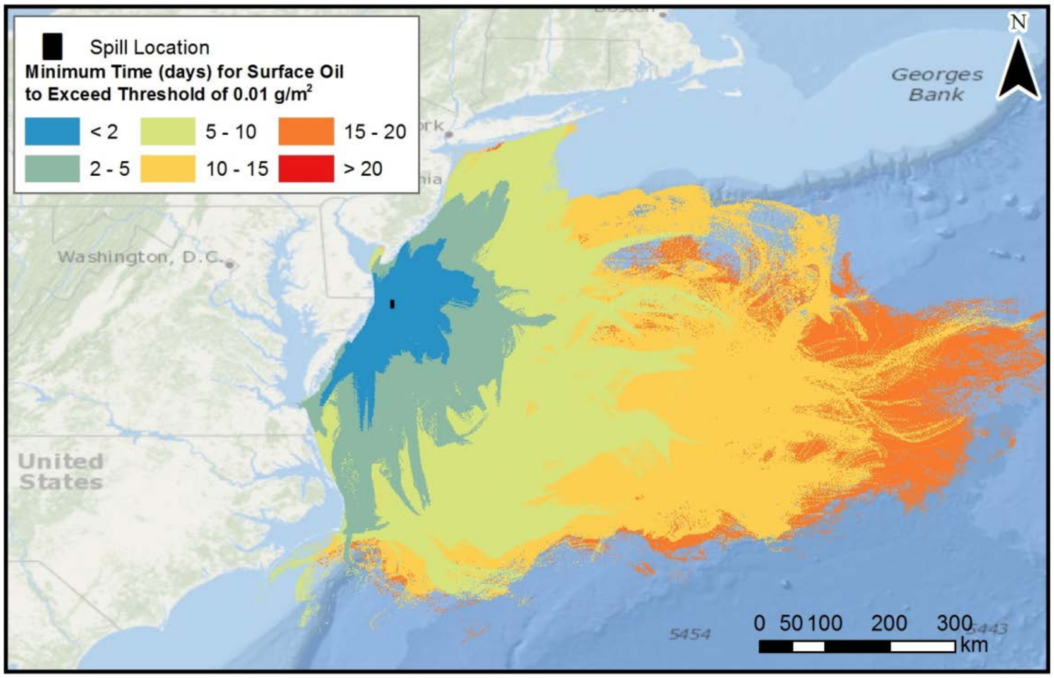


Figure 7.21 Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



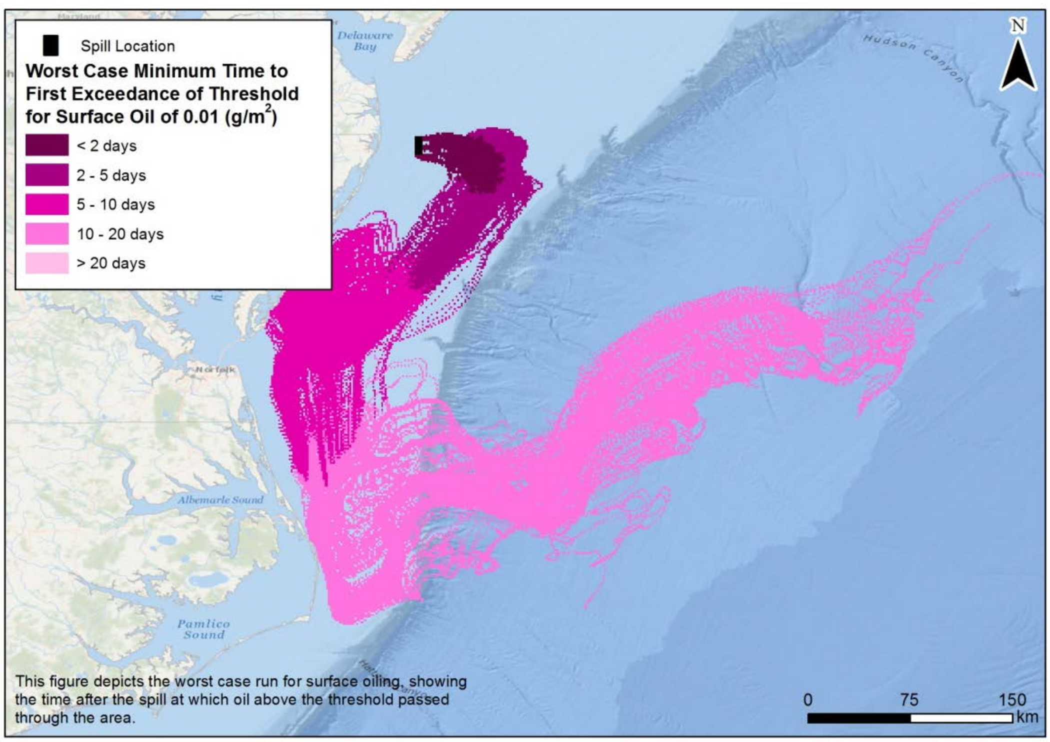


Figure 7.22 Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

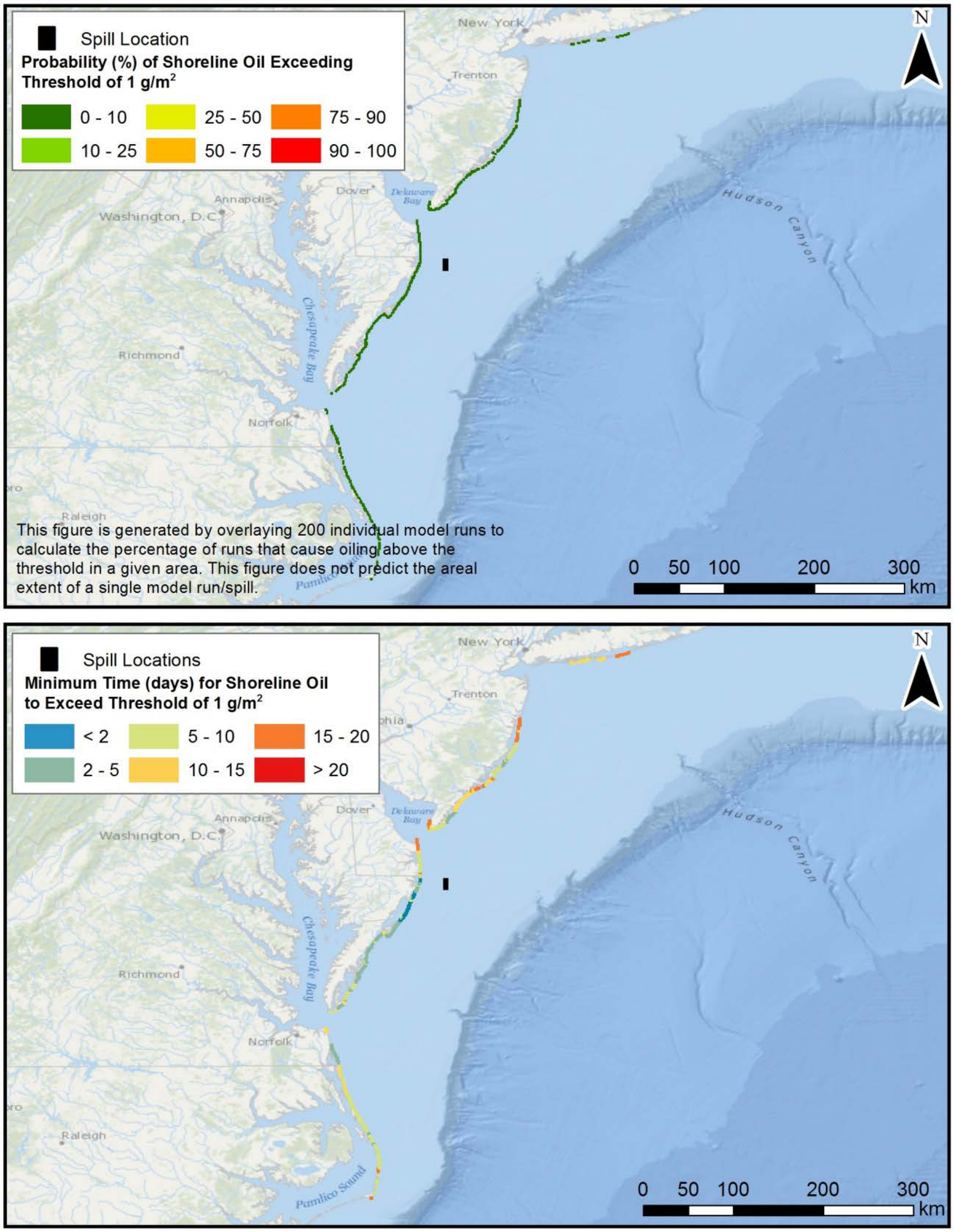


Figure 7.23 Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

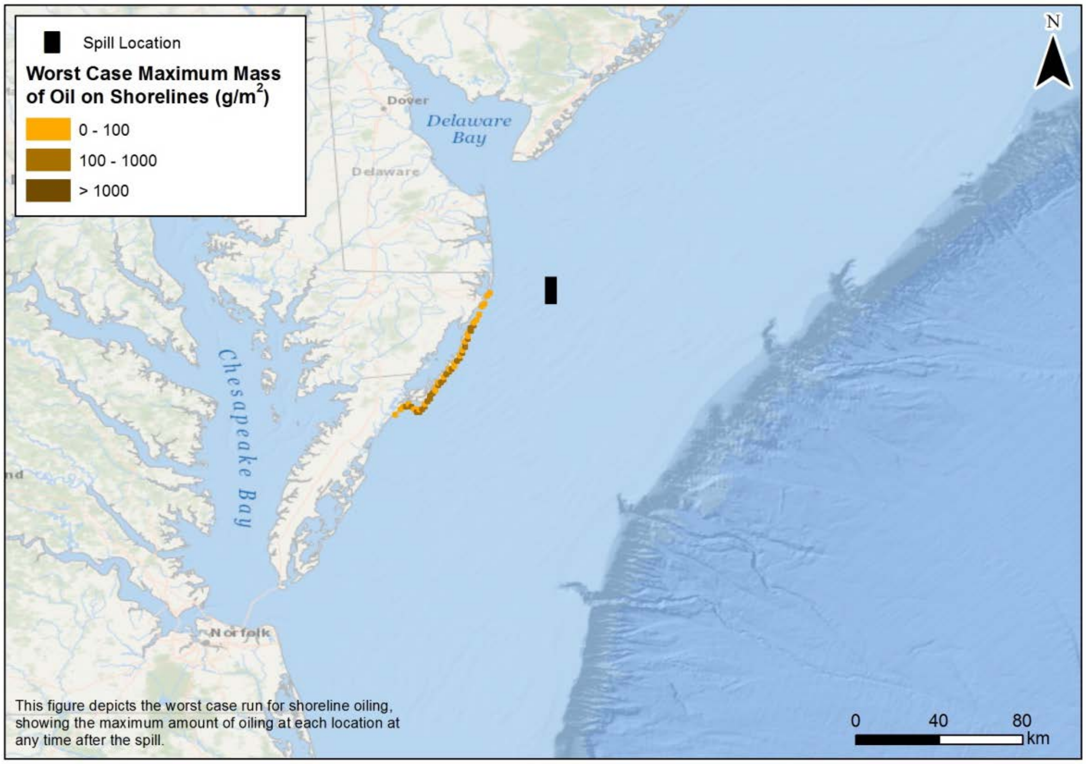


Figure 7.24 Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the MD WEA. Map represents a single simulation.

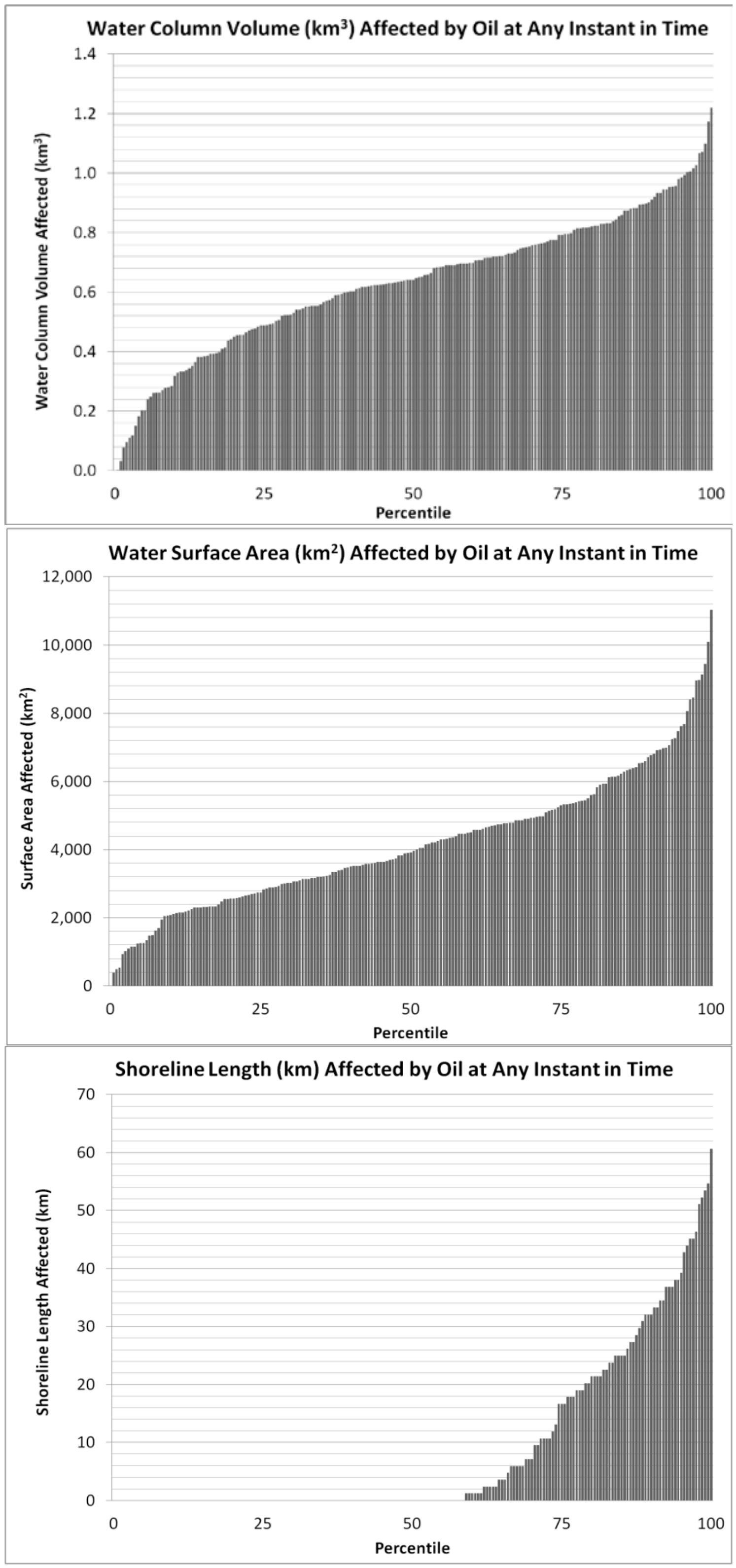


Figure 7.25 Summary of 200 model simulations of a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the RI-MA WEA showing the estimated water column volume (top), surface water area (middle), and shoreline length (bottom) impacted above the exposure risk SRAR thresholds.

7.6 NORTH CAROLINA CALL AREA OIL SPILL MODELING RESULTS

7.6.1 Ecological and Socioeconomic Resources at Risk

The North Carolina Call Area (NC Call Area), off Albemarle Sound, is located about 6 nautical miles off the North Carolina coastline (Figure 7.26).

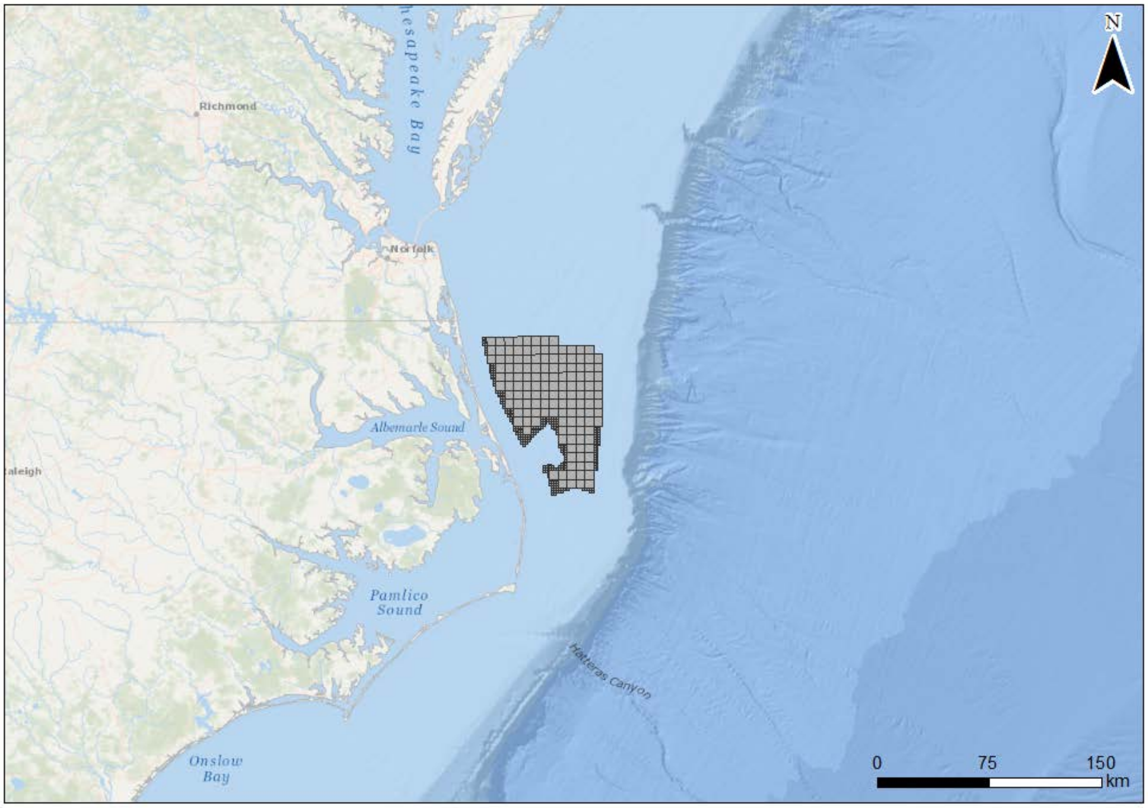


Figure 7.26 Location of the NC Call Area.

Ecological resources at risk from a release of oil from NC Call Area (Table 7.19) include numerous guilds of birds present in nearshore/offshore waters, particularly those sensitive to surface oiling while rafting or plunge diving to feed. Large numbers of birds winter in both coastal and offshore waters and significant stretches of barrier island support nesting seabirds. Oceanic waters in the region are extremely productive given the confluence of the Gulf Stream and colder northern waters north of Cape Hatteras. Temperature fronts and eddies provide important foraging habitat for numerous species of seabirds, marine mammals, and fish.

Table 7.19
Ecological resources at risk from releases of oil and chemicals from the NC Call Area. FT = Federal threatened; FE = Federal endangered; ST = State threatened; SE = State endangered.

Species Group	Species Subgroup and Geography	Seasonal Presence
Pelagic seabirds	Outer Continental Shelf (OCS) offshore of Cape Hatteras has the greatest diversity of seabirds and highest density of tropical seabirds in SE United States, including shearwaters, storm-petrels, Bermuda petrels, and tropicbirds • Mid-Atlantic inshore/offshore waters: 150K loons, 6K pelicans, 100s of thousands of cormorants and terns, millions of gulls *Spring/Summer* • Seabird species groups using Mid-Atlantic US waters include boobies (~300K) and alcids (tens of thousands) • Significant percentage of the global population of black-capped petrels (FE) may be present around *Sargassum* mats off Cape Hatteras • Audubon's shearwaters (50-75% of population) concentrate along the continental shelf break off NC (~3,800 pairs) • Outer Banks/inshore waters NC-VA are foraging area for gulls and terns	OCS assemblages change seasonally Petrels more common summer to early fall; black-capped petrels can be found year round in the Gulf Stream Shearwaters off of NC-VA in late summer Terns more common spring/summer
	Migratory • Nearshore waters are a key migration corridor for loons and sea ducks • Hatteras National Seashore is a critical migratory area for red knot	Red knot present Jul and Apr
	Wintering Bufflehead, mergansers, goldeneyes (12K) use waters from 0-14 nm offshore • Surf scoter (up to tens of thousands) and black scoter (thousands) use waters > 2nm from shore in NC waters • Shoals are aggregation areas for loons, pelicans, cormorants, sea ducks, gulls, terns, alcids; scoters are 10X more abundant than other species on shoals and large numbers concentrate off VA/Chesapeake Bay • Wintering skuas, northern gannets, razorbills, red-breasted merganser and red phalaropes are common in offshore waters near Cape Hatteras	Sea ducks, loons present in winter; migrate in fall and spring (Oct-Apr) Winter use of shoals (Dec-Mar); summer use of shoals likely farther north Gannets and red-breasted merganser wintering
Shorebirds and Colonial Nesting Birds	• Outer Banks and Cape Hatteras: globally important for coastal birds with 365+ species • Least terns (FT; 464 nests) nesting on NC beaches of Hatteras National Seashore and north to Manteo • Piping plover wintering critical habitat at Oregon Inlet and Cape Hatteras • Willet, American oystercatcher, black skimmer, least tern, common tern nest along the NC-VA shoreline	Colonial and beach nesters peak Apr-Aug Winter migration stop for plovers

Table 7.19 continued

<table>
<tr><th>Species Group</th><th>Species Subgroup and Geography</th><th>Seasonal Presence</th></tr>
<tr><td>Sea Turtles</td><td>Nesting mostly occurs in NC (annual counts along shorelines with most probable impacts).
• 650+ Loggerhead (FT)
• < 20 Green (FT)
• < 10 Leatherback (FE)
Distribution:
• Offshore hot spots not well known
• Newly hatched loggerheads can be found in the Gulf Stream
• Young associate with Sargassum mats off of Cape Hatteras
• Bays and sounds are foraging grounds for juvenile green, loggerhead, and Kemp's ridley (FE)</td><td>Nesting season:
Adults: May-Sept
Hatching: May-Dec
In water:
Year round with Apr-Dec peak</td></tr>
<tr><td>Marine Mammals</td><td>Baleen whales: Primarily North Atlantic right whale (FE) and fin whale (FE) with occasional humpback (FE), sei (FE), and minke whales
• Right whales are critically endangered (< 400 individuals left); coastal waters are used as a migratory pathway and border the northern extent of calving grounds
• Juvenile humpbacks forage offshore during the winter
Inshore cetaceans: Bottlenose dolphin and harbor porpoise use coastal waters out to the shelf break
Offshore cetaceans: Pilot whale, Risso's dolphin, striped dolphin, common dolphin, Atlantic spotted dolphin, spinner dolphin, false killer whale
• Often associated with shelf edge features, convergence zones (fronts), and Sargassum mats (summer)</td><td>Baleen whales present fall-spring. Adults migrate from feeding grounds in North Atlantic to calving grounds further south
Bottlenose dolphins present year round</td></tr>
<tr><td>Fish and Invertebrates</td><td>Coastal ocean waters support many valuable fisheries and/or species of concern in the region:
• Benthic or bottom associated: Sea scallop, scup, black sea bass, butterfish, goosefish, scamp, horseshoe crab, tilefish, other reef species
• Midwater: Atlantic mackerel, Spanish mackerel, shortfin squid, bluefish, menhaden, spiny dogfish, smooth dogfish,
• Pelagic: Bluefin tuna, yellowfin tuna, wahoo, dolphinfish, bigeye tuna, swordfish, marlins, sunfish
• Diadromous: Alewife, blueback herring, American shad, hickory shad, Atlantic tomcod, American eel, Atlantic sturgeon (Fed. species of concern), shortnose sturgeon (FE), striped bass
• Estuarine dependent: Southern flounder, spotted seatrout, blue crab, Atlantic croaker, spot, weakfish, shrimp
Important concentration/conservation areas are:
• Pelagic species can be more concentrated around the shelf break and at oceanographic fronts in the region
• The Point (offshore of Cape Hatteras) – Essential Fish Habitat/Habitats Areas of Particular Concern (EFH/HAPC) for coastal migratory pelagics and dolphin/wahoo
• Many anadromous and estuarine dependent species overwinter in nearshore Atlantic waters
• Sargassum mats off Cape Hatteras provide foraging opportunities and shelter for juvenile fish and invertebrates
• Coastal sharks use nearshore and estuarine waters as pupping and nursery grounds</td><td>Benthic and midwater species are present throughout the year
Bluefin tunas present fall-spring; dolphin more common in the summer; other pelagic fish present year round
Anadromous fish migrate inshore to spawn in fresh water in the spring
American eel migrates offshore to spawn in the winter
Estuarine dependent fish migrate offshore in the fall/winter to spawn; juveniles and adults use estuaries during the spring/summer</td></tr>
</table>

In addition to natural resource impacts, spills from the NC Call Area have the potential to cause social and economic impacts. Socio-economic resources potentially at risk from oiling are listed in Table 7.20. The potential economic impacts include disruption of coastal economic activities such as commercial and recreational fishing, boating, vacationing, commercial shipping, and other activities that may become claims following a spill. Specifically, recreational beaches are found in the area and highly utilized during summer. Shore fishing is also important particularly during spring and fall. Hotspots for chartered fishing vessels and recreational fishing party vessels are also common in the area, particularly off the outer banks of North Carolina. Many areas along the entire potential spill zone are widely popular seaside resorts and support recreational activities such as boating, diving, sightseeing, sailing, fishing, and wildlife viewing. In addition to two national seashores, several port areas could potentially be affected by a release from the offshore wind facility. Commercial fishing is also economically important to the region.

Table 7.20

Socio-economic resources at risk from releases of oil and chemicals from the NC Call Area.

Resource Type	Resource Name	Economic Activities
Tourist Beaches	Virginia Beach, VA Corolla Beach, NC Coquina Beach, NC Rodanthe Beach, NC Oregon Inlet Beach, NC	Potentially affected beach resorts and beachfront communities in Virginia and North Carolina provide recreational activities (e.g., swimming, boating, recreational fishing, wildlife viewing, nature study, sports, dining, camping, and amusement parks) with substantial income for local communities and state tax income. Many of these recreational activities are limited to or concentrated into the late spring into early fall months.
National Seashores	Cape Hatteras National Seashore, NC	National seashores provide recreation for local and tourist populations as well as preserve and protect the nation's natural shoreline treasures. National seashores are coastal areas federally designated as being of natural and recreational significance as a preserved area.
National Wildlife Refuge	Currituck NWR (NC) Pea Island NWR (NC)	National wildlife refuges in two states may be impacted. These federally managed and protected lands provide refuges and conservation areas for sensitive species and habitats.
State Parks	False Cape State Park, VA	Coastal state parks are significant recreational resources for the public (e.g., swimming, boating, recreational fishing, wildlife viewing, nature study, sports, dining, camping, and amusement parks). They provide income to the states. Many of these recreational activities are limited to or concentrated into the late spring into early fall months.
Commercial Fishing	A number of fishing fleets use potentially affected waters for commercial fishing purposes.	
	Beaufort-Morehead City, NC	Total Landings (2010): $9.2M
	Belhaven-Washington, NC	Total Landings (2010): $3.7M
	Elizabeth City, NC	Total Landings (2010): $5.4M
	Wanchese-Stumpy Point, NC	Total Landings (2010): $22.0M

7.6.2 EcoRAR Impact Risk Analysis Results for All Scenarios

EcoRAR impact risk analyses were conducted for all oil spill scenarios in the NC Call Area listed in Table 2.12, as summarized below.

- The *realistic* simulations of each scenario (Table 7.21) suggest that spill risks are generally high for small volume spills (WTG-Hyd-90, WTG-Nap-370, WTG-Lub-220) and the 3,400 gallon oil mixture (5WTG-Mix1-3400), moderate for intermediate size spills (ESP-Nap-10K and ESP-Diesel-2K) plus the small naphthenic oil spill (ESP-Nap-500), and low for the all other scenarios (ESP-Nap-1K, ESP-Nap-40K, All-Mix2-129K).
- Two of the spill scenarios, a 2,000 gallon spill of diesel (ESP-Diesel-2K) and a 128,600 gallon spill of an oil mixture (All-Mix2-129K) had the greatest probability of water column impacts (35% and 99%, respectively); thus, contaminating more than 5.18 million m^3 of water using the 1 µg/L threshold and leading to moderate to high impacts to the water column. While the 10,000 and 40,000 gallon spills of naphthenic mineral oil (ESP-Nap-10K and ESP-Nap-40K, respectively) had a moderate probability of shoreline threshold exceedances (44%, and 60%, respectively), these spills would oil a relatively small segment of the shoreline (range: 2.99 and 6.67 km, respectively).
- The overall risk, which combines the relative contribution of spill and impact risk probability and consequence (or degree of oiling), is low for most scenarios, except for the catastrophic 128,600 gallon spill of an oil mixture (All-Mix2-129K). EcoRAR risk analyses for the *worst case* simulations (Table 7.22) are similar to those of the *realistic* simulations (Table 7.21), except that there is a potential for oiling of a greater water column volume and shoreline area. For example, while the *realistic* simulation of the 128,600 gallon scenario (All-Mix2-129K) could impact over 550 million m^3 of the water column, the extent of oiling for the *worst case* simulation would be twice that volume. Similarly, the results for the *realistic* simulation of that same scenario show potential impact 12.2 km of shoreline, while the *worst case* simulation results in an extent of oiling of 39.1 km (primarily sand beaches). For the *worst case* simulation, the overall risk is generally low except for the 128,600 gallon spill of an oil mixture (All-Mix2-129K).

Table 7.21

Risk Scoring for EcoRAR based on *realistic* case model outputs for several spill scenarios in the NC Call Area. *Realistic* refers to the average degree of oiling across all model runs with oiling results. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	0	0	0	12.4	0	0	0	0	0	0	0	Low
ESP-Nap-1K	1 time in >50 years	0	0	0	0	24.1	0	0	0	0	0	0	0	Low
ESP-Nap-10K	1 time in 10-50 years	0	0	43.5	4,650	220	0	2.99	0	0	0	0	2.99	Low
ESP-Nap-40K	1 time in >50 years	0	0	60	104,000	541	0	6.53	0.02	0	0.01	0.11	6.67	Low
ESP-Diesel-2K	1 time in 10-50 years	35	0	0	5,700,000	9.23	0	0	0	0	0	0	0	Low
WTG-Hyd-90	1 time in <10 years	0	0	0	0	4.54	0	0	0	0	0	0	0	Low
WTG-Nap-370	1 time in <10 years	0	0	0	0	17.3	0	0	0	0	0	0	0	Low
WTG-Lub-220	1 time in <10 years	0	0	0.5	0	44.5	0	0	0	0	0	0	0	Low
5WTG-Mix1-3400	1 time in <10 years	0	0	0.5	0	422	0	1.12	0	0	0	0	1.12	Low
All-Mix2-129K	1 time in >50 years	99	1.5	21.5	558,000,000	353	0	11.6	0.06	0	0.25	0.34	12.2	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (10 g/m^2 threshold); [3] Probability of Shoreline Impact (100 g/m^2 threshold).

Table 7.22
Risk Scoring for EcoRAR based on *worst case* model outputs for several spill scenarios in the NC Call Area. *Worst case* refers to the maximum degree of oiling. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	0	0	0	109	0	0	0	0	0	0	0	Low
ESP-Nap-1K	1 time in >50 years	0	0	0	0	200	0	0	0	0	0	0	0	Low
ESP-Nap-10K	1 time in 10-50 years	0	0	43.5	328,000	1,190	0	6.71	0	0	0	0	6.71	Low
ESP-Nap-40K	1 time in >50 years	0	0	60	3,320,000	2,540	0	14.5	2.24	0	0.04	3.36	20.1	Low
ESP-Diesel-2K	1 time in 10-50 years	35	0	0	28,700,000	92.1	0	0	0	0	0	0	0	Low
WTG-Hyd-90	1 time in <10 years	0	0	0	0	53.0	0	0	0	0	0	0	0	Low
WTG-Nap-370	1 time in <10 years	0	0	0	0	127	0	0	0	0	0	0	0	Low
WTG-Lub-220	1 time in <10 years	0	0	0.5	0	238	0	0	0	0	0	0	0	Low
5WTG-Mix1-3400	1 time in <10 years	0	0	0.5	0	1,830	0	1.12	0	0	0	0	1.12	Low
All-Mix2-129K	1 time in >50 years	99	1.5	21.5	1,220,000,000	3,070	0	29.1	2.24	0	3.36	3.36	39.1	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (10 g/m^2 threshold); [3] Probability of Shoreline Impact (100 g/m^2 threshold).

7.6.3 Modeling Results for Catastrophic Release of All Oils Using EcoRAR Impact Thresholds

This section provides a more detailed interpretation of the scenario of the catastrophic release of 128,600 gallons of all oils (All-Mix2-129K) spilled from an entire wind turbine facility in the NC Call Area using the EcoRAR thresholds of impacts, as presented in Figures 7.27 through 7.31 and summarized in Table 7.23.

Table 7.23

Summary of Exposure Risk and Impact Risk analysis results for catastrophic release of all oils (All-Mix2-129K) in NC Call Area using EcoRAR thresholds.

Modeling Parameter	Result	Reference
Probability of exceedance above surface oil exposure risk threshold (10 g/m^2)	Greatest in immediate proximity of release with 1-10% probability further from release point	Figure 7.2
Probability of exceedance above surface oil impact risk threshold (2,590 km^2 above 10 g/m^2)	1.5% (3 out of 200 model simulations)	Tables 7.22 and 7.23
Minimum time (days) to exceed the exposure risk surface water threshold (10 g/m^2) for all simulations	< 2 days within approximately 200 km of spill site	Figure 7.28 (top)
Minimum time (days) to exceed the exposure risk surface water threshold (10 g/m^2) for *worst case* out of 200 simulations	< 2 days within approximately 75 km northeast of spill site, 2-5 days within approximately 150 km northeast of spill site	Figure 7.28 (bottom)
Probability of exceedance above shoreline exposure risk threshold (100 g/m^2)	0-10% within approximately 200 km of spill site	Figure 7.29 (top)
Minimum time (days) to exceed the exposure risk shoreline threshold (100 g/m^2) for all simulations	< 2 days within 100 km of spill site	Figure 7.29 (bottom)
Probability of exceedance above shoreline impact risk threshold (16 km above 100 g/m^2)	21.5% (43 out of 200 model simulations)	Tables 7.22 and 7.23
Maximum oil mass (g/m^2) on shorelines to exceed the exposure risk shoreline oiling threshold (100 g/m^2) for *worst case* out of 200 simulations	100 g/m^2 to 1,000 g/m^2 with most oiling north/northwest of spill site	Figure 7.30
Water column volume affected by oil above the exposure threshold (1µg/L) at any instant in time	90% of simulations at < 1 km^3, 75% at < 0.8 km^3	Figure 7.31 (top)
Water surface area (km^2) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	90% of simulations at < 2,000 km^2; 75% of simulations at < 400 km^2	Figure 7.31 (middle)
Shoreline length (km) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	90% of simulations at < 25 km; over 75% with negligible shoreline impacts	Figure 7.31 (bottom)

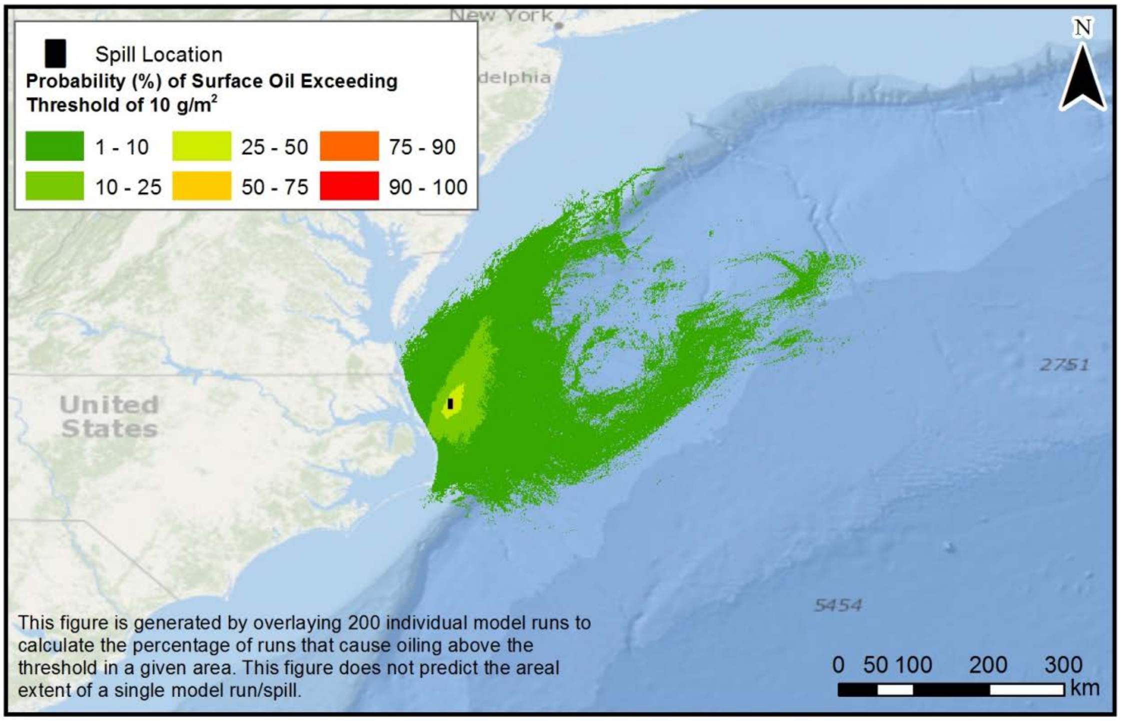


Figure 7.27 Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

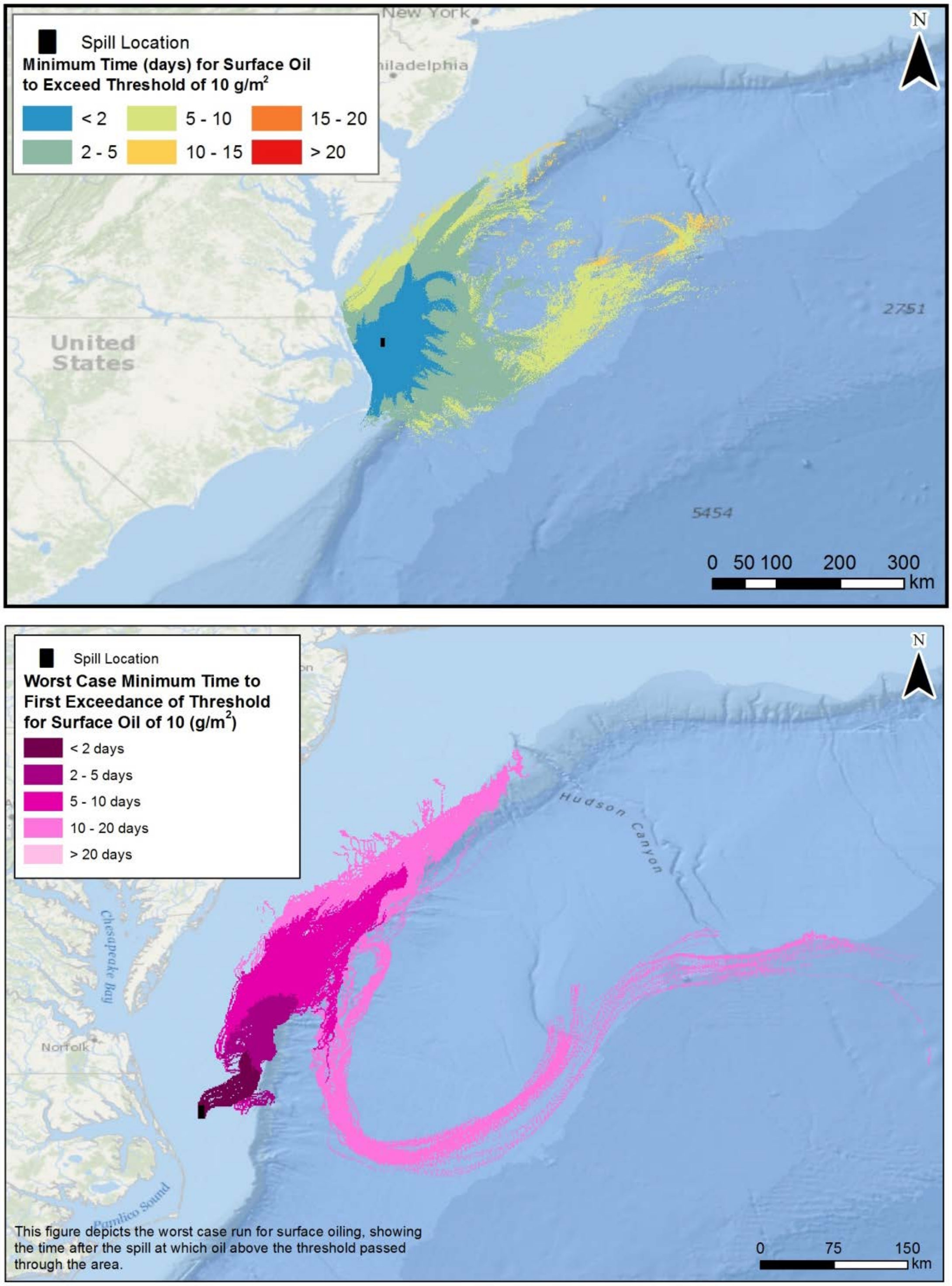


Figure 7.28 Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

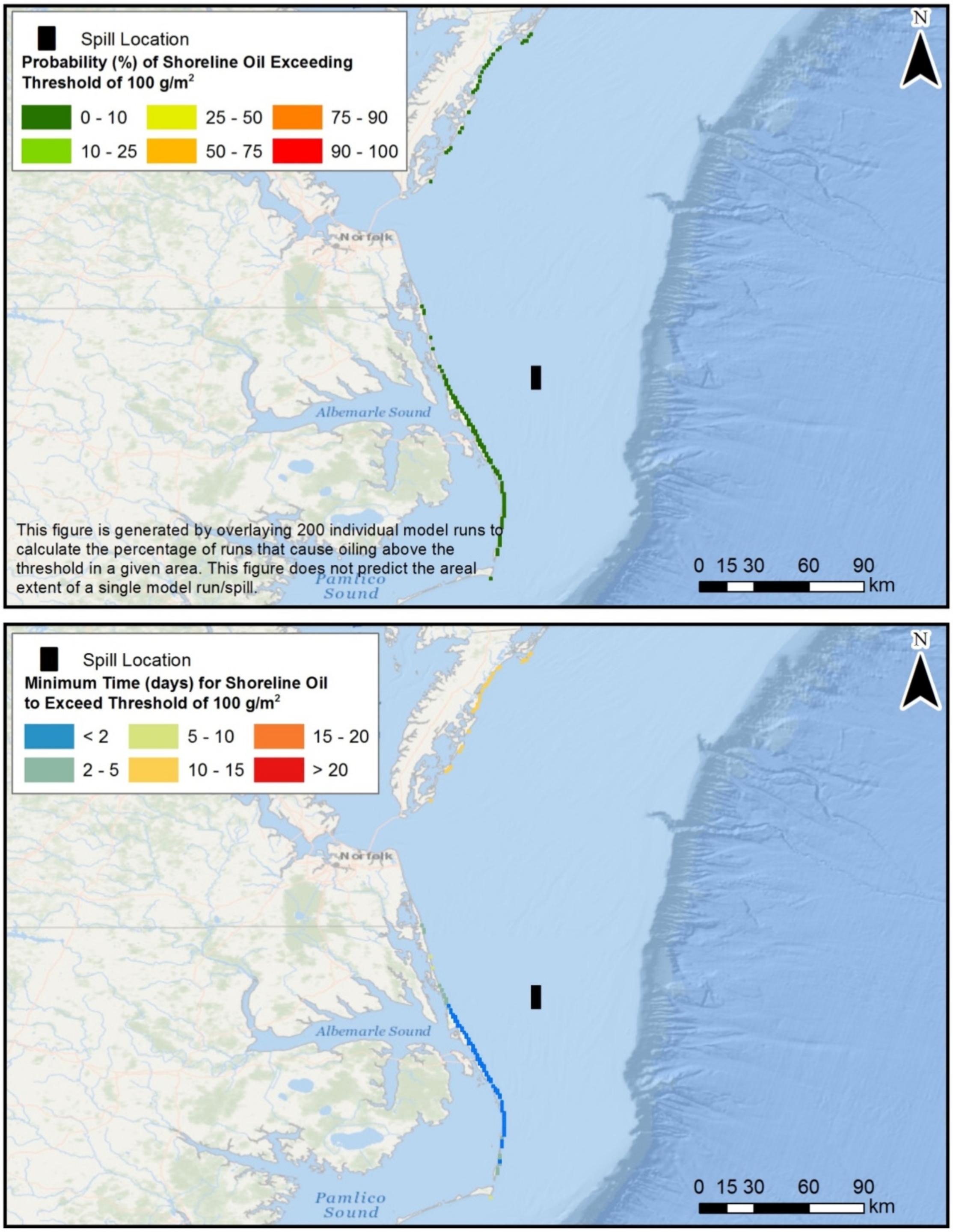


Figure 7.29 Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

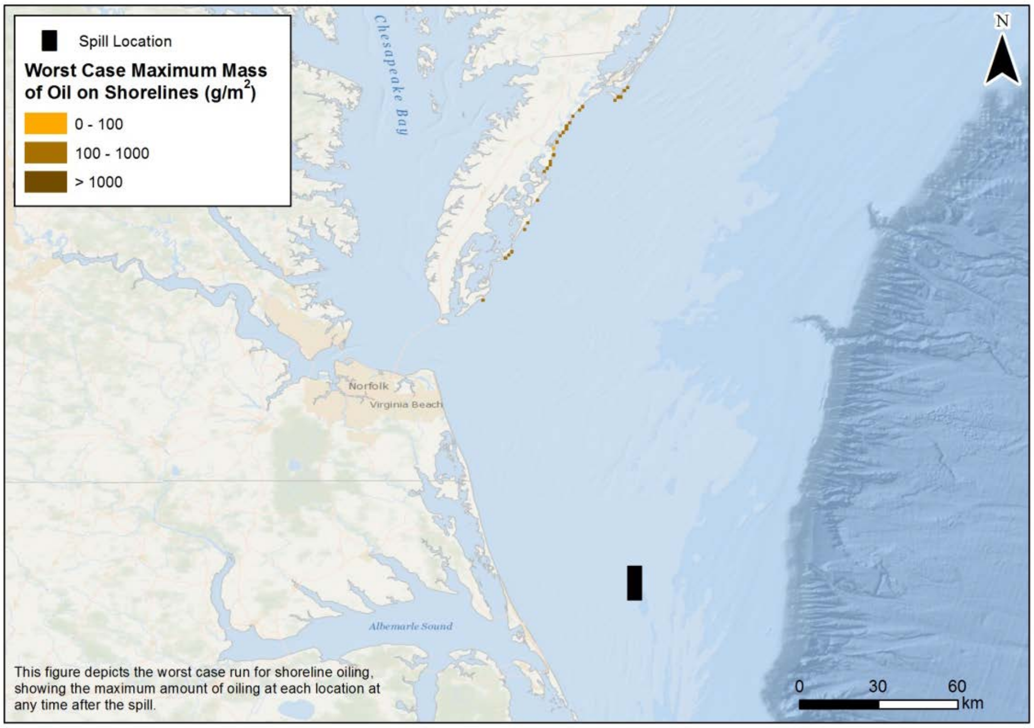


Figure 7.30 Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area. Map represents a single simulation.

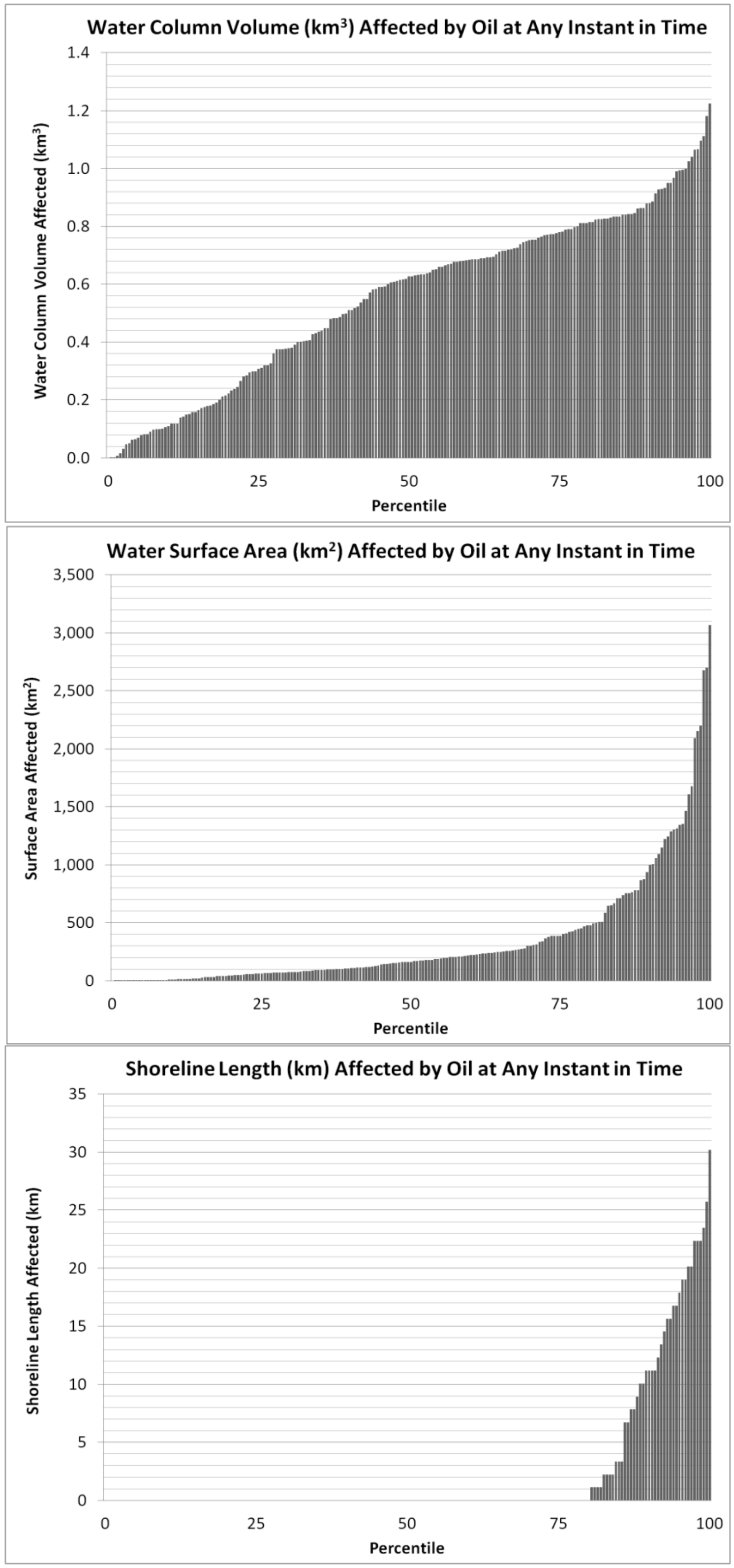


Figure 7.31 Summary of 200 model simulations of a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area showing the estimated water column volume (top), surface water area (middle), and shoreline length (bottom) impacted above the exposure risk EcoRAR thresholds.

7.6.4 SRAR Impact Risk Analysis Results for All Scenarios

SRAR impact risk analyses were conducted for all oil spill scenarios in the NC Call Area listed in Table 2.12, as summarized below.

- The *realistic* simulations of the modeling scenarios (Table 7.24) are similar to those of the EcoRAR analysis (Table 7.21), except that the probability of shoreline threshold exceedance is between moderate to high (range: 31.5% to 71%) for some of the spill scenarios. Consequently, the shoreline length impacted above thresholds is greater than those of the EcoRAR scenarios.
- The probability of water surface threshold exceedance is between moderate to high (range: 17.5% to 77%) for some of the scenarios, but only the 128,600 gallon spill of an oil mixture (All-Mix2-129K) would lead to moderate impacts to the water surface.
- The overall risk of impacts is low for the *realistic* simulations of most scenarios (Table 7.24) except for 10,000 and 40,000 gallon spill of naphthenic mineral oil (ESP-Nap-10K and ESP-Nap-40K, respectively), and the 128,600 gallon spill of an oil mixture (All-Mix2-129K).
- SRAR risk analyses for the *worst case* simulations (Table 7.25) are very similar to those of the *realistic* simulations (Table 7.24), except that there is a potential for oiling of a greater water column volume and shoreline area. For example, while the *realistic* simulation of the 128,600 gallon oil mixture scenario (All-Mix2-129K) could impact over 550 million m^3 of the water column, the *worst case* simulation for that scenario could result in an extent of oiling nearly twice that volume. Similarly, results for the *realistic* simulation of that same scenario show potential could impact 50.5 km of shorelines (mostly sand beaches), while the *worst case* simulation results in an extent of oiling of 238 km (mostly sand beaches).
- For the *worst case* simulations (Table 7.25), the overall risk is generally low for most scenarios, except for the 10,000 and 40,000 gallon spill of naphthenic mineral oil (ESP-Nap-10K and ESP-Nap-40K, respectively)), the 2,000 gallon spill of diesel (ESP-Diesel-2K) and the 128,600 gallon spill of an oil mixture (All-Mix2-129K).

Table 7.24

Risk Scoring for SRAR based on realistic case model outputs for several spill scenarios in the NC Call Area. Realistic refers to the average degree of oiling across all model runs with oiling results. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
							Weighted Shoreline (km)							
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	0.5	43.5	0	658	0.13	13.2	0	0	0	0.01	13.3	Low
ESP-Nap-1K	1 time in >50 years	0	1.5	52	0	760	0.20	18.8	0	0	0.02	0.08	19.1	Low
ESP-Nap-10K	1 time in 10-50 years	0	17.5	68	4,650	1,310	0.41	52.8	0.05	0	0.25	0.52	54.0	Moderate
ESP-Nap-40K	1 time in >50 years	0	42.5	71	104,000	2,350	0.48	68.8	0.05	0	0.34	1.11	70.8	Moderate
ESP-Diesel-2K	1 time in 10-50 years	35	0	31.5	5,700,000	30.1	0.03	8.1	0	0	0	0	8.13	Moderate
WTG-Hyd-90	1 time in <10 years	0	4	0.5	0	1,130	1.12	0	0	0	0	0	1.12	Low
WTG-Nap-370	1 time in <10 years	0	6.5	8.5	0	1,280	0.26	5.17	0	0	0	0	5.43	Low
WTG-Lub-220	1 time in <10 years	0	0	12.5	0	794	0.47	7.70	0	0	0	0	8.17	Low
5WTG-Mix1-3400	1 time in <10 years	0	0	17	0	830	0.53	35.1	0	0	0.03	0.17	35.8	Low
All-Mix2-129K	1 time in >50 years	99	77	29	558,000,000	4,490	0.04	47.3	0.04	0	1.92	1.20	50.5	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 ppb threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (0.01 g/m^2 threshold); [3] Probability of Shoreline Impact (1 g/m^2 threshold).

Table 7.25

Risk Scoring for SRAR based on *worst case* model outputs for several spill scenarios in the NC Call Area. *Worst case* refers to the maximum degree of oiling. See Table 7.2 for details.

Scenario Name	Categorical Spill Probability Risk	Percent Probability of Risk Threshold Exceedance (%) out of 200 model runs			Degree of Oiling									Overall Risk
		Water Column[1]	Water Surface[2]	Shoreline[3]	Water Column (m^3)	Water Surface (km^2)	Weighted Shoreline (km)							
							Artificial	Sand	Rock	Gravel	Mudflat	Wetland	Shoreline Total	
ESP-Nap-500	1 time in 10-50 years	0	0.5	43.5	0	2,660	2.24	33.6	0	0	0	1.12	37.0	Low
ESP-Nap-1K	1 time in >50 years	0	1.5	52	0	3,270	2.24	47.0	0	0	1.12	2.24	52.6	Low
ESP-Nap-10K	1 time in 10-50 years	0	17.5	68	328,000	4,680	6.71	171	4.47	0	2.24	5.59	190	Moderate
ESP-Nap-40K	1 time in >50 years	0	42.5	71	3,320,000	10,400	7.83	142	2.24	0	3.36	5.59	161	Moderate
ESP-Diesel-2K	1 time in 10-50 years	35	0	31.5	28,700,000	304	1.12	20.1	0	0	0	0	21.2	Moderate
WTG-Hyd-90	1 time in <10 years	0	4	0.5	0	3,130	1.12	0	0	0	0	0	1.12	Low
WTG-Nap-370	1 time in <10 years	0	6.5	8.5	0	3,920	1.12	23.5	0	0	0	0	24.6	Low
WTG-Lub-220	1 time in <10 years	0	0	12.5	0	2,180	1.12	26.9	0	0	0	0	28.0	Low
5WTG-Mix1-3400	1 time in <10 years	0	0	17	74,200	2,330	3.36	104	0	0	1.12	1.12	109	Low
All-Mix2-129K	1 time in >50 years	99	77	29	1,220,000,000	13,700	2.24	222	2.24	0	1.12	10.1	238	Moderate

[1] Probability of Water Column Impact > 5.18 million m^3 (1 µg/L threshold); [2] Probability of Water Surface Impact > 2.59 billion m^2 (0.01 g/m^2 threshold); [3] Probability of Shoreline Impact (1 g/m^2 threshold).

7.6.5 Modeling Results for Catastrophic Release of All Oils Using SRAR Impact Thresholds

This section provides a more detailed interpretation of the scenario of 128,600 gallons of all oils (All-Mix2-129K) spilled from an entire wind turbine facility in the NC Call Area using the SRAR thresholds for impacts, as presented in Figures 7.32 through 7.36 and summarized in Table 7.26.

Table 7.26
Summary of Exposure Risk and Impact Risk analysis results for catastrophic release of all oils (All-Mix2-129K) in NC Call Area using SRAR thresholds.

Modeling Parameter	Result	Reference
Probability of exceedance above surface oil exposure risk threshold (0.1 g/m^2)	Greatest in immediate proximity of release with 1-10% probability further from release point; larger area of 25-50% probability of exceedance than with EcoRAR thresholds (Fig. 7.26)	Figure 7.32
Probability of exceedance above surface oil impact risk threshold (2,590 km^2 above 0.1g/m^2)	77% (154 out of 200 model simulations)	Tables 7.25 and 7.26
Minimum time (days) to exceed the exposure risk surface water threshold (0.1 g/m^2) for all simulations	< 2 days within approximately 300km of spill site	Figure 7.33 (top)
Minimum time (days) to exceed the exposure risk surface water threshold (0.1 g/m^2) for *worst case* out of 200 simulations	< 2 days within approximately 75km southeast of spill site	Figure 7.33 (bottom)
Probability of exceedance above shoreline exposure risk threshold (1 g/m^2)	0-10% within 150 km of spill site	Figure 7.34 (top)
Minimum time (days) to exceed the exposure risk shoreline threshold (1 g/m^2) for all simulations	< 2 days	Figure 7.34 (bottom)
Probability of exceedance above shoreline impact risk threshold (16 km above 1 g/m^2)	29% (58 out of 200 model simulations)	Tables 7.25 and 7.26
Maximum oil mass (g/m^2) on shorelines to exceed the exposure risk shoreline oiling threshold (1 g/m^2) for *worst case* out of 200 simulations	100 g/m^2 to > 1,000 g/m^2 with most oiling northwest of spill site	Figure 7.35
Water column volume affected by oil above the exposure threshold (1µg/L) at any instant in time	90% of simulations at <1 km^3 *, 75% at 0.8 km^3	Figure 7.36 (top)
Water surface area (km^2) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	95% of simulations at < 12,000 km^2; 75% of simulations at < 6,000 km^2	Figure 7.36 (middle)
Shoreline length (km) affected by oil above the exposure threshold (10 g/m^2) at any instant in time	90% of simulations at < 40 km; over 70% with negligible shoreline impacts	Figure 7.36 (bottom)

* Note that the output for water column volume with concentrations exceeding the SRAR threshold is the same as that for the EcoRAR threshold (Figure 7.31, top) because both scenarios use 1µg/L as the threshold for impacts.

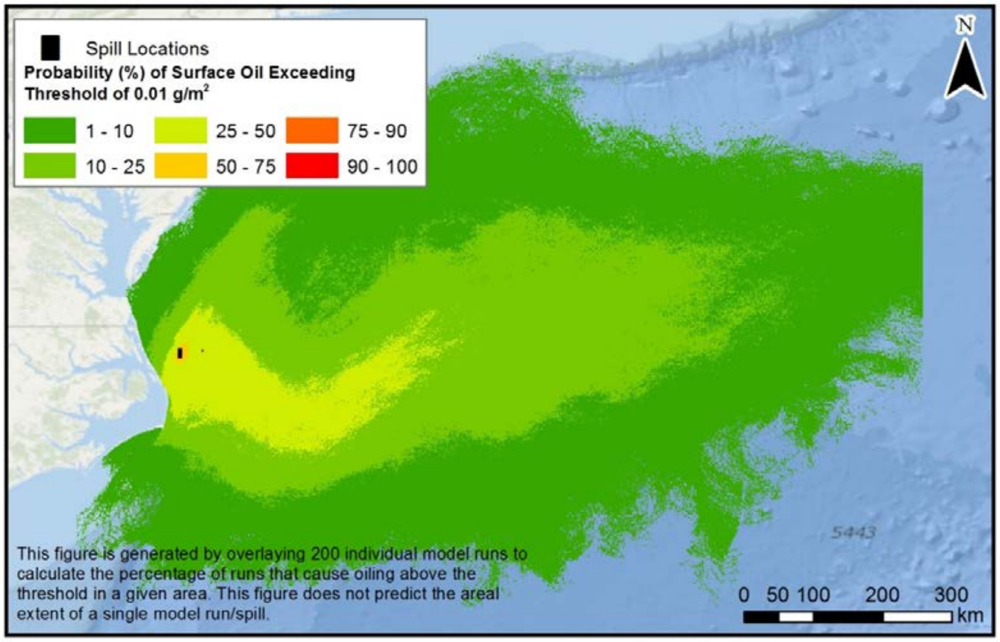


Figure 7.32 Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

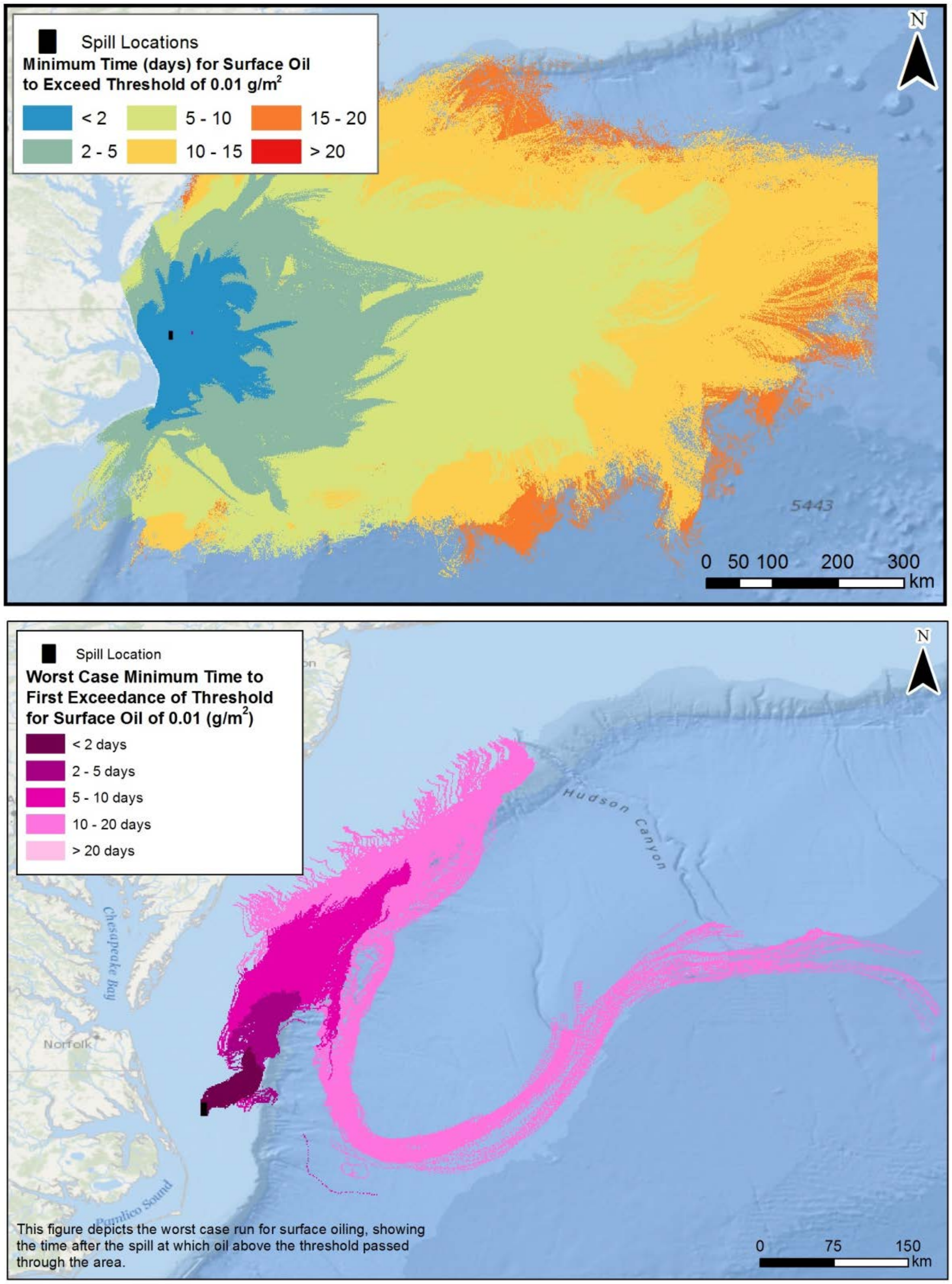
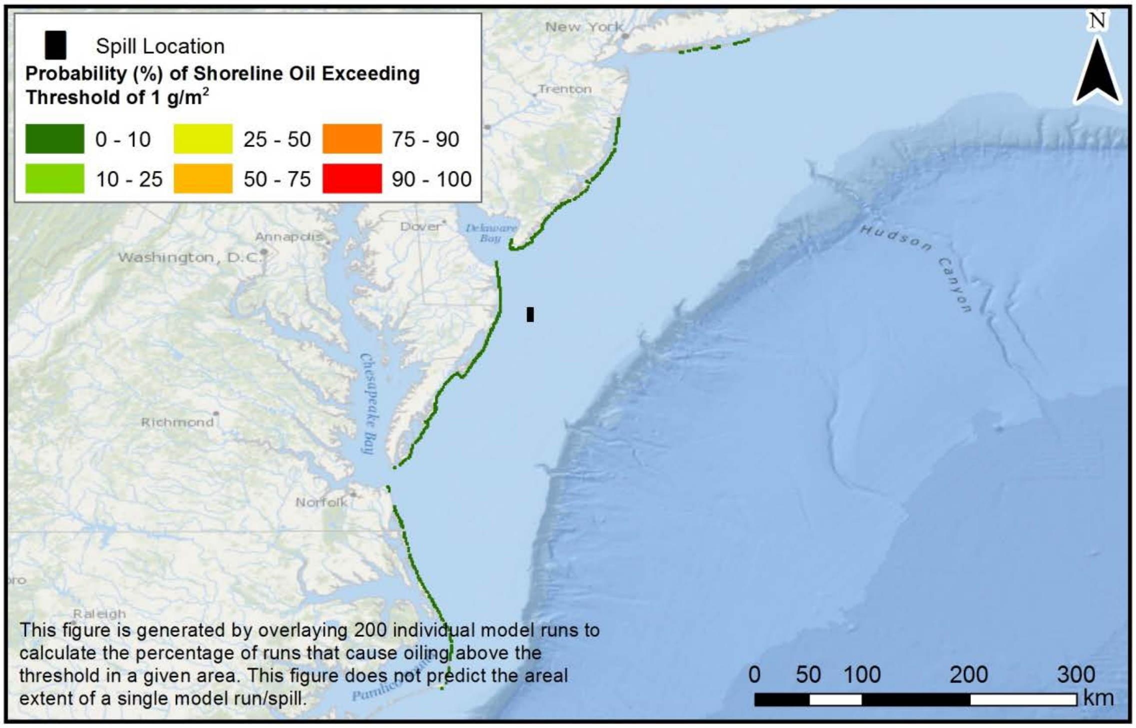


Figure 7.33 Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



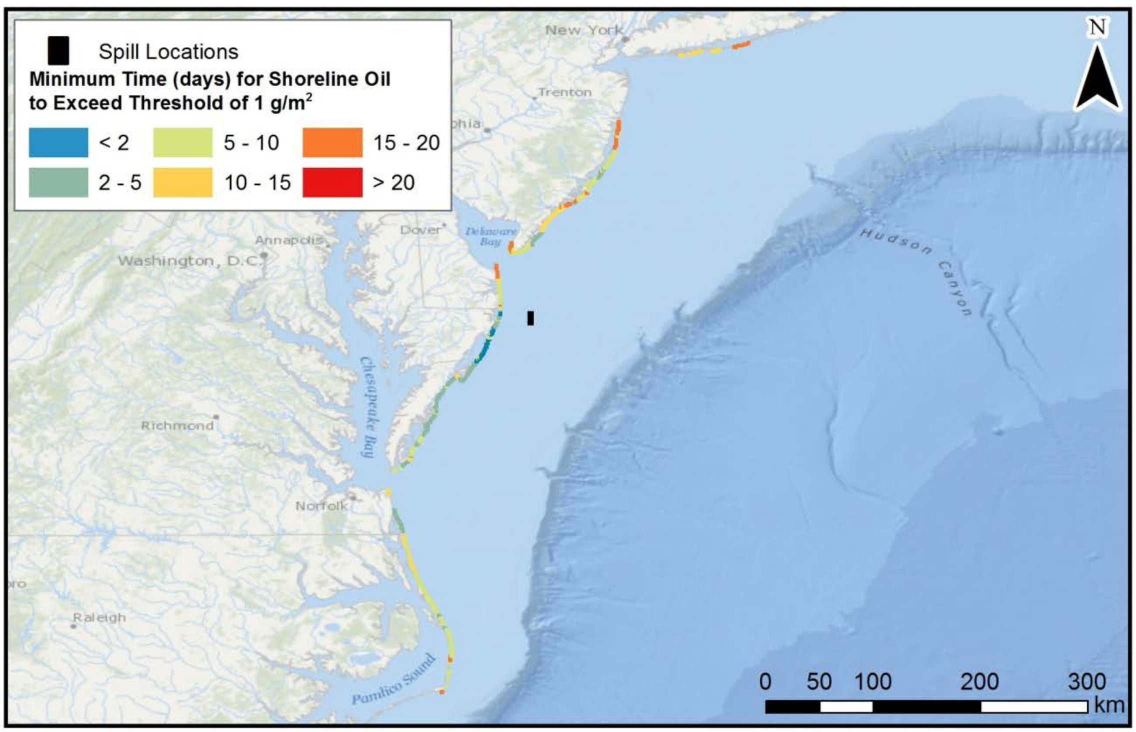


Figure 7.34 Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

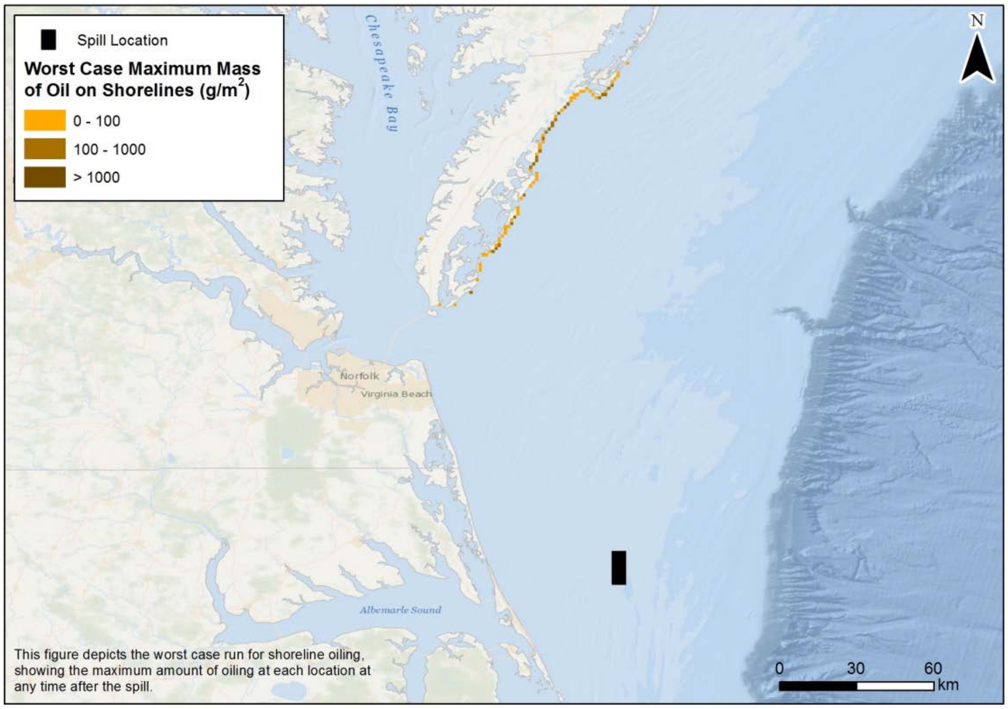


Figure 7.35 Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area. Map represents a single simulation.

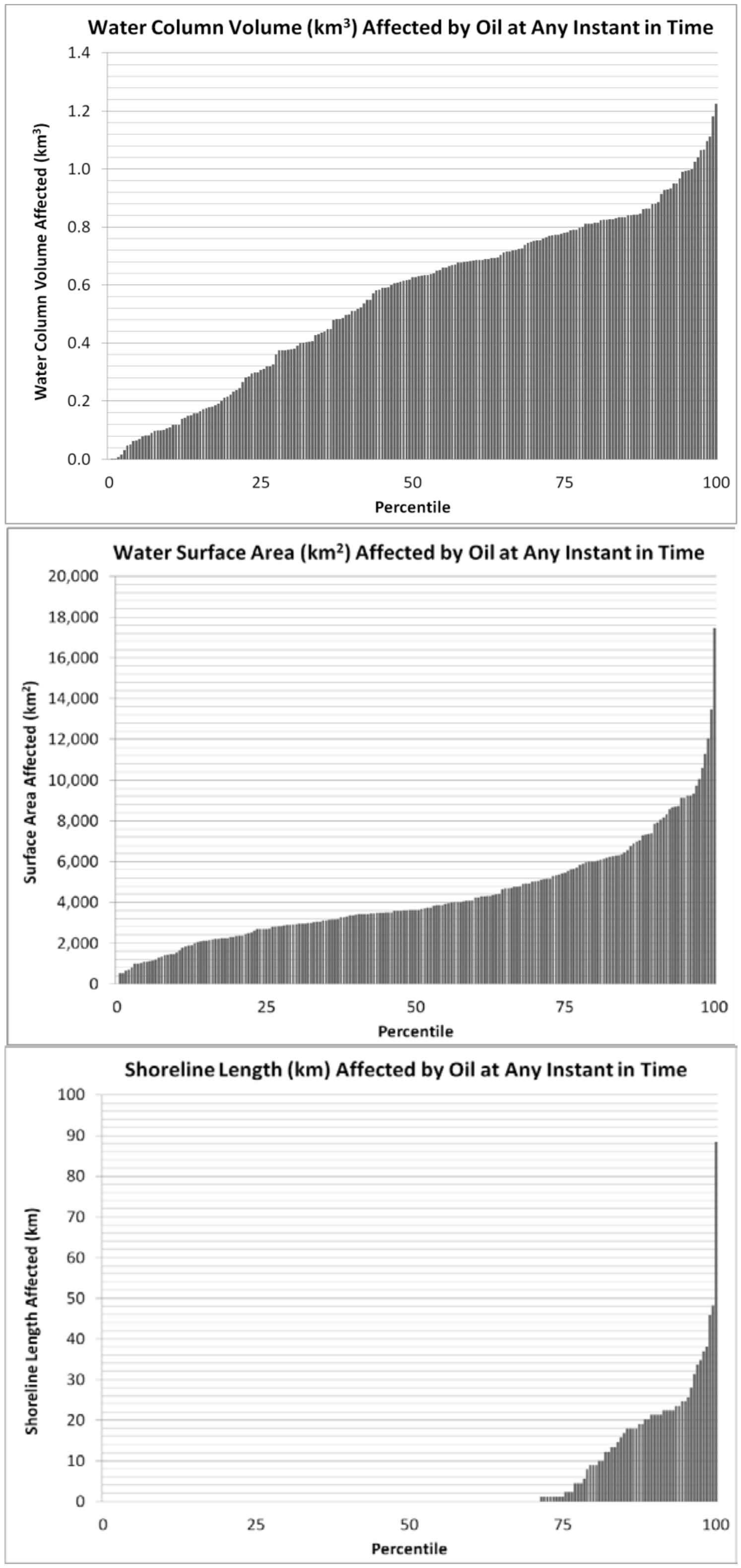


Figure 7.36 Summary of 200 model simulations of a catastrophic spill of 128,600 gallons of all oils from a wind turbine in the NC Call Area showing the estimated water column volume (top), surface water area (middle), and shoreline length (bottom) impacted above the exposure risk SRAR thresholds.

7.7 DISCUSSION ON OIL RELEASES FROM CALL AND WIND ENERGY AREAS

A more detailed analysis of the estimated water column dissolved aromatic doses generated through modeling of each release scenario at each of the Call Area/WEA locations is shown in Table 7.27. These doses represent the average of the maximum dose of each of the 200 model simulations per scenario, and the maximum of all doses across the 200 model simulations per scenario (worst case exposure concentrations). As a reference, the dose threshold of dissolved aromatics from oil is 144 parts per billion-hours (ppb-h), equivalent to the lethal threshold (LC_{50}) of 6 µg/L, and 24 ppb-h, to the sub-lethal threshold (LC_{50}) of 1 µg/L at an exposure time of 24 hours for the most sensitive (2.5th percentile) species (French-McCay 2002).

Most release scenarios had doses below the lethal threshold, even for the most sensitive species, except the releases of 128,600 gallons of an oil mixture (All-Mix2-129K). Similarly, most release scenarios had doses below the sub-lethal threshold, except for ESP-Diesel-2K and All-Mix2-129K. It is important to note that area-specific oceanographic conditions influenced the estimated doses. Regardless of the location, a release of 128,600 gallons of an oil mixture (All-Mix2-129K) would result in an average of the maximum dose > 190 ppb-h. However, these modeled doses put into a larger context, and given the conservative nature of the thresholds used in these analyses, show relatively moderate environmental impacts to surface and water column resources. Furthermore, the overall risk is influenced not only by the spill risk probability, but also the probability of impact risk threshold exceedance (out of 200 model simulations). As discussed in Section 3.0, the assumptions used in fault tree analyses were conservative resulting in over-estimation of spill risk probability. A similar precautionary approach was used for probabilities of impact risk threshold exceedance. For example, if at any point during each of 160 (out of 200) model simulations for a particular model scenario there was an exceedance of the EcoRAR impact risk threshold to water column (e.g., contamination in more than 5.18 million m^3 of water using the 1 µg/L threshold), the percent threshold exceedance would be 80%. This is clearly a conservative estimate leading to potentially higher than expected overall risks.

Table 7.27

Summary of the estimated mean of maximum across 200 model simulations at each geographic location. As a reference, the dose threshold of dissolved aromatics from oil is 144 ppb-h, equivalent to the lethal threshold of 6 µg/L at exposure time of 24 hours (French-McCay 2002).

Scenario Name	Average of Maximum Dose (± standard deviation) (ppb-h)		
	RI-MA WEA	MD WEA	NC Call Area
ESP-Nap-500	0±0	0±0	0±0
ESP-Nap-1K	0±1	0±0	0±0
ESP-Nap-10K	3±10	0±1	1±5
ESP-Nap-40K	15±30	1±7	3±8
ESP-Diesel-2K	73±83	27±34	17±24
WTG-Hyd-90	0±0	0±0	0±0
WTG-Nap-370	0±0	0±0	0±0
WTG-Lub-220	0±0	0±0	0±0
5WTG-Mix1-3.4K	0±0	0±2	0±2
All-Mix2-129K	229±169	466±211	192±106

While the catastrophic oil release scenario (All-Mix2-129K) included in these analyses showed potential moderate effects to ecological and socio-economic resources, the probability of occurrence of these types of releases are very small. By contrast, the most likely types of releases (e.g., a release of a few thousand gallons of petroleum and non-petroleum oils) would cause minimal impacts, which would likely occur in the immediate vicinity of the point of release. These impacts would be of short spatial and temporal duration. Overall, the approach used in these spill scenario analyses was biased towards overestimation of risks suggesting that potential ecological and socioeconomic impacts may be actually lower than those presented here.

7.8 CHEMICAL SPILL MODELING RESULTS

Using the information presented in Table 2.13, model outputs were used to characterize potential risks for each of the release scenarios. Table 7.28 (EcoRAR analysis only) shows the risk analysis summary for other chemicals of interest (sulfuric acid and glycols).

Spill Risk ranges between low to high, but both Exposure Risk and Impact Risk to water column resources would be low for most scenarios given the rapid dissolution of these chemicals into the water column. One exception is the chemical release of glycols and sulfuric acid (29,000 gallons[43]), which would result in high Exposure Risk particularly in the proximity of the point of release (< 305 m). The overall risk of each scenario, which combines the relative contribution of Spill Risk, Exposure Risk, and Impact Risk, is generally low for two of the scenarios and mostly moderate for the largest ethylene glycol release and the catastrophic release of all chemicals. However, it is important to note (as discussed below) that even though the ethylene glycol threshold was exceeded, this exceedance was short lived, suggesting that these analyses are conservative towards overprotection of aquatic resources. A graphic representation of the fate of the catastrophic release of 28,630 gallons of ethylene glycol for each of the WEA areas is shown in Figures 7.37-7.39. Note that for the scenarios in the RI-MA and MD locations, the lowest chemical threshold (23,800 mg/m^3 for glycols) is only exceeded for the first 2½ hours after chemical release. By comparison, in the NC Call Area, the ethylene glycol threshold is exceeded for the first 3½ hours after chemical release because of stronger currents (i.e., 0.4 m/s as compared to 0.2 m/s for the RI-MA and MD locations). While CHEMMAP model outputs and the analyses presented here indicate a potential moderate overall risk to aquatic resources from two of the chemical releases, these risks were derived using a conservative approach likely resulting in over-estimation of anticipated risks.

[43] Modeled as ethylene glycol as the additive impacts associated with sulfuric acid did not result in increased threshold exceedances.

Table 7.28
Risk Scoring for all ECORAR spill scenarios involving other chemicals of interest. See Table 7.2 for details.

Location	Scenario	Spill Risk	Exposure Risk	Impact Risk	Overall Risk
		Spill Probability	Ratio peak:threshold	Volume above Threshold	
			Water Column (unitless)	Water Column (m^3)	
RI-MA WEA	WTG-Ethyl-440[a]	1 time in <10 years	0.74	0	Low
	ESP-Ethyl-30[a]	1 time in 10-50 years	0.05	0	Low
	ESP-Sulf-335[b]	1 time in 10-50 years	0.89	0	Low
	AllChem-29K[c]	1 time in >50 years	48	12,344,000	Moderate
MD WEA	WTG-Ethyl-440[a]	1 time in <10 years	0.75	0	Low
	ESP-Ethyl-30[a]	1 time in >50 years	0.05	0	Low
	ESP-Sulf-335[b]	1 time in >50 years	0.93	0	Low
	AllChem-29K[c]	1 time in >50 years	49	11,888,000	Moderate
NC Call Area	WTG-Ethyl-440[a]	1 time in <10 years	0.74	0	Moderate
	ESP-Ethyl-30[a]	1 time in 10-50 years	0.05	0	Low
	ESP-Sulf-335[b]	1 time in 10-50 years	0.94	0	Low
	AllChem-29K[c]	1 time in >50 years	49	15,224,000	Moderate

[a] Ethylene glycol, threshold 23,800 mg/m^3; [b] Sulfuric acid, threshold 1,265,041 mg/m^3; [c] Model as ethylene glycol as the additive impacts associated with sulfuric acid did not result in exceedances of its threshold.

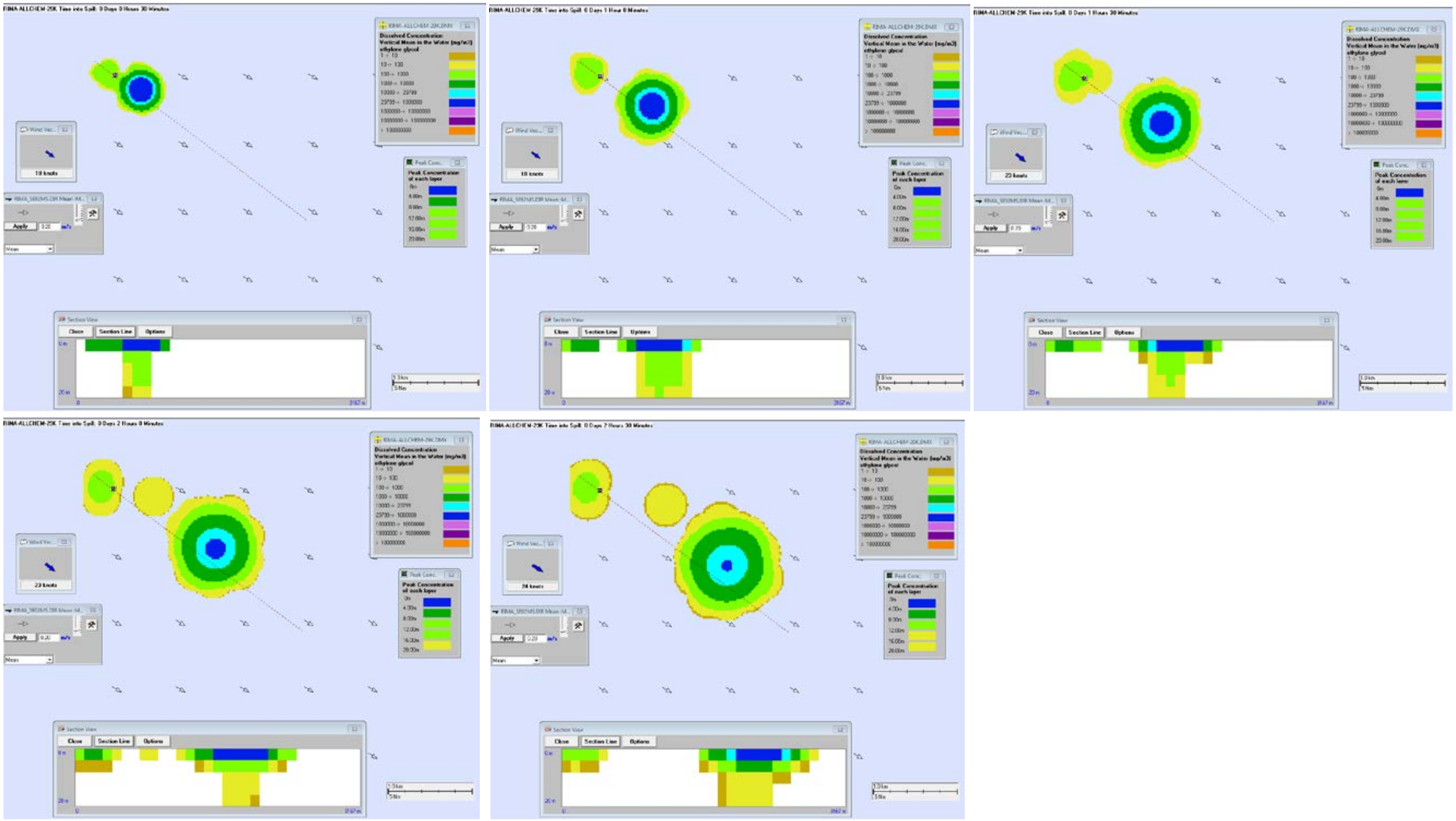


Figure 7.37 Time-series peak concentration sequence (every 30 minutes; left to right, top to bottom) following a release of 28,630 gallons of ethylene glycol in the immediate vicinity of the RI-MA WEA. The lowest chemical threshold (23,800 for mg/m^3 glycols) falls within the dark blue concentration range of estimated environmental concentrations. Peak chemical concentrations were within 190 m of the point of release. Each plot shows the model outputs in plain view and cross section.

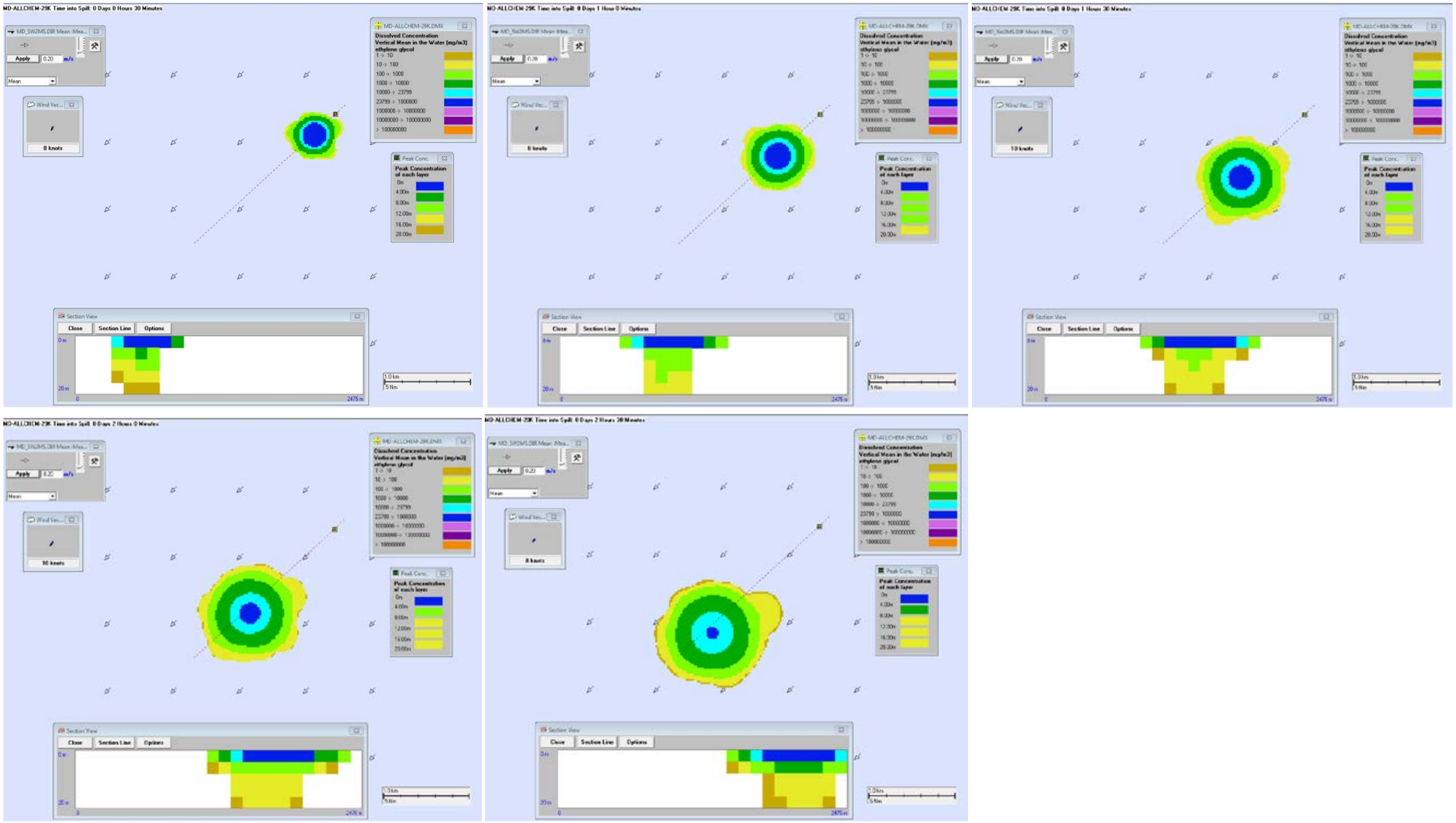


Figure 7.38 Time-series peak concentration sequence (every 30 minutes; left to right, top to bottom) following a release of 28,630 gallons of ethylene glycol in the immediate vicinity of the MD WEA. The lowest chemical threshold (23,800 for mg/m^3 glycols) falls within the dark blue concentration range of estimated environmental concentrations. Peak chemical concentrations were within 198 m of the point of release. Each plot shows the model outputs in plain view and cross section.

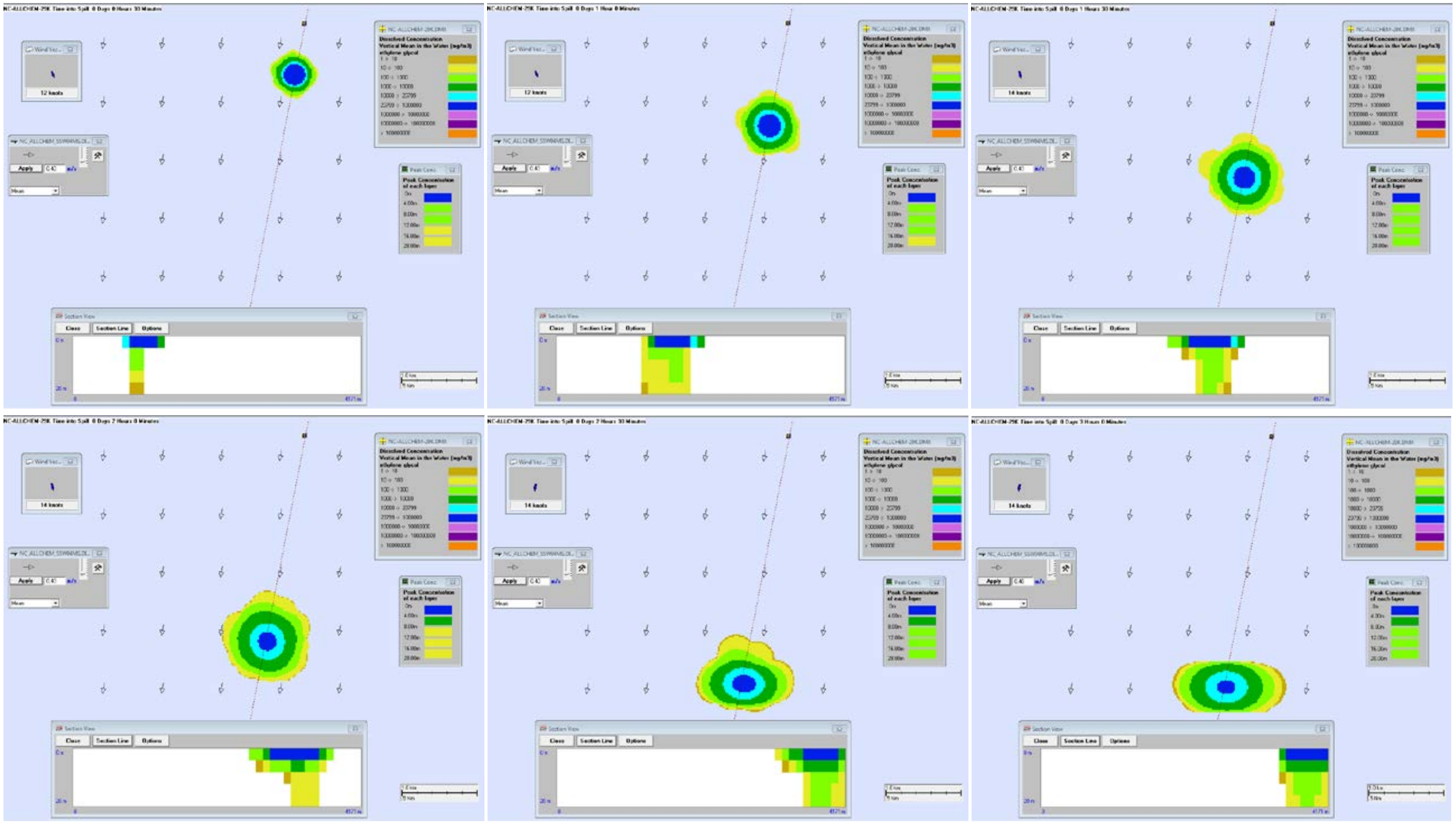


Figure 7.39 Time-series peak concentration sequence (every 30 minutes; left to right, top to bottom) following a release of 28,630 gallons of ethylene glycol in the immediate vicinity of the NC Call Area. The lowest chemical threshold (23,800 for mg/m^3 glycols) falls within the dark blue concentration range of estimated environmental concentrations. Peak chemical concentrations were within 302 m of the point of release. Each plot shows the model outputs in plain view and cross section.

8. SUMMARY AND CONCLUSIONS

Increasing interest in renewable energy projects, particularly offshore wind energy, requires a careful examination of the environmental risks, fates, and effects of accidental releases of chemicals stored in ESP and WTG structures. Interestingly, one of the greatest challenges identified during the development of this project was the paucity of information on the types and volumes of chemicals and oils used in offshore wind facilities. Despite this limitation, a survey of the available information, including a report for the Cape Wind Energy Project (Etkin 2006a), provided the basis for selecting chemicals and oils of potential concern, as well as the volumes used for modeling exercises of spill scenarios (Section 2). Key compounds of interest included petroleum and mineral oils, and a selected number of chemicals (glycols and sulfuric acid) used in different components and equipment.

Oil and chemical spill scenarios used here (Tables 2.12 and 2.13) included a variety of conditions, from spills associated with regular maintenance to catastrophic spills. A key component of determining the potential environmental consequences associated with these scenarios included analyses of the probability that these releases would occur. As shown in Section 3, these release probabilities are a function of a series of event probabilities (i.e., maintenance, transfer, impact-related releases due to strong wind events, hurricanes earthquakes, tsunamis, allisions from vessels, etc.). Using a fault tree approach, the combined probabilities of possible events leading to a release were used to determine the spill probability associated with each scenario. These probabilities were allowed to vary to account for uncertainties. Overall, the highest release probabilities (1 time per month) were in the NC Call Area, resulting from vessel allisions causing small releases of up to several hundred gallons (WTG-Hyd-90, WTG-Gly-440, WTG-Nap-370, WTG-Lub-220). It is important to note that the probabilities of these incidents would be significantly reduced by the presence of well-enforced vessel exclusion zones and changes in vessel traffic lanes. By contrast, the probability of catastrophic spills (e.g., All-Mix2-129K and WCD-Chems-29K) at all Call Area/WEAs would be very low (1 time in ≥1,000 years). As discussed in Section 2, these probabilities were derived using a series of conservative assumptions (e.g., allision analysis, assumption of a complete release in the event of a catastrophic event) leading to a potential over-estimation of release probabilities.

To facilitate an analysis of the potential environmental consequences of releases from wind energy facilities, models were reviewed and evaluated for their applicability to this analysis (Section 4). The comparison of seven models (summarized in Table 4.1) indicated that SIMAP and CHEMMAP provide the most comprehensive capabilities of spill impact assessment in terms of 2D trajectory, 3D fate and transport modeling, 3D biological exposure and toxicity modeling, and environmental risk. These two models have been extensively validated in publications and reports and vetted by the scientific community. While other models (e.g., COSIM and OSCAR) may provide similar capabilities, their documentation is not publicly available, limiting their use in these types of consequence analyses. As a result, SIMAP and CHEMMAP were selected for the analyses presented here.

As part of the consequence analysis, an evaluation of the potential environmental effects to selected marine resources from accidental exposure to oils and chemicals accidentally released from offshore wind facilities was conducted via a review of the scientific literature (Section 5).

In most cases and based on currently available information, spills of chemicals identified in Section 2 would result in low adverse effects to marine resources, with a few exceptions where highly viscous oils (e.g., biodiesel and dielectric insulating fluids) may pose moderate fouling risks to marine mammals and birds. However, as pointed out in this section, these risks are also a function of the volume of the release, as well as on the concentration of these marine resources, which may influence the encounter rate. Consequently, small releases of these viscous oils may not necessarily cause adverse effects on marine resources. The toxicity of other chemicals of interest (sulfuric acid and glycols) in seawater has not been extensively studied, but the existing information indicates low to very low toxicity. Based on interpretation of aquatic toxicity data, a toxic threshold 1 µg/L of dissolved PAHs (French McCay 2002) was used for petroleum and non-petroleum oils. This value represents the concentration at which sublethal effects may be observed in the most sensitive marine species (e.g., 2.5th percentile of species). For sulfuric acid and glycols, SSDs were used to derive the concentration at which 5% of the species on the curve would be impacted. Using this approach, the 5th of the curve produced a toxic threshold of a pH of 4.71 that, after accounting for the buffering capacity of seawater (French McCay et al. 2003), produced a final threshold concentration of 265,041 mg/m^3. Limited information is available for pure and formulated ethylene glycol and propylene glycol. Consequently, SSDs were derived using a combination of SAR and ICE models, and with safety factors to account for uncertainty, were used to calculate a 48-h EC_{50} of 23.8 mg/L as the threshold value. As pointed out in Section 5, the thresholds used in the analyses presented here are extremely conservative, as exposures to an accidental spill of these chemicals in open waters are expected to be short lived.

The evaluation of potential environmental consequences to marine species was performed through modeling using the SIMAP and CHEMMAP (Section 6 and Appendix A). Modeling inputs include habitat and depth mapping, winds, currents, other environmental conditions, chemical composition and properties of the oils and chemicals of interest, and specifications of the release (amount, location, etc.). Model outputs for each scenario (Tables 2.12 and 2.13) were then integrated into the consequence analysis (Section 7). This analysis assessed the potential risks to ecological and socioeconomic resources from each release scenario as a function of the probability that an event would occur (spill risk), the probability that a resources of interest would be exposed to the spilled material (exposure risk), and the impacts that the event would have on such resources (impact risk).

A detailed interpretation of the catastrophic oil release scenario of all the oils from every wind turbine generator and the electrical service platform (All-Mix2-129K; all other scenarios in Appendix C) indicated, under realistic and worst case model outputs, potential moderate impacts to ecological and socioeconomic resources at all locations. However, as pointed put in Section 7, the probabilities of occurrence of these types of releases are very small. By contrast, the most likely types of releases (e.g., a release of up to a few thousand gallons of petroleum and non-petroleum oils) would cause minimal impacts, which would likely be limited spatially and temporally to the immediate vicinity of the point of release. The consequence analysis of petroleum and non-petroleum oils used a conservative approach biased towards overestimation of risks. Consequently, potential ecological and socioeconomic impacts may be actually lower than those presented here.

Similarly, release scenarios involving other chemicals of interest (sulfuric acid and glycols) show low to moderate risks to ecological resources (socioeconomic resources were not evaluated because of the very small area of exposure). As discussed in Section 7, while a release of 28,630 gallons of ethylene glycol exceeded the toxic threshold in the immediate vicinity of the point of release, this exceedance was short lived (peak concentrations lasting a few hours within a few hundred meters of the release site), suggesting that these analyses are conservative towards overprotection of aquatic resources. Furthermore, the thresholds used here were derived using information from 24-48 hour exposures, conditions which are unlikely to occur under real chemical spill conditions.

Some of the data gaps identified in these analyses include:

- There is limited information publically available on the types and volumes of chemicals used in wind energy facilities;
- Spill scenarios were developed in close collaboration with BOEM using the best available information. The oils and chemicals used in this assessment are representative of the types likely to be used in offshore wind facilities in the near term; however, new products are certain to be identified in the future;
- Fault tree analyses used a series of assumptions that could be refined based on information specific for each wind facility. While there were uncertainties in the generation of event probabilities, conservative assumptions were made possibly leading to greater than expected spill probabilities;
- Limited toxicity data are available for chemicals of concern, specifically glycols. However, based on chemical properties and on existing toxicity data, these chemicals are not expected to be acutely toxic; and
- Consequence analyses were based on a combination of assumptions related to the derivation of spill, exposure, and impact risk. As stated previously, conservative assumptions were made, which were carried over into these analyses.

In conclusion, the analyses presented here, based on relatively conservative assumptions, indicate that there may be moderate to low impacts only in the event of catastrophic releases. However, the probability of these spills occurring is extremely low. By contrast, more realistic releases of hydrocarbon and non-hydrocarbon oils and chemicals from offshore wind facilities are likely to result in low impacts when accounting for the spatial and temporal duration of exposures at or above conservative thresholds.

Future studies may be refined, if information on the types and volumes of chemicals used in wind energy facilities becomes publically available. Increased communication between BOEM, and wind energy facility developers and consultants may facilitate refinements to the current assessment. Similar analyses could also be performed in areas considered for potential development of wind energy projects. Collection of site specific information may also be needed in future fate and effects modeling efforts.

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Appendix A

Model Inputs

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A.1 SPILL SITE LOCATIONS

As discussed in Section 6.2.1 of the main report, the RPI team performed model simulations of potential oil and chemical spills at three representative WEA locations offshore the Atlantic Outer Continental Shelf.

The scale of each WEA was assumed to be similar to that proposed for the Cape Wind project (Minerals Management Service (MMS) 2009). For each geographic location, two points within the WEA were chosen to simulate spills from the ESP and WTG. In general, the locations for the WTGs were assumed to be farther offshore than those for the ESPs based on Green et al. 2007a). For the oil spill scenarios from the five WTGs, the release was assumed to occur from a polyline on the perimeter of each WEA. The catastrophic releases of all available oils from the entire wind facility WTGs and ESP were assumed to occur in a polygon with the dimensions of a typical wind facility (Green et al. 2007a). A description of these spill locations is provided in the following subsection for each geographic location.

Figures A.1 through A.3 provide a summary of the three spill sites for the Rhode Island-Massachusetts, Maryland and North Carolina geographic locations, respectively. The ESP and WTG spill sites are represented by the two point locations, while the spill location for the 5 WTGs is the blue polyline along the perimeter of each WEA. The entire WEA location for the catastrophic release of all oils is shown by the green polygon.

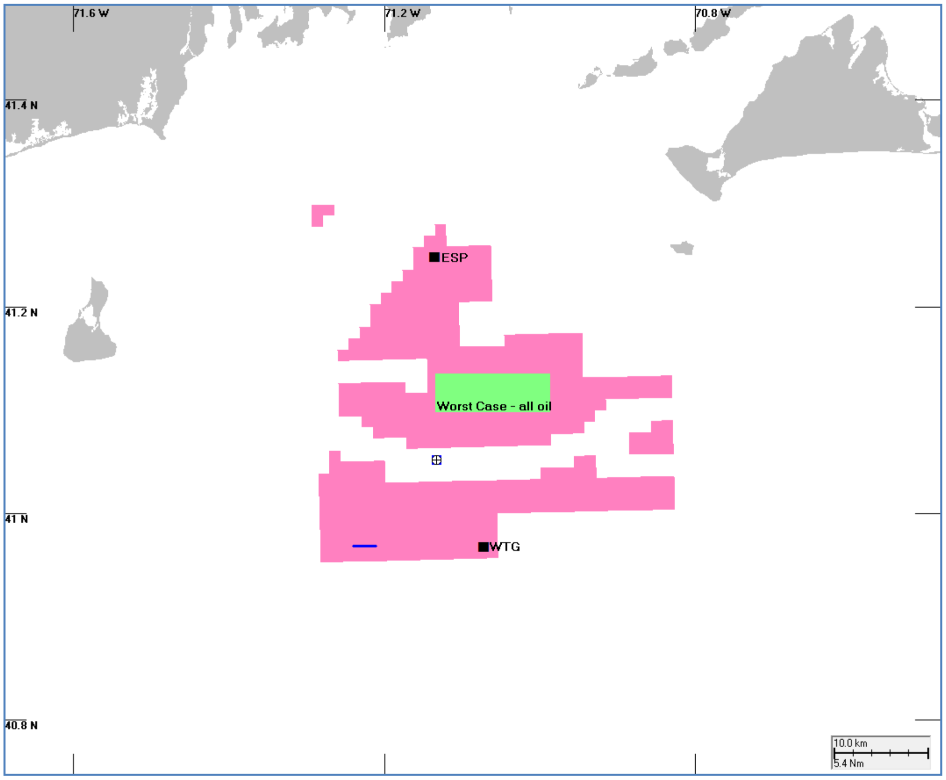

Figure A.1 Spill site locations within the Rhode Island-Massachusetts WEA.

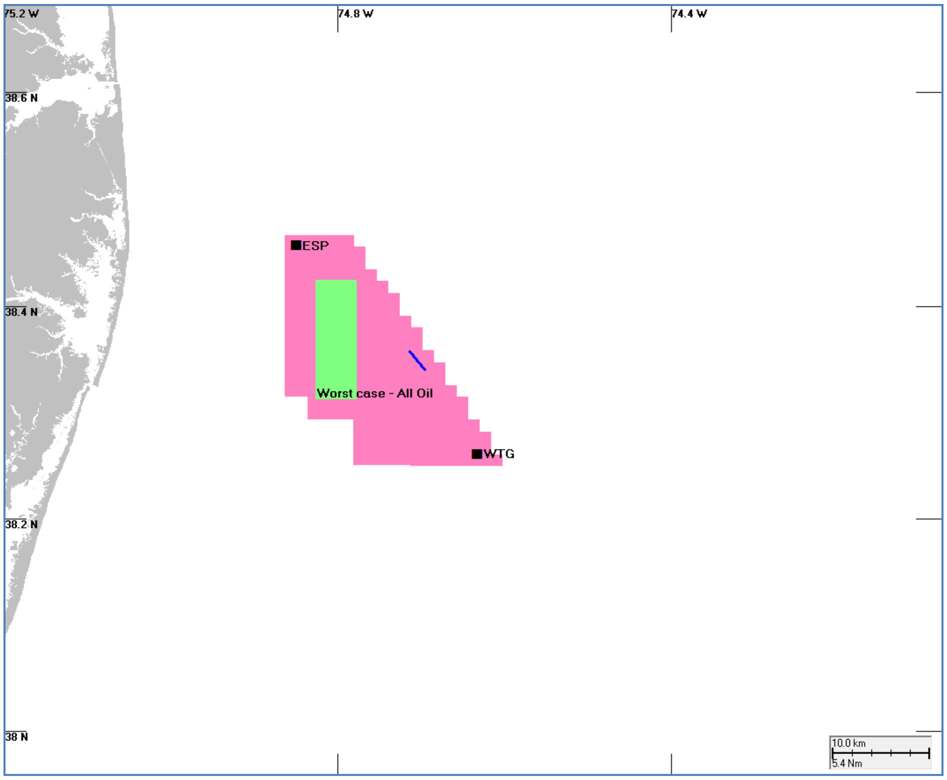

Figure A.2 Spill site locations within the Maryland WEA.

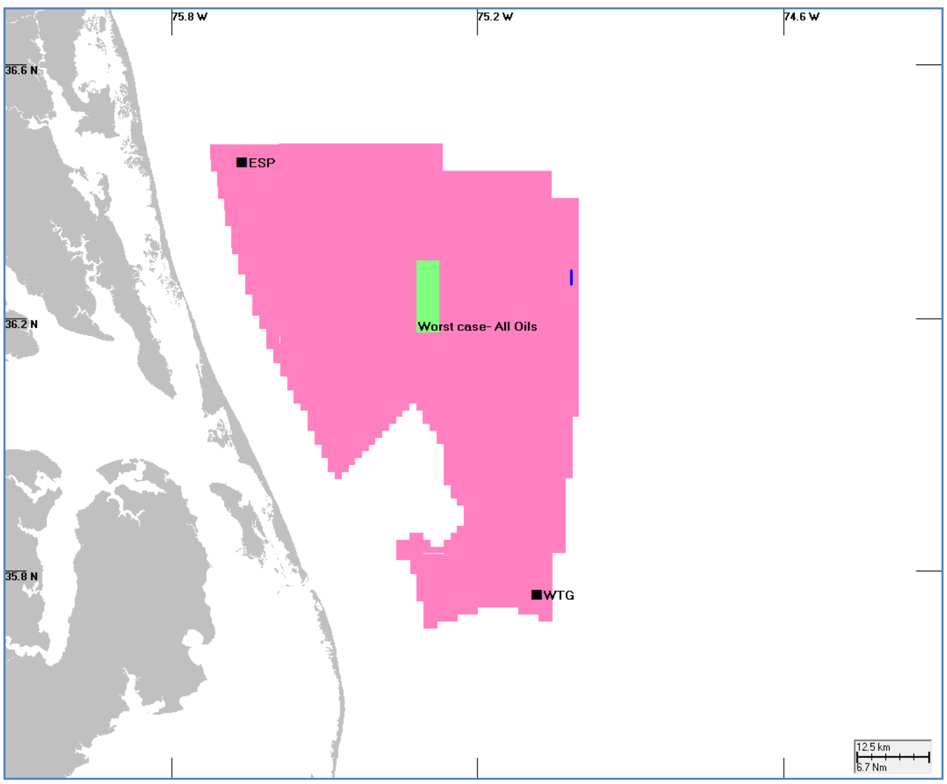

Figure A.3 Spill site locations within the North Carolina Call Area.

A.2 HABITAT AND DEPTH GRIDS

The digital shoreline, shore type, and habitat mapping for the three geographic locations were obtained from the Environmental Sensitivity Index (ESI) Atlas databases for the shorelines between Massachusetts to North Carolina (compiled by Research Planning, Inc. (RPI), and distributed by NOAA HAZMAT, Seattle, WA).

Depth data are typically obtained from bathymetric contours within the GEBCO Digital Atlas (BODC (GEBCO) et al. 2003).

The gridded habitat and depth data for all three locations are shown in Figures A.4 through A.9.

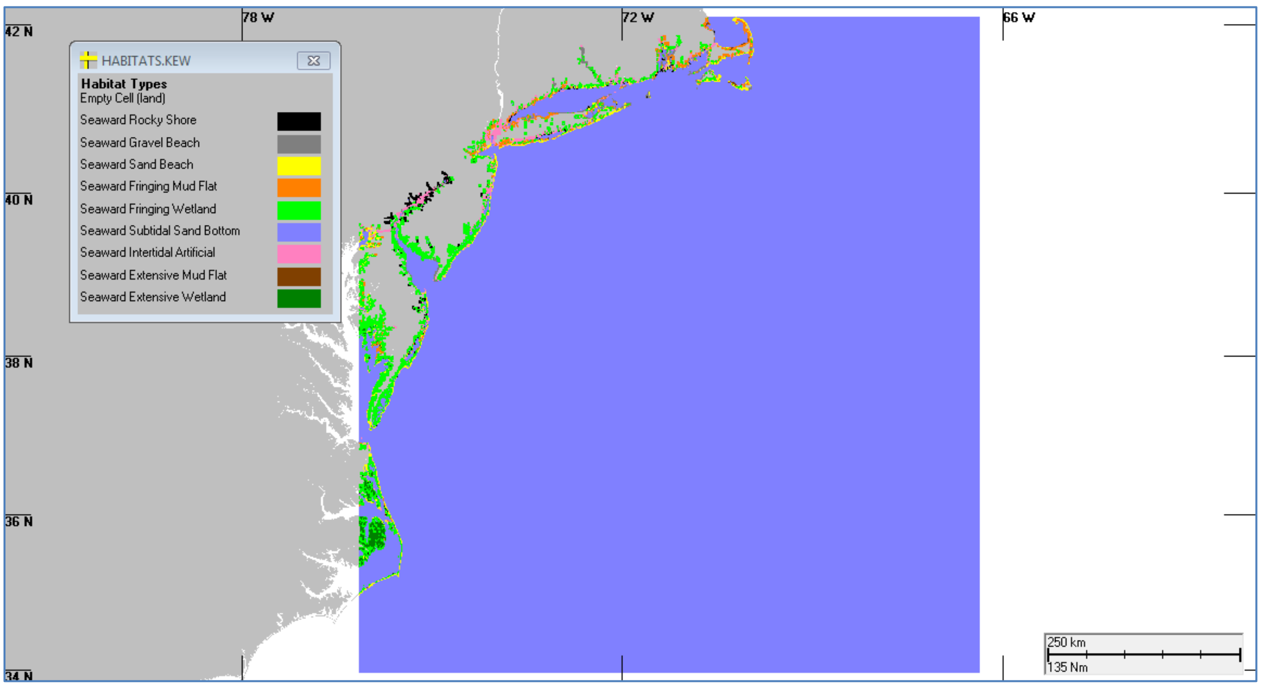

Figure A.4 Habitat grid developed for the Rhode Island-Massachusetts location.

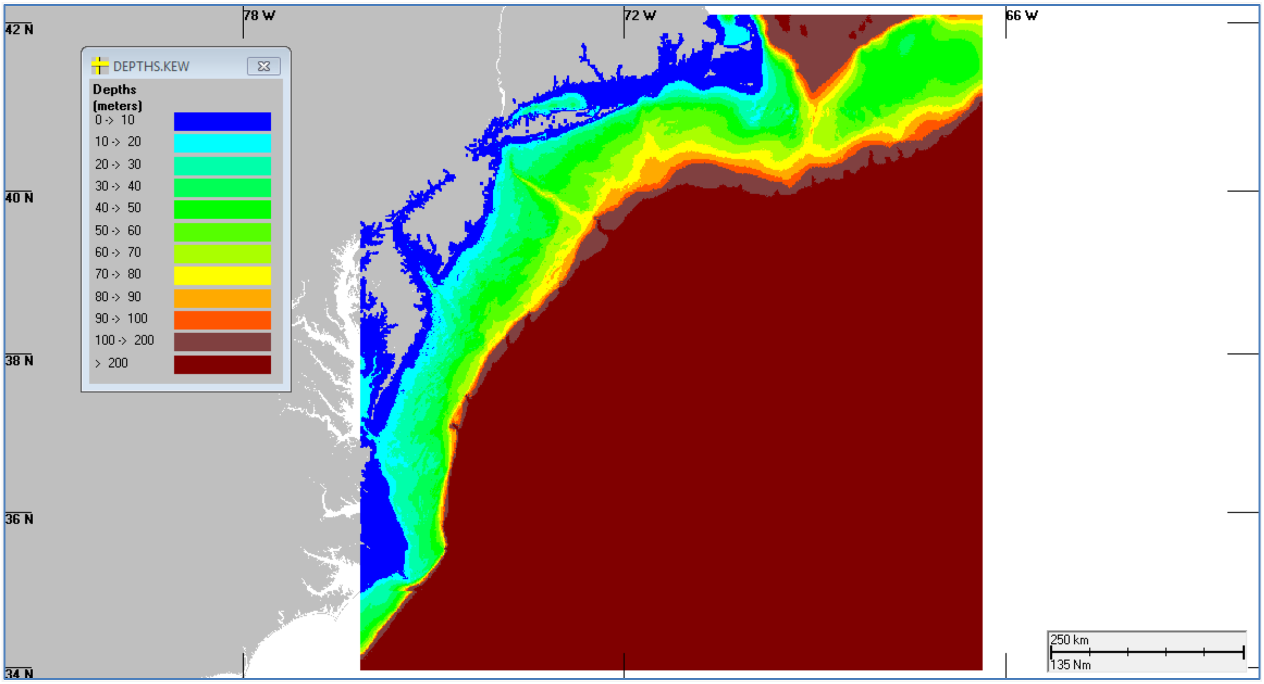

Figure A.5 Habitat grid developed for the Rhode Island-Massachusetts location.

Table A.1
Dimensions of the habitat grid cells used to compile statistics for Rhode Island-Massachusetts model runs.

Habitat grid	RIMA2_HABGRID.HAB
Grid W edge	76.143 ^{o} W
Grid S edge	33.971 ^{o} N
Cell size (^{o} longitude)	0.010^{o} W
Cell size (^{o} latitude)	0.010^{o} N
Cell size (m) west-east	902.19
Cell size (m) south-north	1,087.86
# cells west-east	1,000
# cells south-north	831
Water cell area (m^{2})	981,456.50
Shore cell length (m)	990.68
Shore cell width – Rocky shore (m)	2.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	3.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	140.0
Shore cell width – Wetlands (fringing, m)	140.0

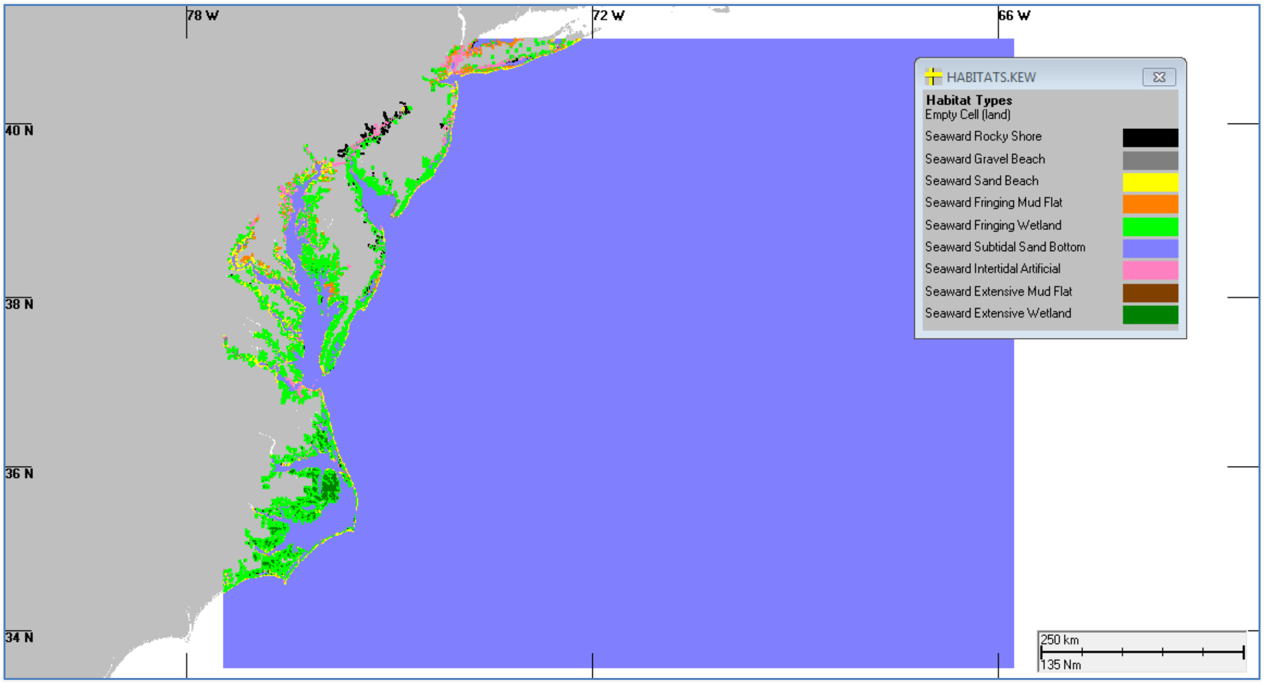

Figure A.6 Habitat grid developed for the Maryland location.

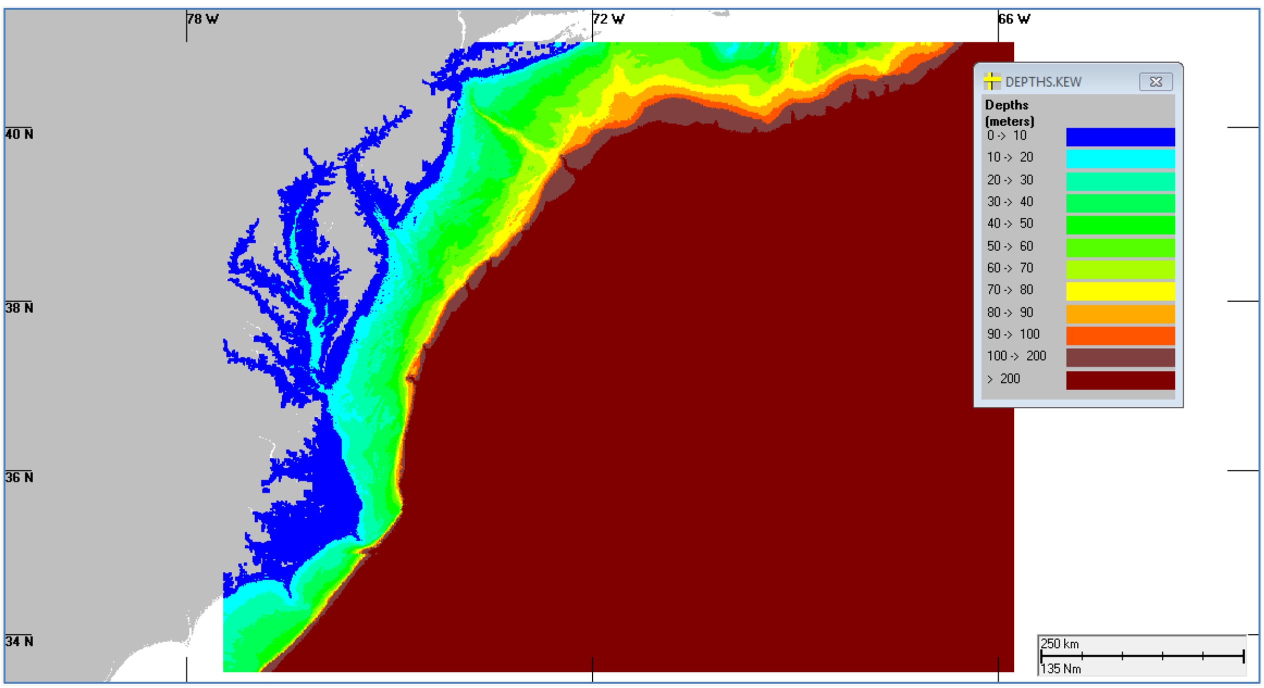

Figure A.7 Depth grid developed for the Maryland location.

Table A.2
Dimensions of the habitat grid cells used to compile statistics for Maryland model runs.

Habitat grid	MD3_HABGRID.HAB
Grid W edge	77.456 ° W
Grid S edge	33.552 ° N
Cell size (° longitude)	0.012° W
Cell size (° latitude)	0.012° N
Cell size (m) west-east	1,084.83
Cell size (m) south-north	1,301.71
# cells west-east	1,000
# cells south-north	633
Water cell area (m^2)	1,412,134.38
Shore cell length (m)	1,188.33
Shore cell width – Rocky shore (m)	2.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	3.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	140.0
Shore cell width – Wetlands (fringing, m)	140.0

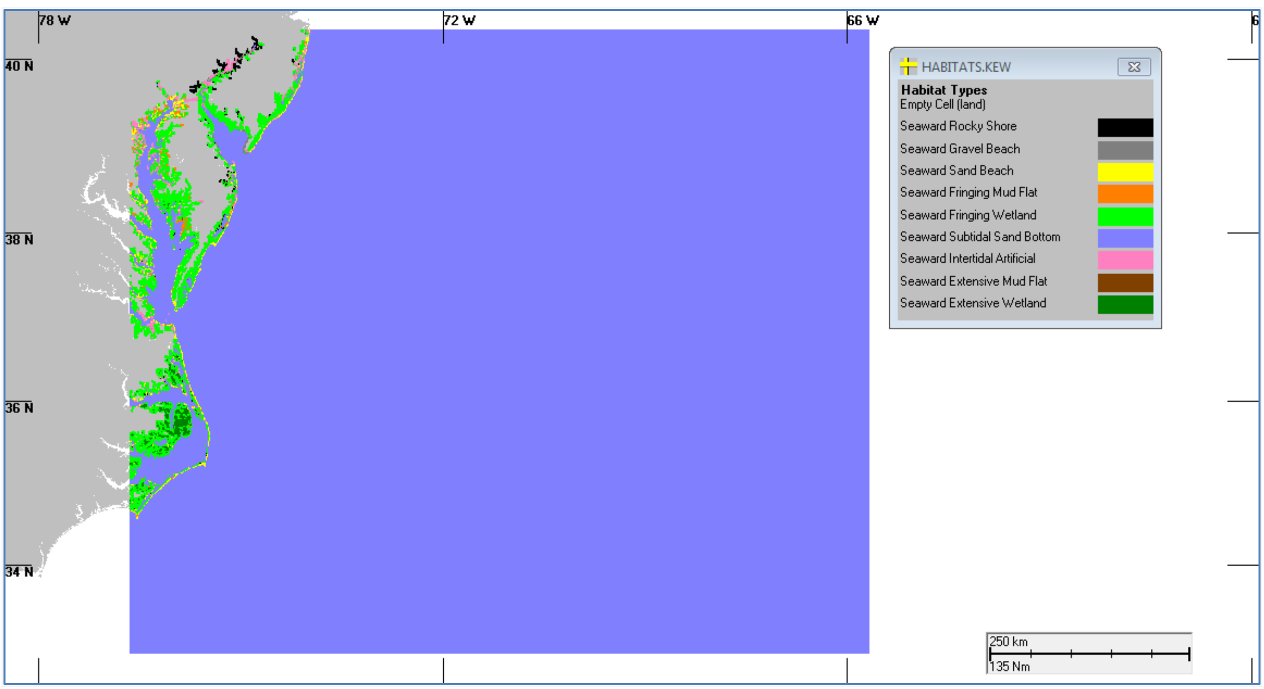

Figure A.8 Habitat grid developed for the North Carolina location.

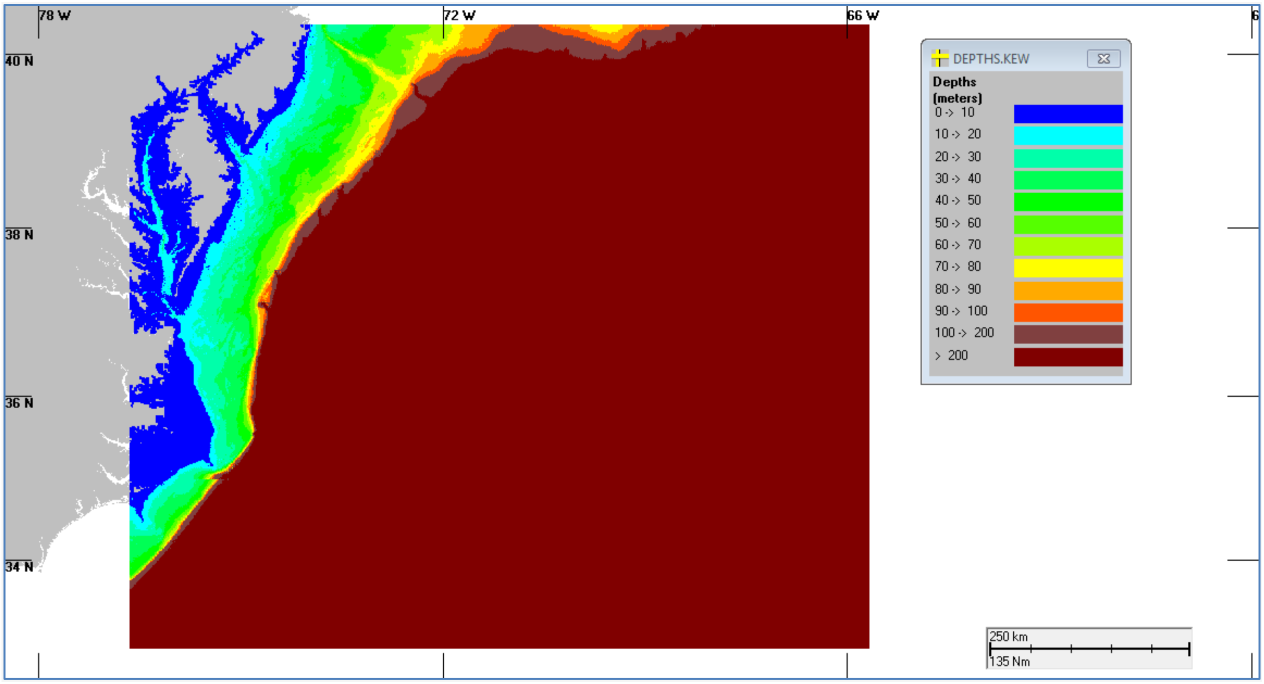

Figure A.9 Depth grid developed for the North Carolina location.

Table A.3

Dimensions of the habitat grid cells used to compile statistics for North Carolina model runs.

Habitat grid	NC2_HABGRID.HAB
Grid Wedge	76.643 ° W
Grid Sedge	32.908 ° N
Cell size (° longitude)	0.011° W
Cell size (° latitude)	0.011° N
Cell size (m) west-east	1,025.06
Cell size (m) south-north	1,220.98
# cells west-east	1,000
# cells south-north	677
Water cell area (m^2)	1,252,580.50
Shore cell length (m)	1,118.74
Shore cell width – Rocky shore (m)	2.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	3.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	140.0
Shore cell width – Wetlands (fringing, m)	140.0

A.3 CURRENTS

A.3.1 OIL SPILL SIMULATIONS

The same hydrodynamics file was used for oil spill modeling in all three geographic locations. Currents were based on the study "Mid-Atlantic Ocean Model Calculations" performed for BOEM by Xu and Oey (2011). The hydrodynamic model is the Princeton Ocean Model (The Princeton Ocean Model (POM) 1996), which includes wind, waves, rivers, tides, slope and shelf-break currents, the Gulf Stream, rings and eddies, as well as the large-scale Atlantic Ocean influences. The model operates a nesting scheme with ECCO (Estimating the Circulation and Climate of the Ocean; an MIT8 JPL-SIO consortium model based on the MIT GCM with data assimilation). The hindcast simulation (year 1993-2008) was forced by winds from the blended NCEP/QSCAT product and a regional high-resolution atmospheric model, surface heat and salt fluxes, weekly discharges from major rivers along the east coast, ECCO temperature and salinity fields as initial conditions, ECCO density and transport at the eastern PROFS (Princeton Regional Ocean Forecast System) open boundary in the Atlantic Ocean and tides. BOEM provided the hindcast data set, and ASA subsequently created a subset of surface velocities to the appropriate SIMAP domain for the period 1993 to June 2000. Figure A.10 provides an example of the current component data used in oil spill modeling for all three geographic locations.

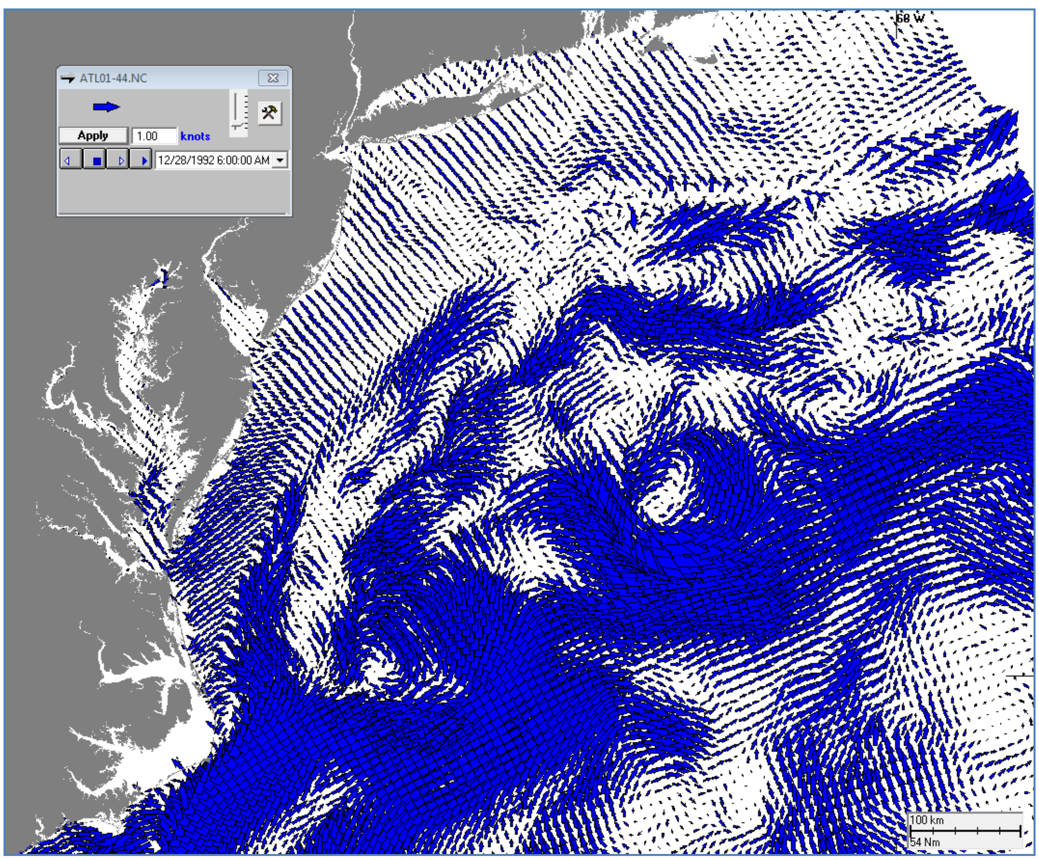

Figure A.10 Example of current component data used in oil modeling for all three geographic locations. Vector length indicates speed in the indicated direction.

In general, the currents are typically stronger offshore North Carolina as compared to areas further north off Maryland and Rhode Island due to the proximity of the Gulf Stream. The Gulf Stream usually detaches from the continental margin in the vicinity of Cape Hatteras in North Carolina (Gyory et al. 2013, Xu and Oey 2011, Worthington 1976, Knauss 1986 and Mann 1967).

A.3.2 Chemical Spill Simulations

Chemical spills were modeled through 3D fates scenarios in the immediate vicinity of the spills sites within each WEA, as described in Section 6.1.2 of the main report, using representative current vectors from the BOEM POM model described above for the oil spill modeling (Section 3.1, Figure A.10). For each geographic location, the currents vectors were observed over time to determine a one day period of constant speed and direction. This period was then used to model the release of chemicals over the course of one day as the thresholds of concern (Section 5.2.2 of the main report) were only exceeded for the first few hours after the release. Figures A.11, A.12, and A.13 provide a snapshot of the currents used for this modeling.

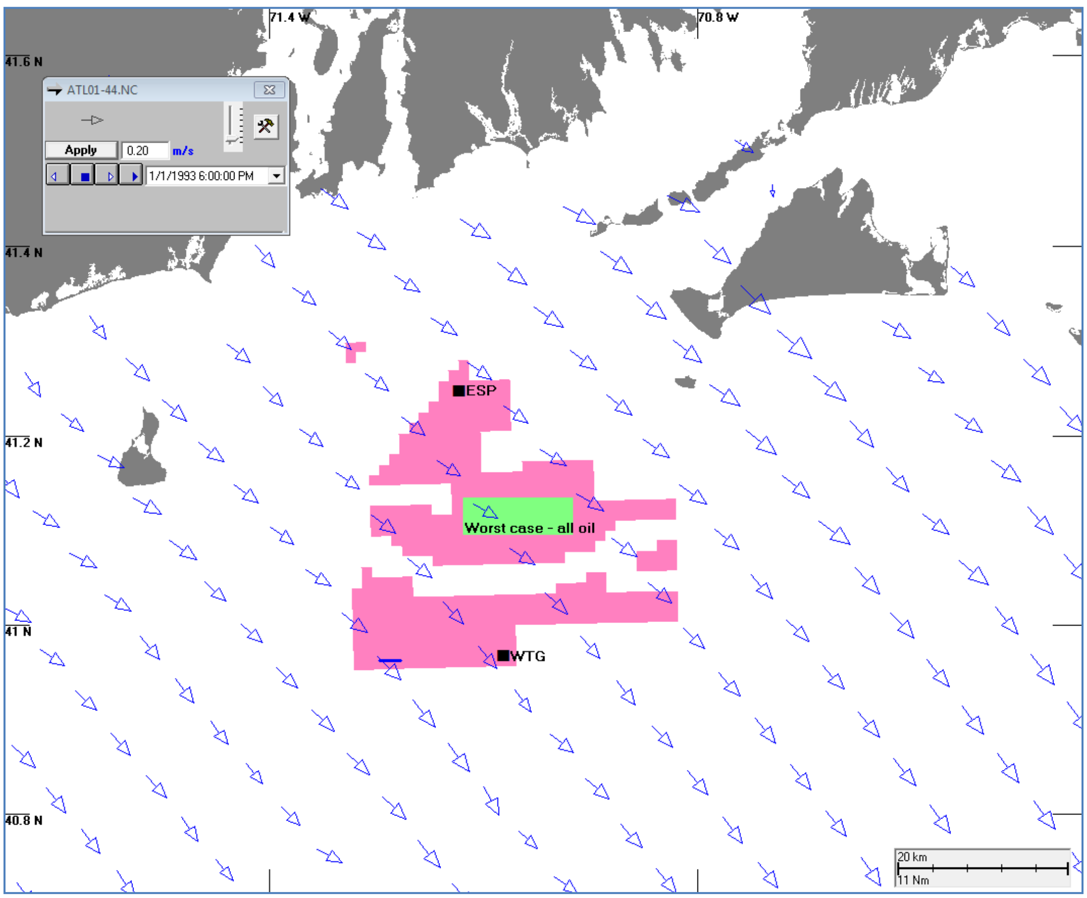

Figure A.11 Example of current component data used in chemical spill modeling for the Rhode Island-Massachusetts location. Vector length indicates speed in the indicated direction.

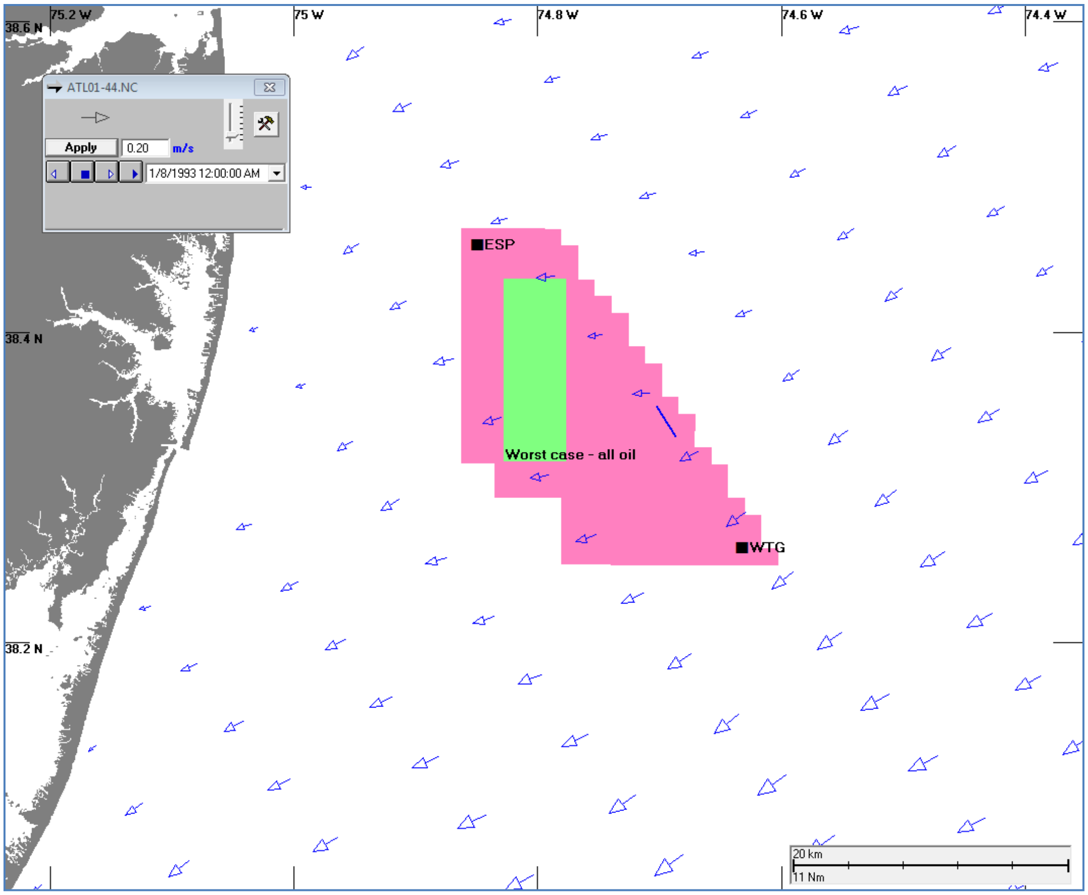

Figure A.12 Example of current component data used in chemical spill modeling for the Maryland location. Vector length indicates speed in the indicated direction.

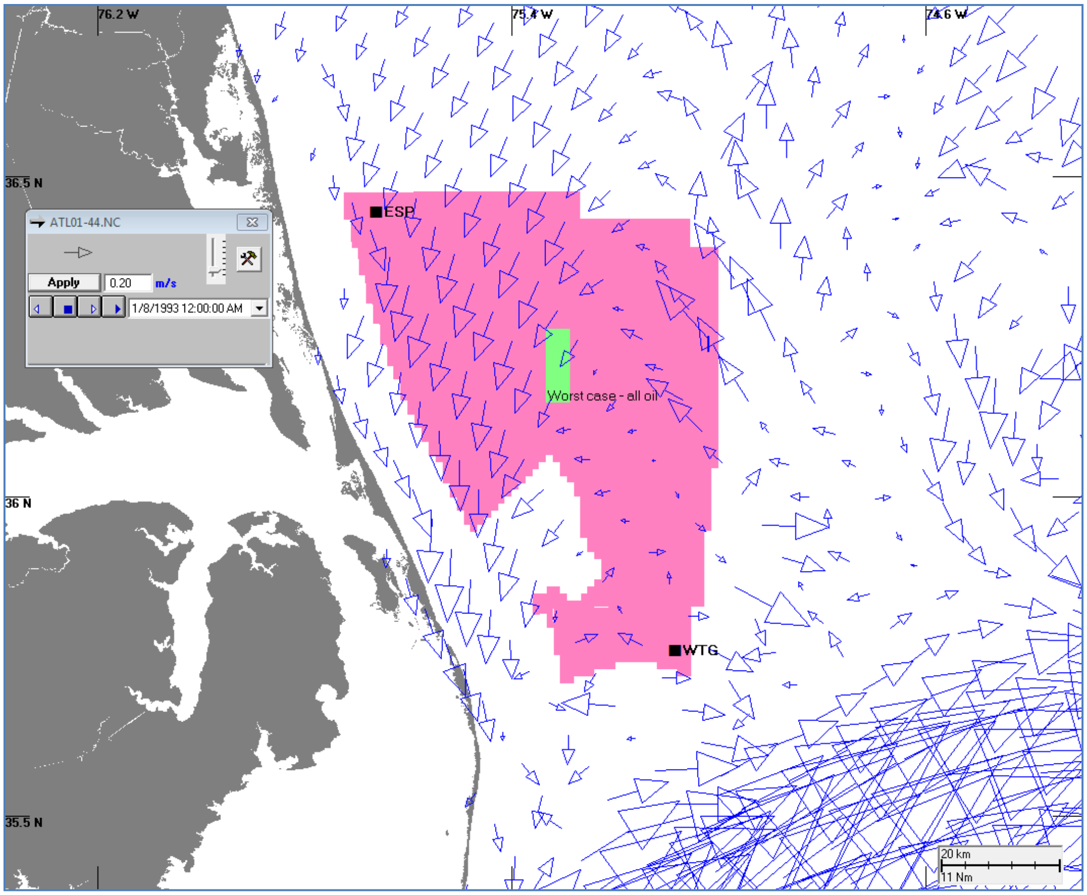

Figure A.13 Example of current component data used in chemical spill modeling for the North Carolina location. Vector length indicates speed in the indicated direction.

A.4 WINDS

For the Rhode Island-Massachusetts WEA, standard meteorological data were acquired from the National Data Buoy Center Internet site for the nearest NDBC buoys, number 44025, "Long Island – 30NM South of Islip, NY," at 40.250°N, 73.167°W and number 44008, "Nantucket 54NM Southeast of Nantucket," at 40.502°N, 69.247°W. Hourly mean wind speed and direction for 44025 buoy over the time period 12/28/1992 to 3/19/2000 and for 44008 buoy over the time period 4\15\1993 to 3\19\2000 were compiled in the SIMAP model input file format.

For the Maryland WEA, standard meteorological data were acquired from the National Data Buoy Center Internet site for the nearest NDBC buoys, number 44009, "Delaware Bay," at 38.464°N, 74.702°W and number 44014, "Virginia Beach 64NM East of Virginia Beach," at 36.611°N, 74.842°W. Hourly mean wind speed and direction for the time period 12/27/1992 to 2/19/2000 for buoy 44009 and 12/28/1992 to 3/19/2000 for buoy 44014 were compiled in the SIMAP model input file format.

For the North Carolina Call Area, standard meteorological data were acquired from the National Data Buoy Center Internet site for the nearest NDBC buoys, number 44014, "Virginia Beach 64NM East of Virginia Beach," at 36.611°N, 74.842°W, number DSLN7, "Diamond Shls

Lt, NC," at 35.153°N, 75.297°W, and number FPSN7, "Frying Pan Shoals, NC," at 33.485°N, 77.590°W. Hourly mean wind speed and direction for the time period 12/28/1992 to 3/19/2000 for all three buoys were compiled in the SIMAP model input file format.

A.5 OIL AND CHEMICAL TYPES

A.5.1 OIL PROPERTIES

Tables A.4 to A.10 provide the properties of the oils modeled in SIMAP, as outlined in Table 2.12 of the main report. In general, the diesel oil and lubricating oil to be used were ones that were already present in RPS ASA's SIMAP oil database. The properties for these oils are provided in Tables A.4 and A.5, below. Further research was done on the transformer mineral oil and hydraulic oil to determine their properties for modeling, as they were not currently present in the SIMAP oil database. The summary of that research is provided below, and the properties of those oils are presented in Tables A.6 and A.7, below. To account for the oil mixtures to be modeled in the releases from the 5 WTGs and the catastrophic release from the entire wind facility (SIMAP Scenarios 5WTG-Mix1-3.4K and All-Mix2-129K in Table 2.12 of the main report), a weighted sum of the different oil types to potentially be spilled was derived. The properties for the two oil mixtures are provided in Tables A.8 and A.9, below. Table A.10 provides properties, specifically for degradation and adsorption that are shared among all 4 oils.

Table A.4

Oil properties for Diesel oil used in SIMAP simulations.

Property	Value	Reference
Density @ 25°C (g/cm^3)	0.831	Jokuty et al. (1999)*
Viscosity @ 25°C (cp)	2.76	Jokuty et al. (1999)*
Surface Tension (dyne/cm)	27.5	Jokuty et al. (1999)*
Pour Point (°C)	-50	Jokuty et al. (1999)*
Fraction monoaromatic hydrocarbons (MAHs)	0.019	Jokuty et al. (1999)*
Fraction 2-ring aromatics	0.011	Jokuty et al. (1999)*
Fraction 3-ring aromatics	0.016	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point < 180°C	0.145	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 180-264°C	0.479	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 264-380°C	0.303	Jokuty et al. (1999)*
Minimum Oil Thickness (mm)	0.00001	McAuliffe (1987)
Maximum Mousse Water Content (%)	0	-
Mousse Water Content as Spilled (%)	0	-
Water content of oil (not in mousse, %)	0	-

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

Table A.5
Oil properties for Lubricating oil used in SIMAP simulations.

Property	Value	Reference
Density @ 25°C (g/cm^3)	0.875	Whiticar et al. (1994)
Viscosity @ 25°C (cp)	157	Whiticar et al. (1994)
Surface Tension (dyne/cm)	16.6	Whiticar et al. (1994)
Pour Point (°C)	-39	Whiticar et al. (1994)
Fraction monoaromatic hydrocarbons (MAHs)	0	Whiticar et al. (1994)
Fraction 2-ring aromatics	0.005	French et al. (1996)
Fraction 3-ring aromatics	0.010	French et al. (1996)
Fraction Non-Aromatics: boiling point < 180°C	0	French et al. (1996)
Fraction Non-Aromatics: boiling point 180-264°C	0.035	French et al. (1996)
Fraction Non-Aromatics: boiling point 264-380°C	0.030	French et al. (1996)
Minimum Oil Thickness (mm)	0.0001	NRC (1985); field data from actual spills
Maximum Mousse Water Content (%)	0	-
Mousse Water Content as Spilled (%)	0	-
Water content of oil (not in mousse, %)	0	-

Table A.6
Oil properties for Naphthenic Mineral oil used in SIMAP simulations.

Property	Value	Reference
Density @ 25°C (g/cm^3)	0.864	Anderson et al (2003); UFA (2008)
Viscosity @ 25°C (cp)	14.01	Anderson et al (2003); UFA (2008)
Surface Tension (dyne/cm)	25.7	Anderson et al (2003); UFA (2008)
Pour Point (°C)	N/A	[assumed liquid]
Fraction monoaromatic hydrocarbons (MAHs)	0	Kaplan et al. (2010)
Fraction 2-ring aromatics	0.0001	Kaplan et al. (2010)
Fraction 3-ring aromatics	0.0002	Kaplan et al. (2010)
Fraction Non-Aromatics: boiling point < 180°C	0	Kaplan et al. (2010)
Fraction Non-Aromatics: boiling point 180-264°C	0.333	Kaplan et al. (2010)
Fraction Non-Aromatics: boiling point 264-380°C	0.238	Kaplan et al. (2010)
Minimum Oil Thickness (mm)	0.0001	NRC (1985); field data from actual spills
Maximum Mousse Water Content (%)	0	-
Mousse Water Content as Spilled (%)	0	-
Water content of oil (not in mousse, %)	0	-

Table A.7
Oil properties for Hydraulic oil used in SIMAP simulations.

Property	Value	Reference
Density @ 25°C (g/cm^3)	0.867	Anderson et al (2003); UFA (2008)
Viscosity @ 25°C (cp)	31.58	Anderson et al (2003); UFA (2008)
Surface Tension (dyne/cm)	25.7	Anderson et al (2003); UFA (2008)
Pour Point (°C)	N/A	[assumed liquid]
Fraction monoaromatic hydrocarbons (MAHs)	0	Wang et al. (2002)
Fraction 2-ring aromatics	0.000005	Wang et al. (2002)
Fraction 3-ring aromatics	0.000002	Wang et al. (2002)
Fraction Non-Aromatics: boiling point < 180°C	0	Kaplan et al (2010)
Fraction Non-Aromatics: boiling point 180-264°C	0.333	Kaplan et al (2010)
Fraction Non-Aromatics: boiling point 264-380°C	0.238	Kaplan et al (2010)
Minimum Oil Thickness (mm)	0.0001	NRC (1985); field data from actual spills
Maximum Mousse Water Content (%)	0	-
Mousse Water Content as Spilled (%)	0	-
Water content of oil (not in mousse, %)	0	-

Table A.8
Oil properties for Oil Mixture 1 used in SIMAP simulations.

Property	Value	Reference
Density @ 25°C (g/cm^3)	0.87	Weighted average of 3 oils*
Viscosity @ 25°C (cp)	62.60	Weighted average of 3 oils*
Surface Tension (dyne/cm)	22.76	Weighted average of 3 oils*
Pour Point (°C)	-12.62	Weighted average of 3 oils*
Fraction monoaromatic hydrocarbons (MAHs)	0.00	Weighted average of 3 oils*
Fraction 2-ring aromatics	0.00	Weighted average of 3 oils*
Fraction 3-ring aromatics	0.00	Weighted average of 3 oils*
Fraction Non-Aromatics: boiling point < 180°C	0.00	Weighted average of 3 oils*
Fraction Non-Aromatics: boiling point 180-264°C	0.24	Weighted average of 3 oils*
Fraction Non-Aromatics: boiling point 264-380°C	0.17	Weighted average of 3 oils*
Minimum Oil Thickness (mm)	0.00	Weighted average of 3 oils*
Maximum Mousse Water Content (%)	23.29	Weighted average of 3 oils*
Mousse Water Content as Spilled (%)	0.00	-
Water content of oil (not in mousse, %)	0.00	-

*Weighted average of Naphthenic oil 12-260, Hydraulic oil 12-260, and Lubricating oil 12-260

Table A.9
Oil properties for Oil Mixture 2 used in SIMAP simulations.

Property	Value	Reference
Density @ 25°C (g/cm^3)	0.86	Weighted average of 4 oils*
Viscosity @ 25°C (cp)	43.89	Weighted average of 4 oils*
Surface Tension (dyne/cm)	24.24	Weighted average of 4 oils*
Pour Point (°C)	-24.30	Weighted average of 4 oils*
Fraction monoaromatic hydrocarbons (MAHs)	0.01	Weighted average of 4 oils*
Fraction 2-ring aromatics	0.00	Weighted average of 4 oils*
Fraction 3-ring aromatics	0.01	Weighted average of 4 oils*
Fraction Non-Aromatics: boiling point < 180°C	0.05	Weighted average of 4 oils*
Fraction Non-Aromatics: boiling point 180-264°C	0.31	Weighted average of 4 oils*
Fraction Non-Aromatics: boiling point 264-380°C	0.21	Weighted average of 4 oils*
Minimum Oil Thickness (mm)	0.00	Weighted average of 4 oils*
Maximum Mousse Water Content (%)	16.01	Weighted average of 4 oils*
Mousse Water Content as Spilled (%)	0.00	-
Water content of oil (not in mousse, %)	0.00	-

*Weighted average of Naphthenic oil 12-260, Hydraulic oil 12-260, Lubricating oil 12-260, and Diesel 2002 12-260

Table A.10
Shared oil properties for all oils used in SIMAP simulations

Property	Value	Reference
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Degradation Rate (/day), Surface and Shore	0.01	French et al. (1996)
Degradation Rate (/day), Hydrocarbons in Water	0.01	French et al. (1996)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)
Degradation Rate (/day), Aromatics in Water	0.01	Mackay et al. (1992)
Degradation Rate (/day), Aromatics in Sediment	0.001	Mackay et al. (1992)

A.5.2 CHEMICAL PROPERTIES

Tables A.11 to A.13 provide the properties of the chemicals modeled in CHEMMAP, as outlined in Table 2.13 of the main report. In general, the chemicals to be used were ones that were already present in RPS ASA’s CHEMMAP chemical database, and no further research was required to determine their chemical properties.

Table A.11
Chemical properties for Ethylene glycol used in CHEMMAP simulations.

Property	Value	Reference
Density @ 25 ^{o}C (g/cm^{3})	1.14	Environment Canada (1984)
Viscosity @ 25 ^{o}C (cp)	5.46	Lyman et al. (1982)
Vapor Pressure at 25^{o}C (atm)	1.18E-04	Mackay et al. (1992)
Octanol-Water Partition Coefficient as Log K_{OW}	-1.36	Mackay et al. (1992)
Sorption Partition Coefficient for organic carbon as Log K_{OC}	-1.34	Di Toro et al. (1991)
Seawater Solubility @ 25 ^{o}C (ppm)	1,000,000	Mackay et al. (1992)
Degradation Rate in Water @ 25 ^{o}C (/day)	0.3024	Mackay et al. (1992)

Table A.12
Chemical properties for Propylene glycol used in CHEMMAP simulations.

Property	Value	Reference
Density @ 25°C (g/cm^{3})	1.14	NIH/EPA (1983)
Viscosity @ 25°C (cp)	3.732	Lyman et al. (1982)
Vapor Pressure at 25°C (atm)	2.105E-04	NIH/EPA (1983)
Octanol Water Partition Coefficient as Log K_{OW}	0.77	Di Toro et al. (1991)
Sorption Partition Coefficient for organic carbon as Log K_{OC}	0.76	US EPA (1986)
Seawater Solubility @ 25 ^{o}C (ppm)	1,000,000	NIH/EPA (1983)
Degradation Rate in Water @ 25 ^{o}C (/day)	0.02132	French et al. (1996)

Table A.13
Chemical properties for Sulfuric acid used in CHEMMAP simulations.

Property	Value	Reference
Density @ 25°C (g/cm^{3})	1.84	NIH/EPA (1983)
Viscosity @ 25°C (cp)	21.0	Environment Canada (1984)
Vapor Pressure at 25°C (atm)	1.32E-06	NIH/EPA (1983)
Octanol Water Partition Coefficient as Log K_{OW}	0.31	Di Toro et al. (1991)
Sorption Partition Coefficient for organic carbon as Log K_{OC}	0.31	French et al. (1996)
Seawater Solubility @ 25 ^{o}C (ppm)	1,000,000	NIH/EPA (1983)
Degradation Rate in Water @ 25 ^{o}C (/day)	0.01899	French et al. (1996)

A.6 REFERENCES

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Appendix B

Fault Tree Designs for Spill Scenarios

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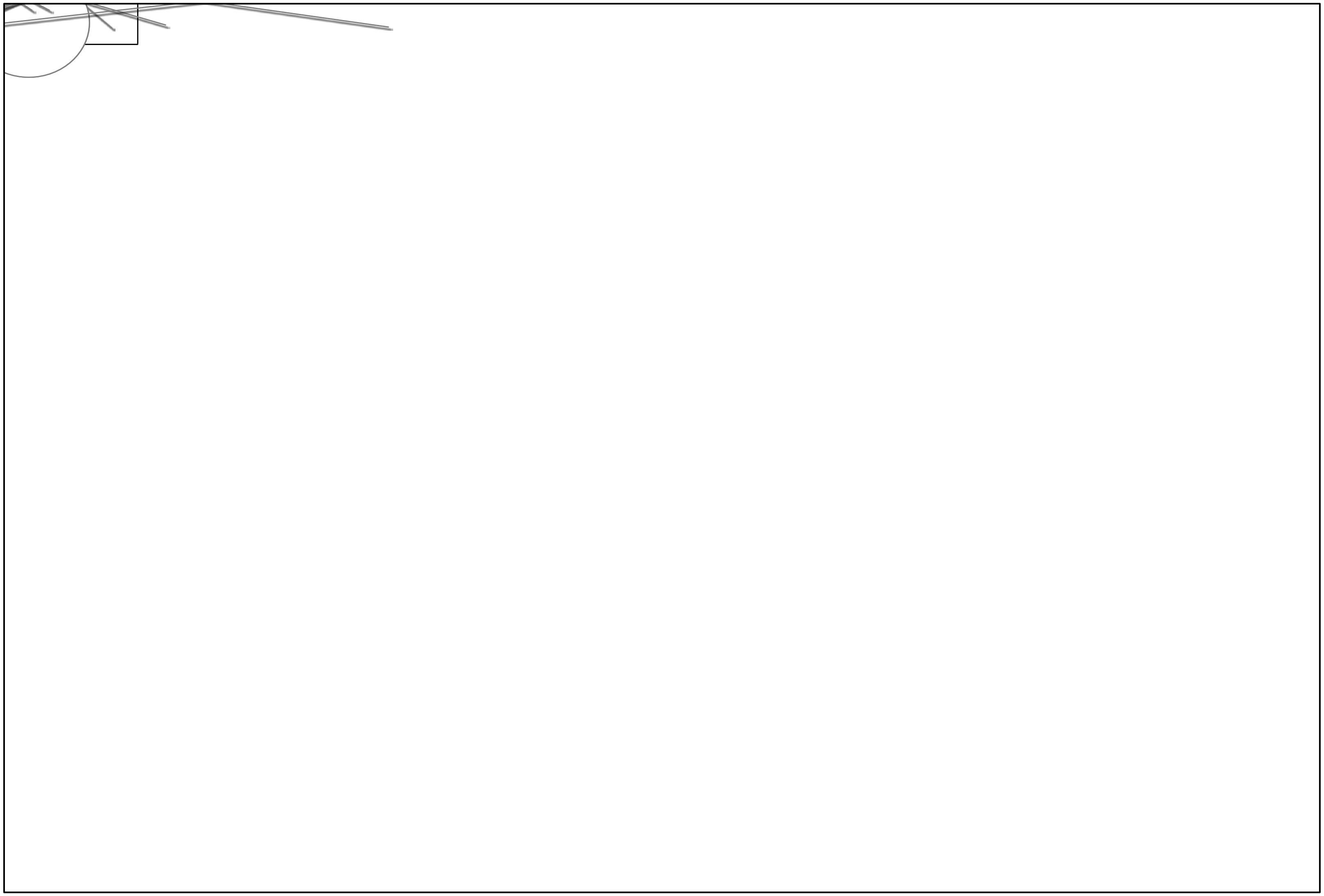

Figure B.1 Fault tree design for 1,000-gallon naphthenic oil spill scenario.

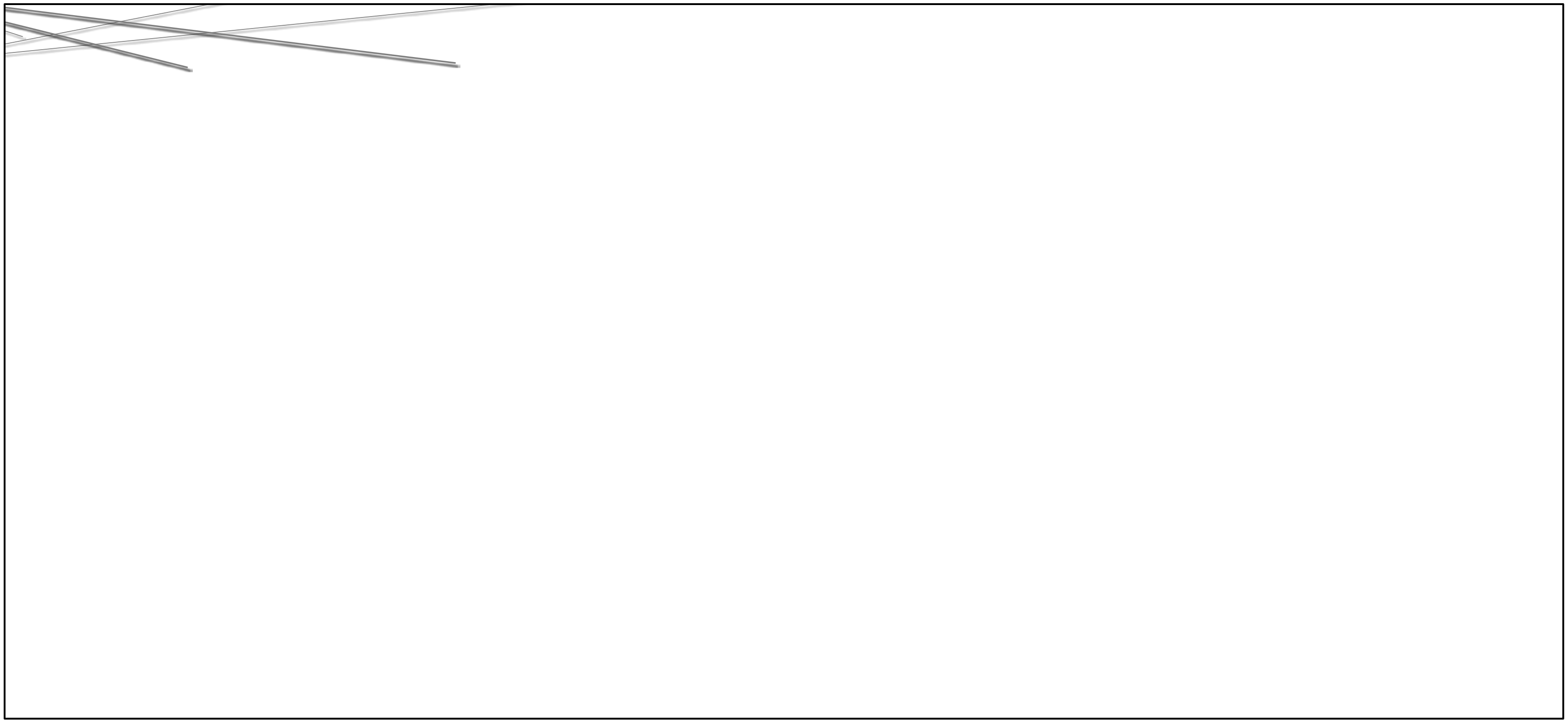

Figure B.2 Fault tree design for 2,000-gallon diesel spill scenario.

Figure B.3 Fault tree design for 10,000-gallon naphthenic oil spill scenario.

Figure B.4 Fault tree design for 40,000-gallon naphthenic oil spill scenario.

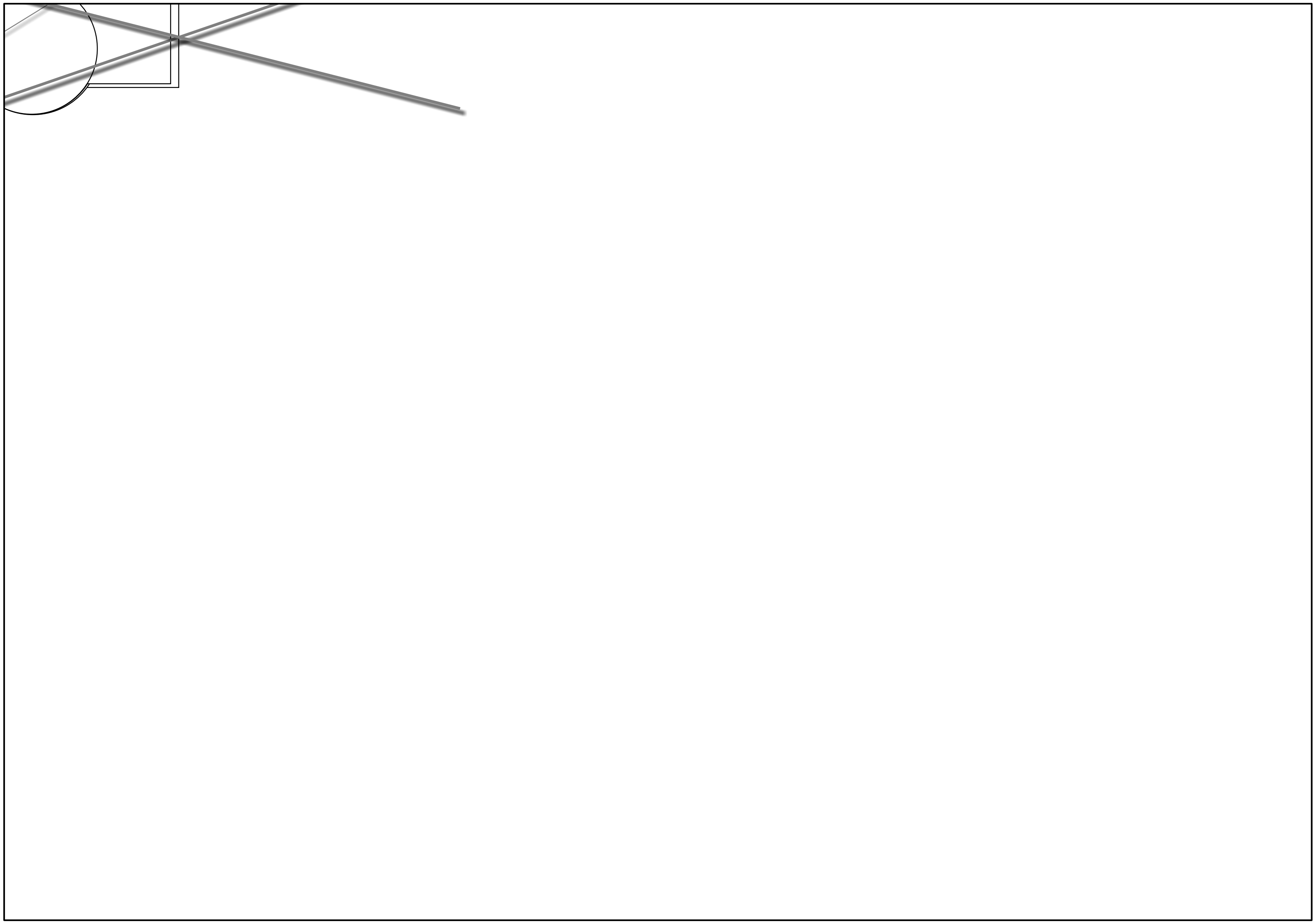

Figure B.5 Fault tree design for 30-gallon ethylene glycol spill scenario.

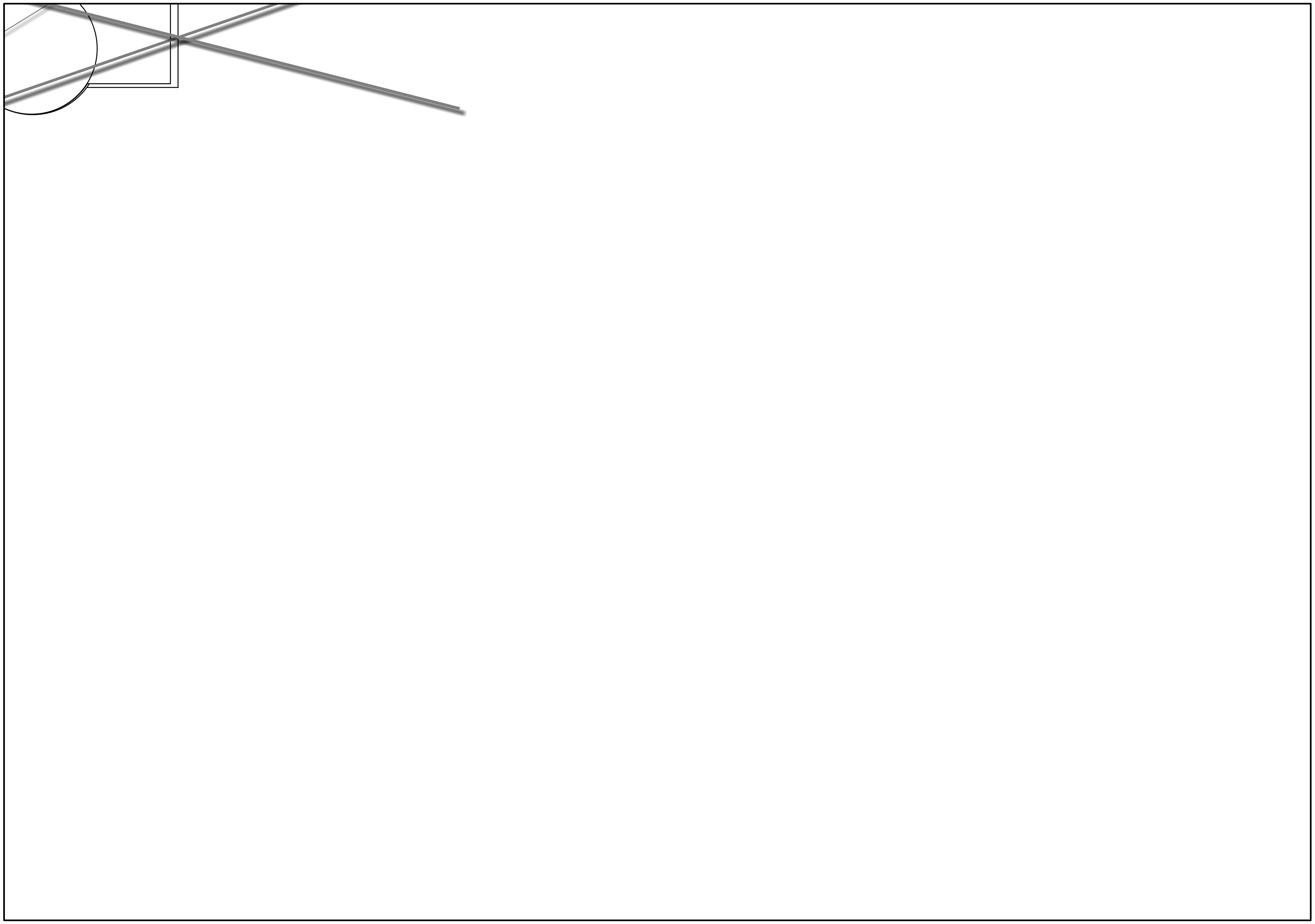

Figure B.6 Fault tree design for 335-gallon sulfuric acid spill scenario.

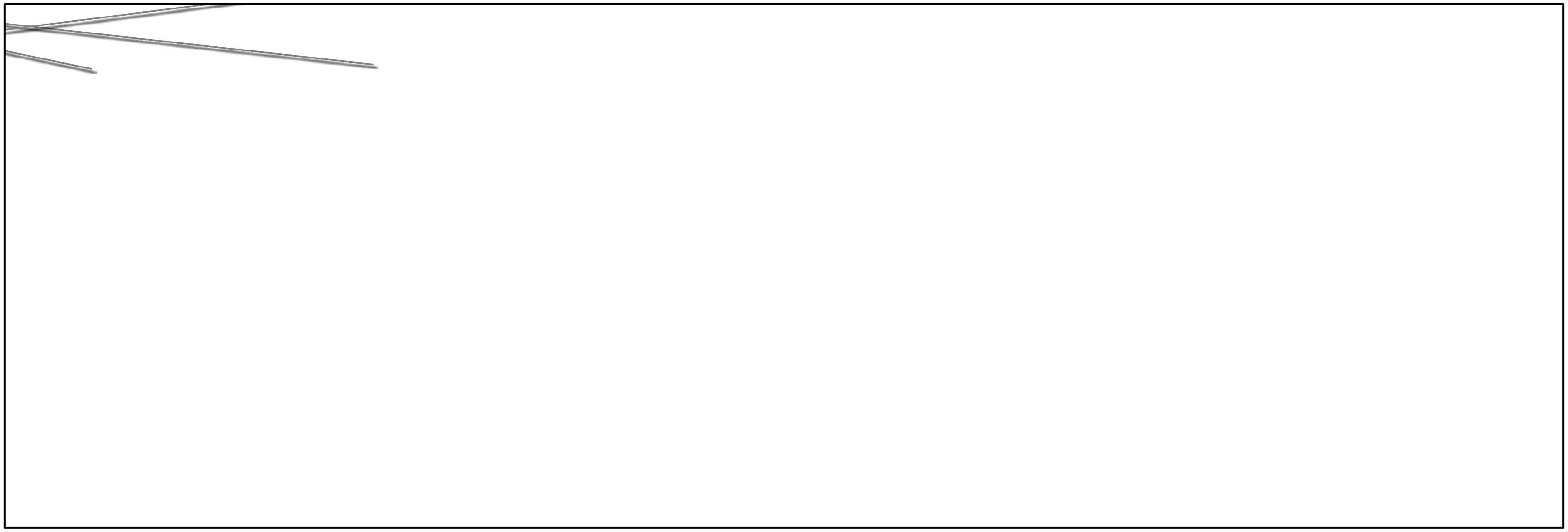

Figure B.7 Fault tree design for 90-gallon hydraulic oil spill scenario.

Figure B.8 Fault tree design for 370-gallon naphthenic oil spill scenario.

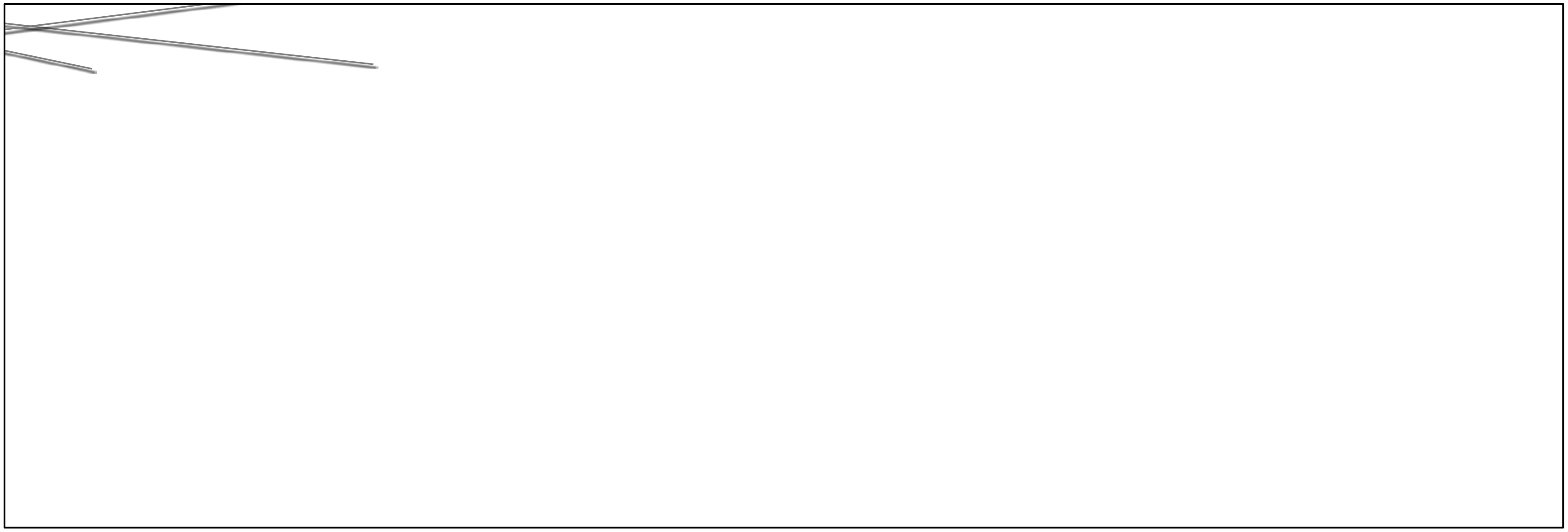

Figure B.9 Fault tree design for 220-gallon lubricating oil spill scenario.

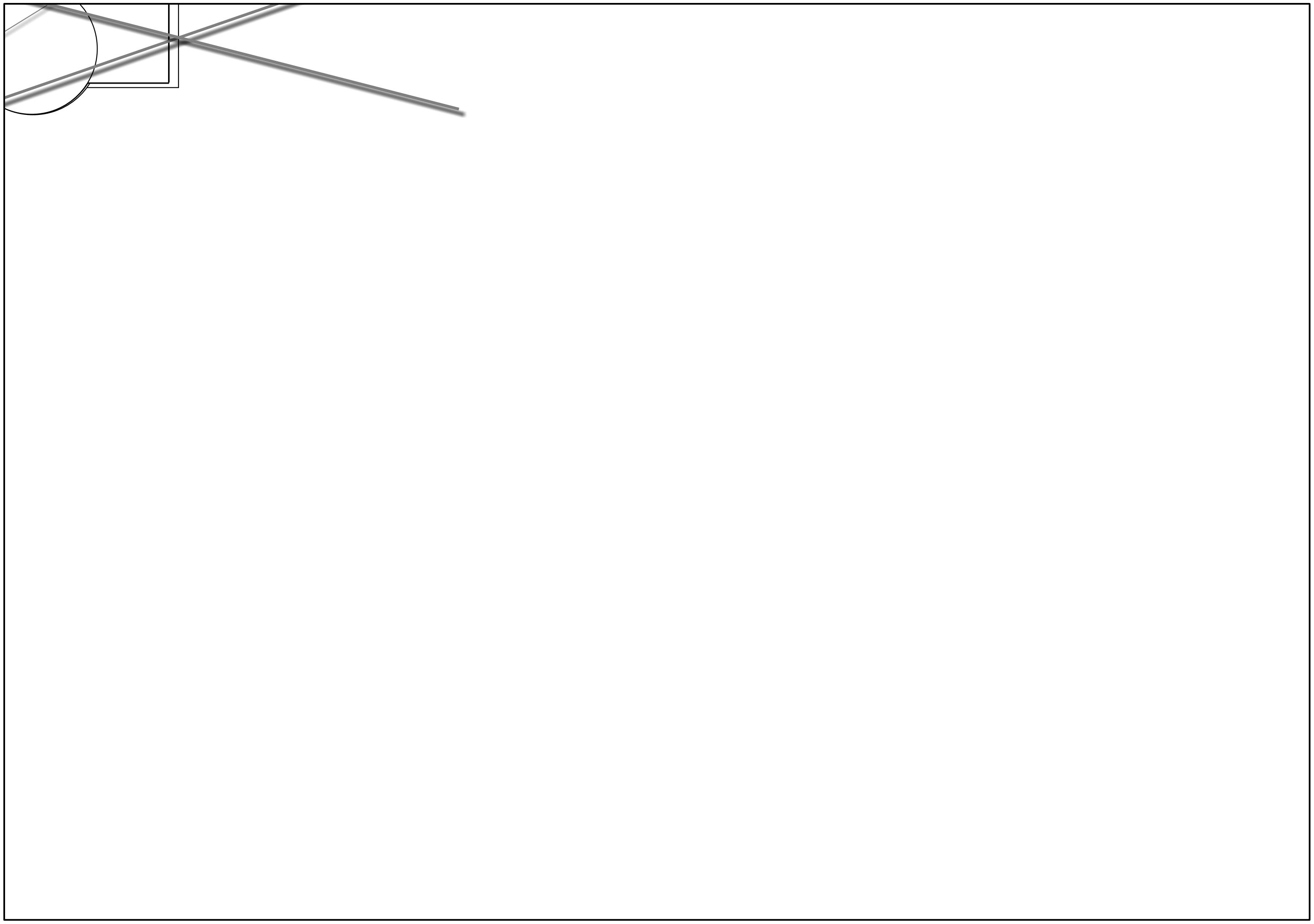

Figure B.10 Fault tree design for 128,600-gallon oil mixture 2 spill scenario.

Figure B.11 Fault tree design for 3,400-gallon oil mixture 1 spill scenario.

Appendix C

Model Maps

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C.1 APPENDIX OVERVIEW

This appendix contains model output maps for spill scenarios at each of the areas of interest. Maps were generated only when exceedances were found across the 200 individual model simulations of a particular modeling scenario. Oil spill model scenario names are as shown in Table C.1.

Table C.1
Potential spill volumes for modeling of impacts of wind turbine-related oil spills.

Scenario Name	Volume (gal)	Oil Type	Situation
ESP-Nap-500	500	Naphthenic mineral oil	ESP transformer maintenance/transfer (small)
ESP-Nap-1K	1,000	Naphthenic mineral oil	ESP transformer maintenance/transfer (large)
ESP-Nap-10K	10,000	Naphthenic mineral oil	ESP transformer impact accident (one transformer)[1]
ESP-Nap-40K	40,000	Naphthenic mineral oil	ESP transformer impact accident (four transformers)
ESP-Diesel-2K	2,000	Diesel	ESP transformer impact accident (two day tanks) during maintenance/transfer
WTG-Hyd-90	90	Hydraulic oil	WTG nacelle impact accident
WTG-Nap-370	370	Transformer oil[2]: Naphthenic mineral oil	WTG nacelle impact accident
WTG-Lub-220	220	Gear oil[3]: lubricating oil	WTG nacelle impact accident
5WTG-MIX1-3400	450 gal hydraulic oil 1,850 gal transformer oil 1,100 gal gear oil (total 3,400 gal)	Naphthenic mineral oil, hydraulic oil, lubricating oil (Oil mixture 1)	WEA Perimeter Allision Worst-Case : 5 WTGs
All-Mix2-129K	128,600	Naphthenic mineral oil, hydraulic oil, lubricating oil, diesel (Oil mixture 2)	Worst Case Discharge : ESP + 130 WTGs, all oils (e.g., Hurricane)

Note that there is an E or an S in each scenario name to indicate model outputs for ecological and socio-economic resources at risk, respectively. In the following sections of this appendix, within each model scenario, figures associated with the analyses that used thresholds for ecological resources are shown first followed by the figures from analyses that used the thresholds for socio-economic resources.

Since the oiling footprints of several of the modeling scenarios looked very similar, with a slight variation in the maximum value of surface or shoreline oiling probability, it was decided that figures did not need to be created for all oil spill modeling scenarios shown in Table C.1. Table C.2 provides the list of the scenarios for which figures were created. In the comments column of Table C.2, an explanation is given to describe which of the chosen figures per geographic location were omitted because no oiling was observed above the threshold of concern.

Table C.2
List of oil spill scenarios for which figures were created.

Scenario Type	Scenario Name	Comments
5 WTGs (Ecological and Socioeconomic Thresholds)	5WTG-MIX1-3400 (E and S)	-
All Oils (Ecological and Socioeconomic Thresholds)	All-Mix2-129K (E and S)	-
ESP Diesel (Ecological and Socioeconomic Thresholds)	ESP-Diesel-2K (E and S)	**MD and NC:** No shoreline probability or worst case shoreline figures for the ecological threshold as no shoreline oiling above the threshold occurred.
ESP 1K and 40K Gallons of Naphthenic Mineral Oil (Ecological and Socioeconomic Thresholds)	ESP-Nap-1K, ESP-Nap-40K (E and S)	**MD and NC:** No shoreline probability or worst case shoreline figures for the 1,000 gallon cases using the ecological threshold as no shoreline oiling above the threshold occurred.
WTG Hydraulic Oil (Ecological Threshold)	WTG-Hyd-90 (E only)	**MD, NC, and RIMA:** No shoreline probability or worst case shoreline figures for the ecological threshold as no shoreline oiling above the threshold occurred.
WTG Lubricating Oil (Ecological Threshold)	WTG-Lub-220 (E only)	**MD, NC, and RIMA:** No shoreline probability or worst case shoreline figures for the ecological threshold as no shoreline oiling above the threshold occurred.

C.2 RHODE ISLAND-MASSACHUSETTS WIND ENERGY AREA

C.2.1 5 WTGs Oil Mixture Scenarios

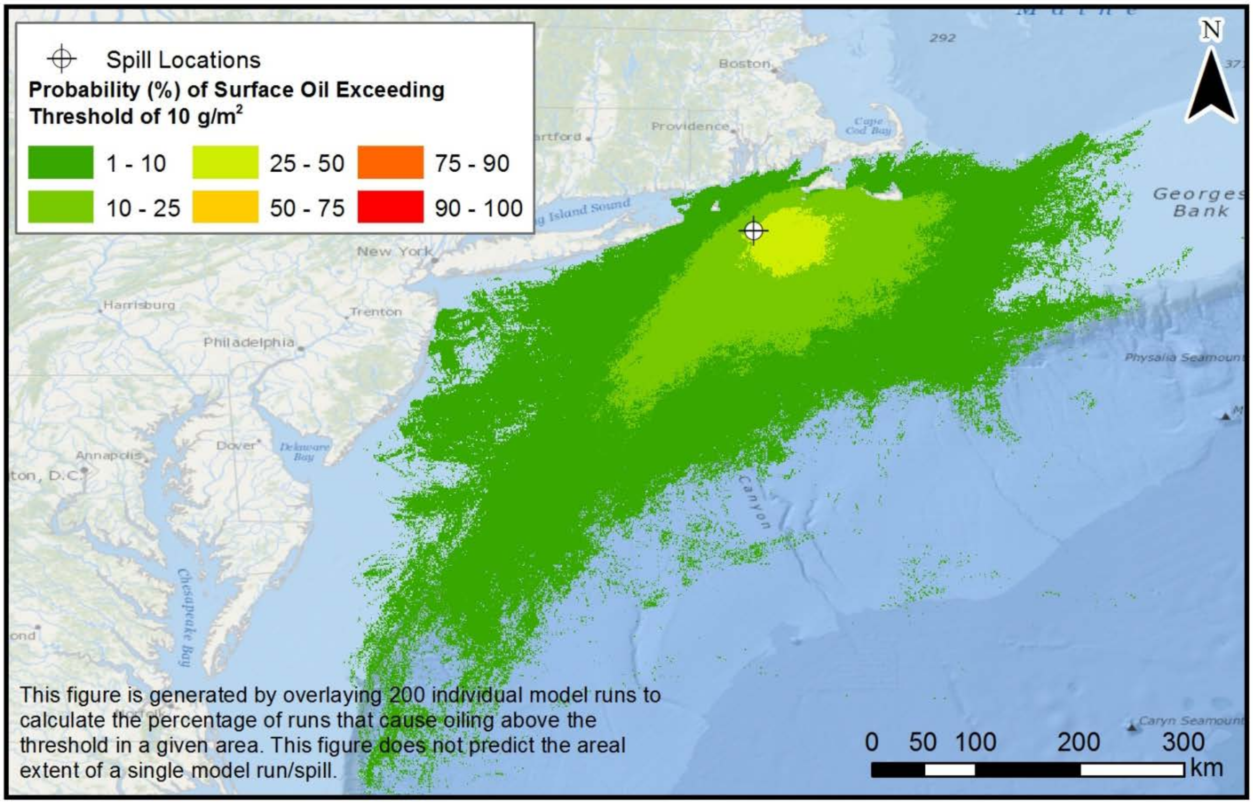


Figure C.1 Model scenario: 5WTG-MIX1-3400. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

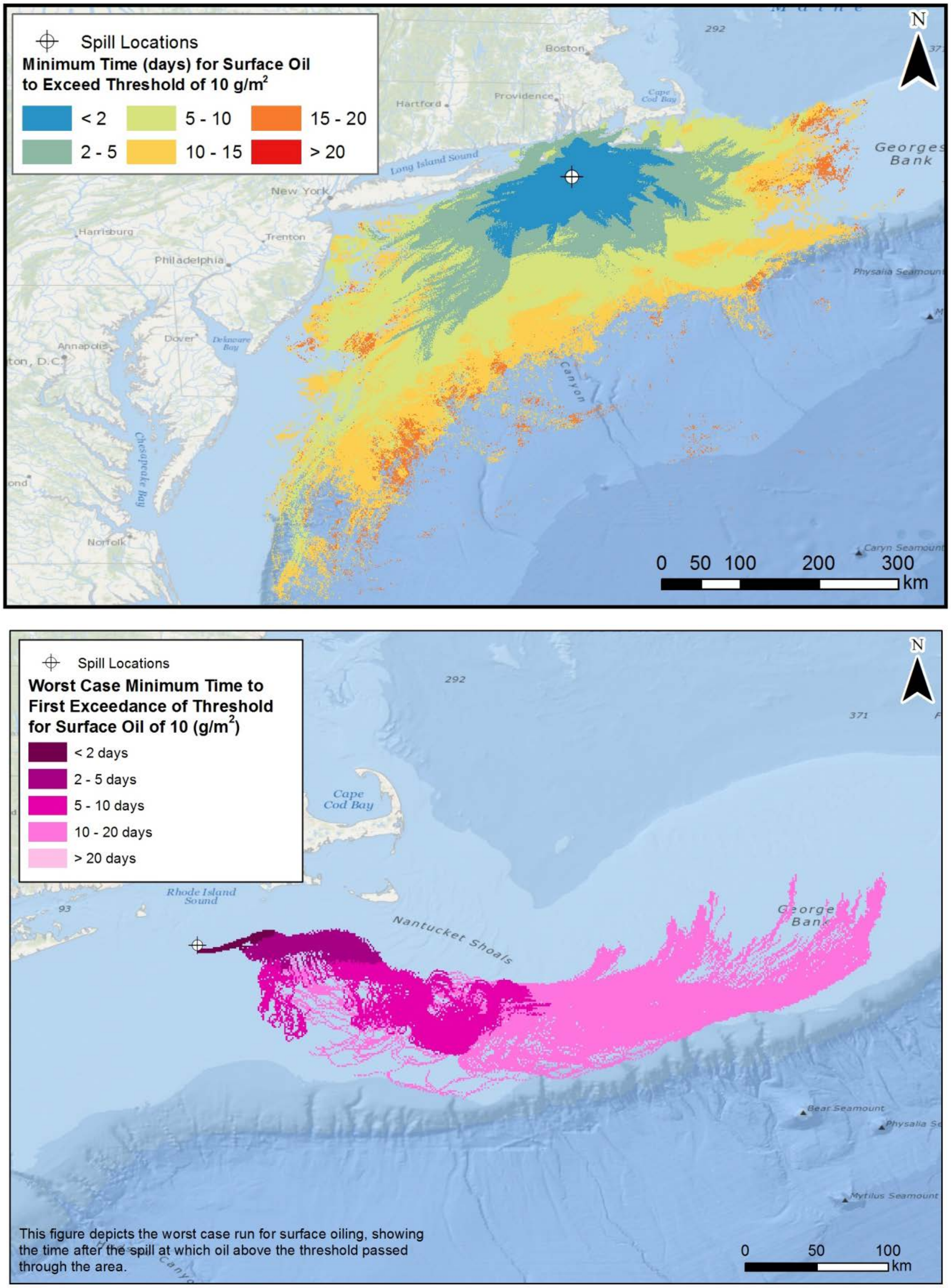
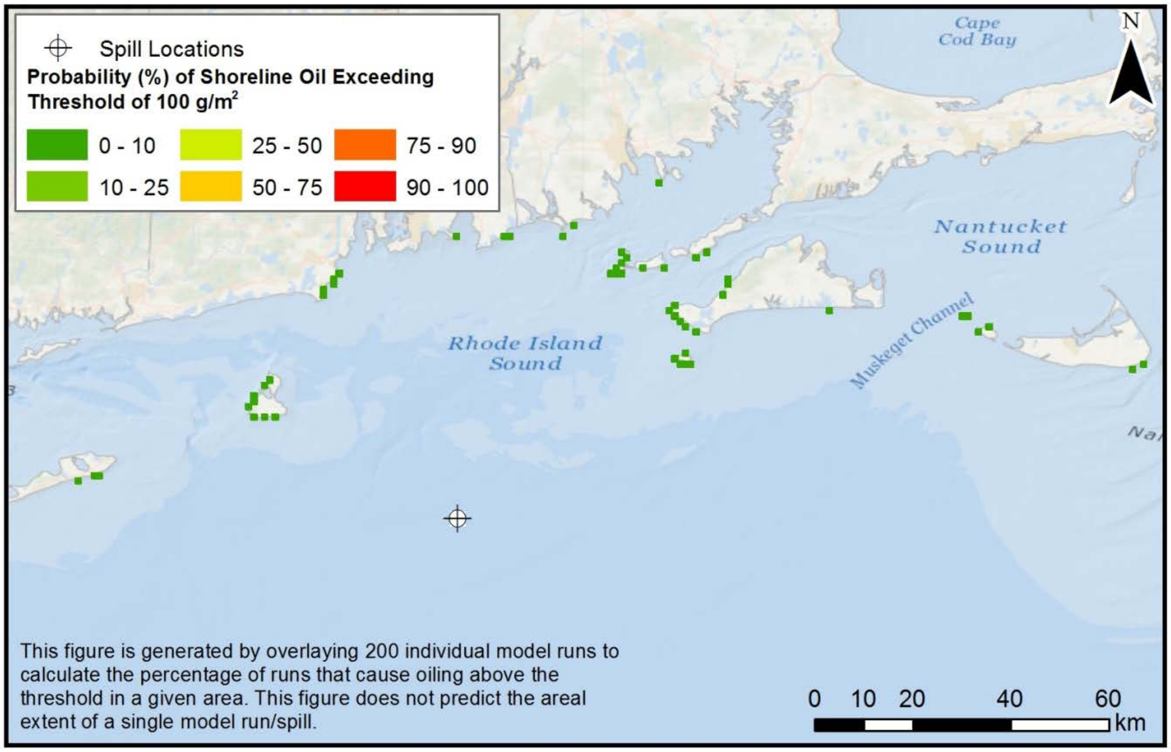


Figure C.2 Model scenario: 5WTG-MIX1-3400. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



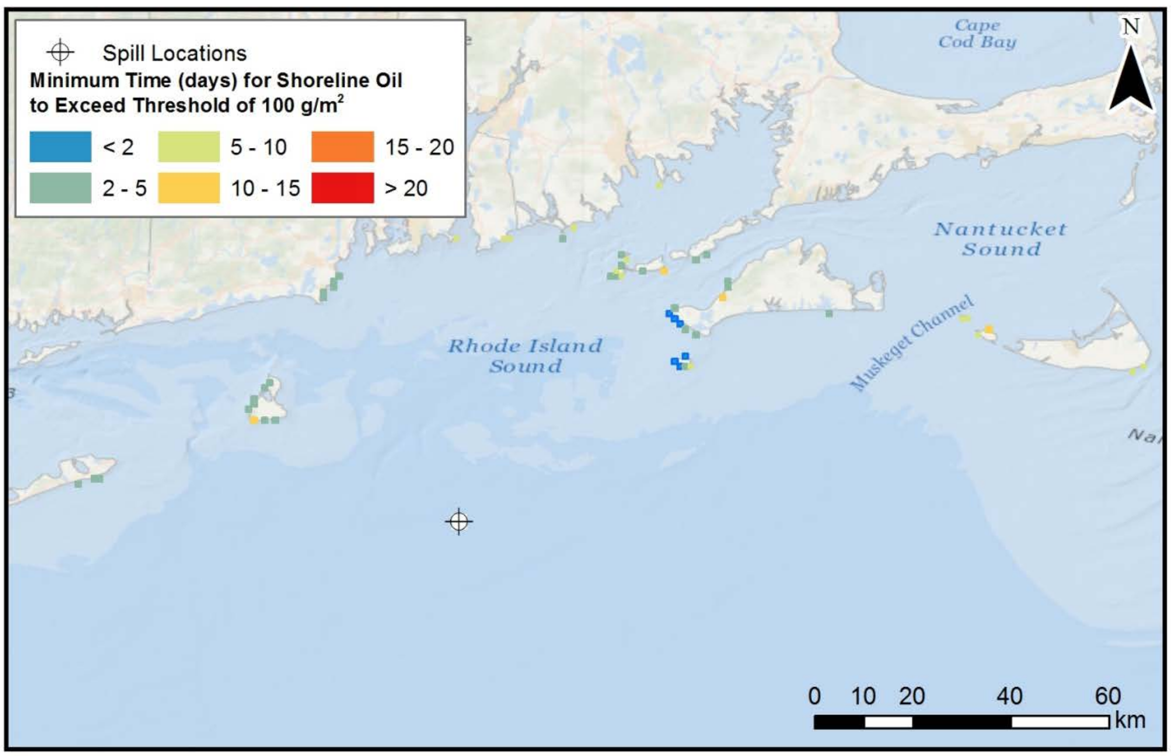


Figure C.3 Model scenario: 5WTG-MIX1-3400. Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

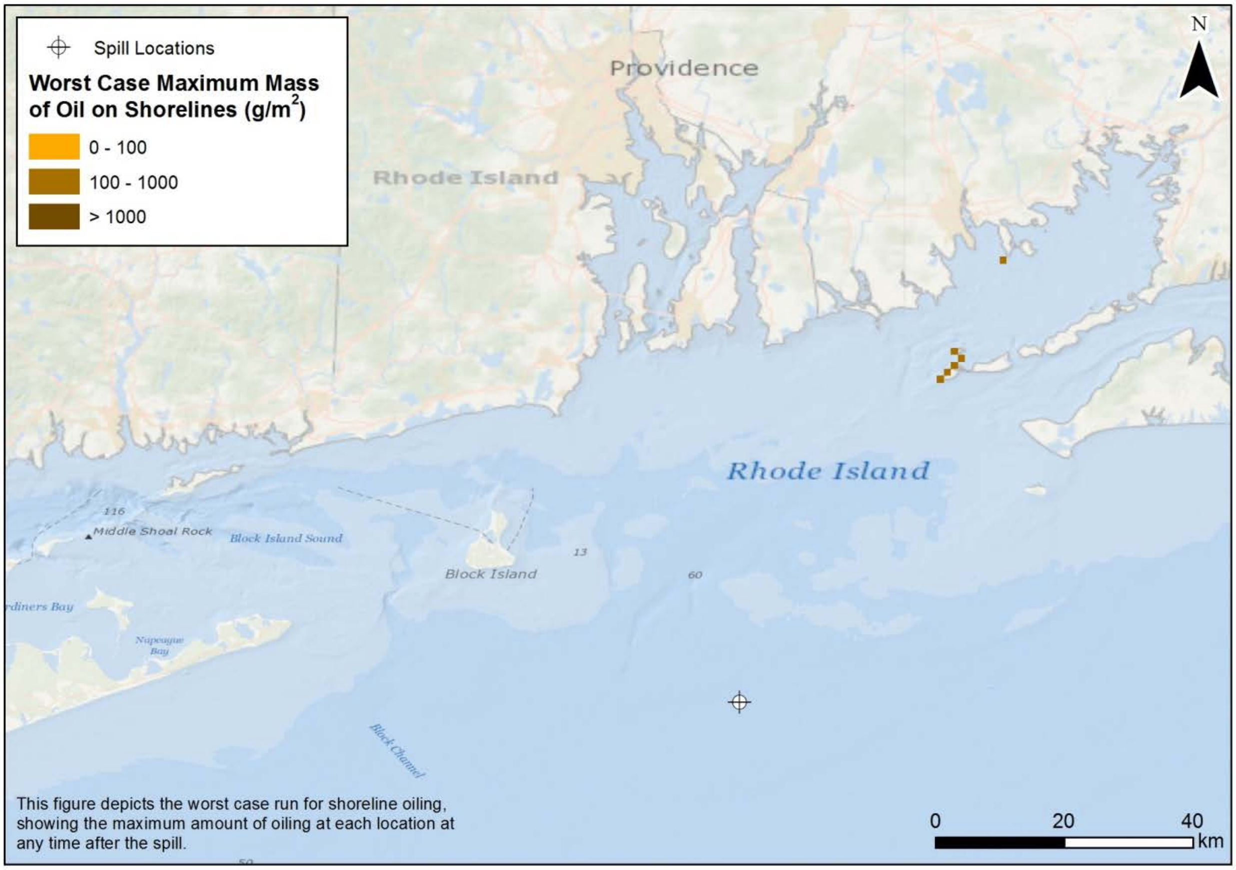


Figure C.4 Model scenario: 5WTG-MIX1-3400. Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the RI-MA WEA. Map represents a single simulation.

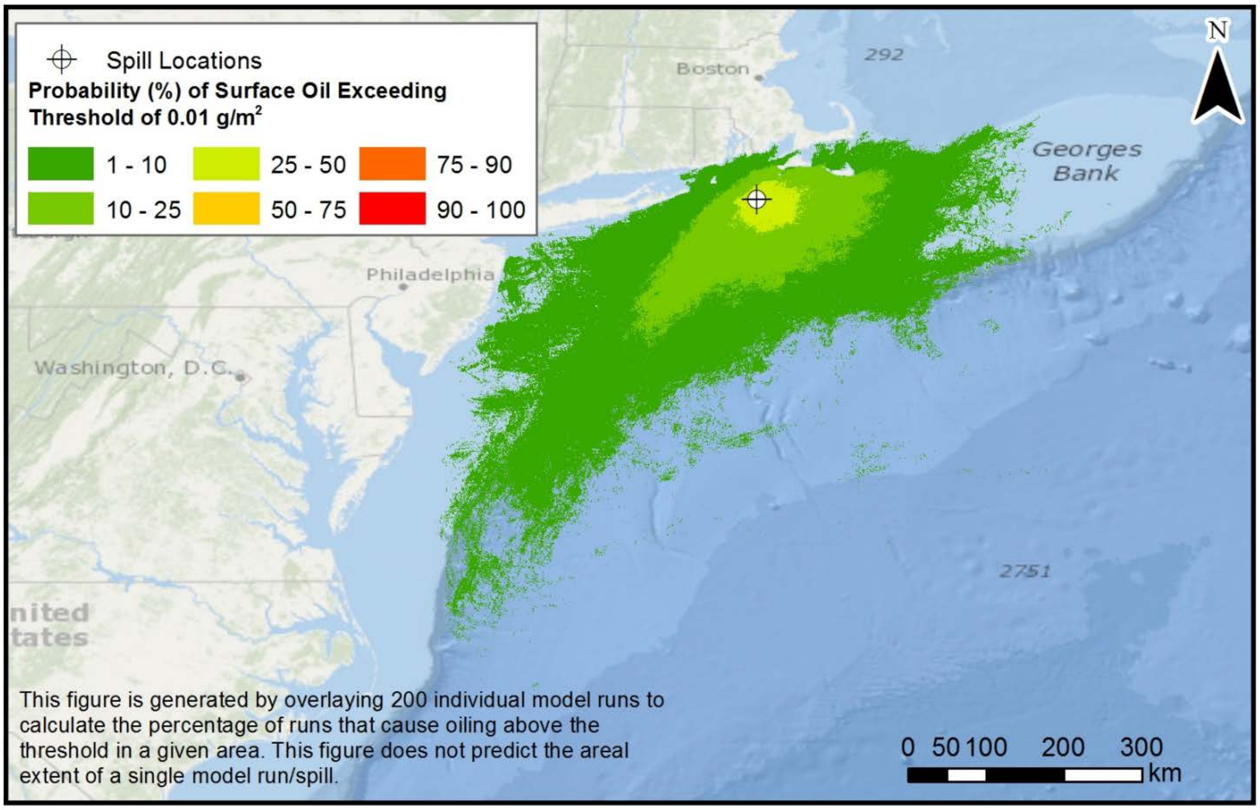
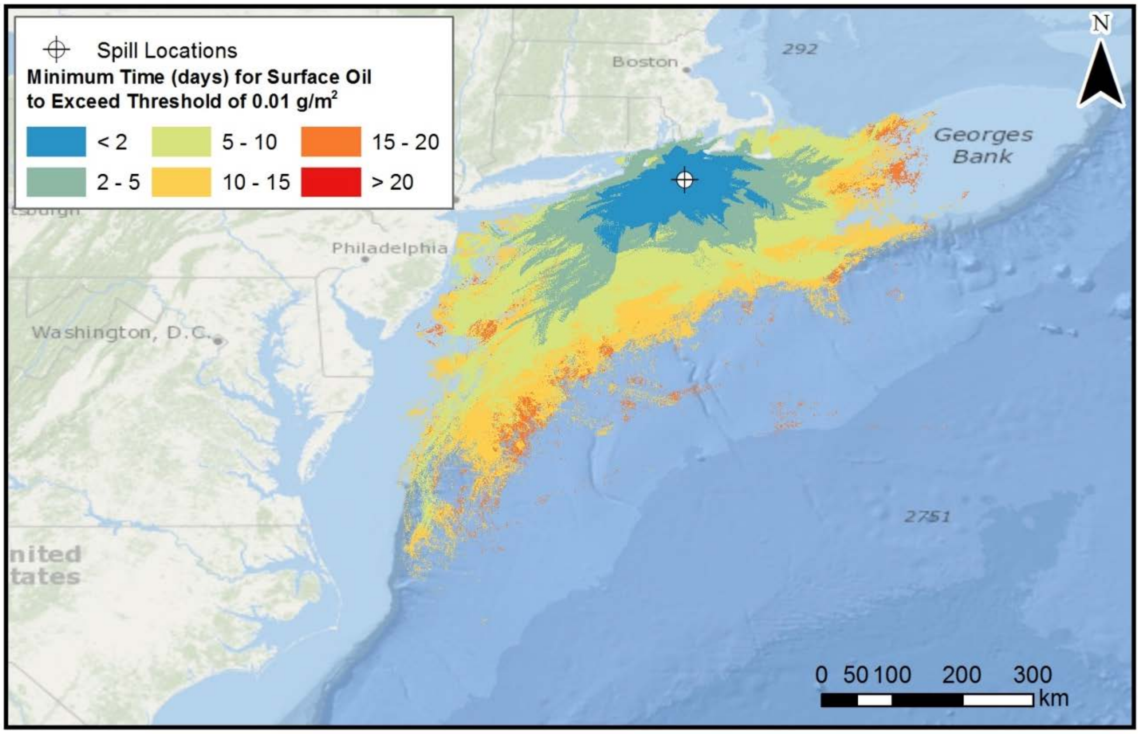


Figure C.5 Model scenario: 5WTG-MIX1-3400. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



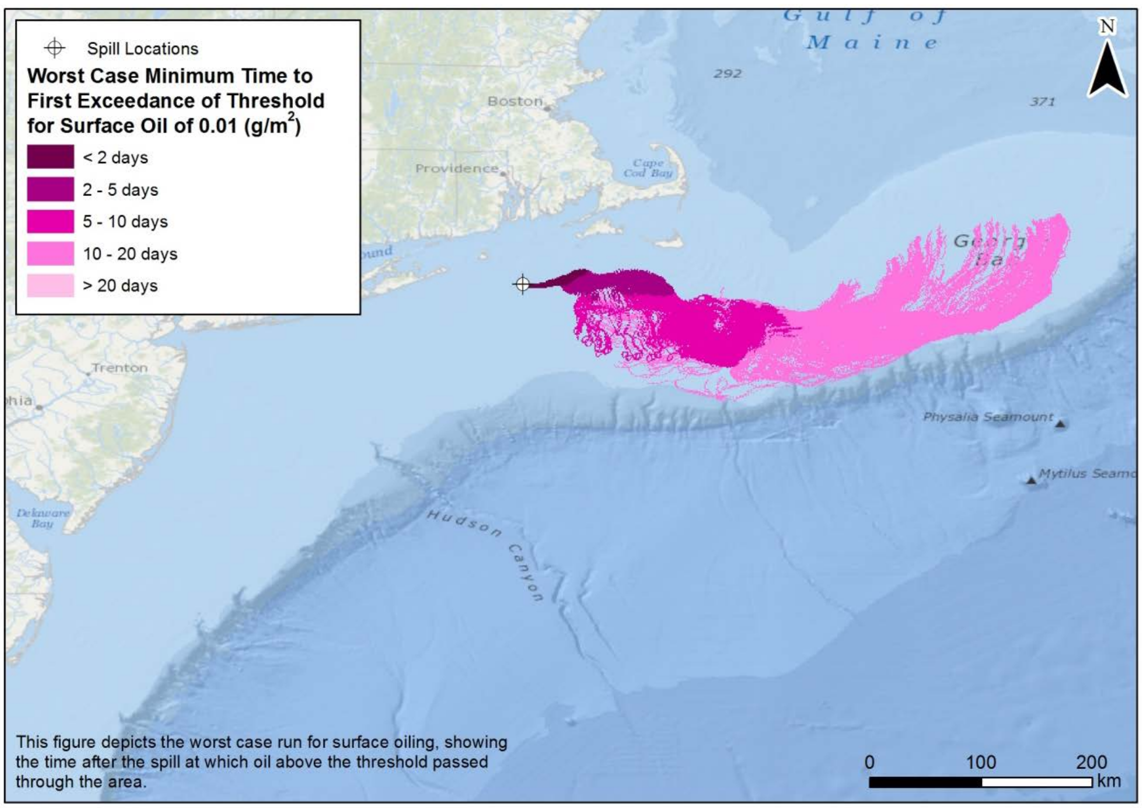


Figure C.6 Model scenario: 5WTG-MIX1-3400. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

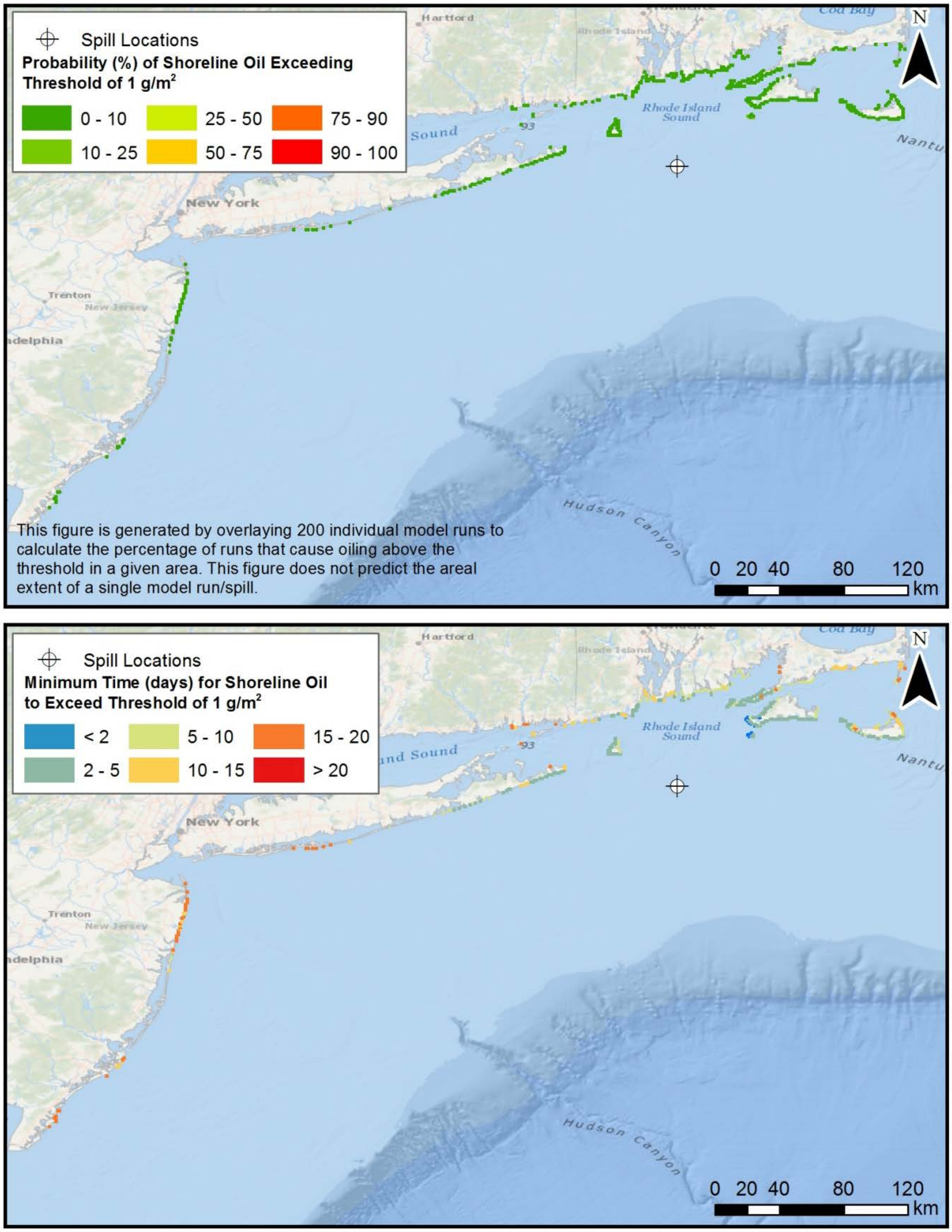


Figure C.7 Model scenario: 5WTG-MIX1-3400. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

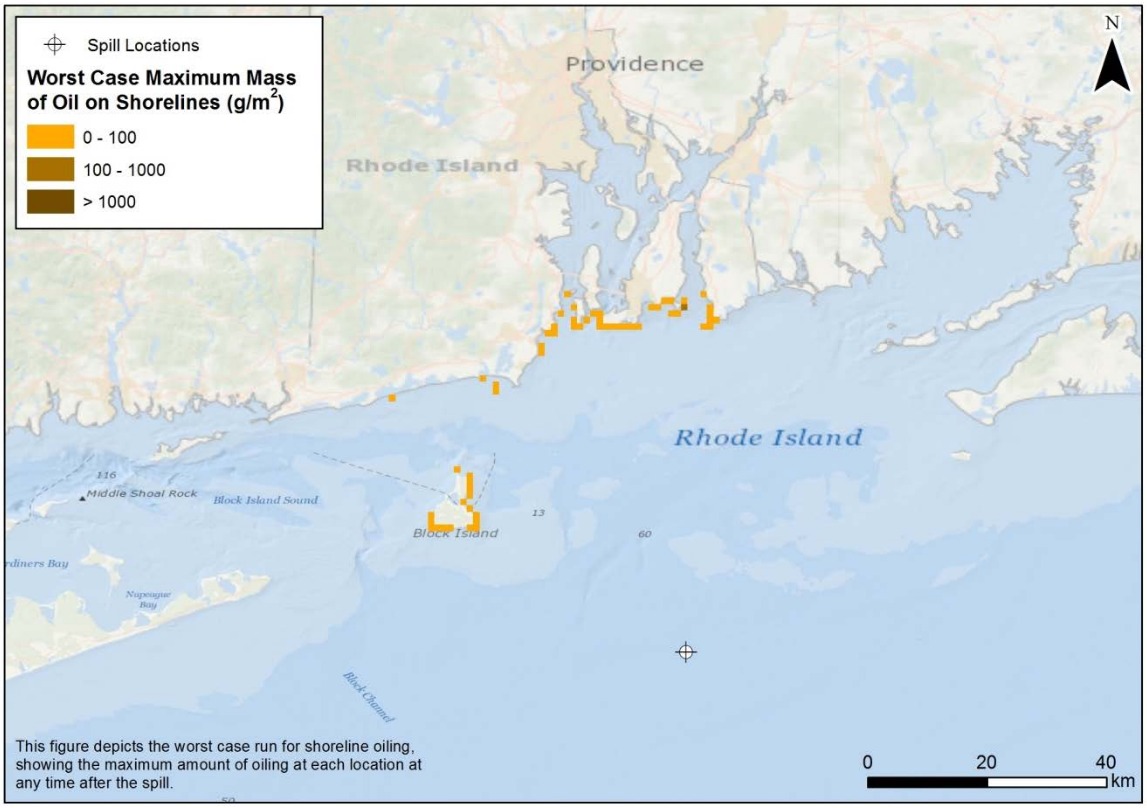


Figure C.8 Model scenario: 5WTG-MIX1-3400. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the RI-MA WEA. Map represents a single simulation.

C.2.2 ESP Naphthenic Mineral Oil Scenarios (1K and 40K Gallons)

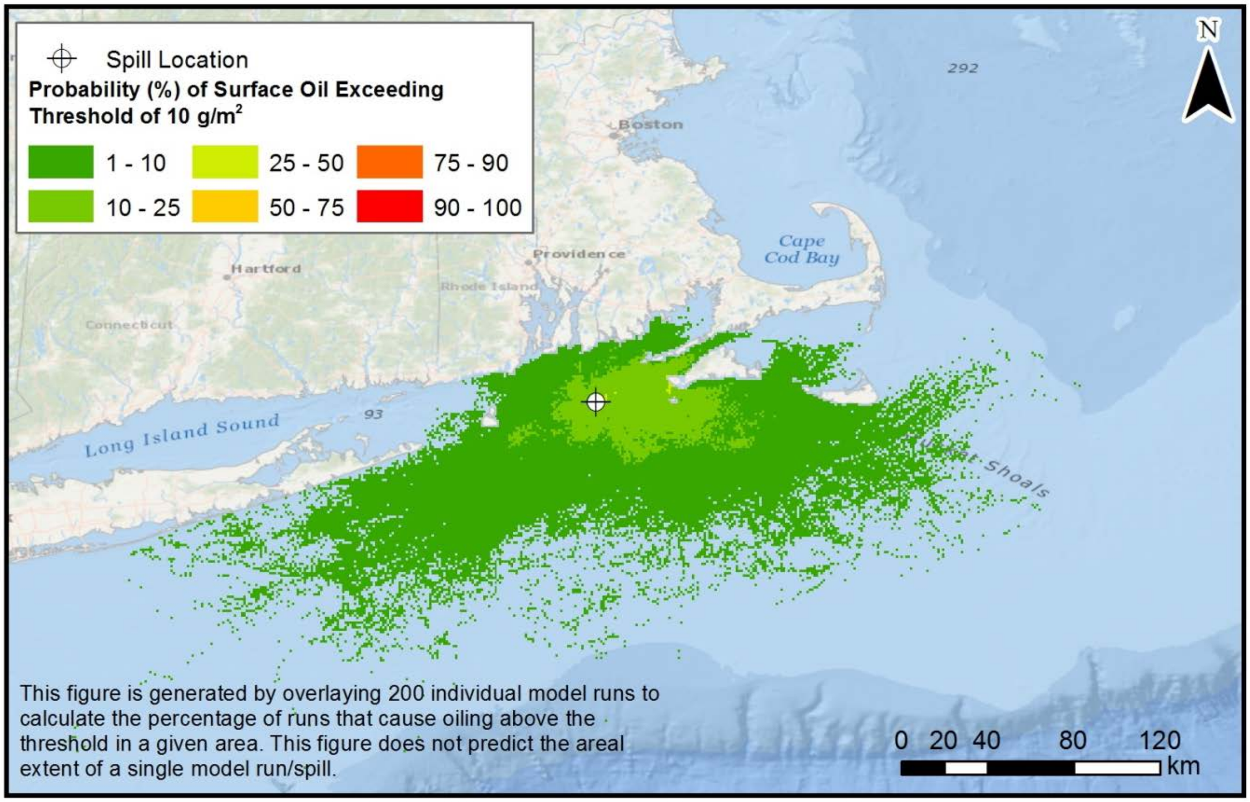
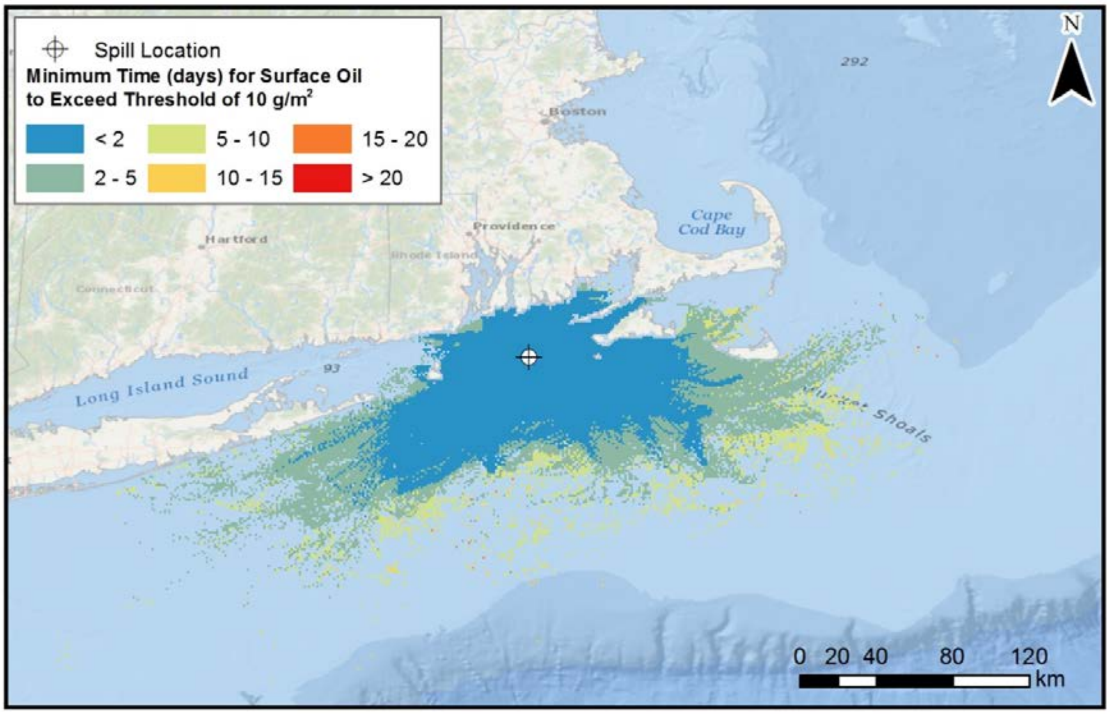


Figure C.9 Model scenario: ESP-NAP-E-1K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



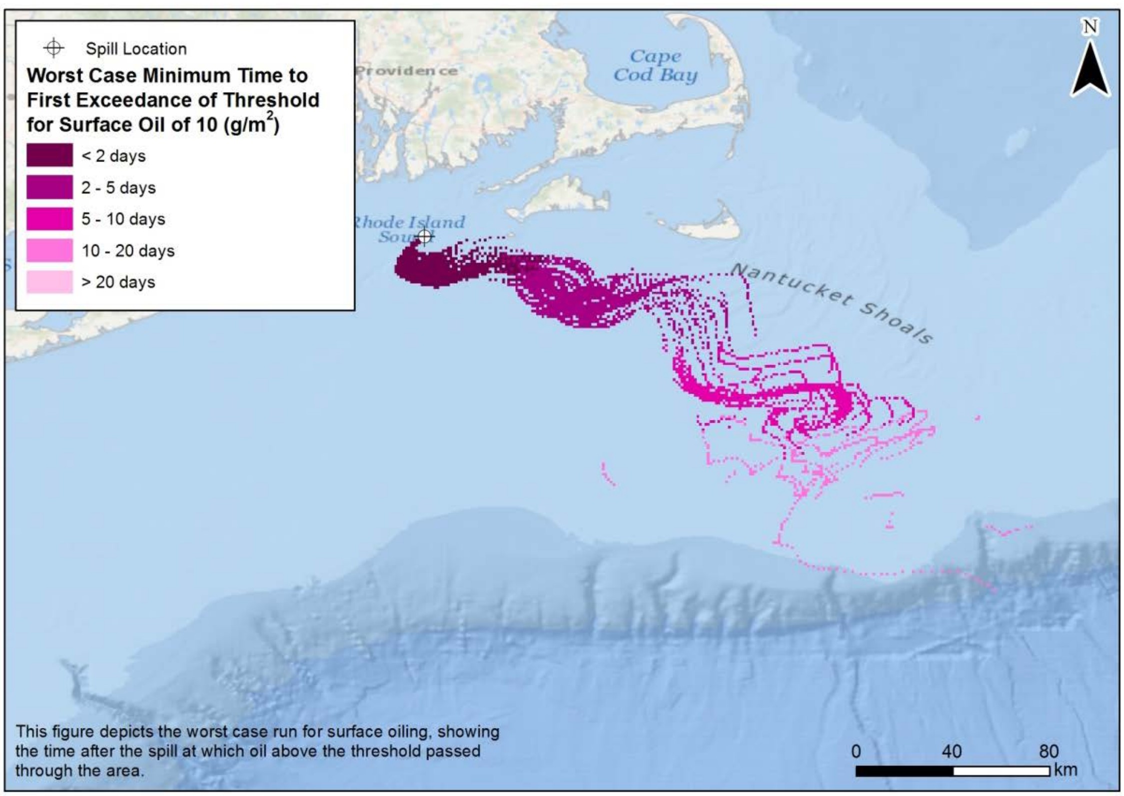
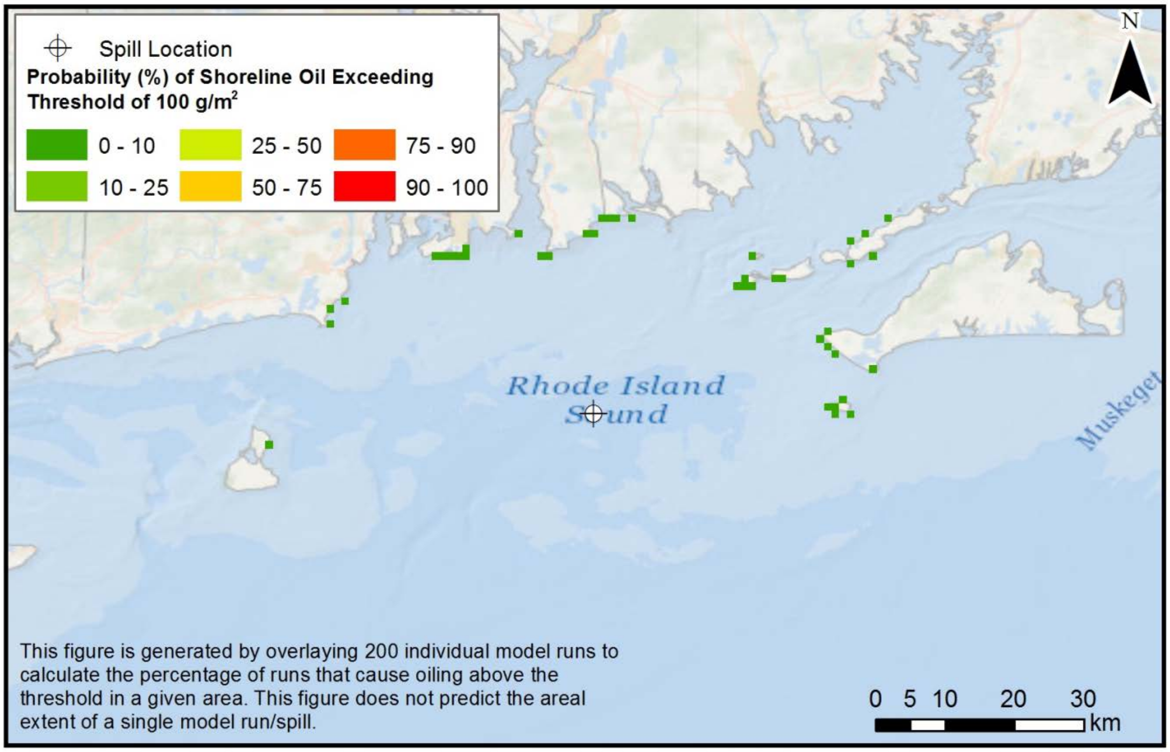


Figure C.10 Model scenario: ESP-NAP-E-1K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



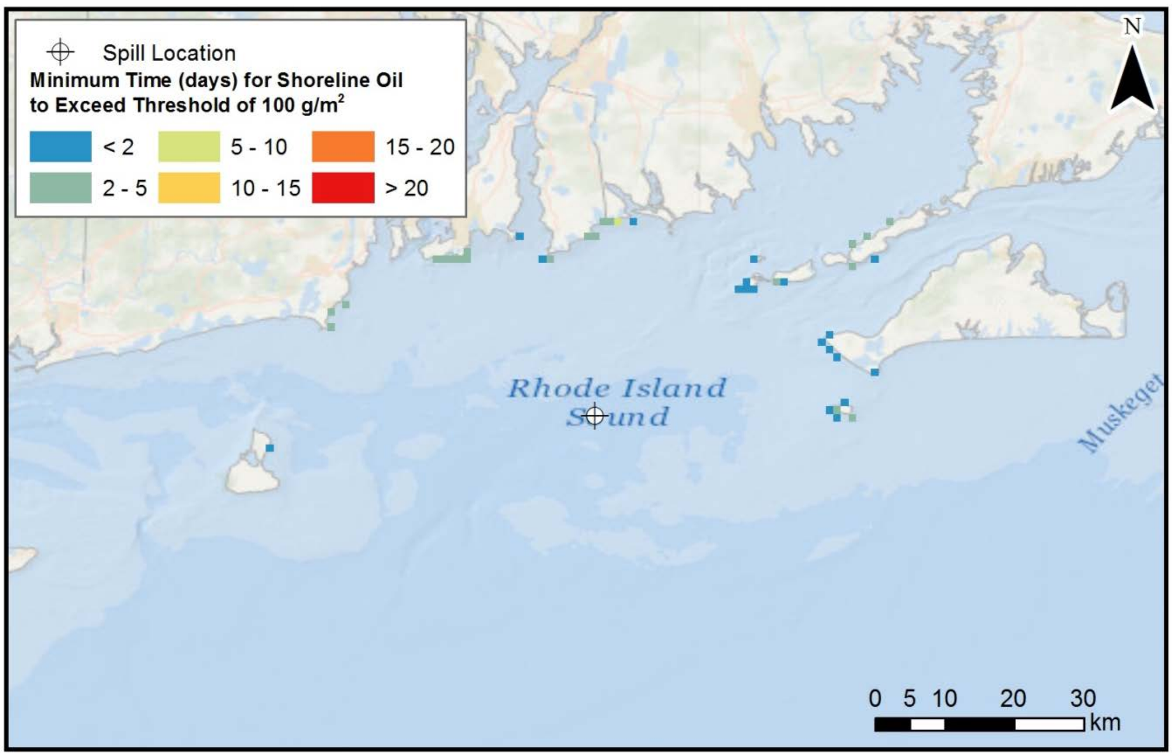


Figure C.11 Model scenario: ESP-NAP-E-1K. Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

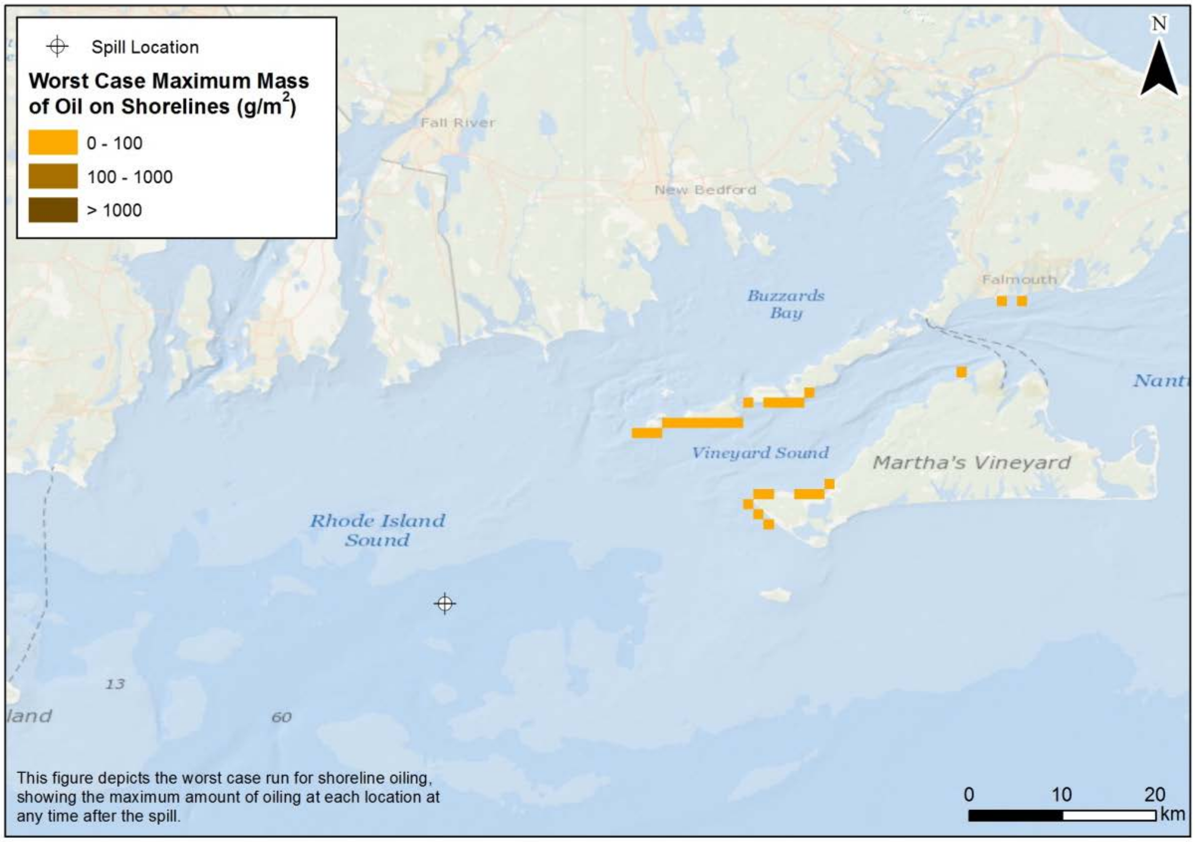


Figure C.12 Model scenario: ESP-NAP-E-1K. Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Map represents a single simulation.

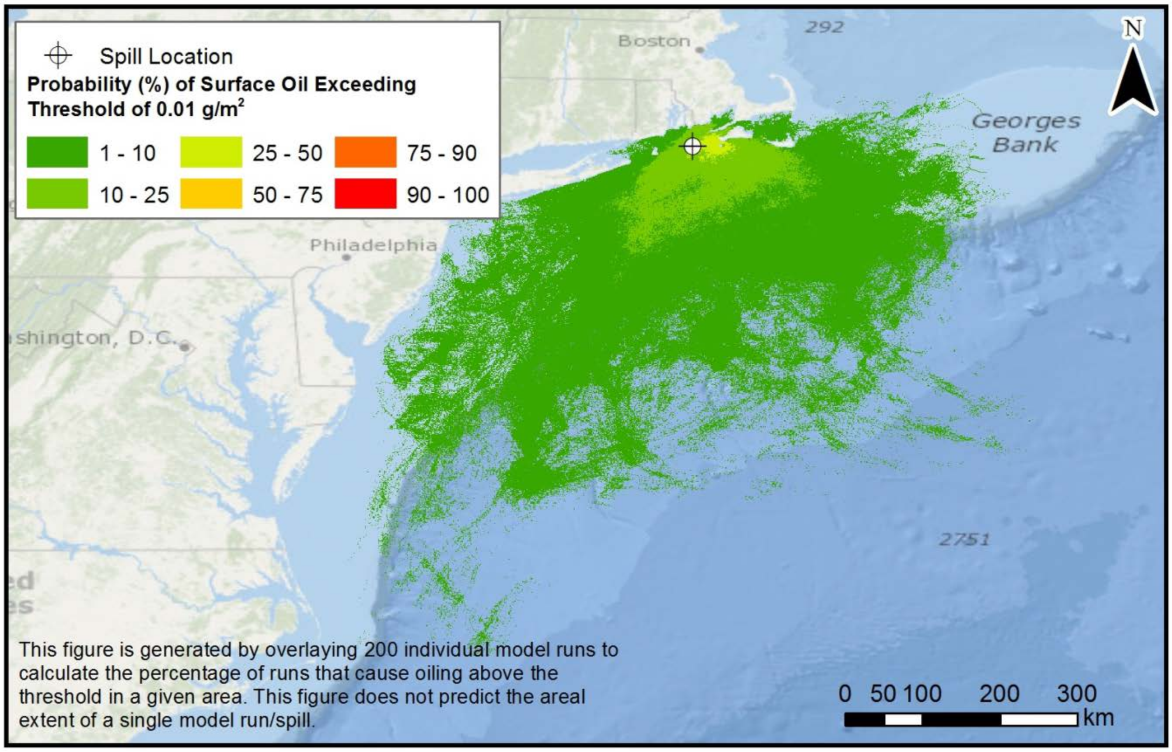
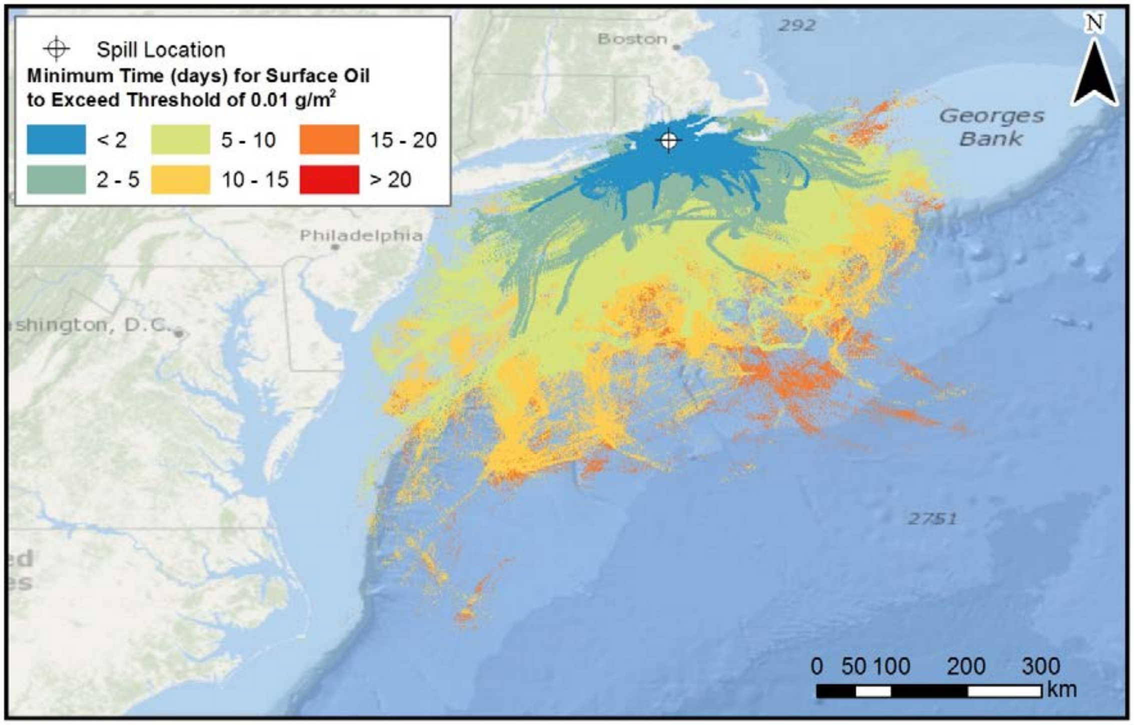


Figure C.13 Model scenario: ESP-NAP-S-1K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



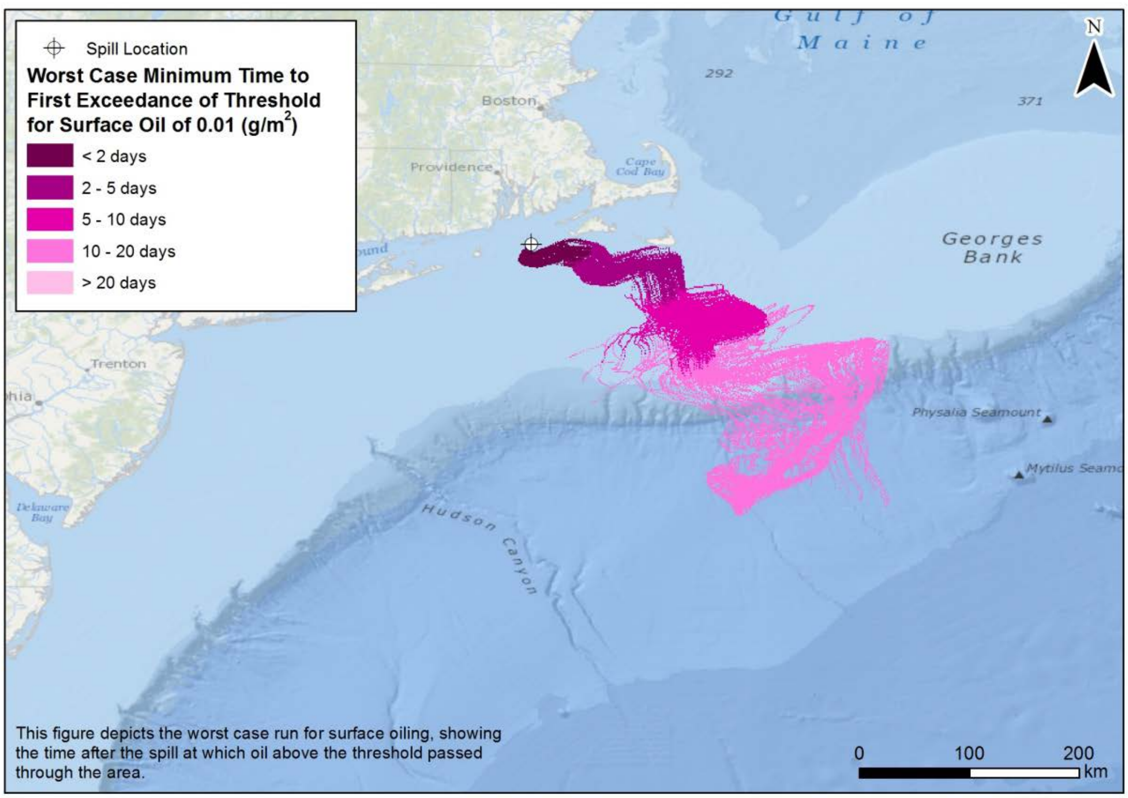


Figure C.14 Model scenario: ESP-NAP-S-1K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

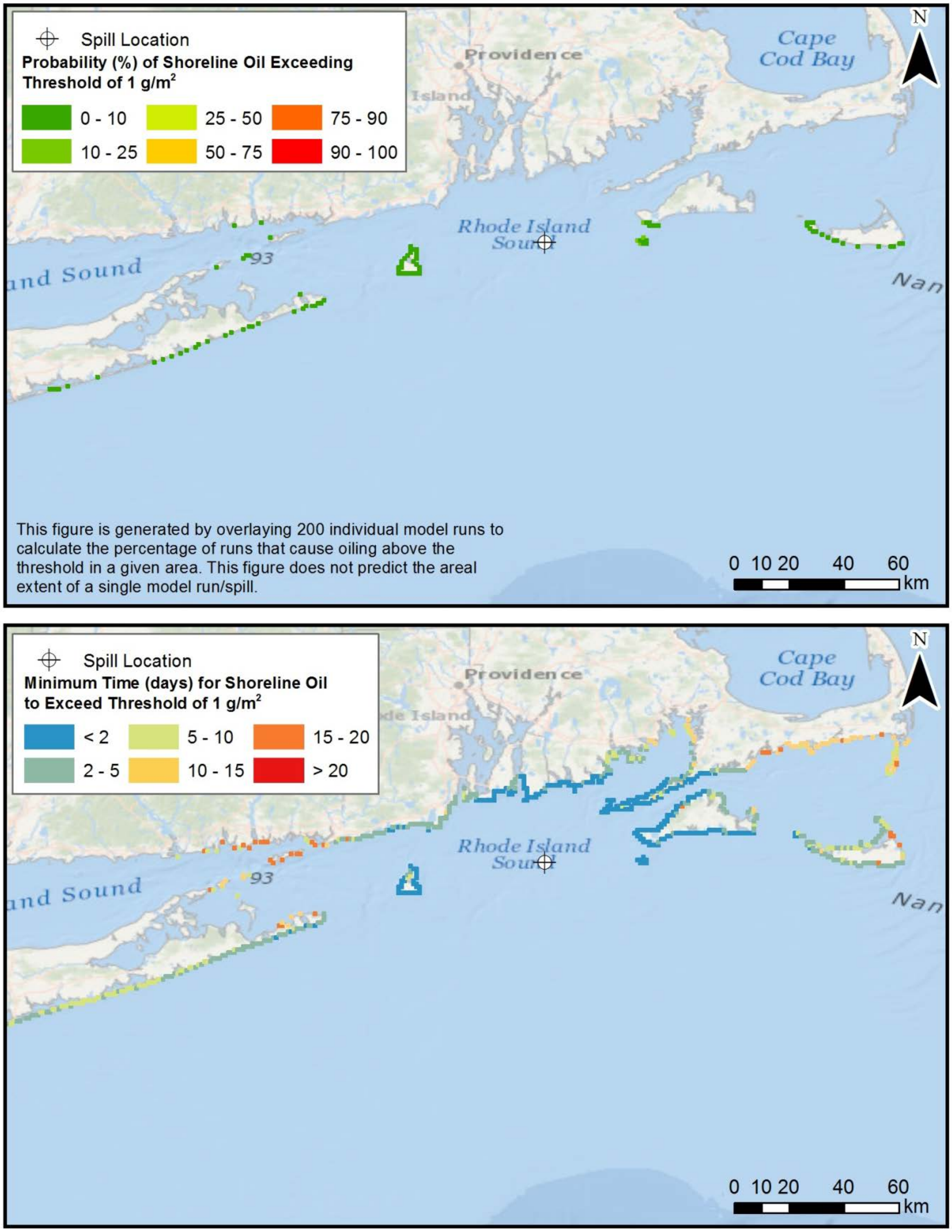


Figure C.15 Model scenario: ESP-NAP-S-1K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

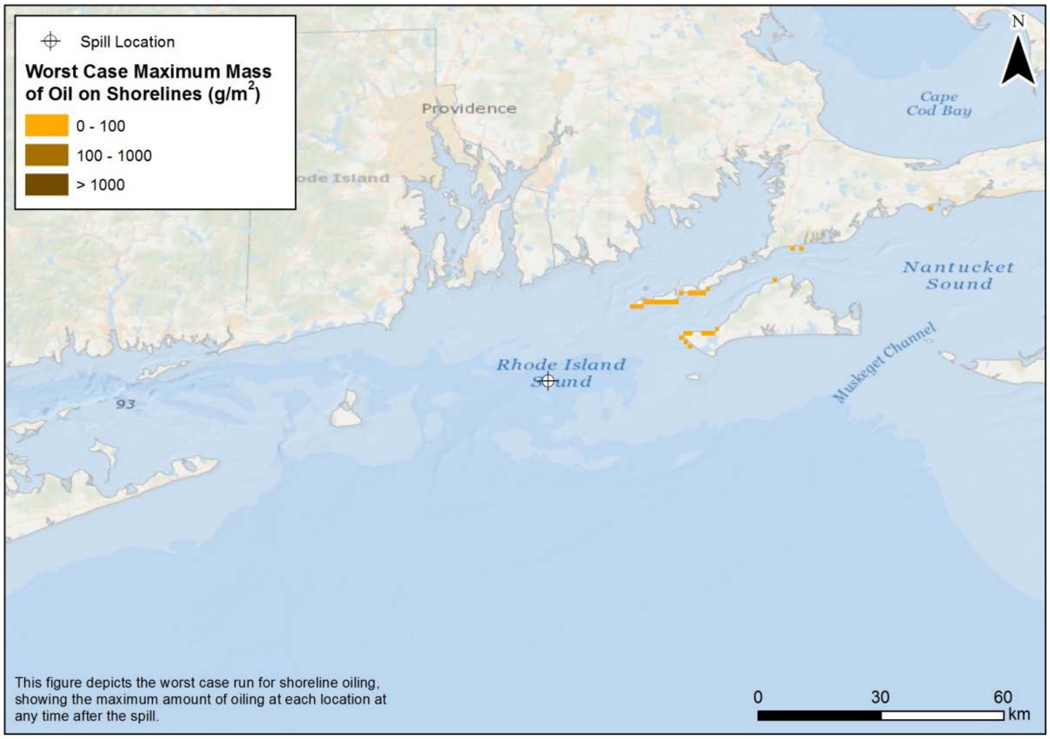


Figure C.16 Model scenario: ESP-NAP-S-1K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Map represents a single simulation.

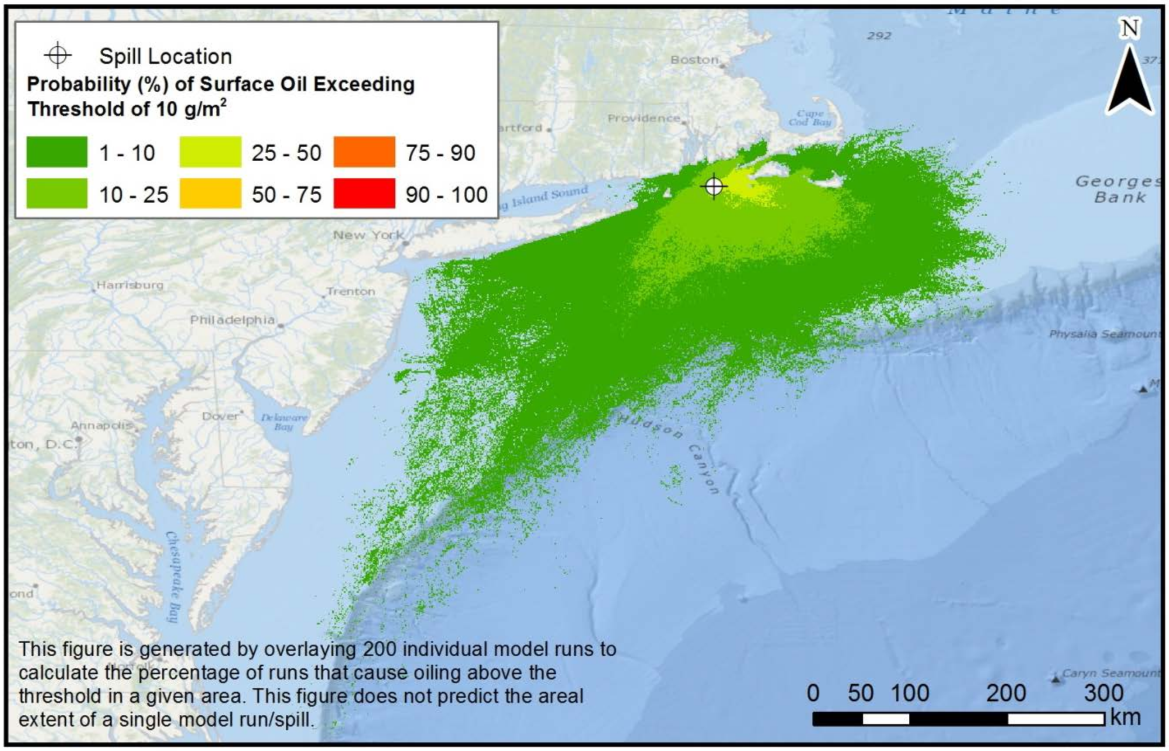
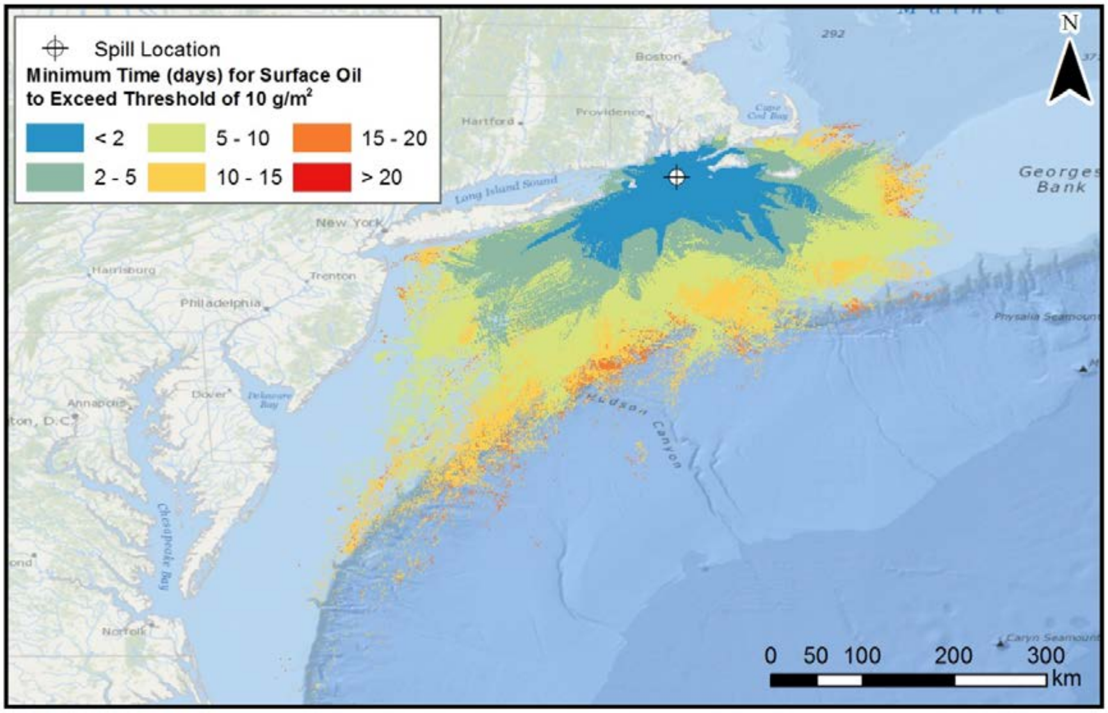


Figure C.17 Model scenario: ESP-NAP-E-40K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



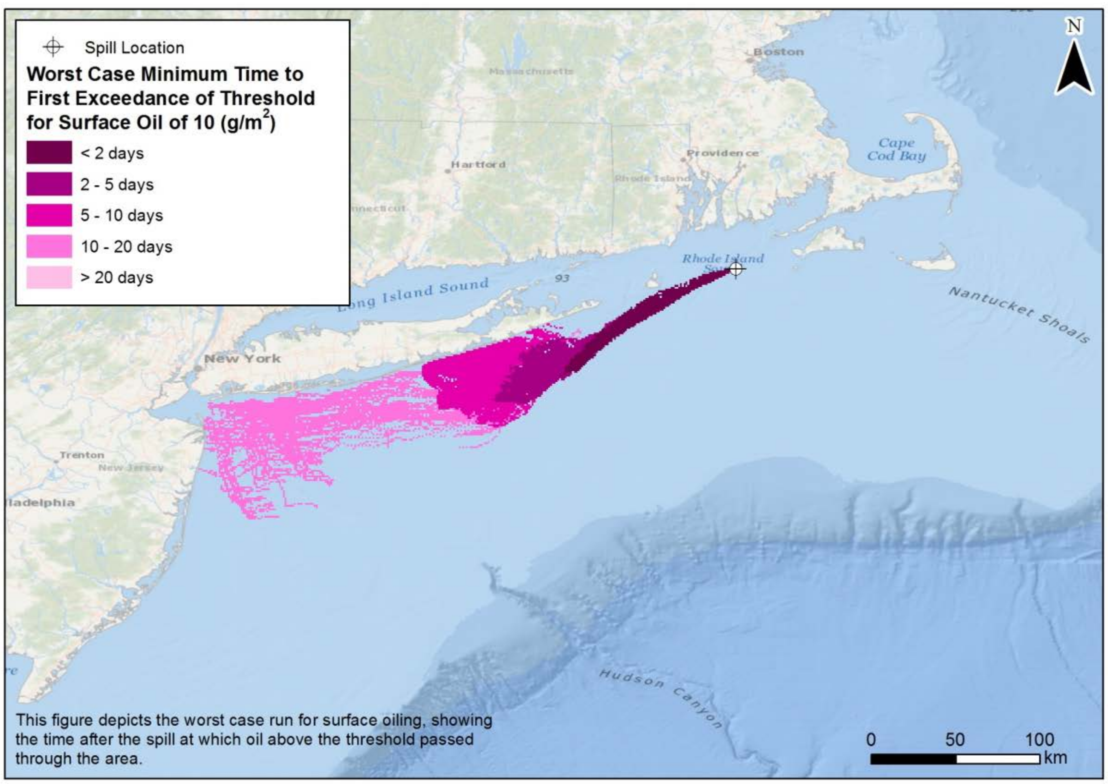
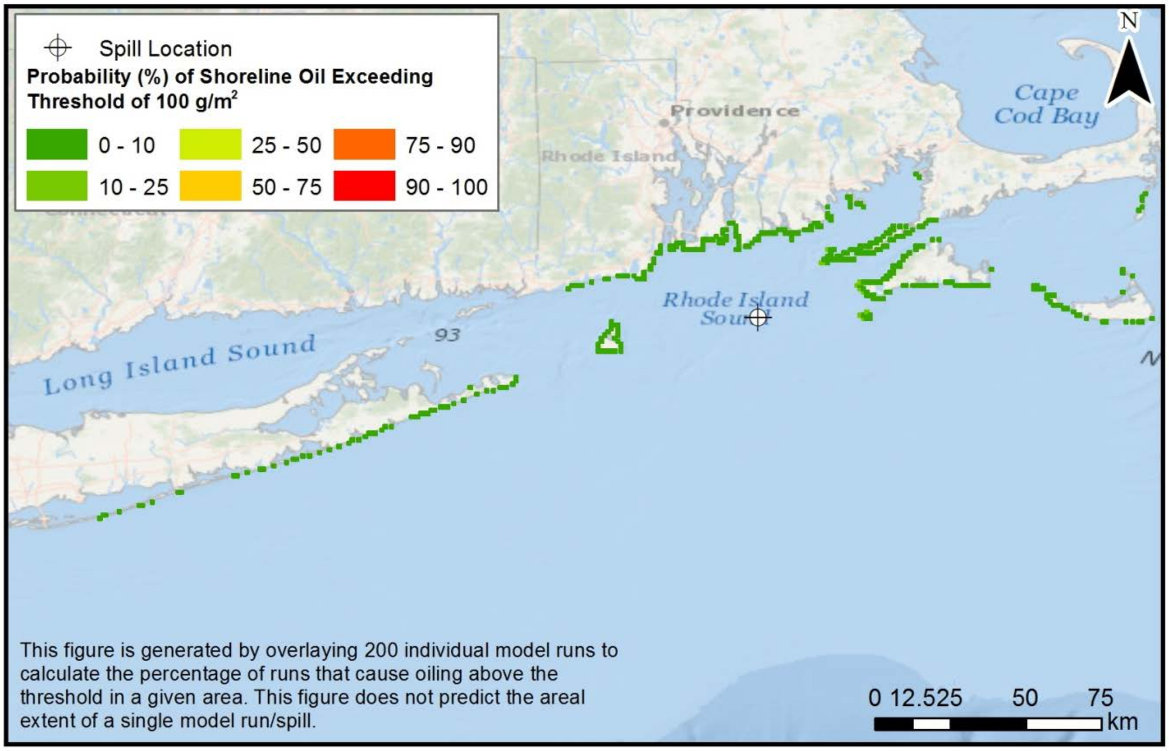


Figure C.18 Model scenario: ESP-NAP-E-40K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



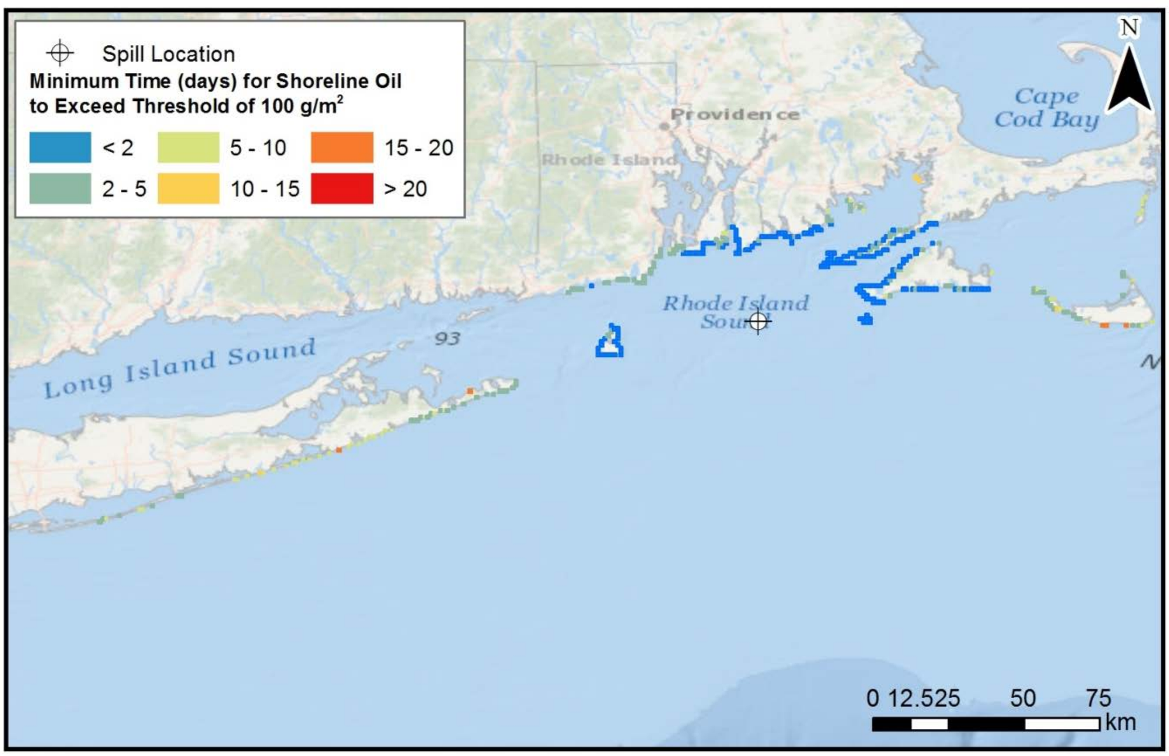


Figure C.19 Model scenario: ESP-NAP-E-40K. Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

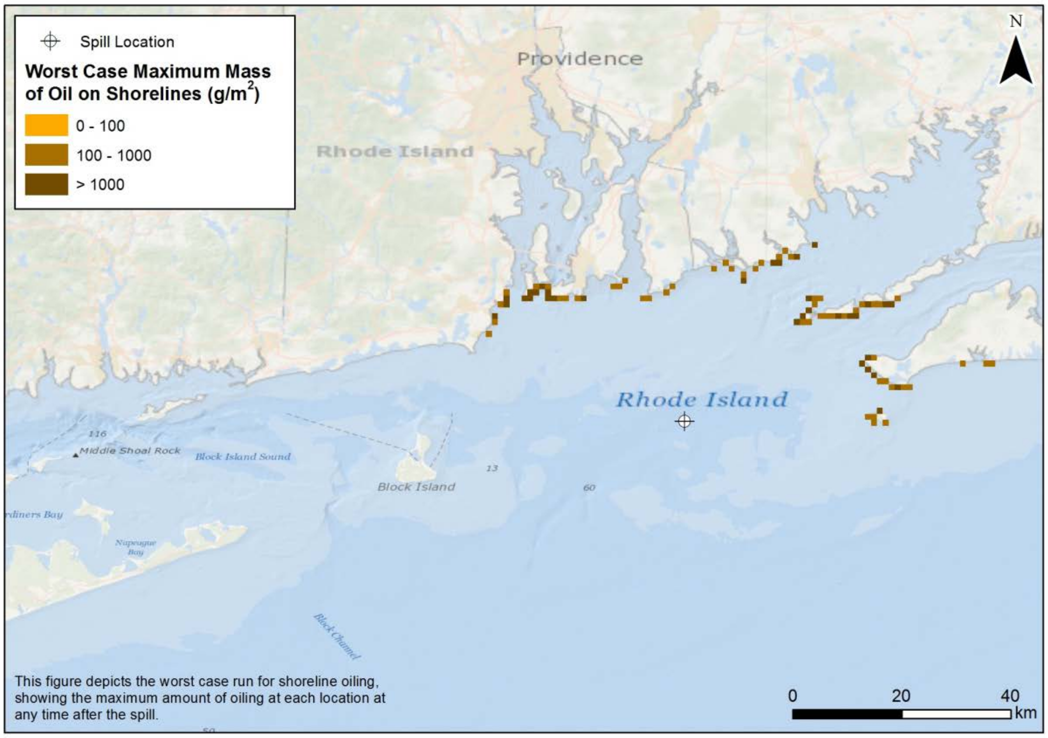


Figure C.20 Model scenario: ESP-NAP-E-40K. Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Map represents a single simulation.

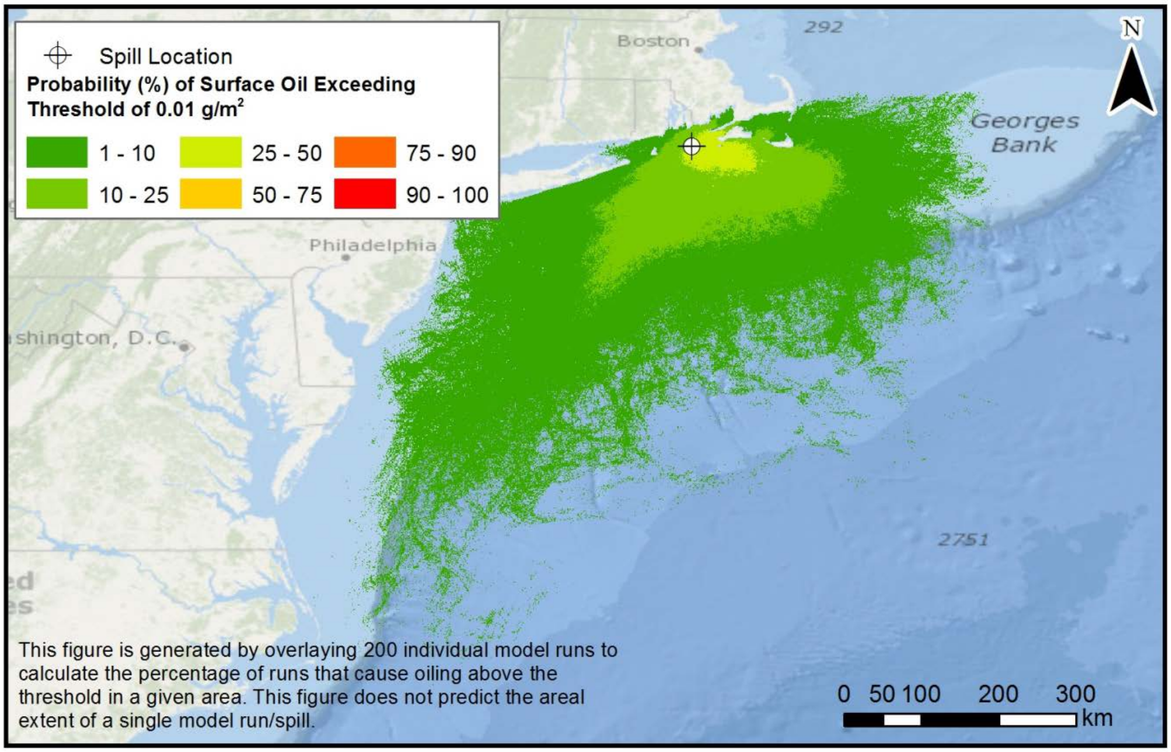
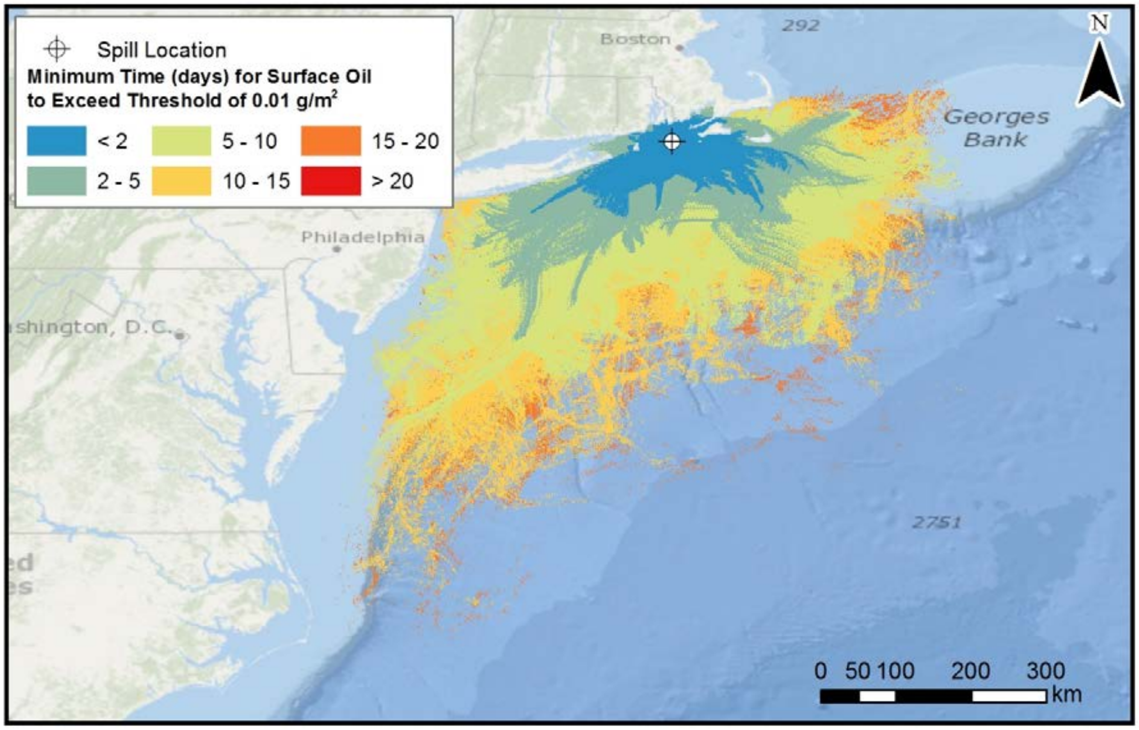


Figure C.21 Model scenario: ESP-NAP-S-40K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



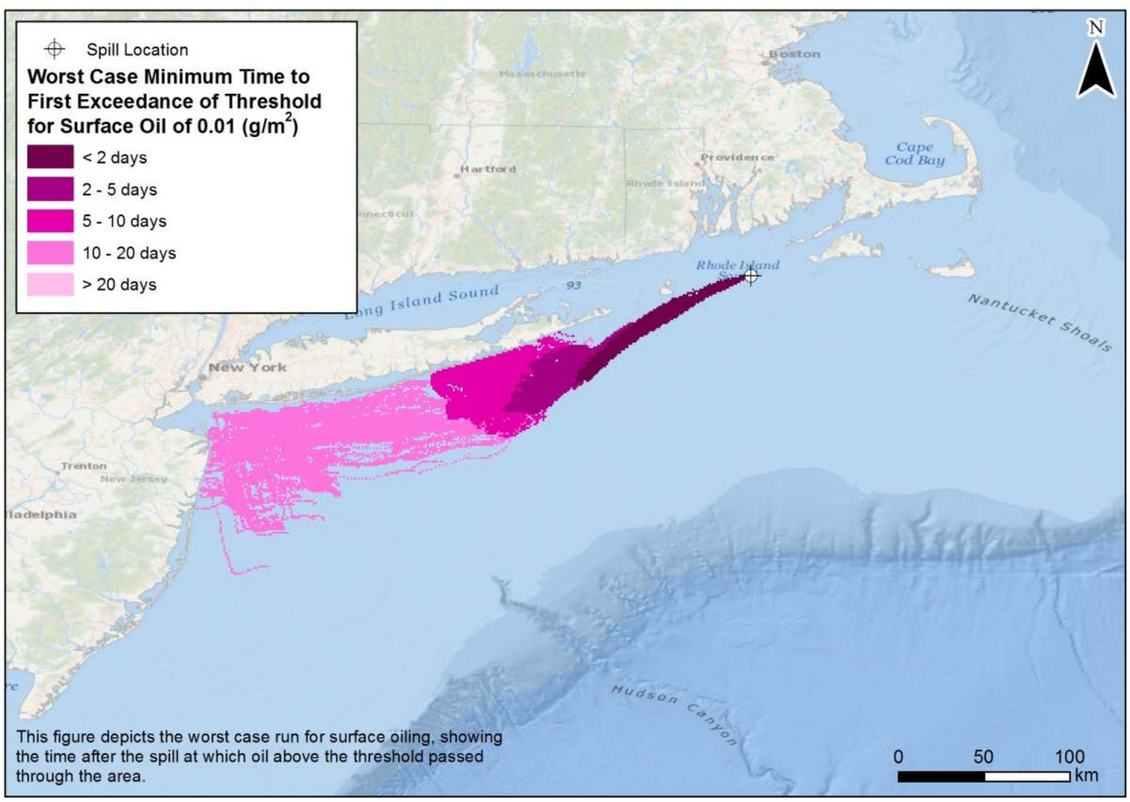
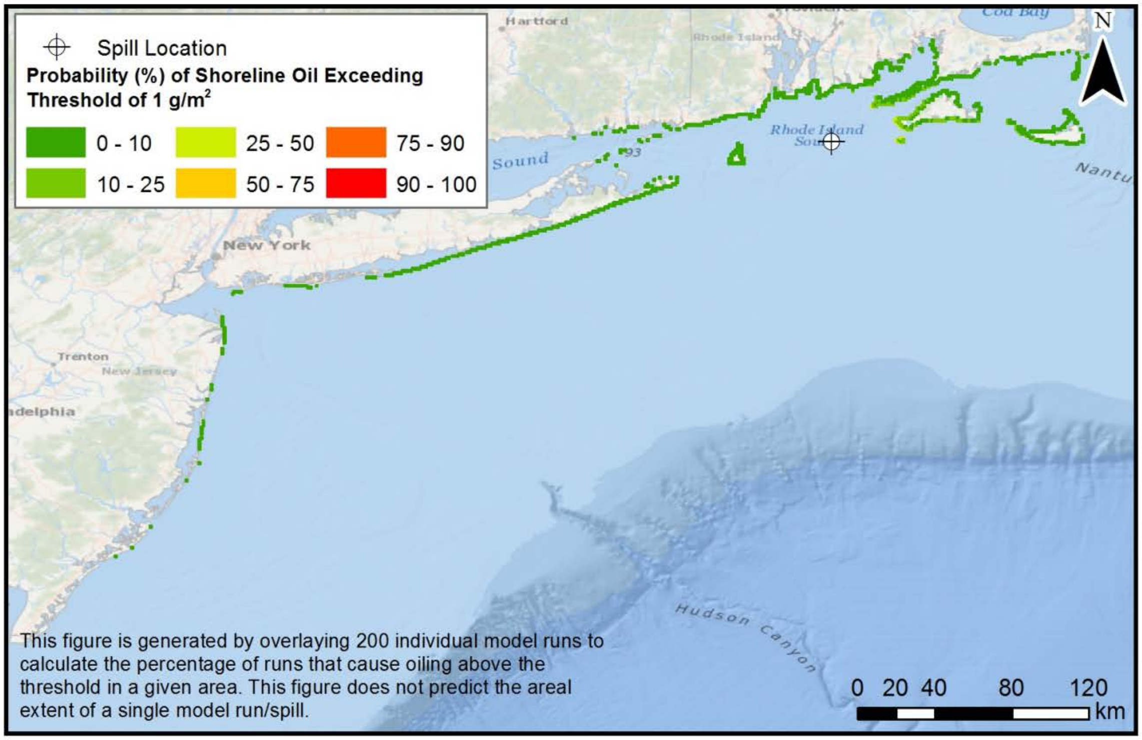


Figure C.22 Model scenario: ESP-NAP-S-40K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



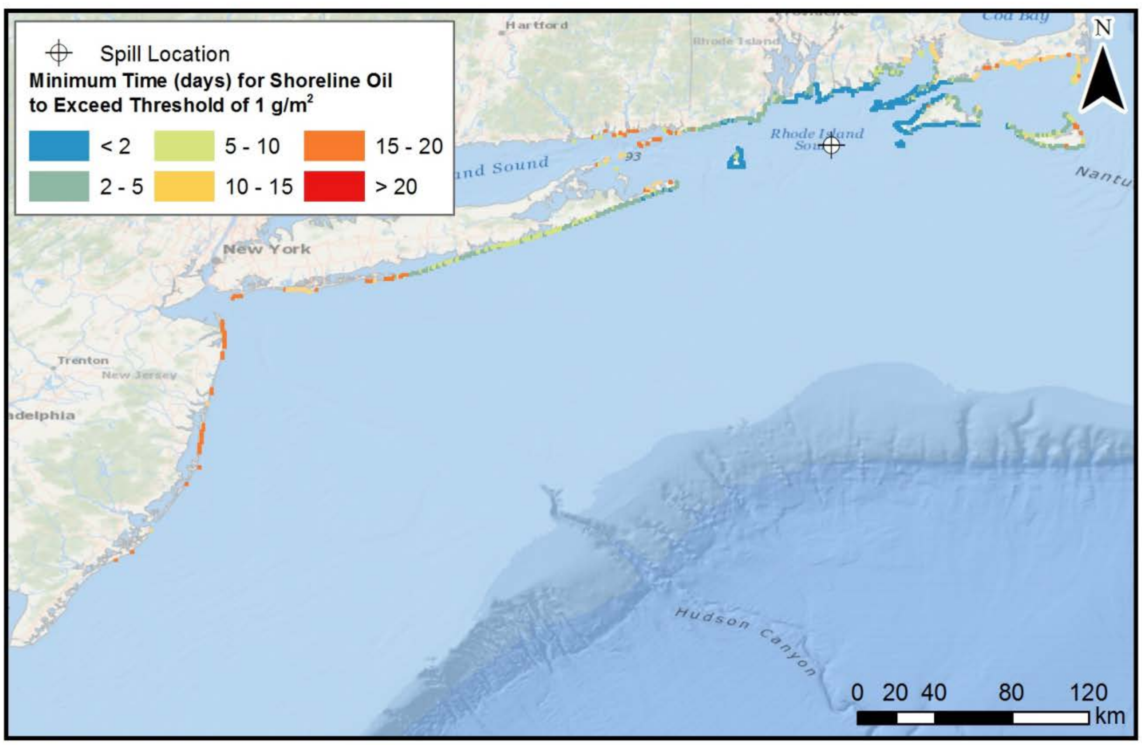


Figure C.23 Model scenario: ESP-NAP-S-40K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

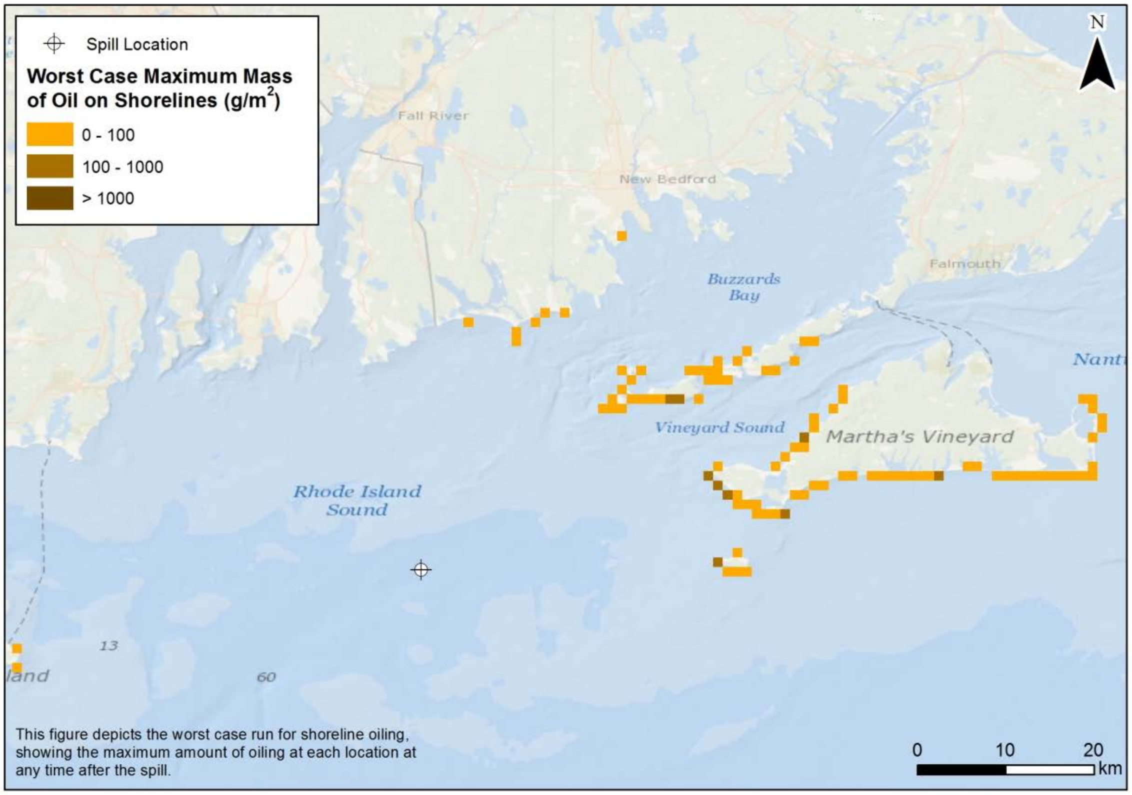


Figure C.24 Model scenario: ESP-NAP-S-40K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the RI-MA WEA. Map represents a single simulation.

C.2.3 ESP DIESEL SCENARIOS

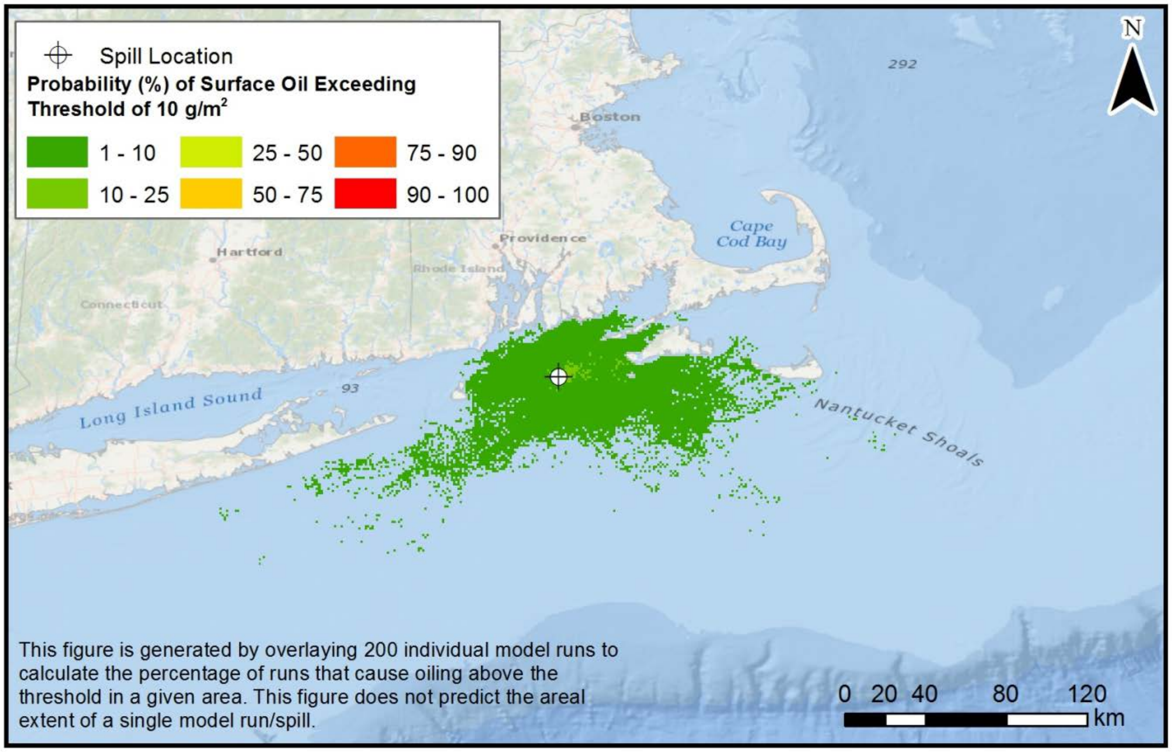
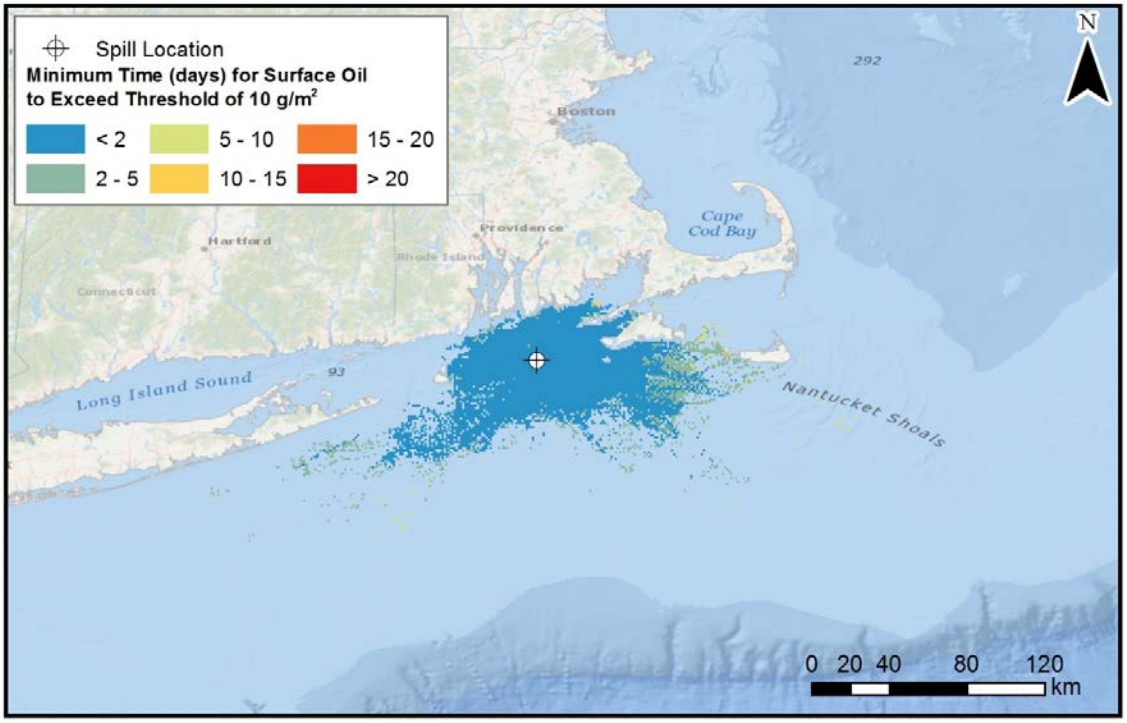


Figure C.25 Model scenario: ESP-DIESEL-E-2K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



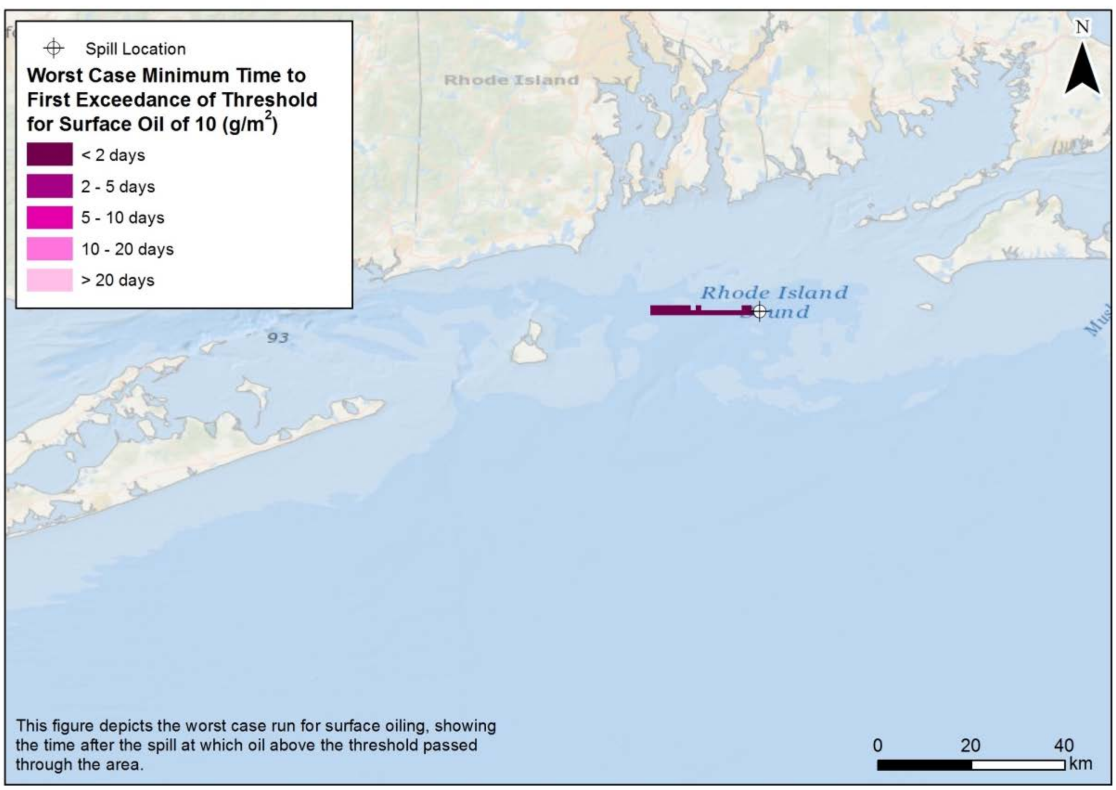


Figure C.26 Model scenario: ESP-DIESEL-E-2K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

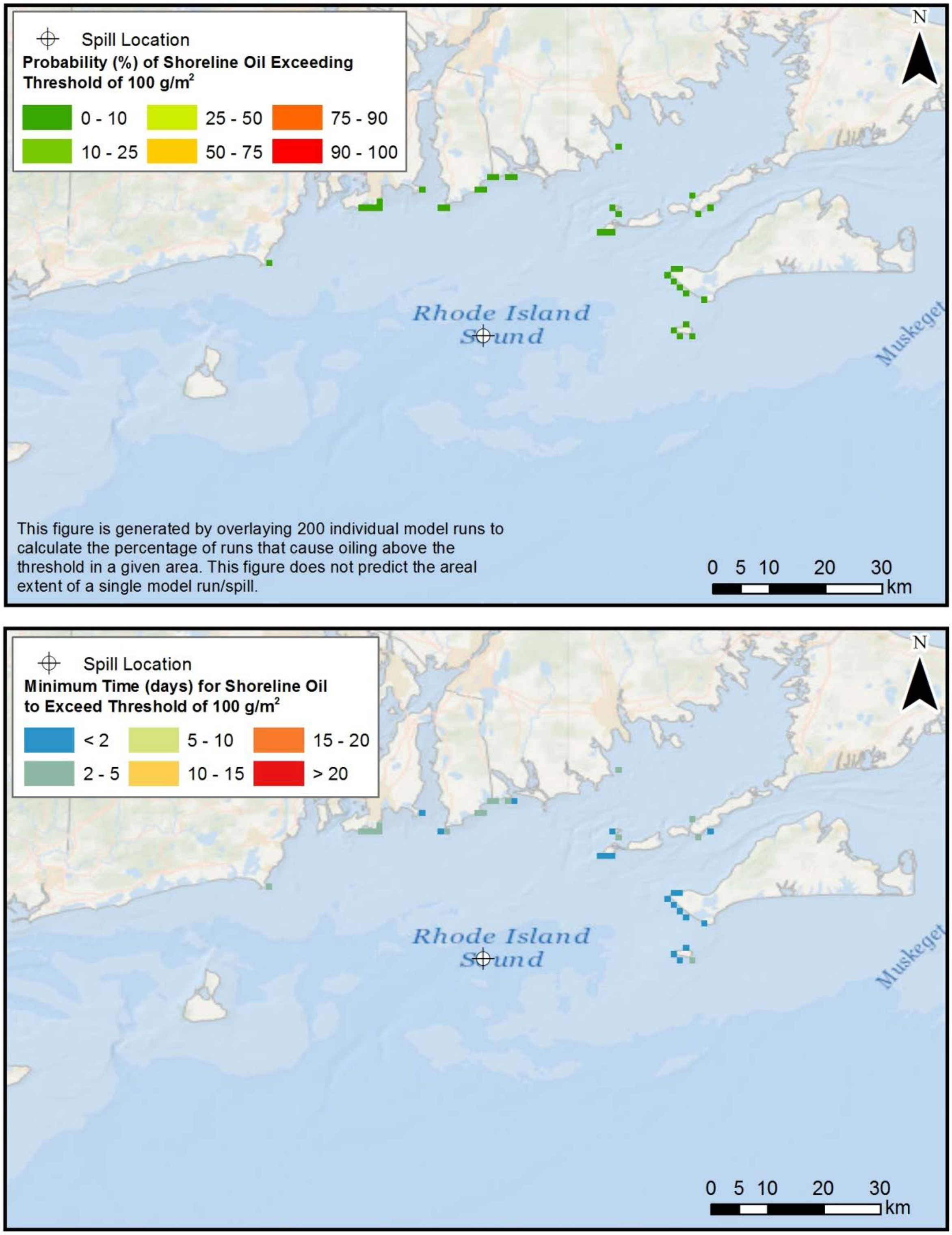


Figure C.27 Model scenario: ESP-DIESEL-E-2K. Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

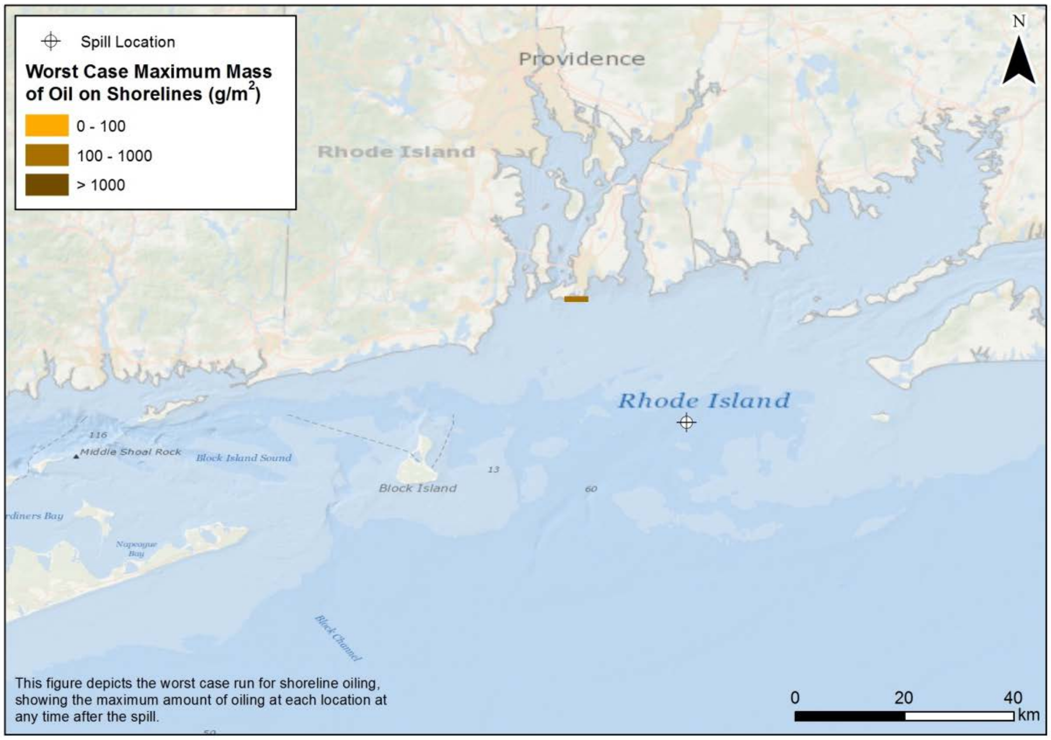


Figure C.28 Model scenario: ESP-DIESEL-E-2K. Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the RI-MA WEA. Map represents a single simulation.

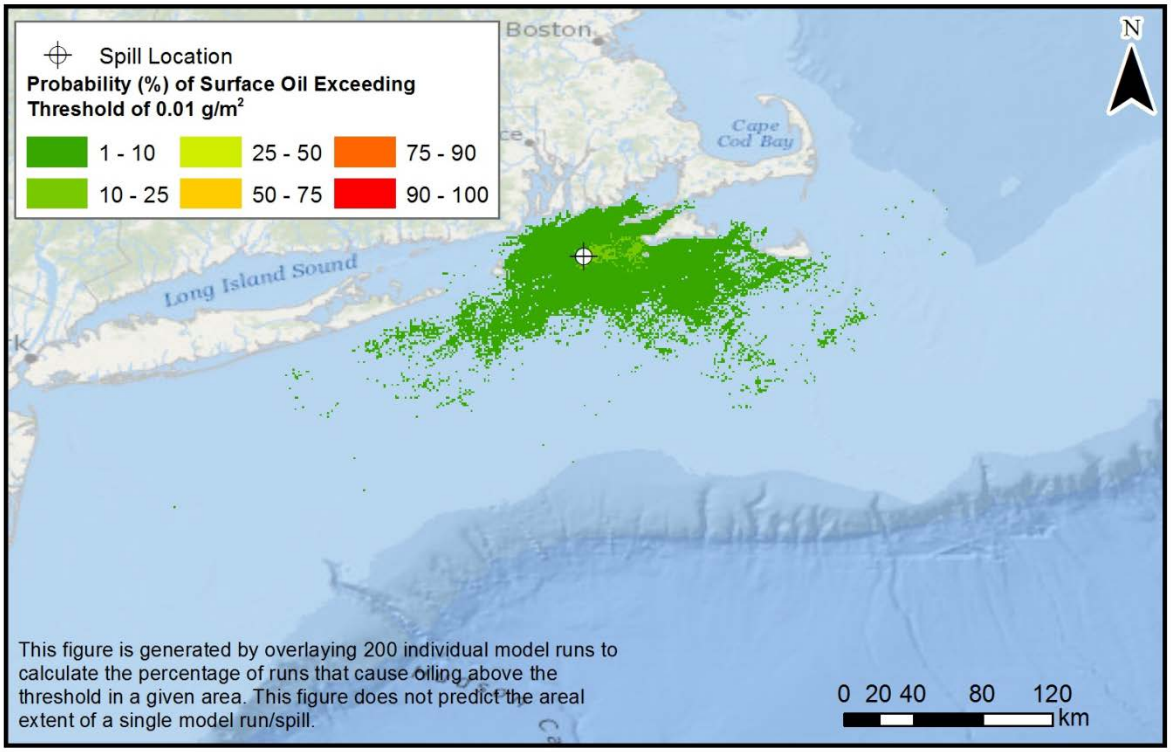
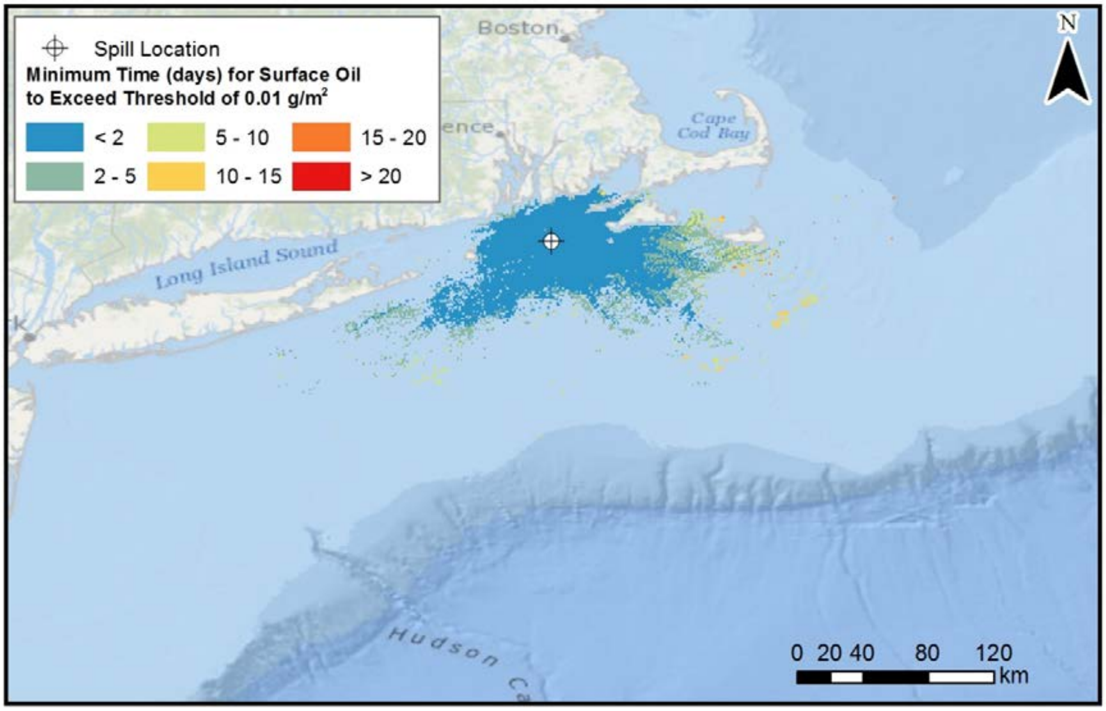


Figure C.29 Model scenario: ESP-DIESEL-S-2K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



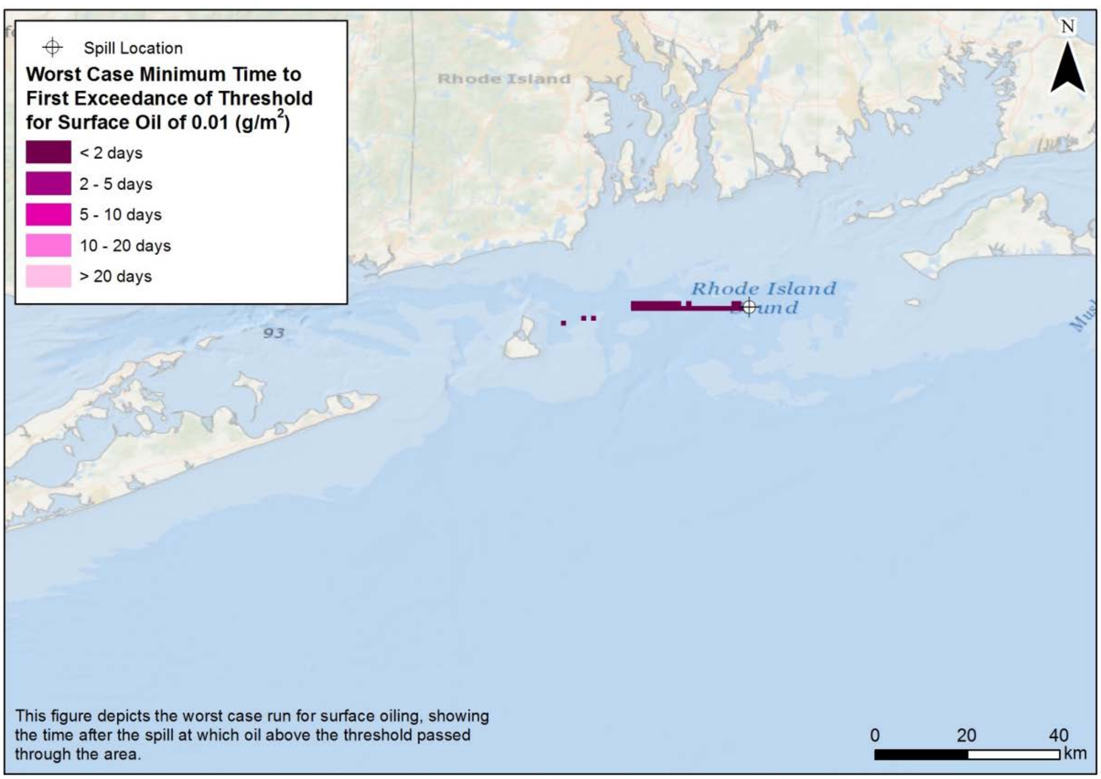
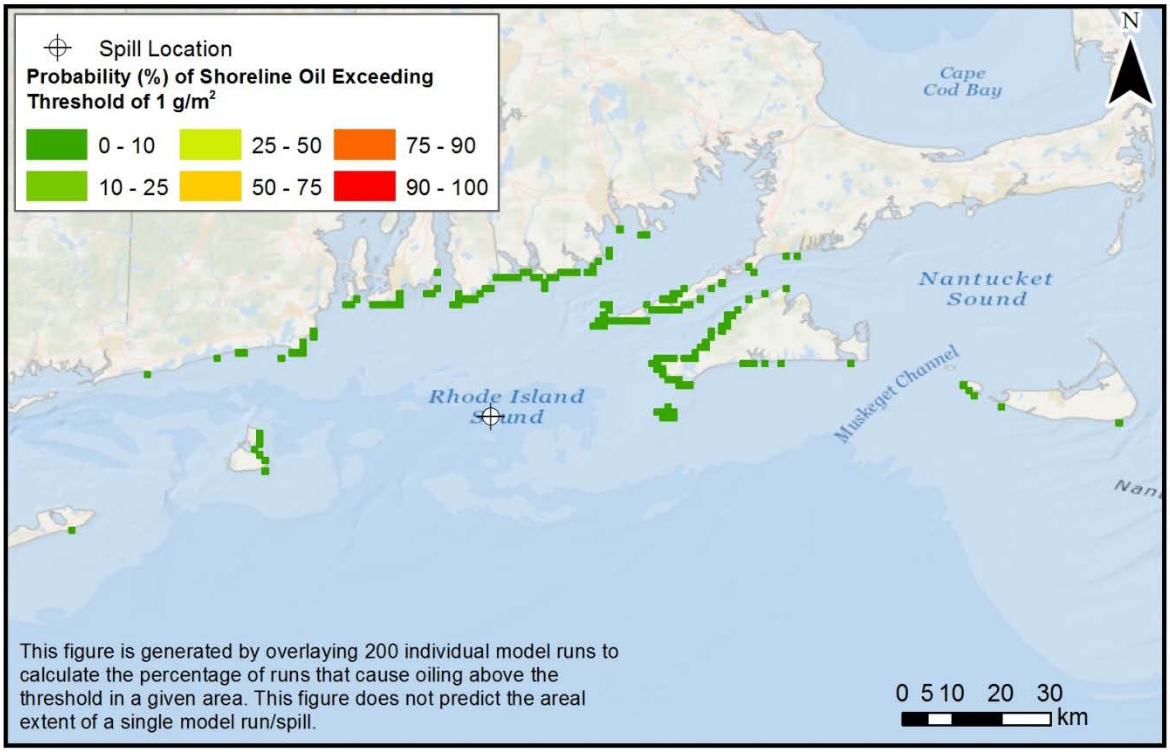


Figure C.30 Model scenario: ESP-DIESEL-S-2K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



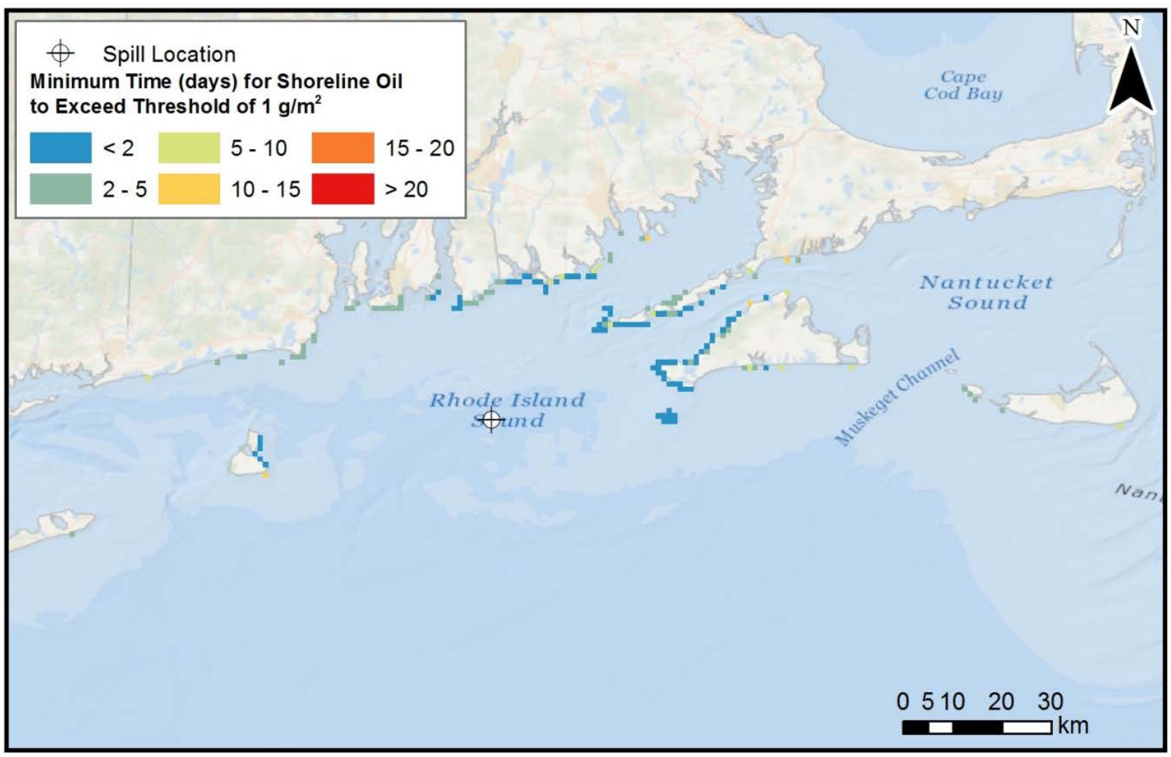


Figure C.31 Model scenario: ESP-DIESEL-S-2K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the RI-MA WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

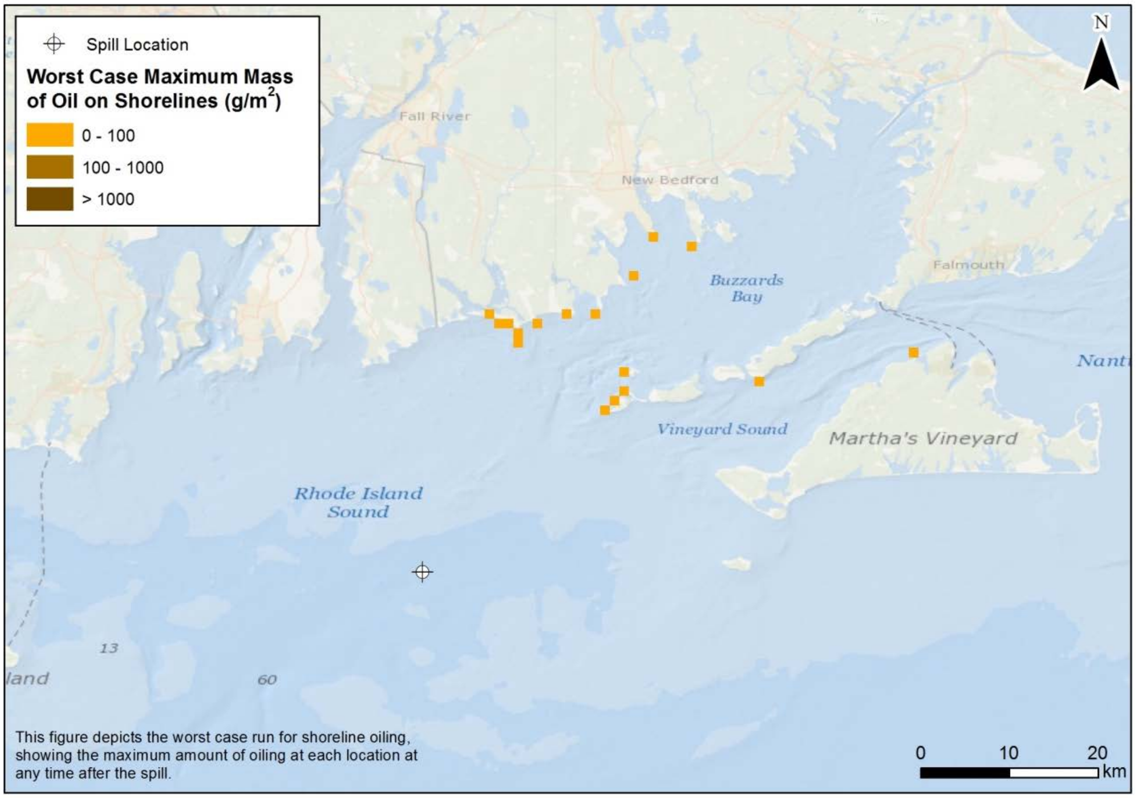


Figure C.32 Model scenario: ESP-DIESEL-S-2K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the RI-MA WEA. Map represents a single simulation.

C.2.4 WTG HYDRAULIC OIL SCENARIO

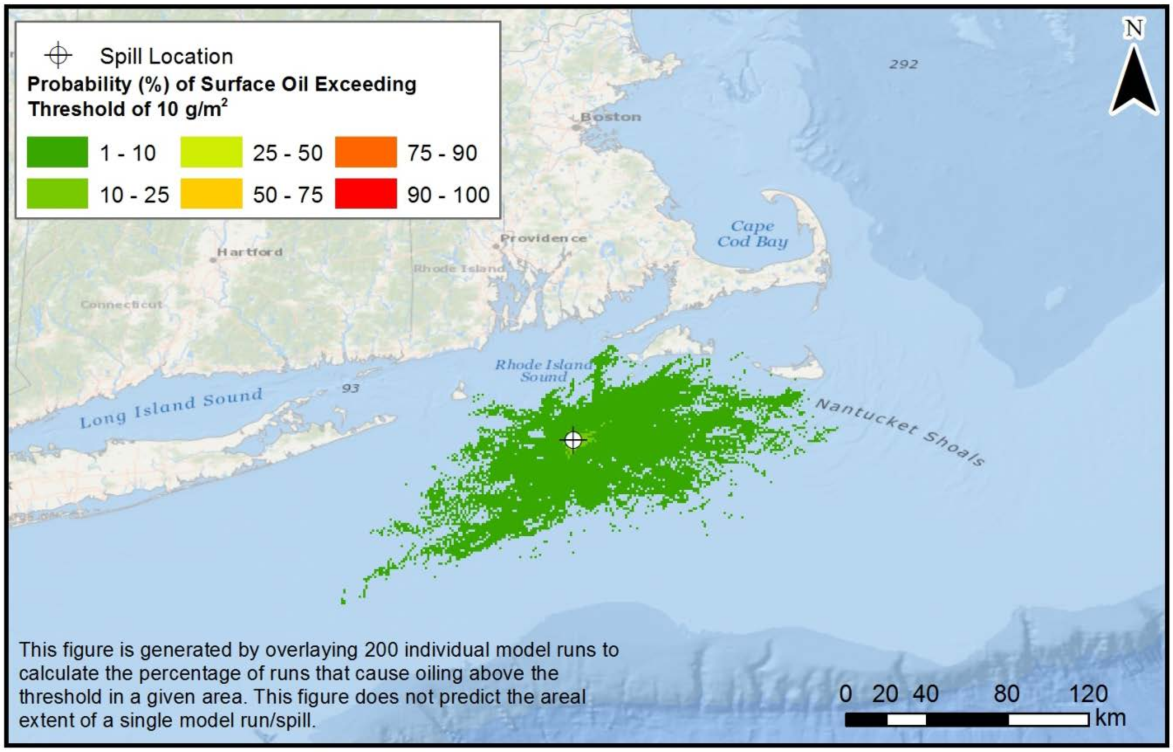
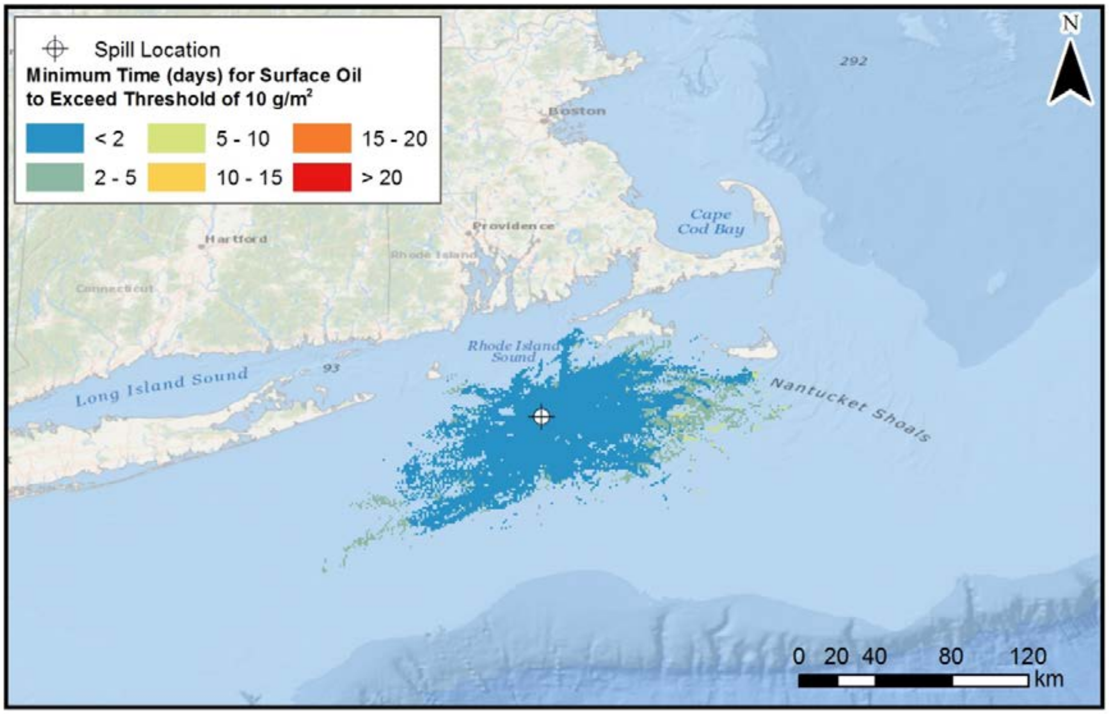


Figure C.35 Model scenario: ESP-WTG-HYD-E-90. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 90 gallons of hydraulic oil from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



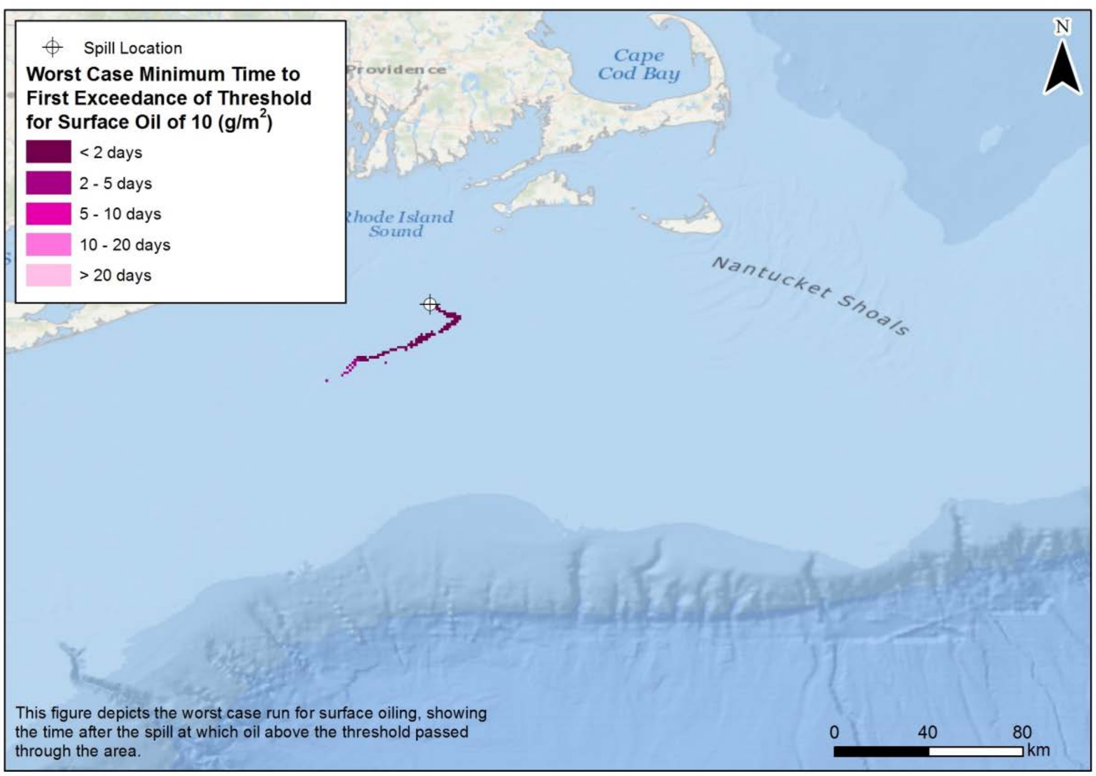


Figure C.36 Model scenario: ESP-WTG-HYD-E-90. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 90 gallons of hydraulic oil from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

C.2.5 WTG Lubricating Oil Scenario

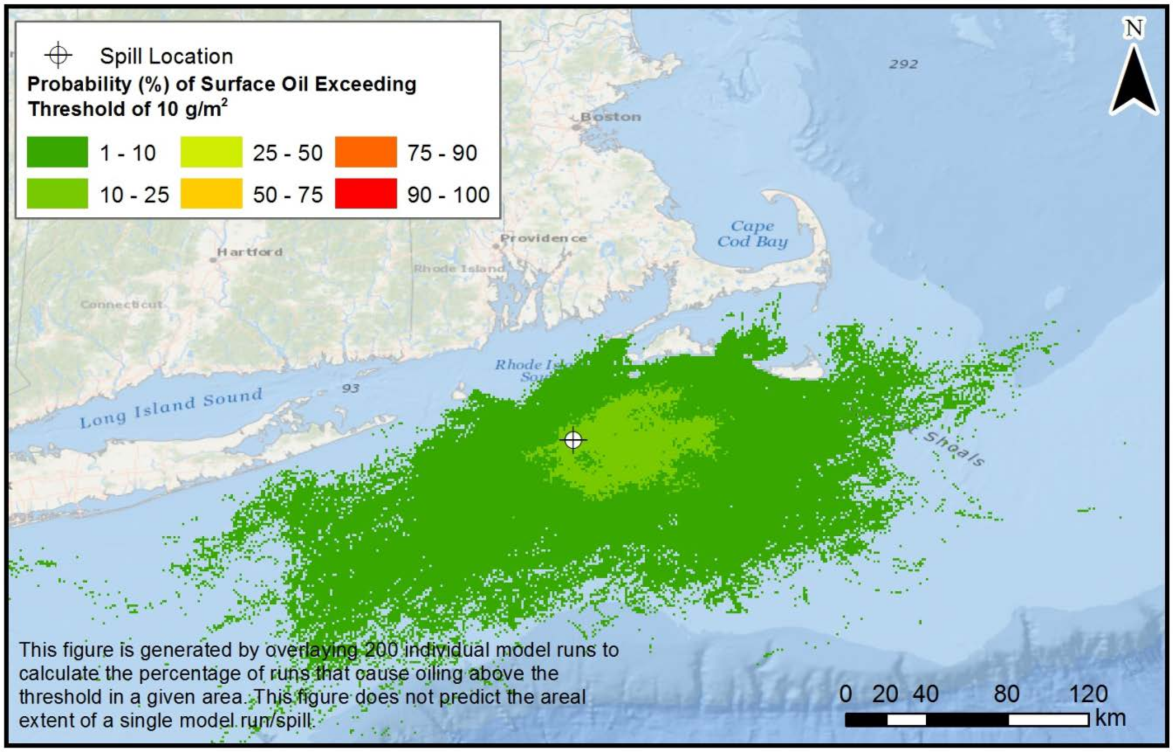
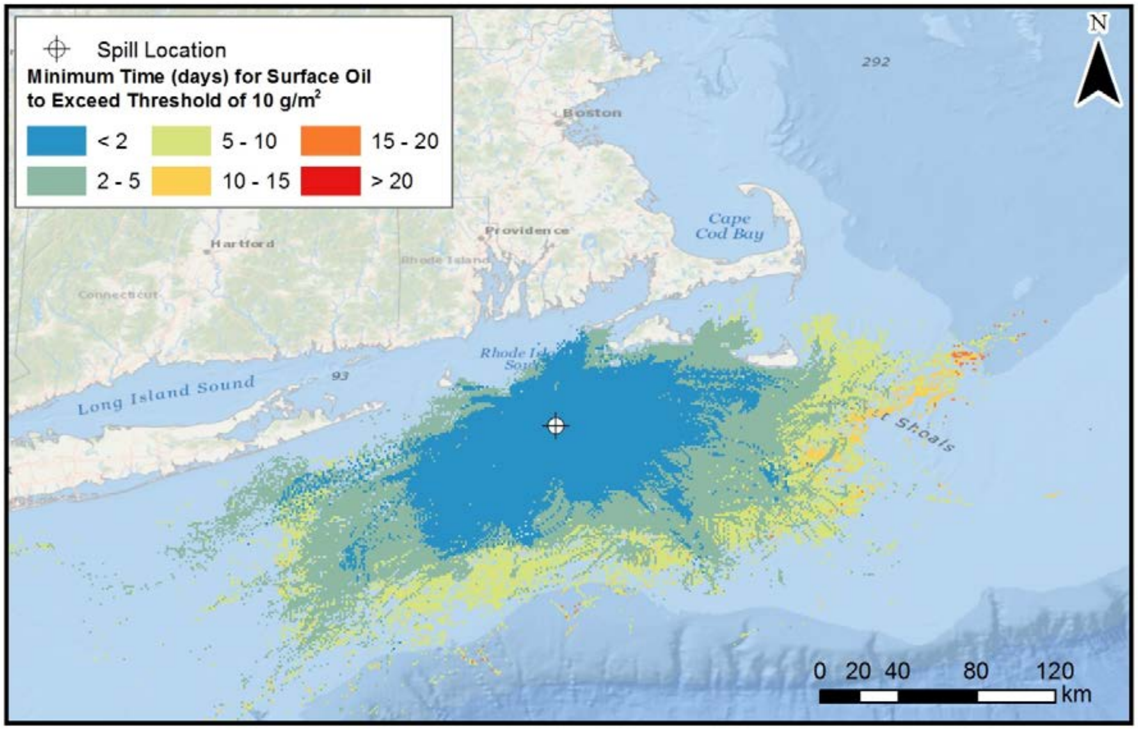


Figure C.37 Model scenario: ESP-WTG-LUB-E-220. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 220 gallons of lubricating oil from a wind turbine in the RI-MA WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



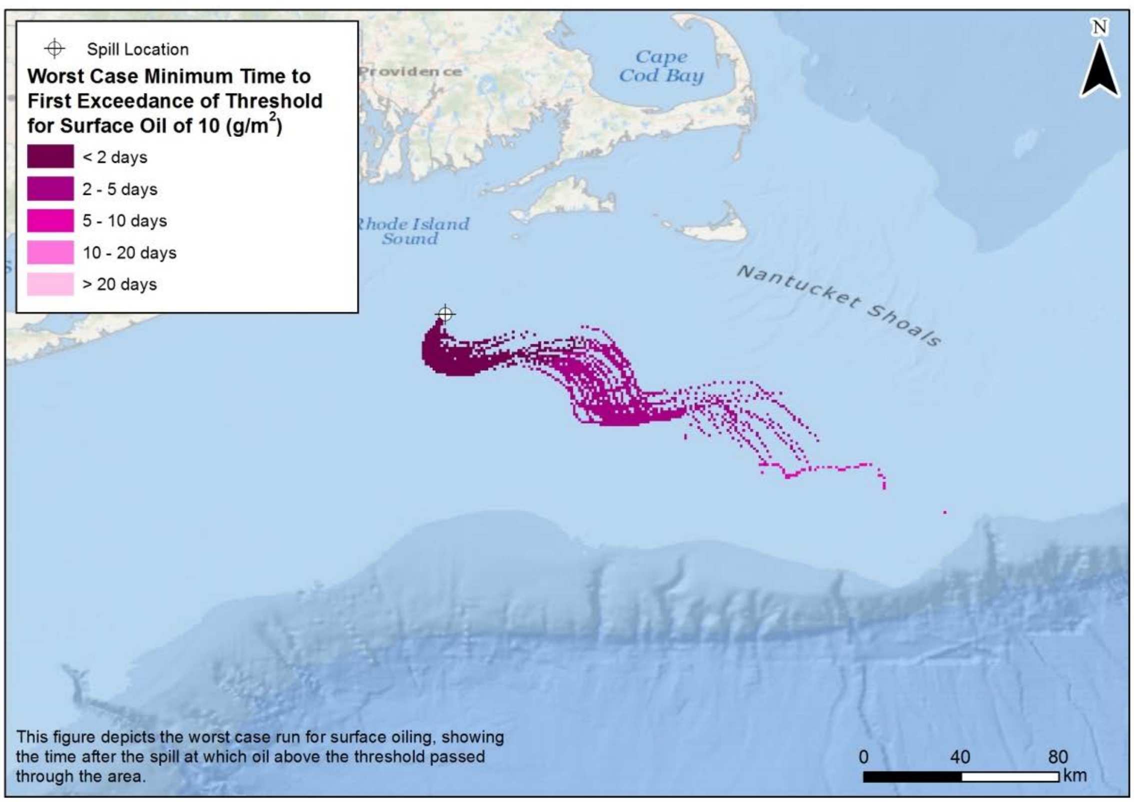


Figure C.38 Model scenario: ESP-WTG-LUB-E-220. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 220 gallons of lubricating oil from a wind turbine in the RI-MA WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

C.3 MARYLAND WIND ENERGY AREA

C.3.1 5 WTGs Oil Mixture Scenarios

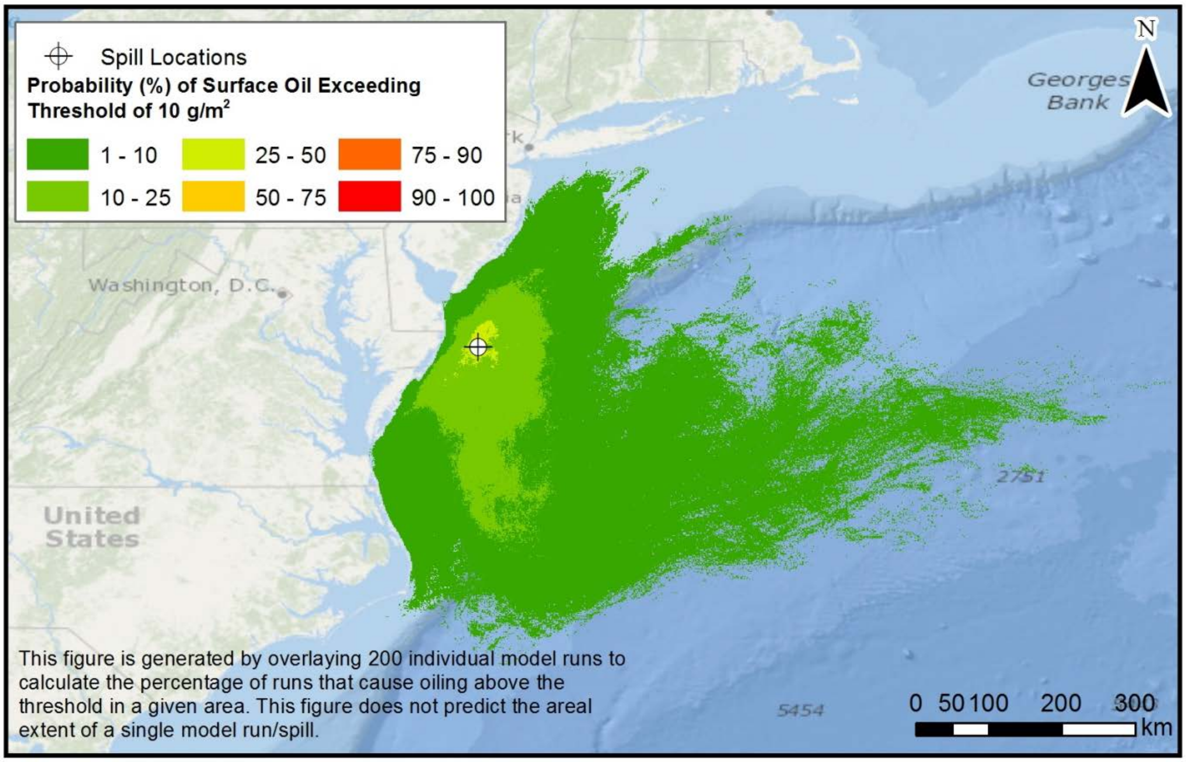
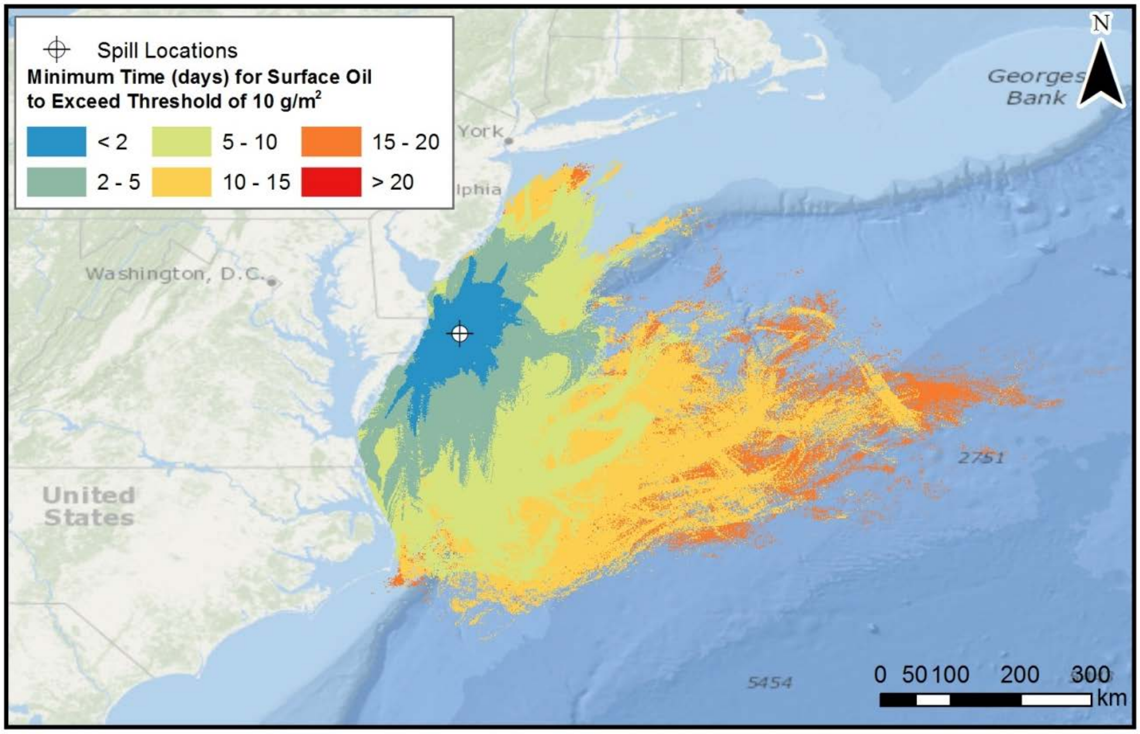


Figure C.39 Model scenario: 5WTG-MIX1-3400. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



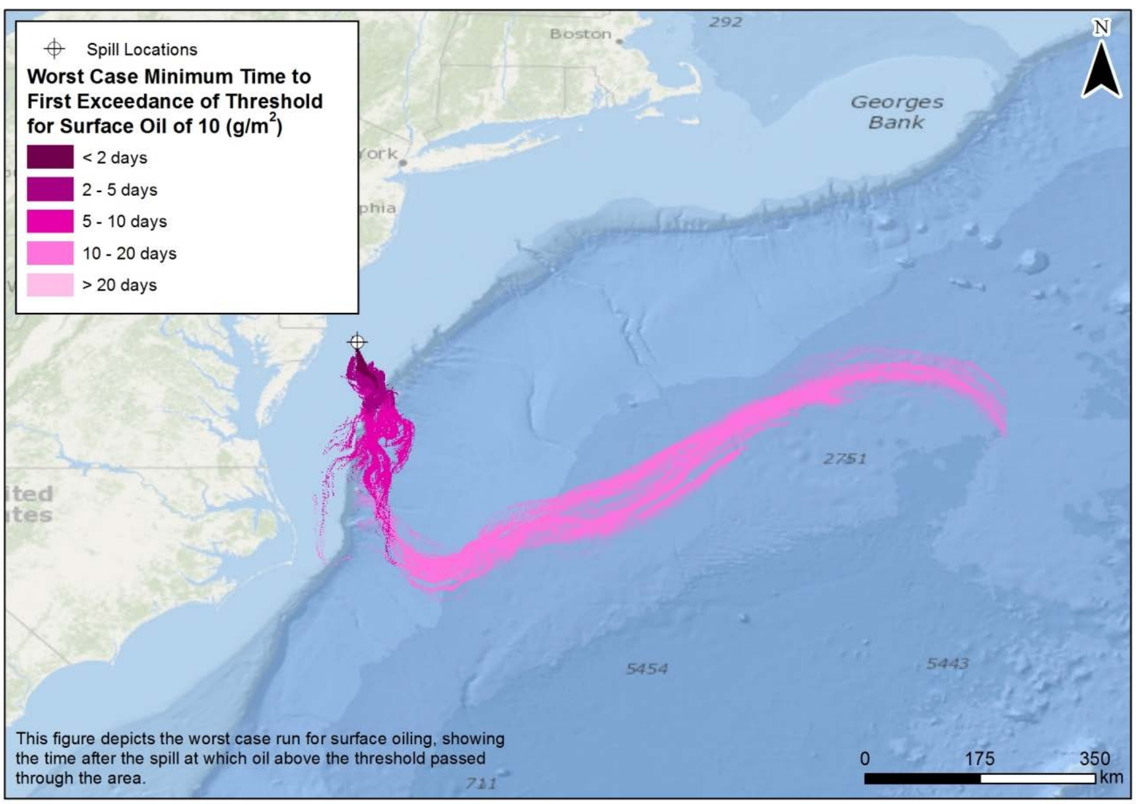
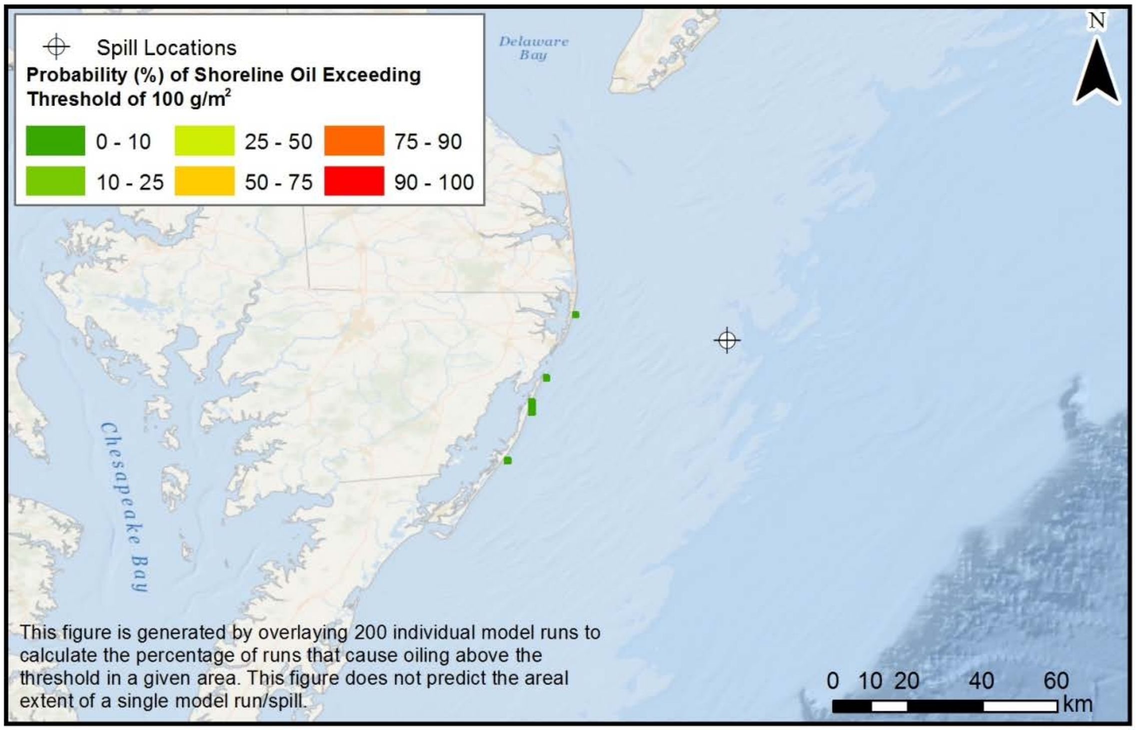


Figure C.40 Model scenario: 5WTG-MIX1-3400. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



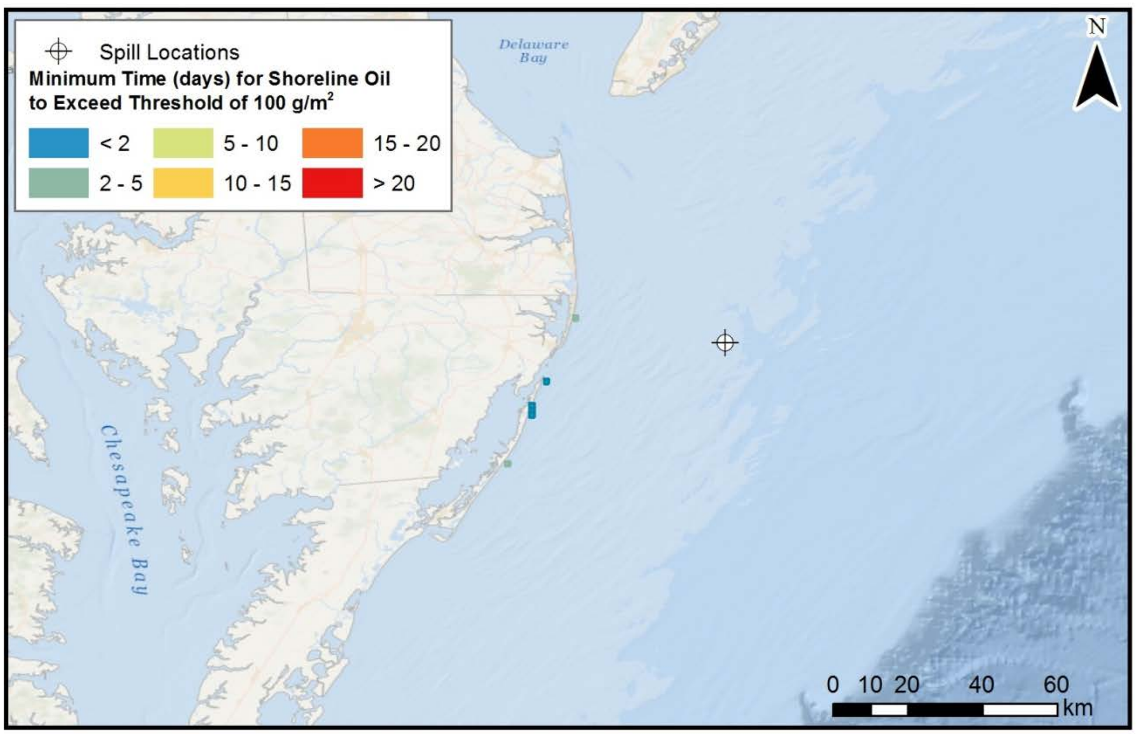


Figure C.41 Model scenario: 5WTG-MIX1-3400. Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the MD WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

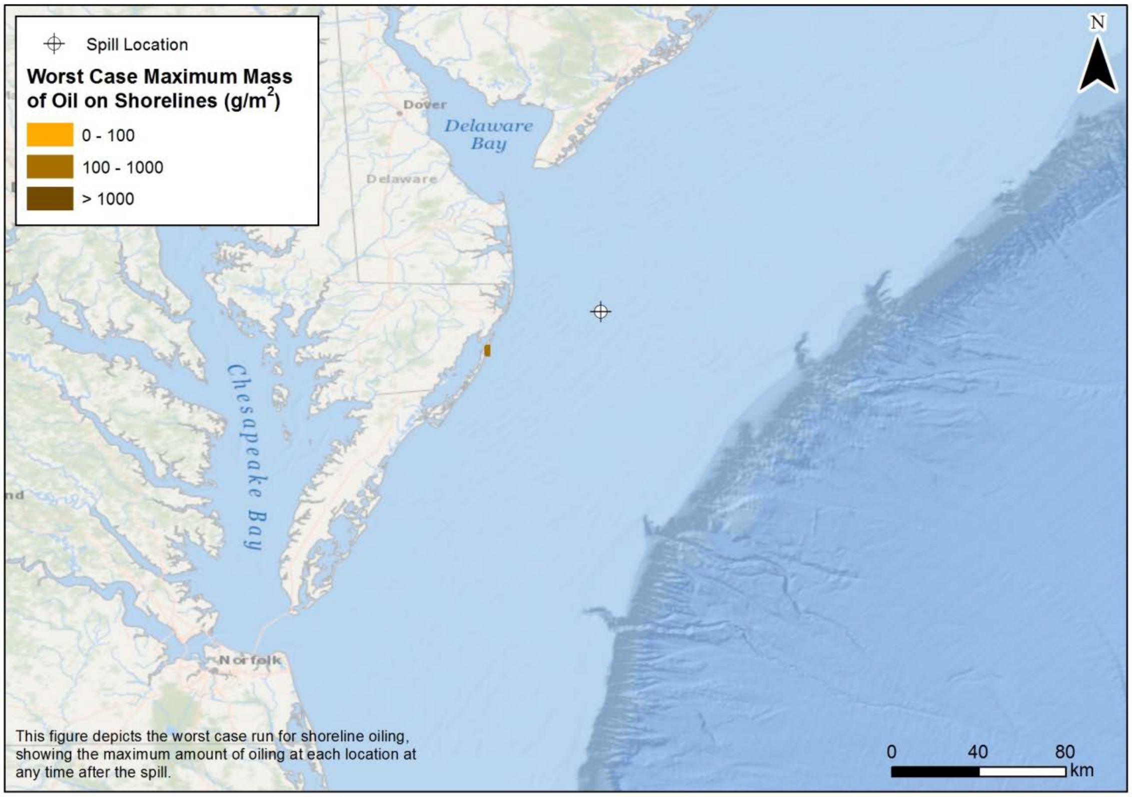


Figure C.42 Model scenario: 5WTG-MIX1-3400. Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the MD WEA. Map represents a single simulation.

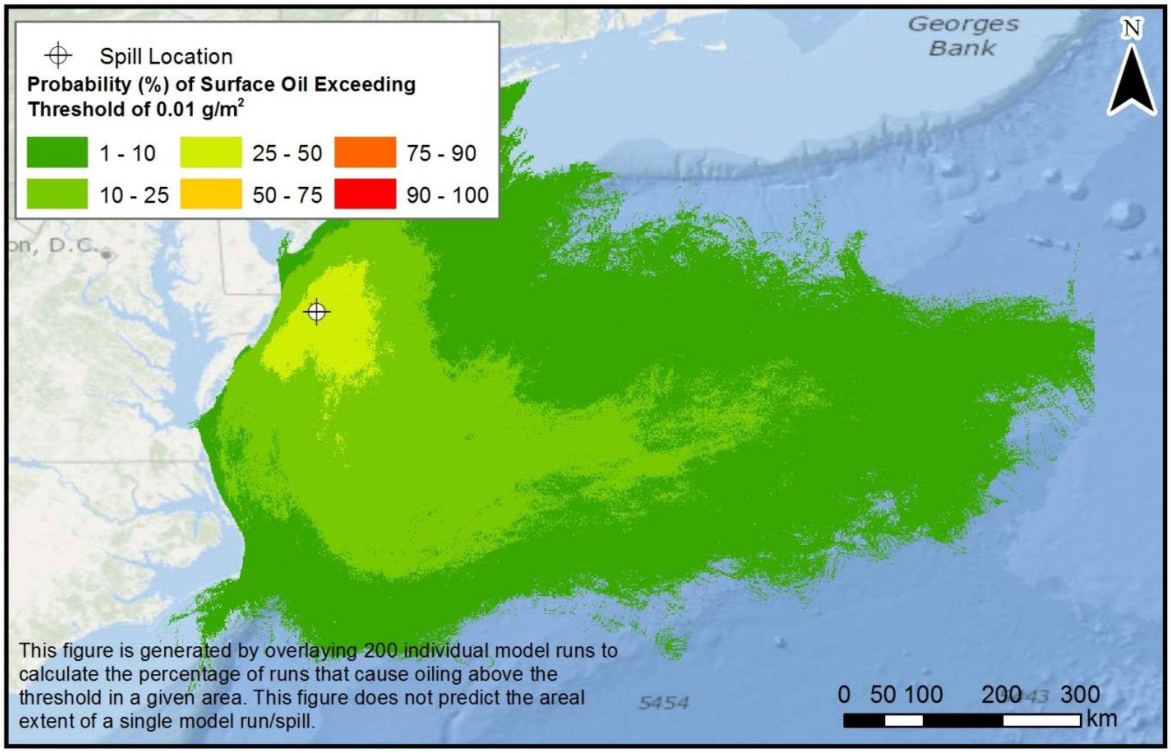


Figure C.43 Model scenario: 5WTG-MIX1-3400. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

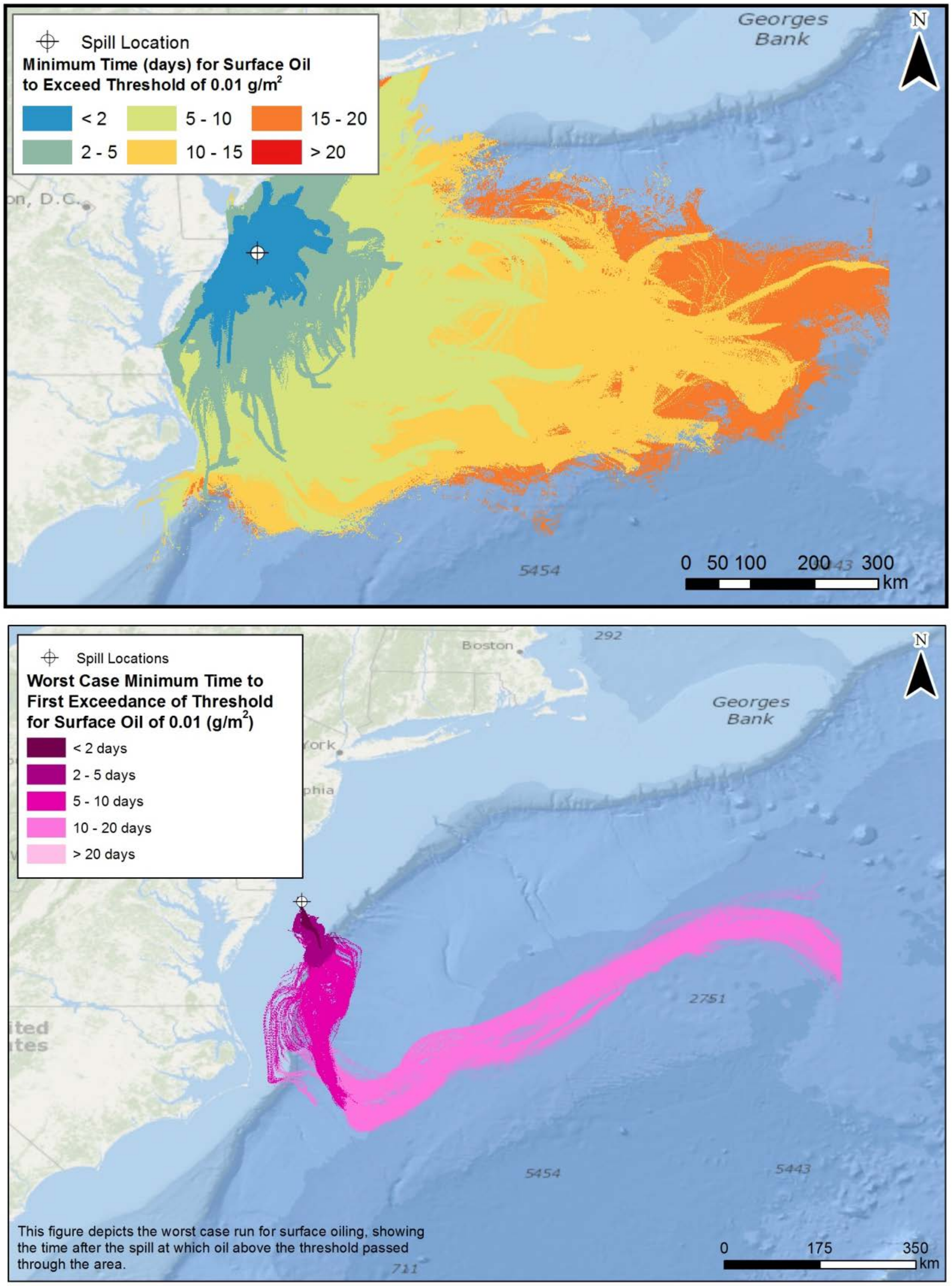


Figure C.44 Model scenario: 5WTG-MIX1-3400. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

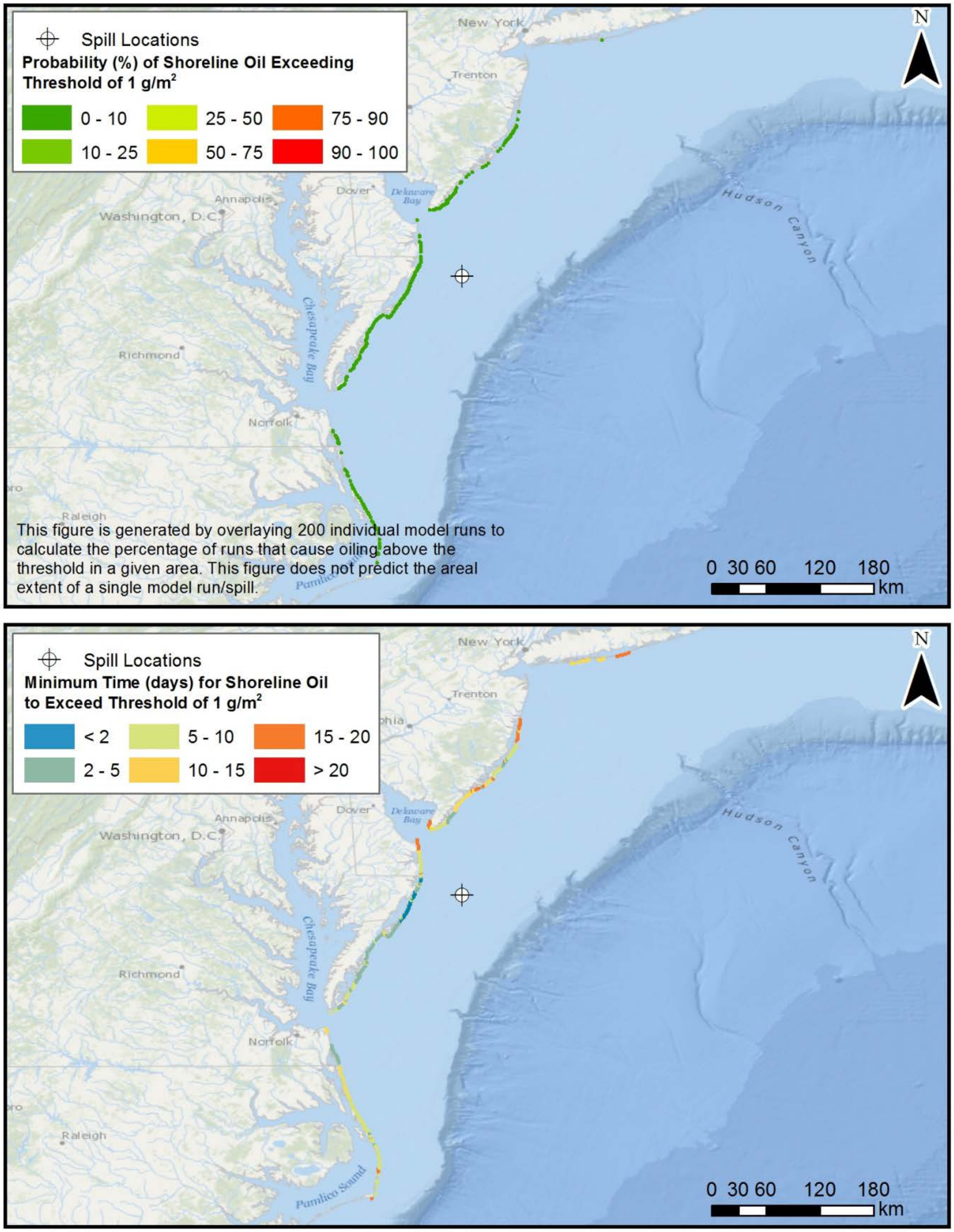


Figure C.45 Model scenario: 5WTG-MIX1-3400. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the MD WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

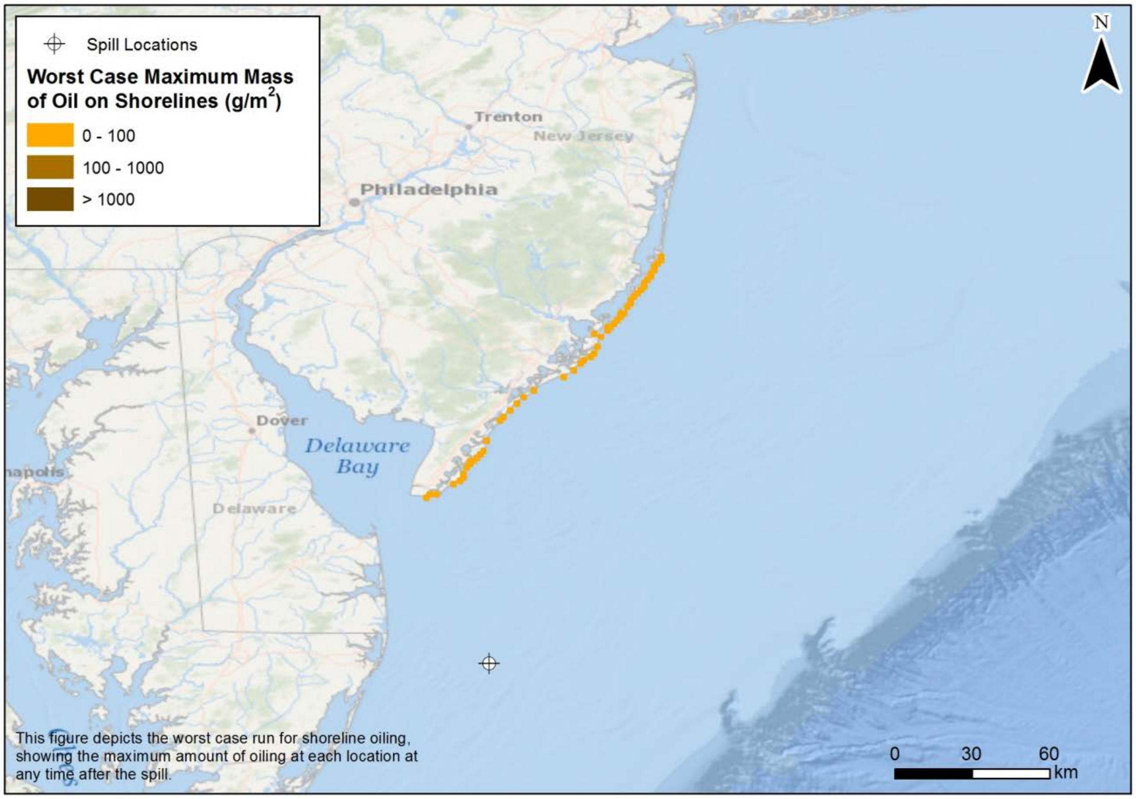


Figure C.46 Model scenario: 5WTG-MIX1-3400. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the MD WEA. Map represents a single simulation.

C.3.2 ESP Naphthenic Mineral Oil Scenarios (1K and 40K Gallons)

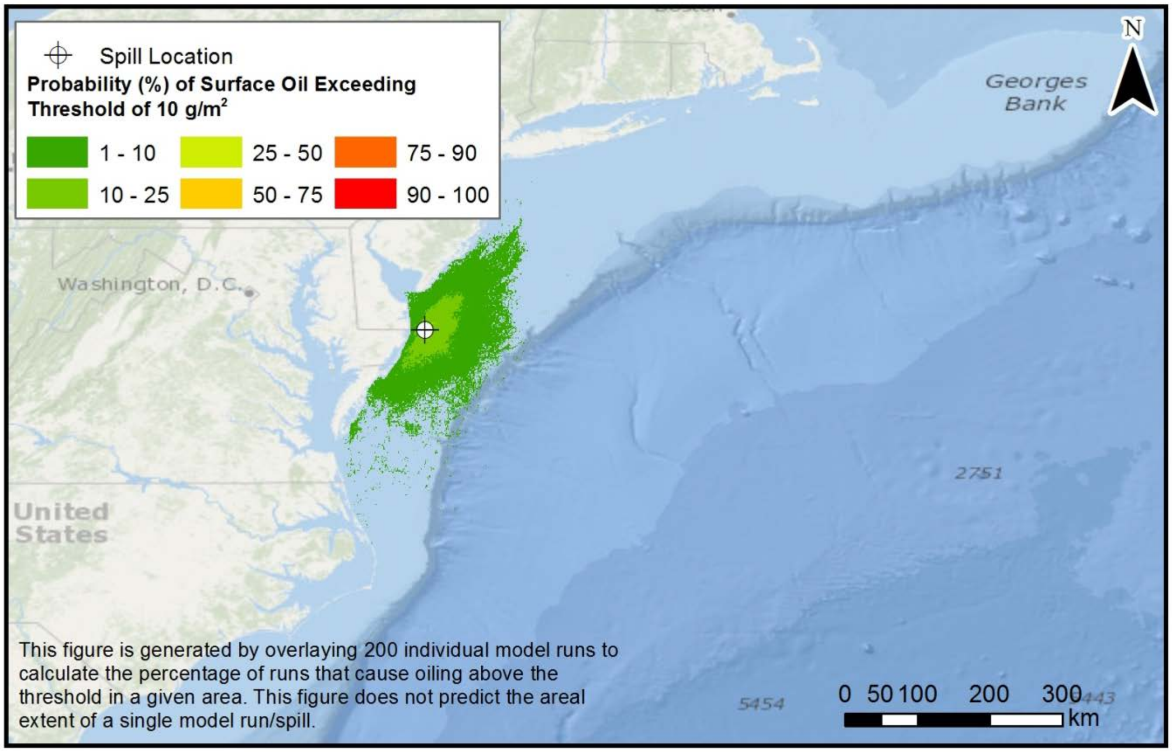


Figure C.47 Model scenario: ESP-NAP-E-1K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

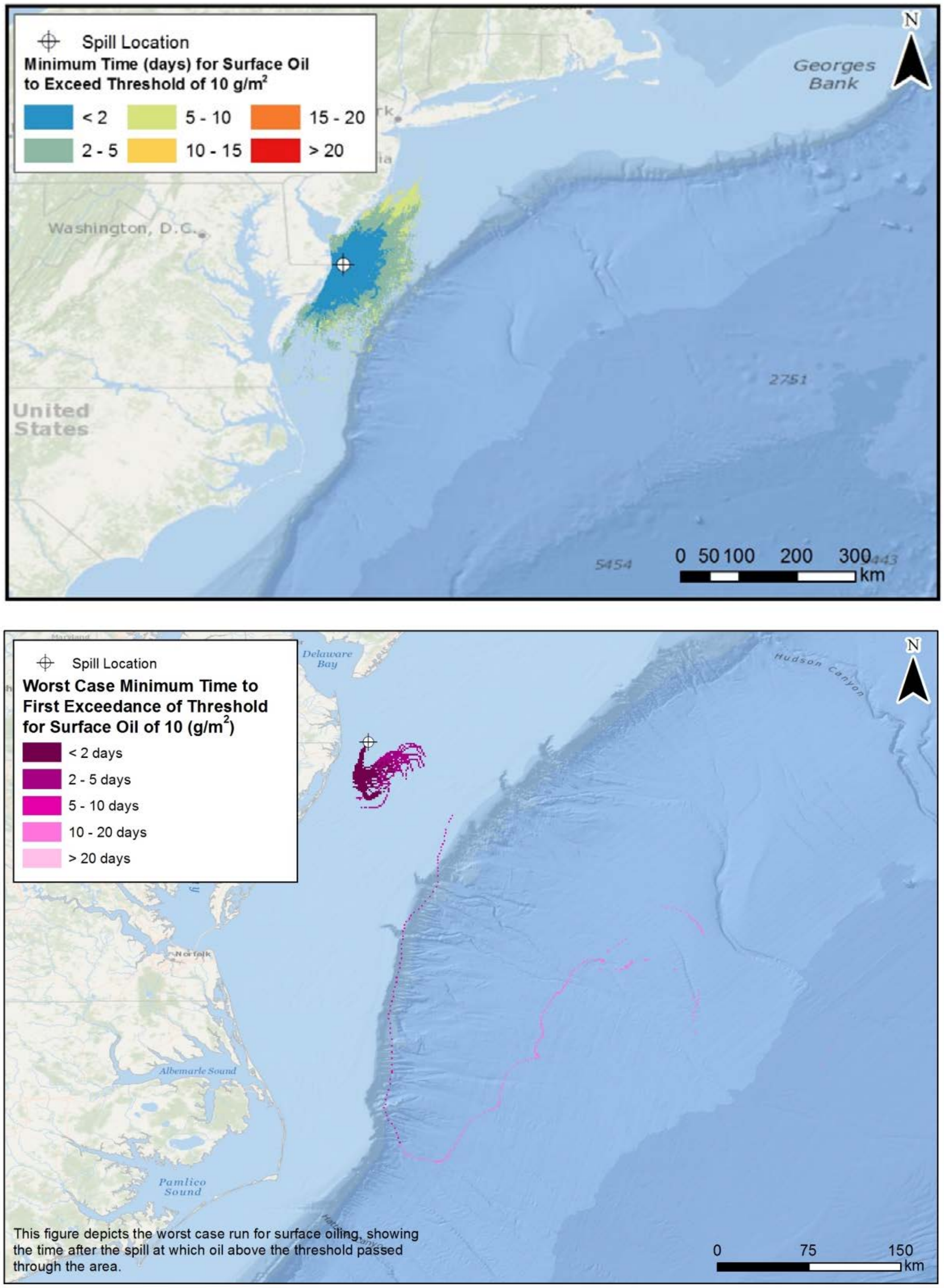


Figure C.48 Model scenario: ESP-NAP-E-1K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

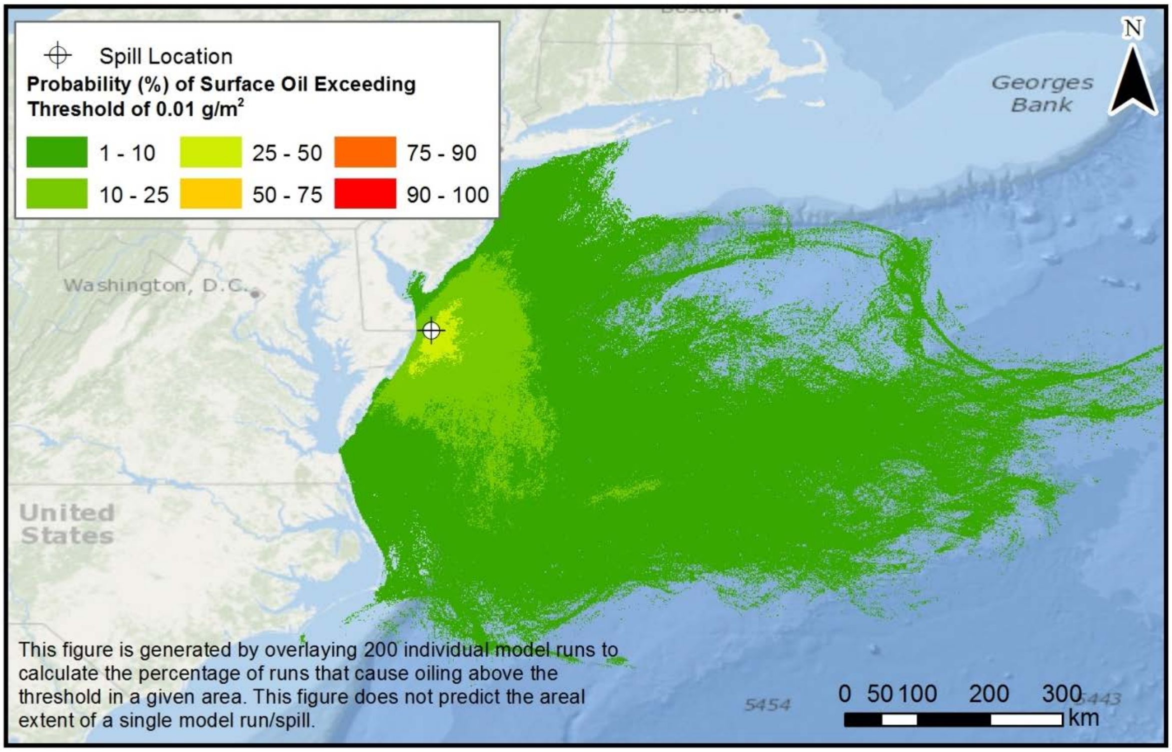
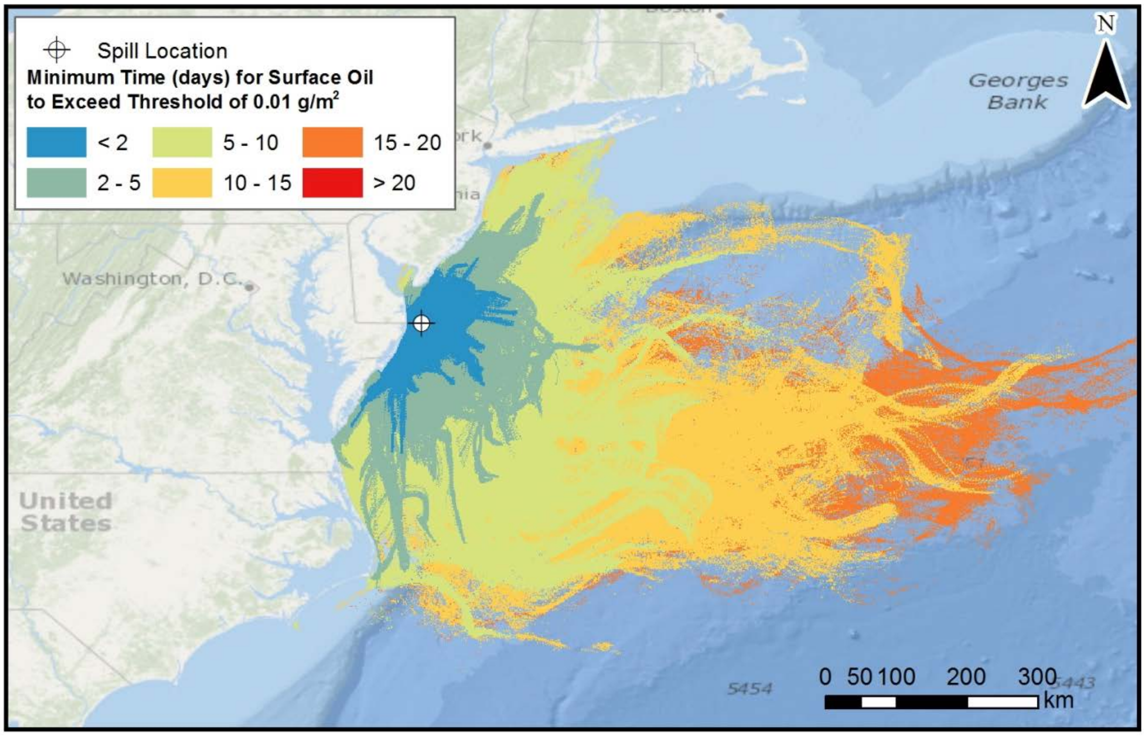


Figure C.49 Model scenario: ESP-NAP-S-1K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



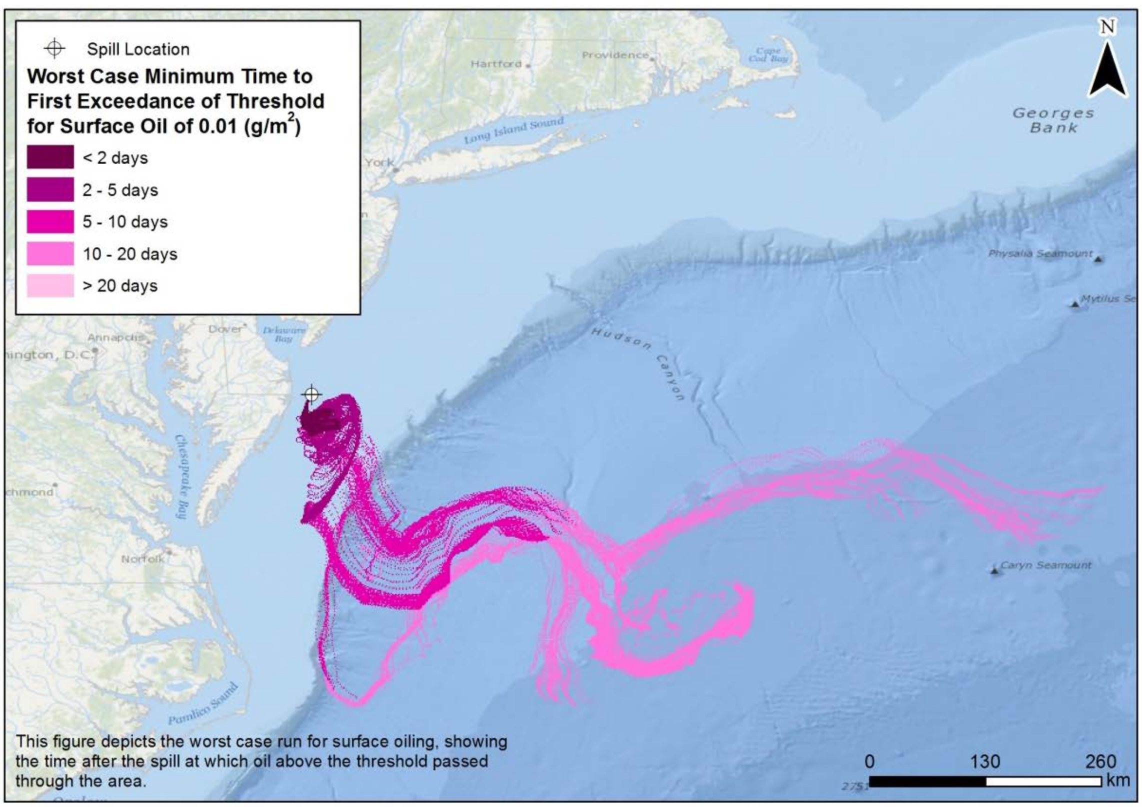
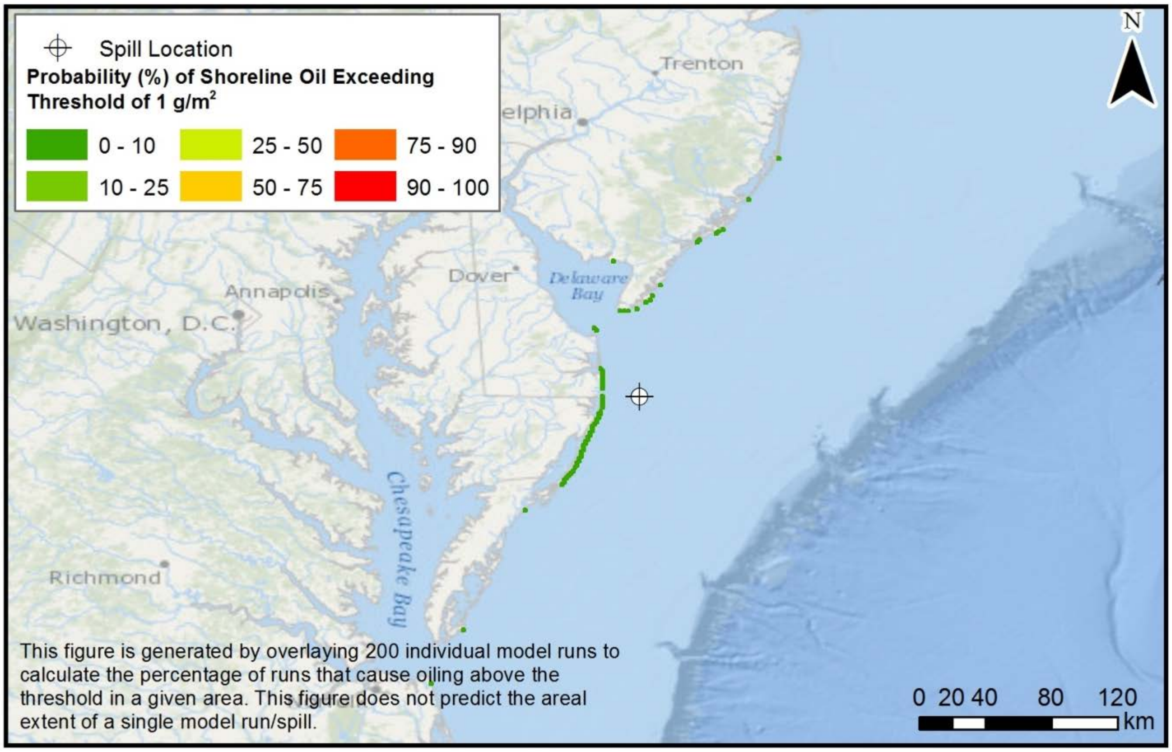


Figure C.50 Model scenario: ESP-NAP-S-1K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



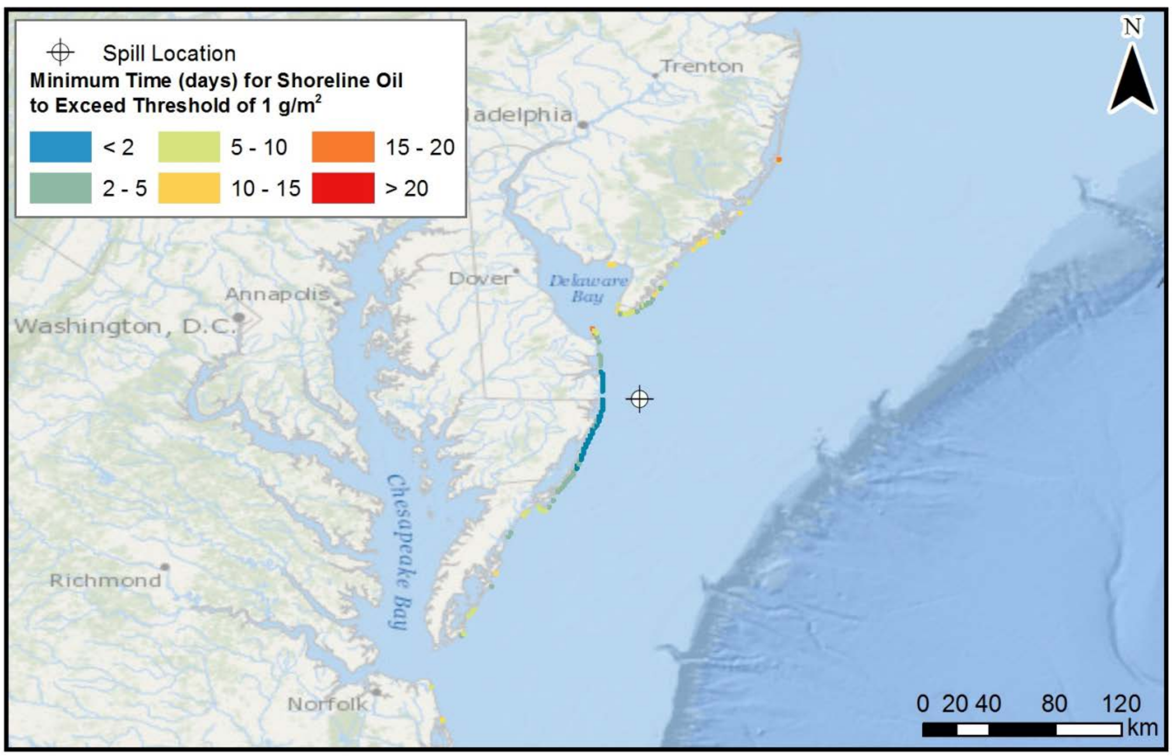


Figure C.51 Model scenario: ESP-NAP-S-1K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

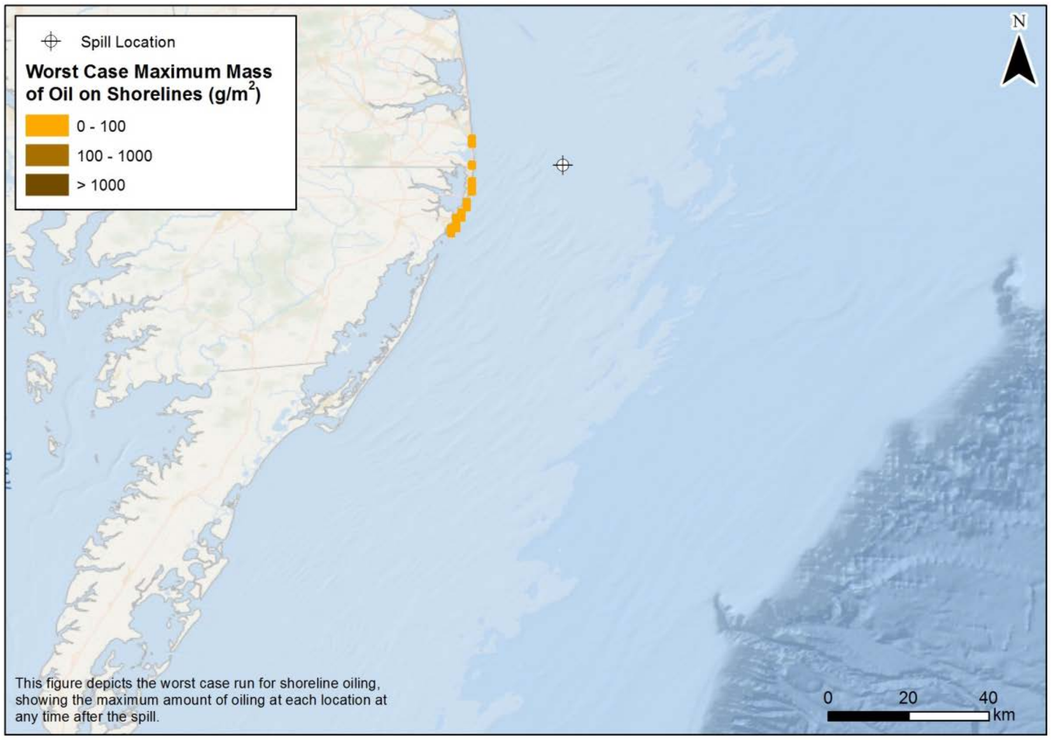


Figure C.52 Model scenario: ESP-NAP-S-1K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Map represents a single simulation.

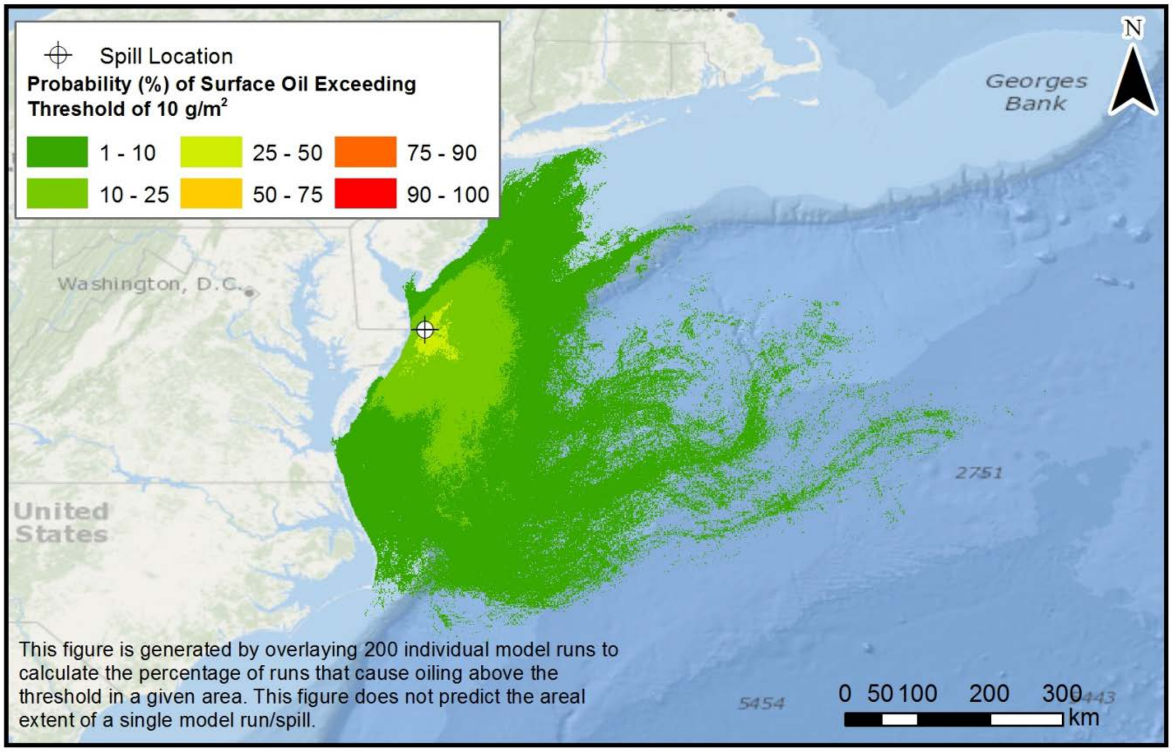
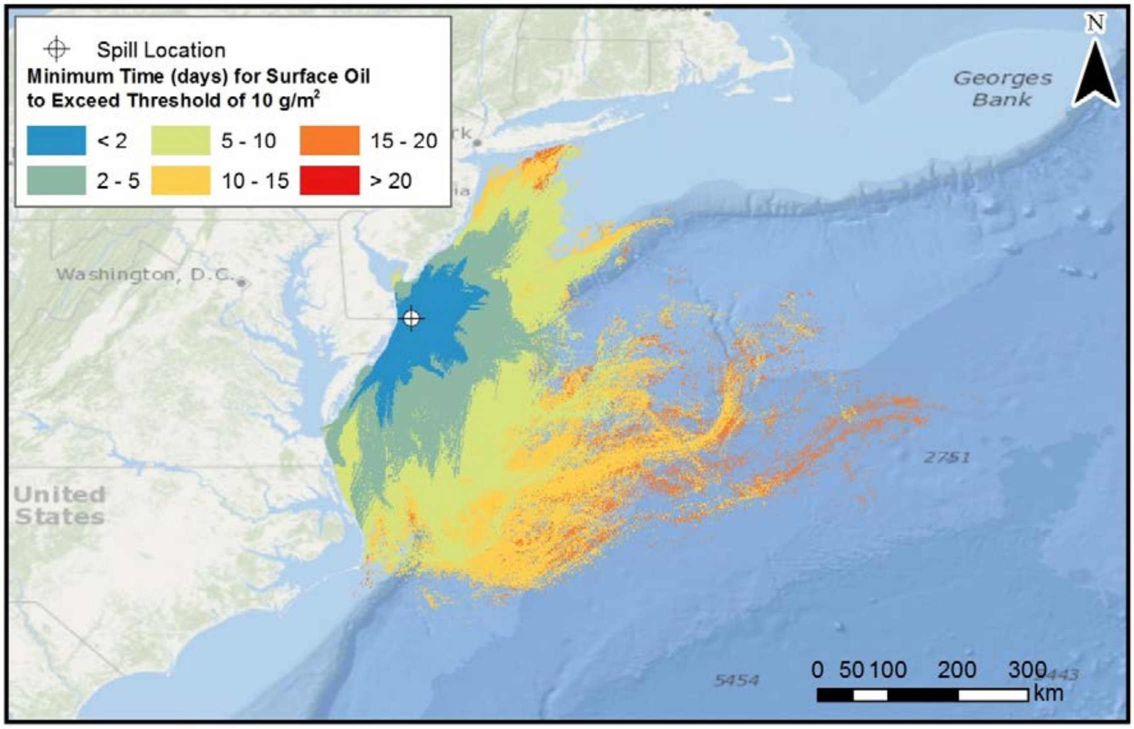


Figure C.53 Model scenario: ESP-NAP-E-40K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



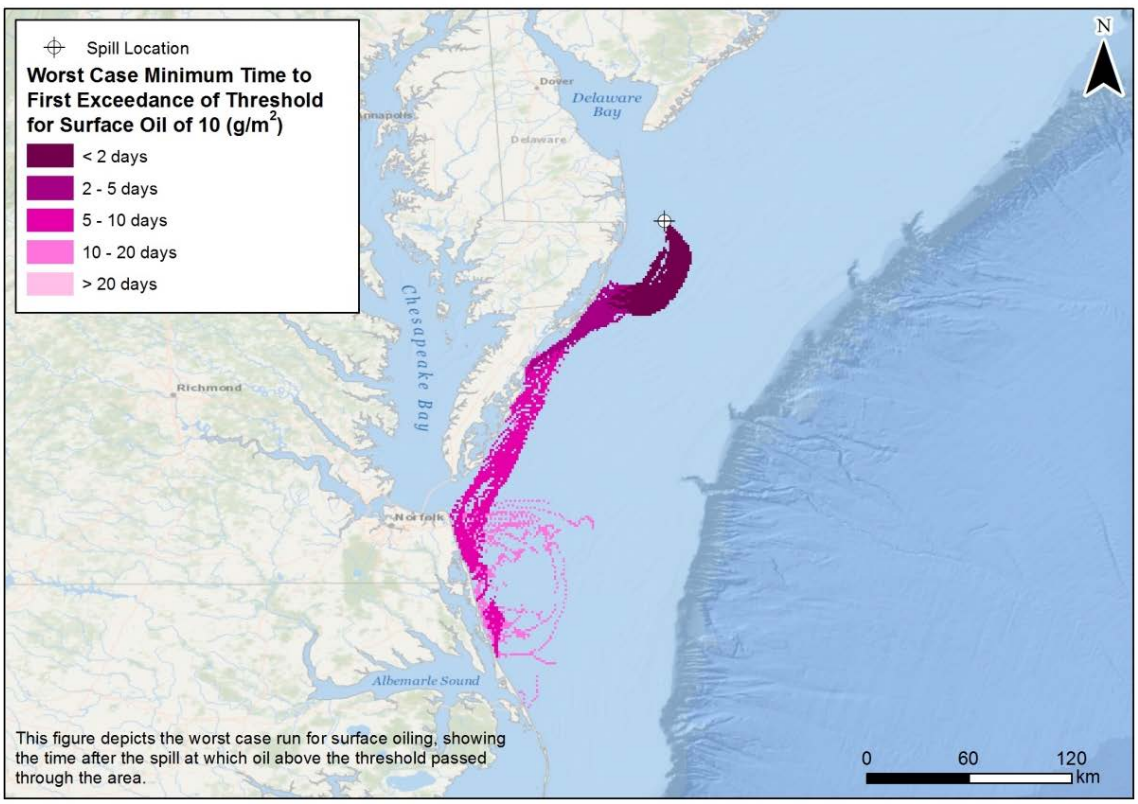
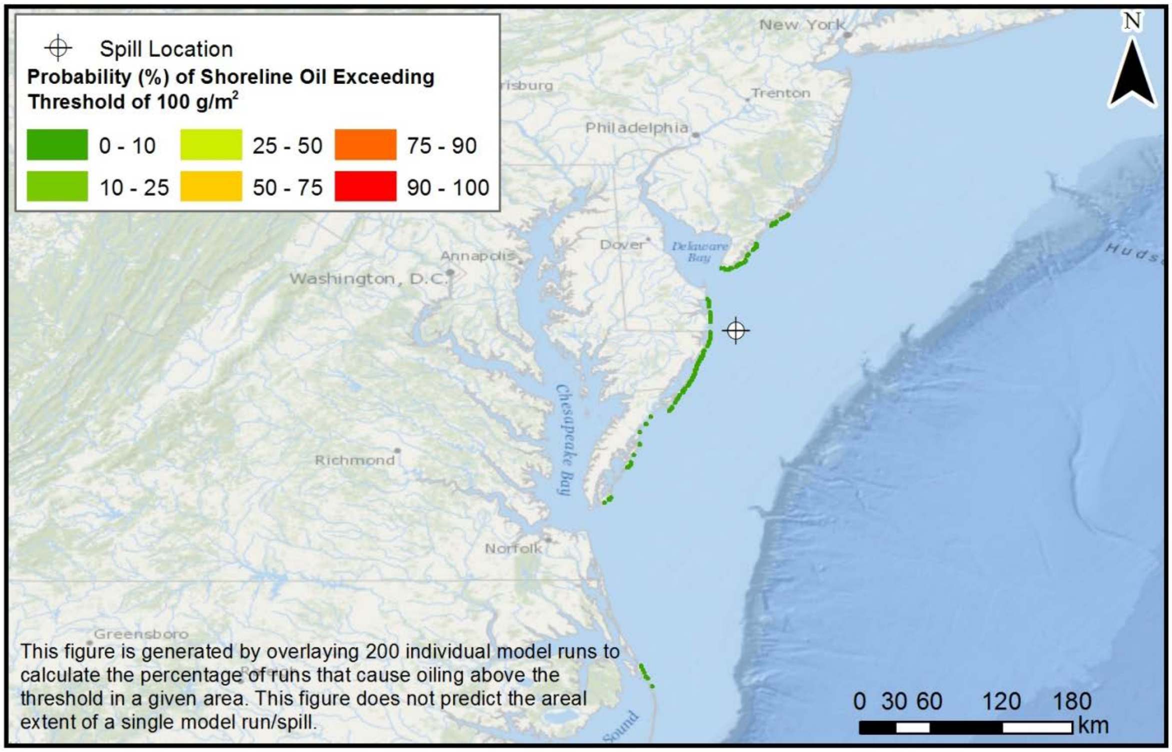


Figure C.54 Model scenario: ESP-NAP-E-40K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



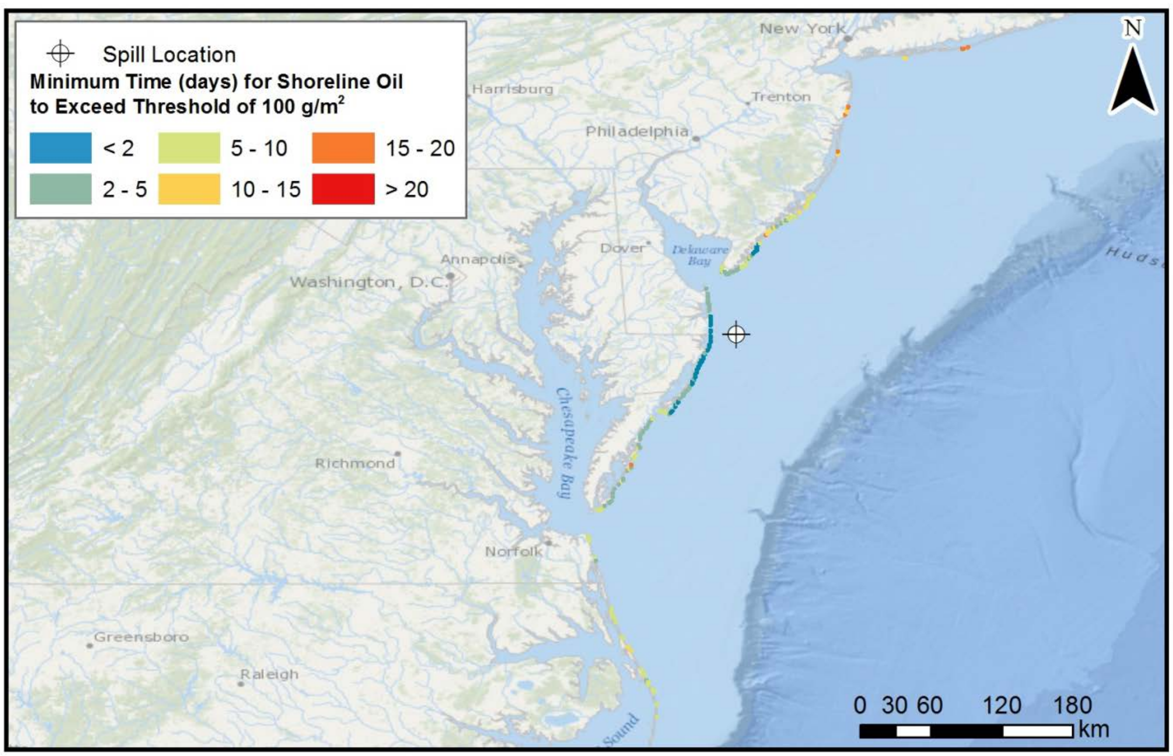


Figure C.55 Model scenario: ESP-NAP-E-40K. Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

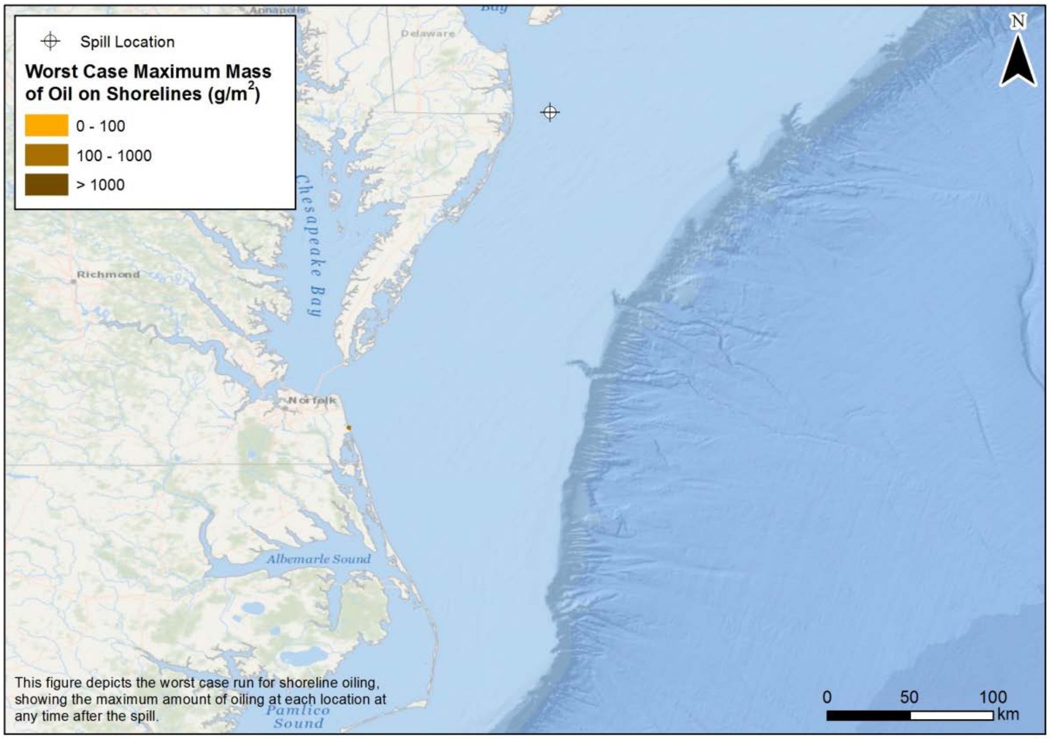


Figure C.56 Model scenario: ESP-NAP-E-40K. Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Map represents a single simulation.

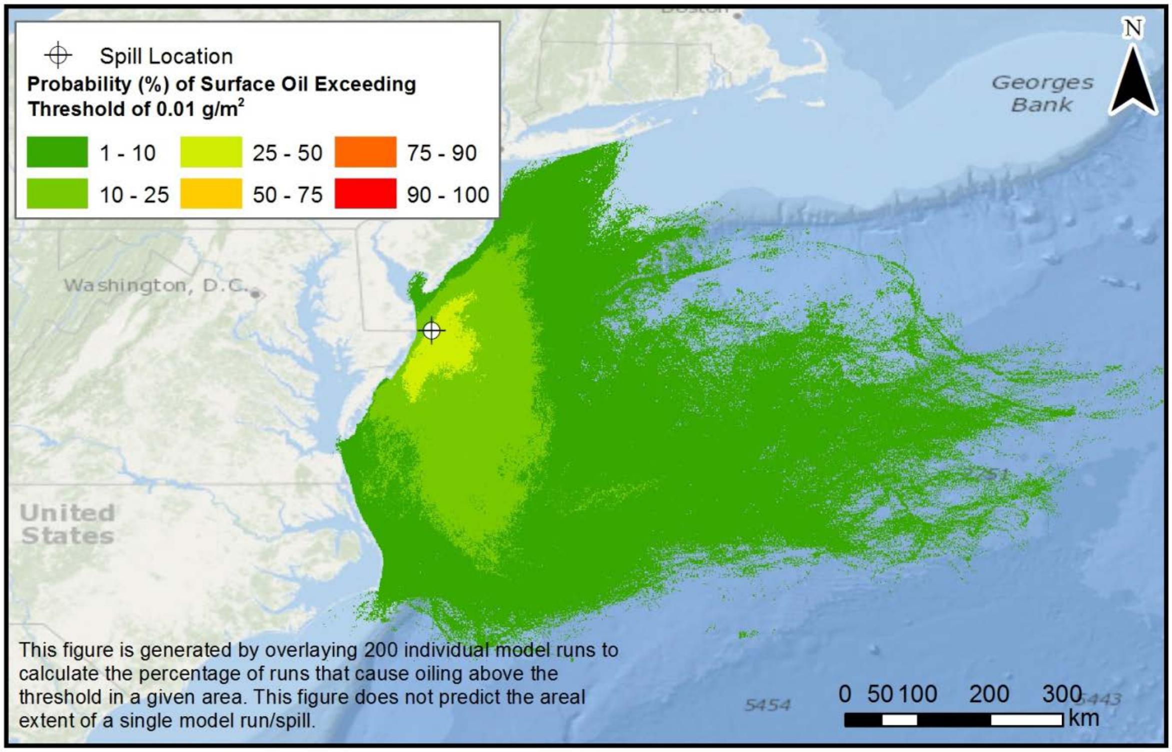
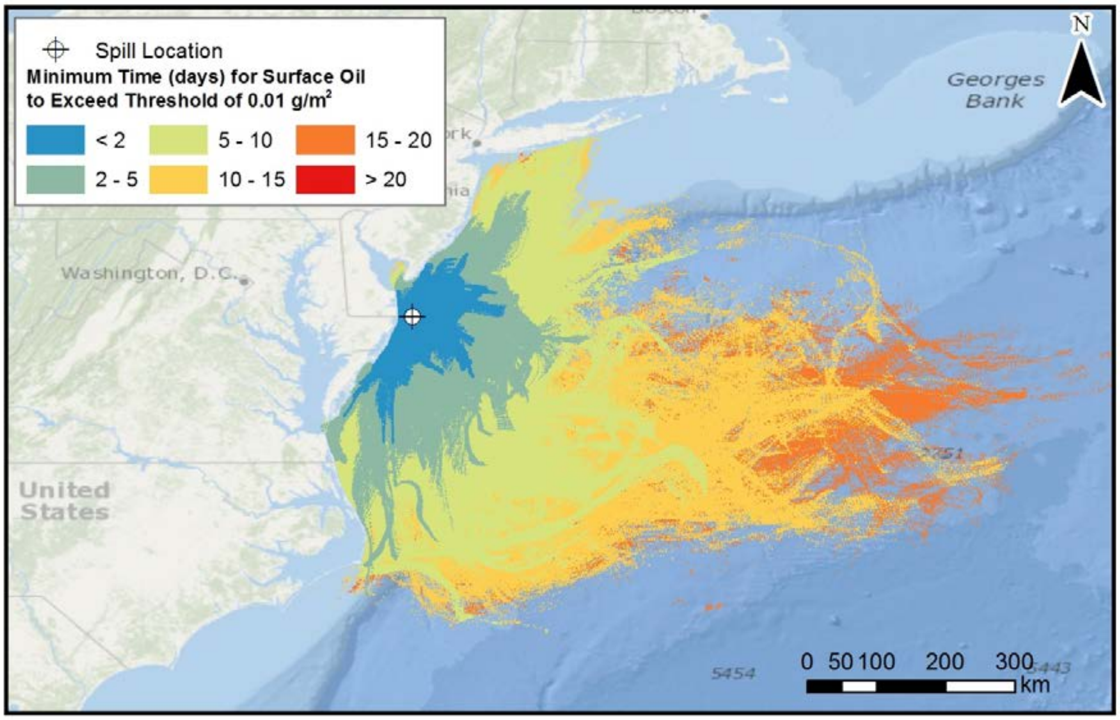


Figure C.57 Model scenario: ESP-NAP-S-40K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



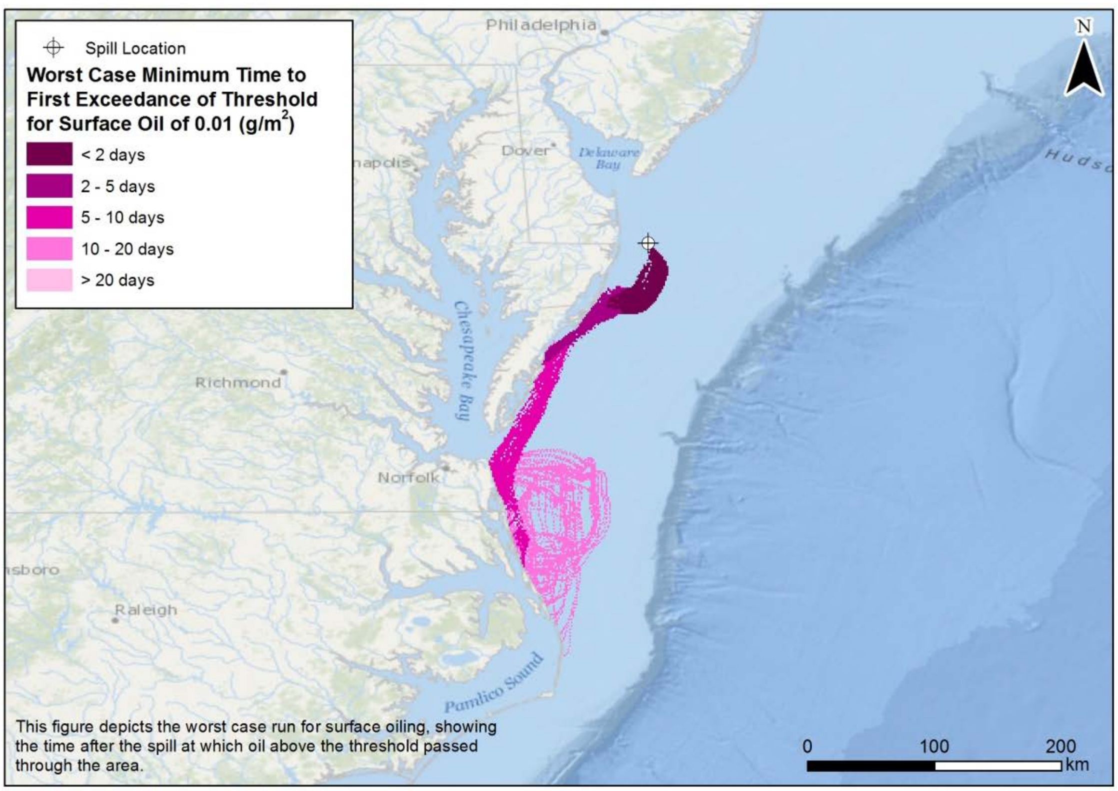
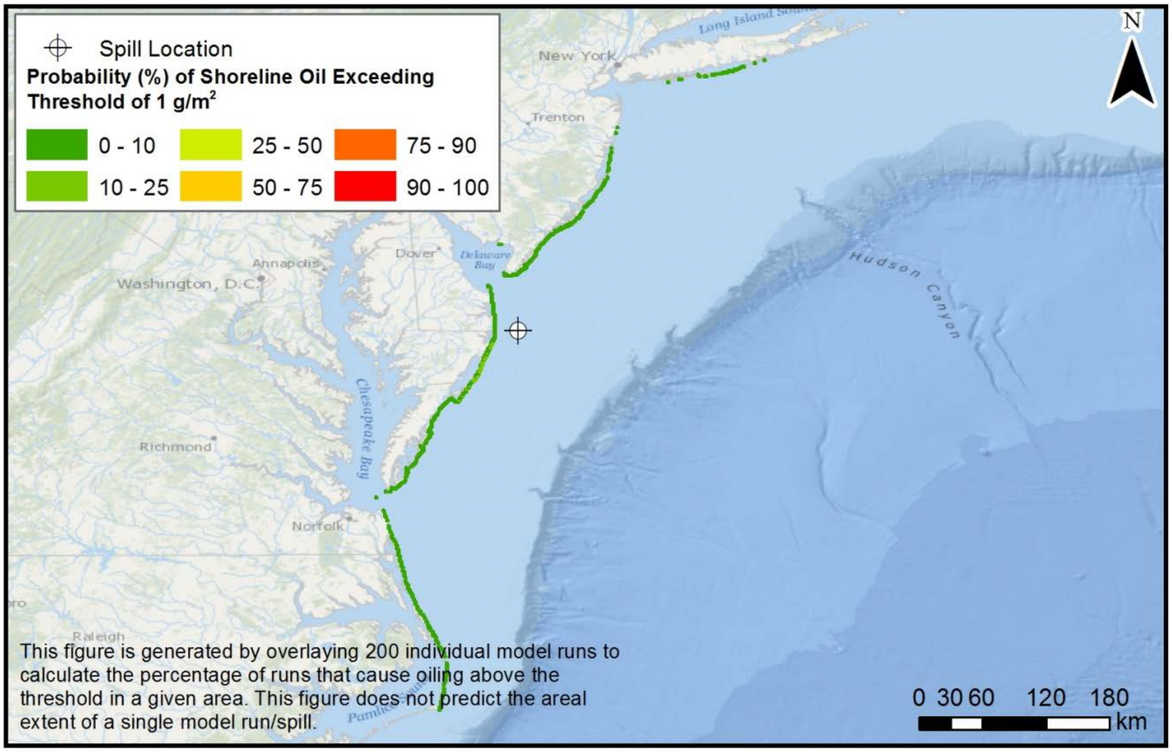


Figure C.58 Model scenario: ESP-NAP-S-40K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



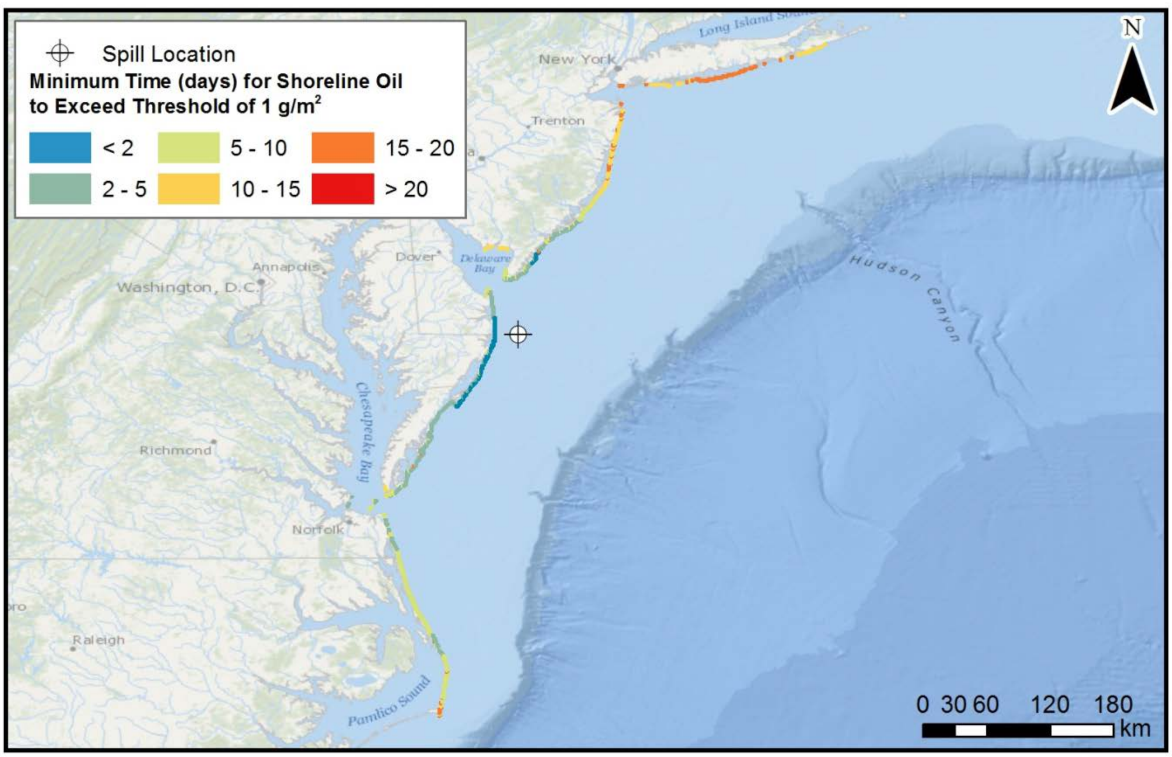


Figure C.59 Model scenario: ESP-NAP-S-40K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

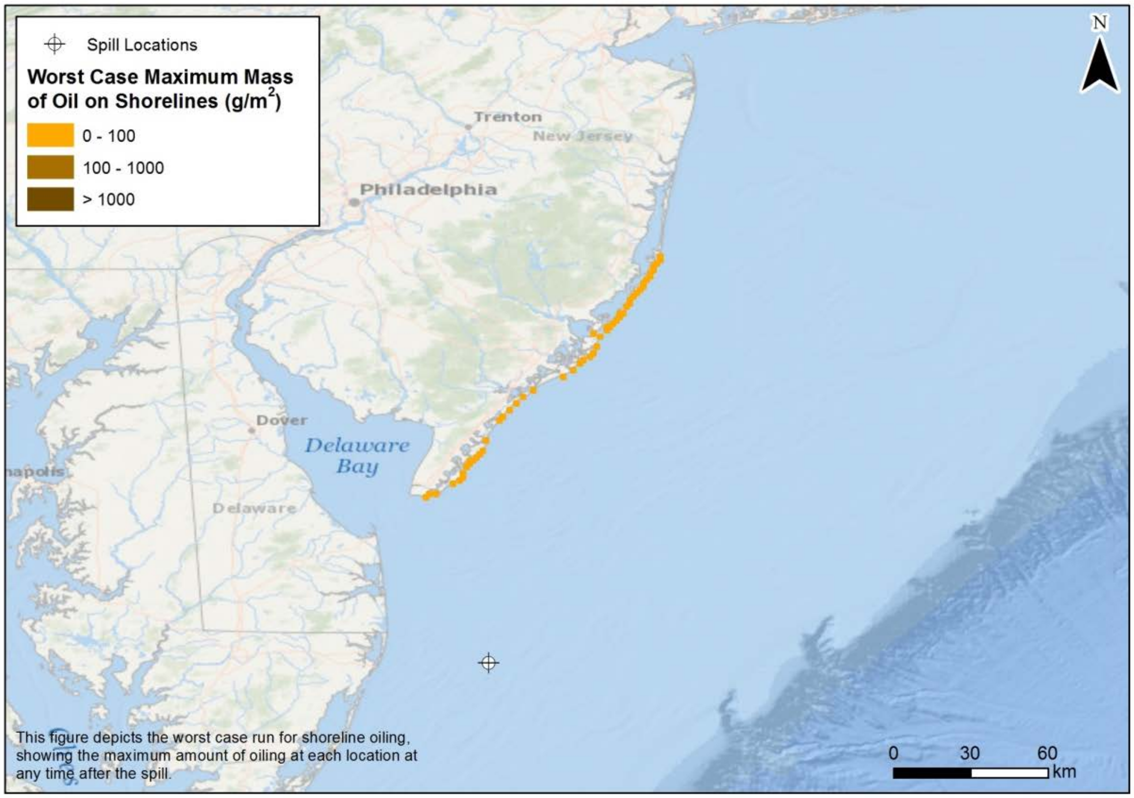


Figure C.60 Model scenario: ESP-NAP-S-40K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the MD WEA. Map represents a single simulation.

C.3.3 ESP DIESEL SCENARIOS

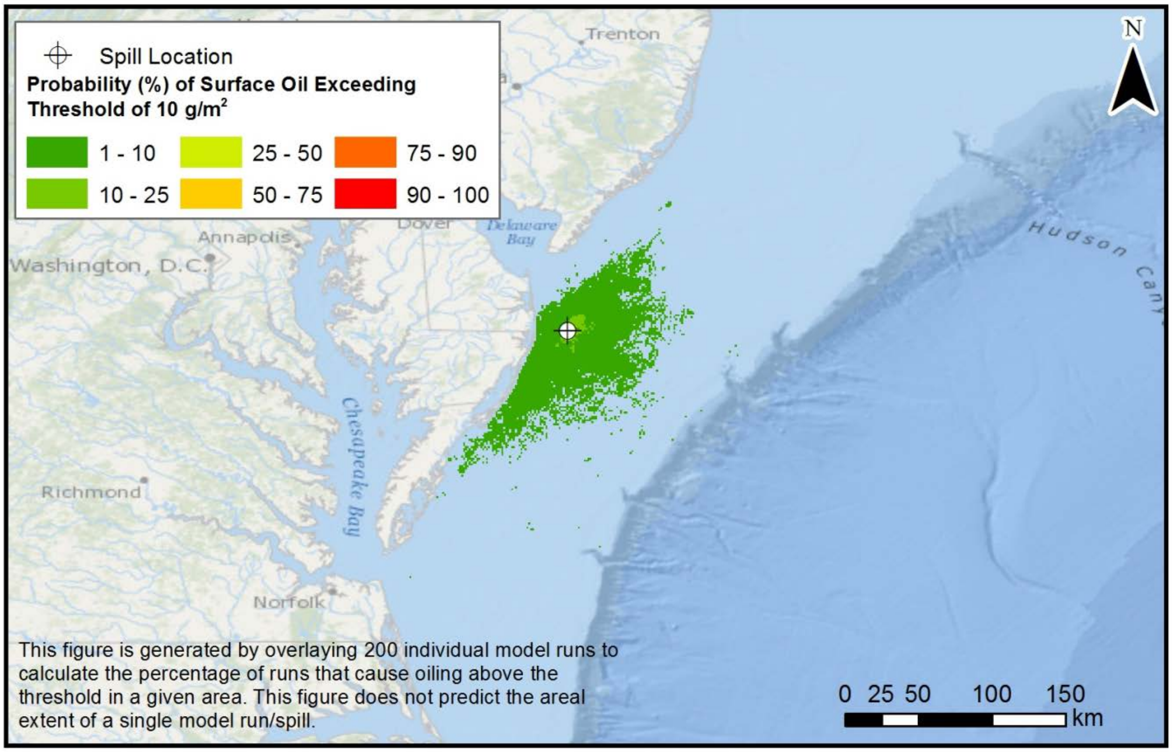
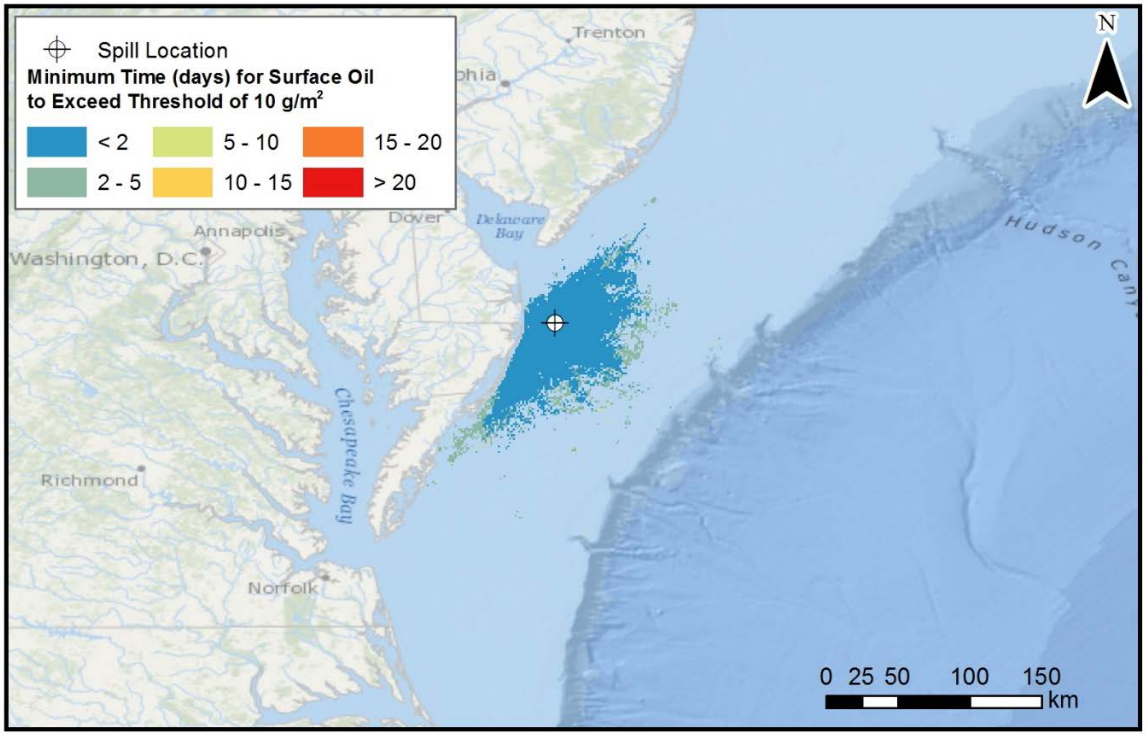


Figure C.61 Model scenario: ESP-DIESEL-E-2K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



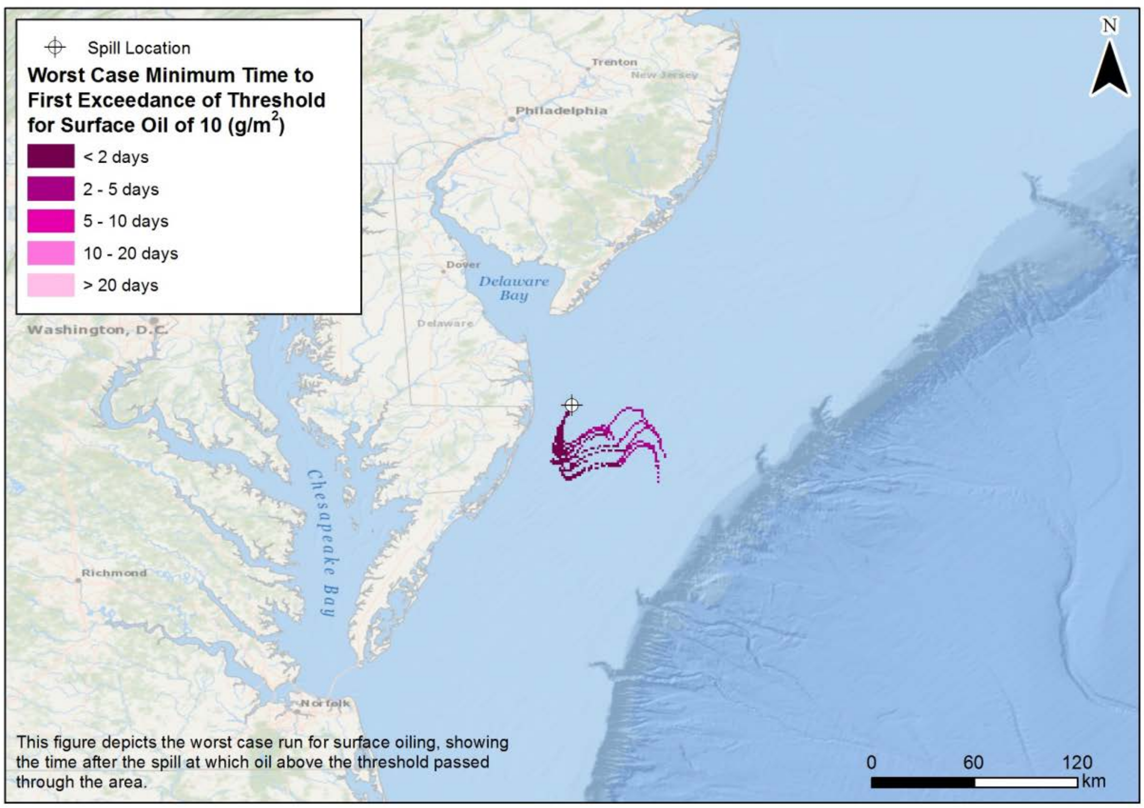


Figure C.62 Model scenario: ESP-DIESEL-E-2K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

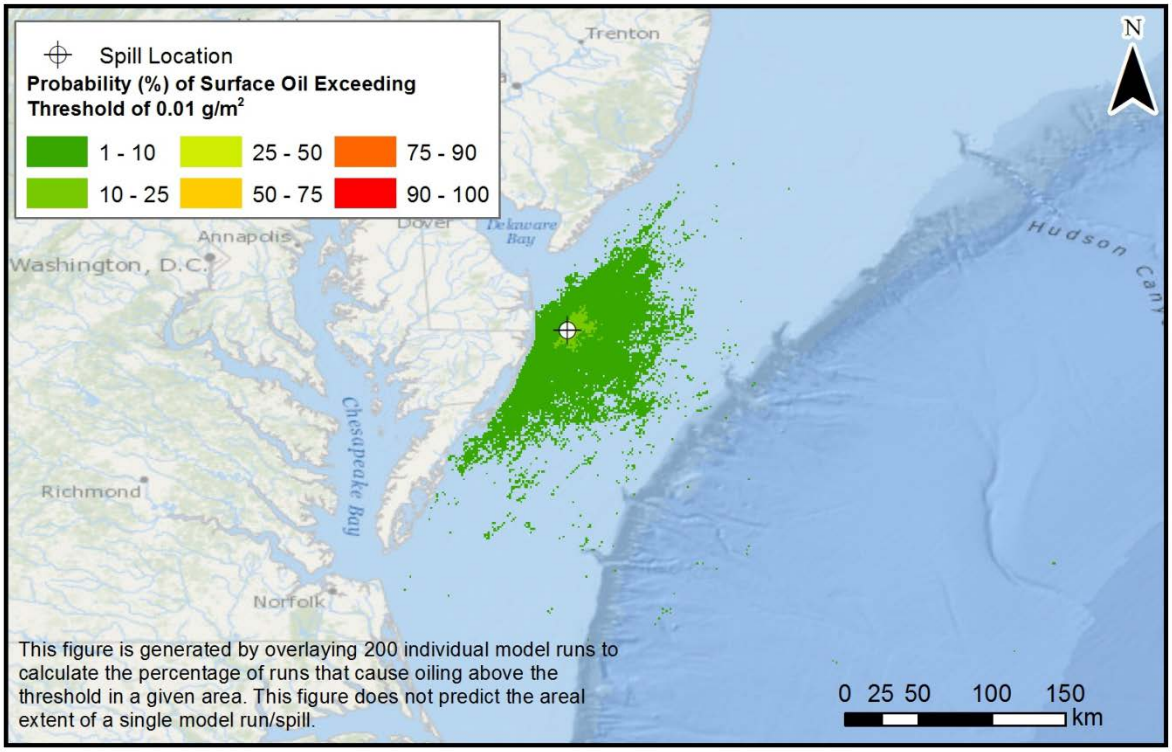
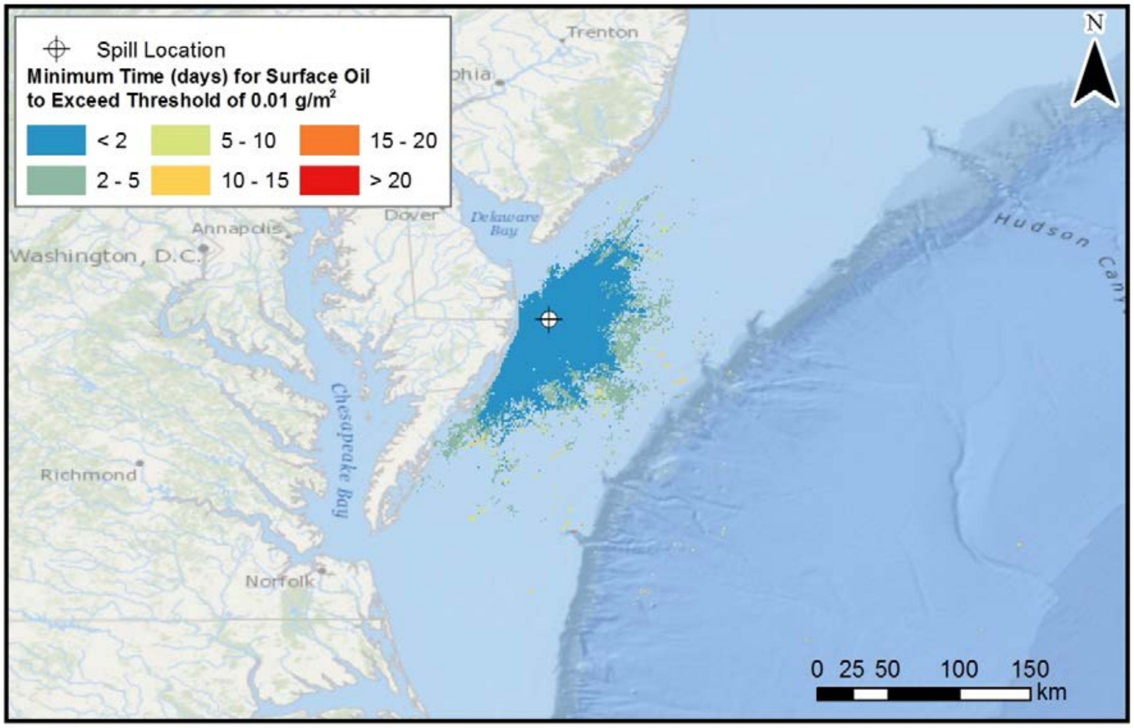


Figure C.63 Model scenario: ESP-DIESEL-S-2K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



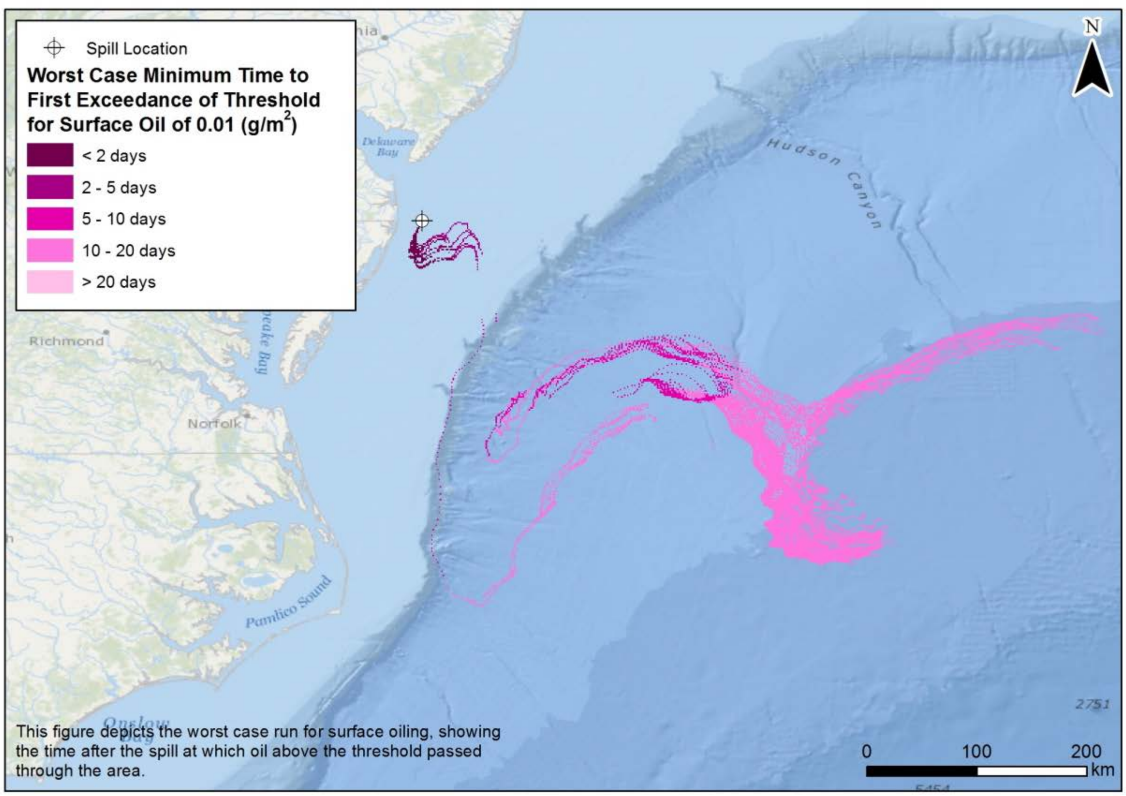
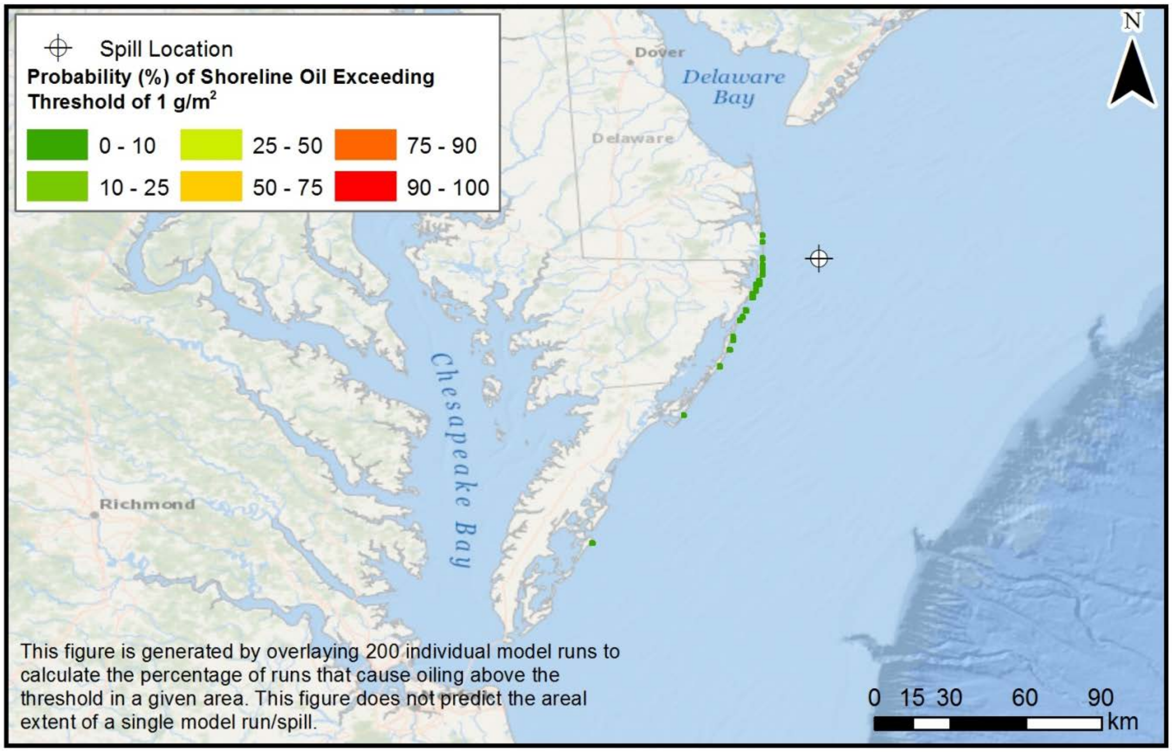


Figure C.64 Model scenario: ESP-DIESEL-S-2K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



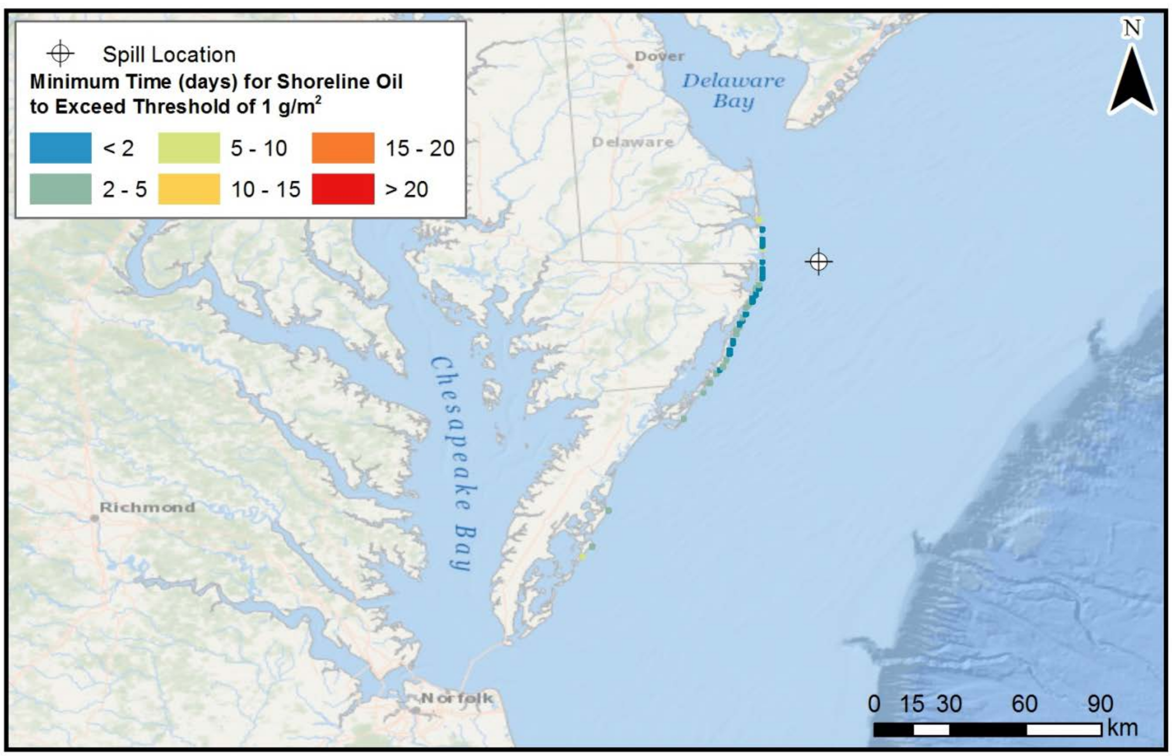


Figure C.65 Model scenario: ESP-DIESEL-S-2K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the MD WEA. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

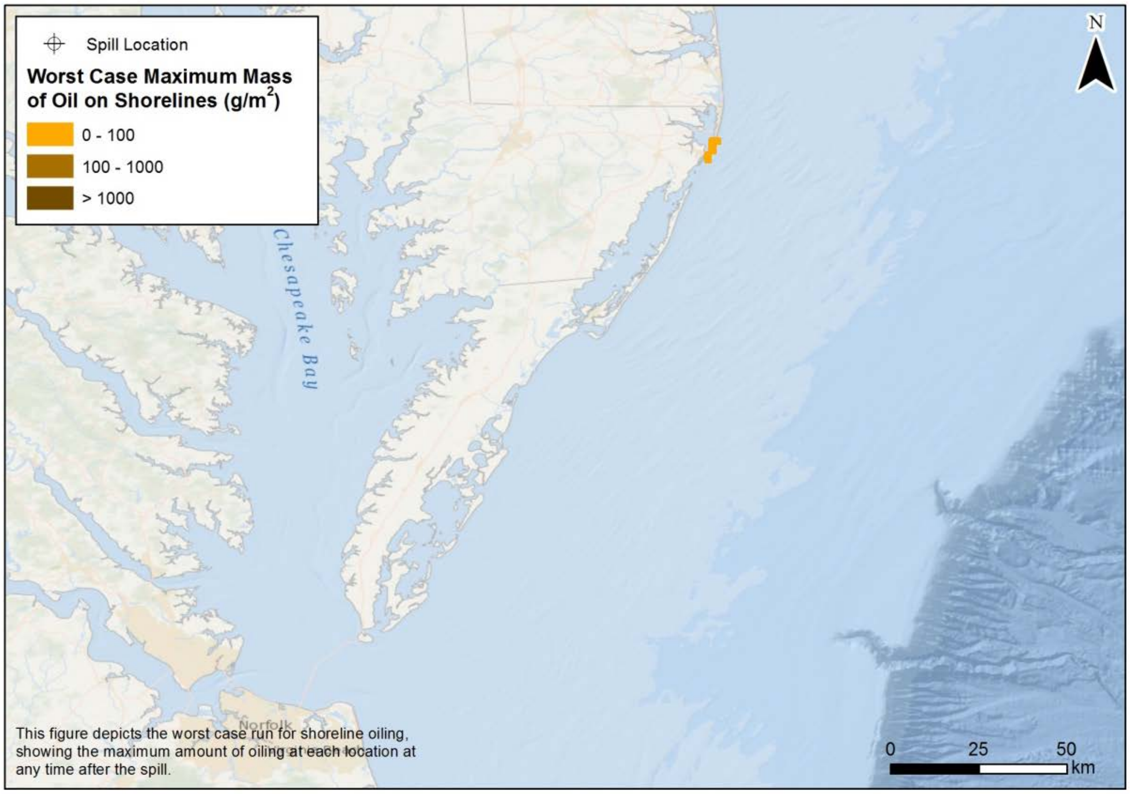


Figure C.66 Model scenario: ESP-DIESEL-S-2K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the MD WEA. Map represents a single simulation.

C.3.4 WTG Hydraulic Oil Scenario

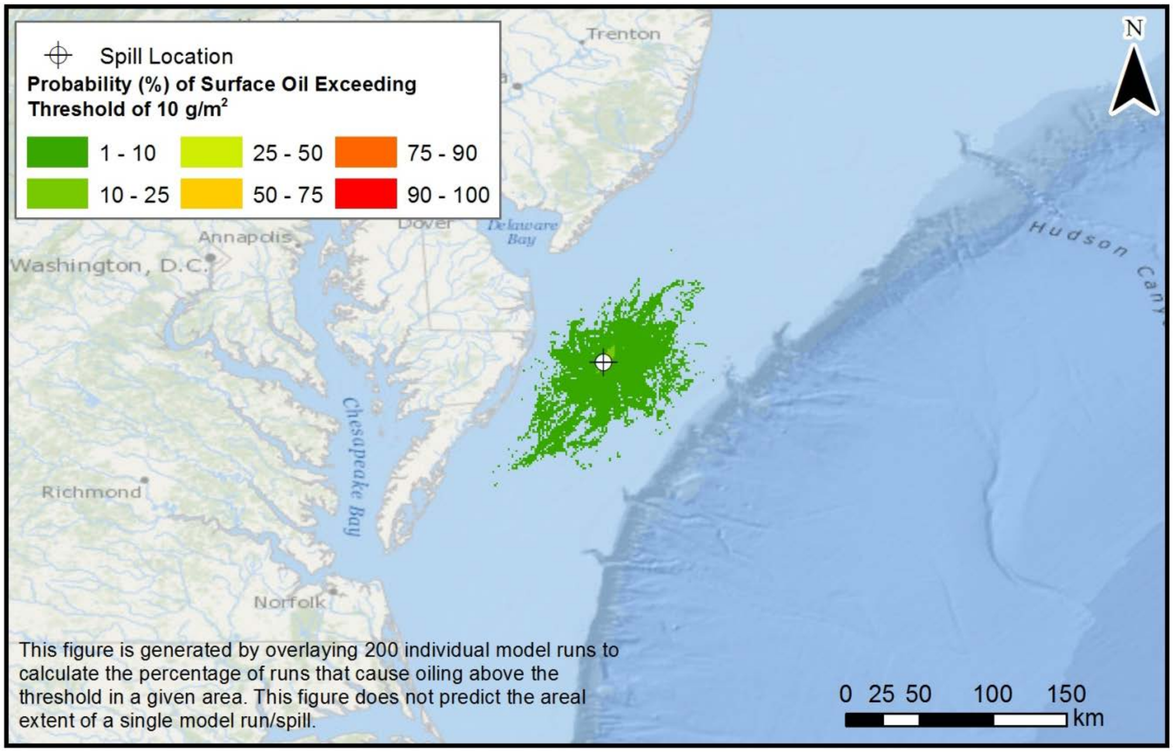
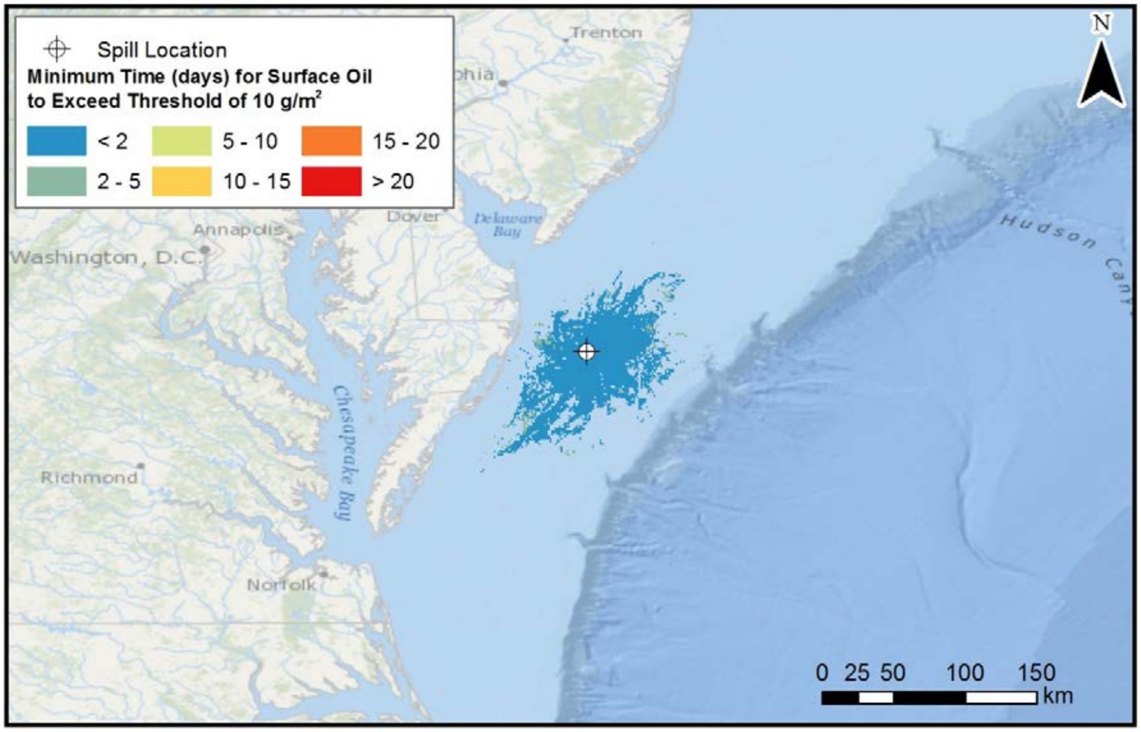


Figure C.67 Model scenario: ESP-WTG-HYD-E-90. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 90 gallons of hydraulic oil from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



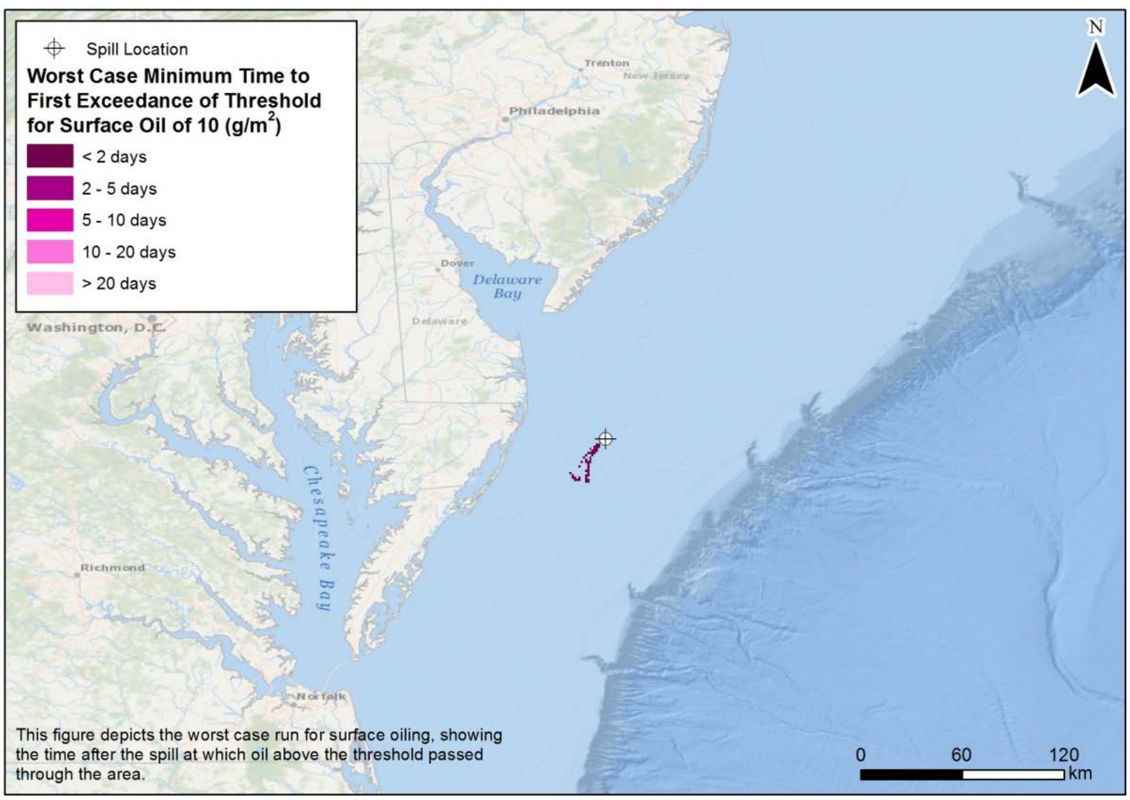


Figure C.68 Model scenario: ESP-WTG-HYD-E-90. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 90 gallons of hydraulic oil from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

C.3.5 WTG Lubricating Oil Scenario

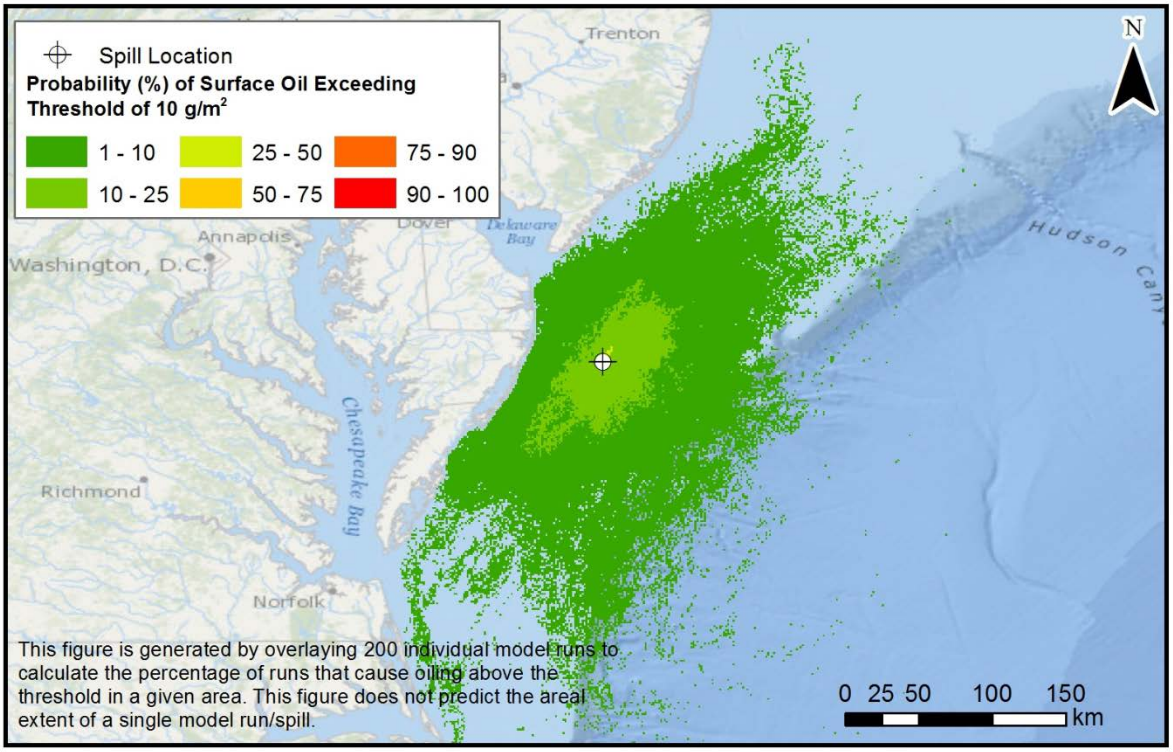
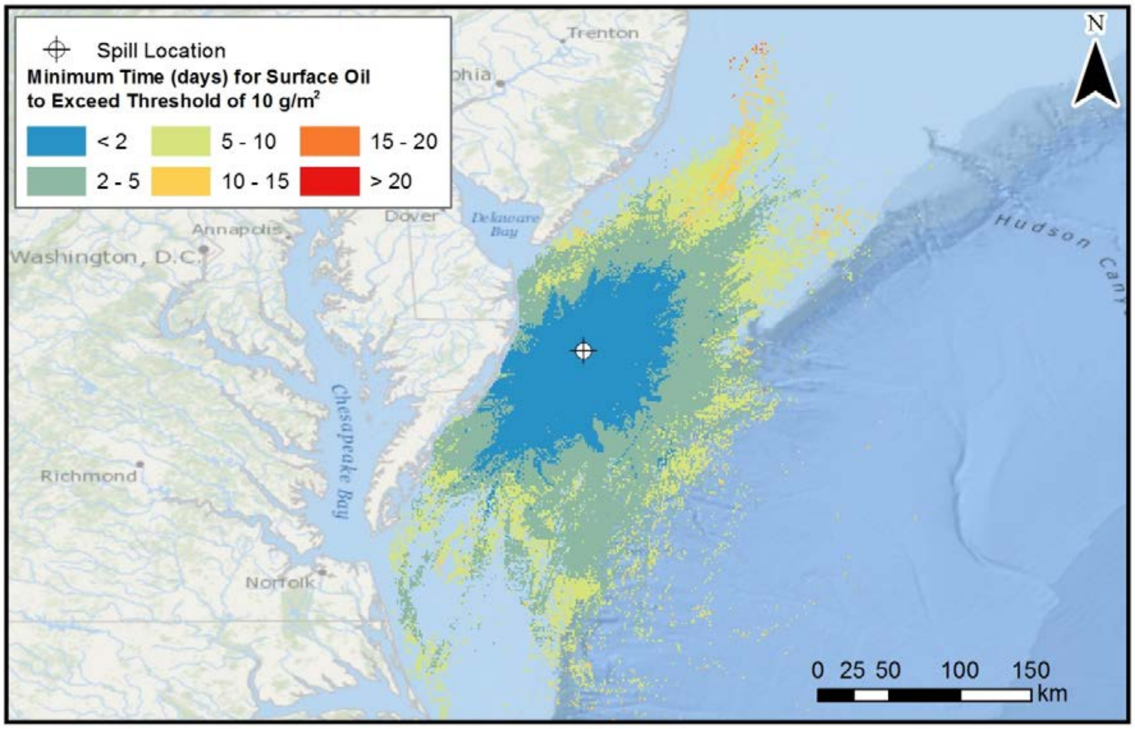


Figure C.69 Model scenario: ESP-WTG-LUB-E-220. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 220 gallons of lubricating oil from a wind turbine in the MD WEA. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



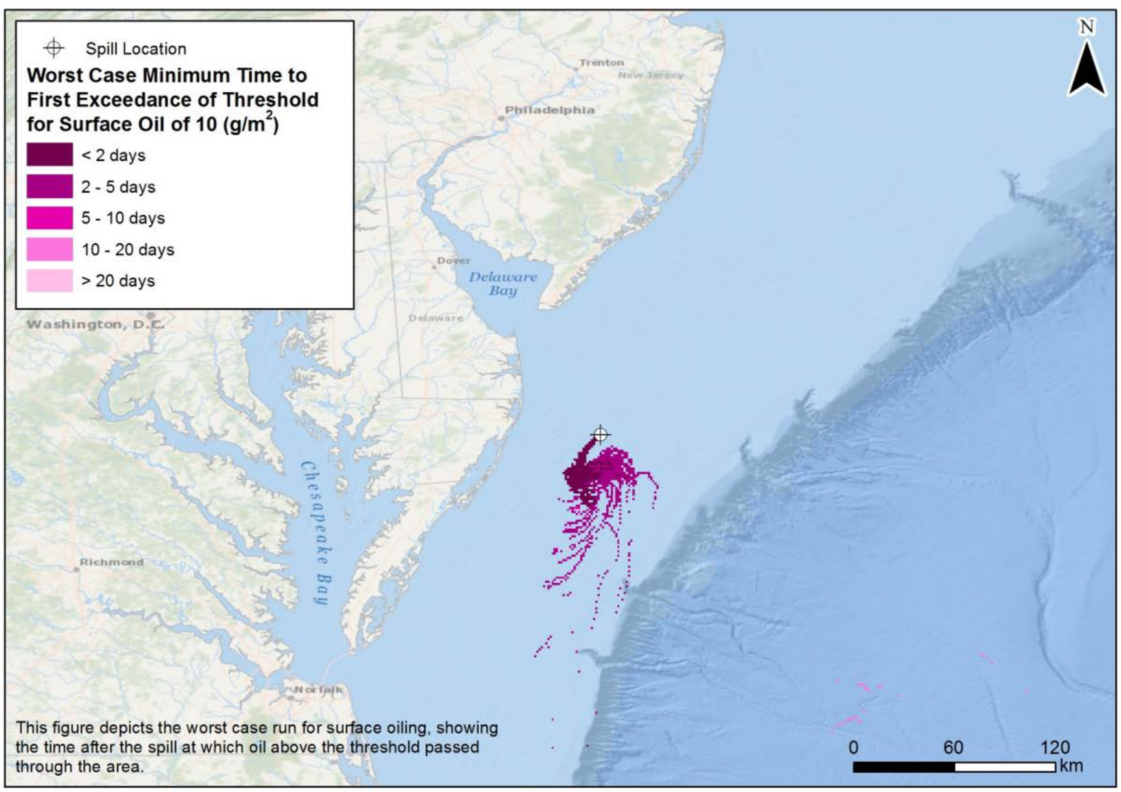


Figure C.70 Model scenario: ESP-WTG-LUB-E-220. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 220 gallons of lubricating oil from a wind turbine in the MD WEA. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

C.4 NORTH CAROLINA CALL AREA

C.4.1 5 WTGs Oil Mixture Scenarios

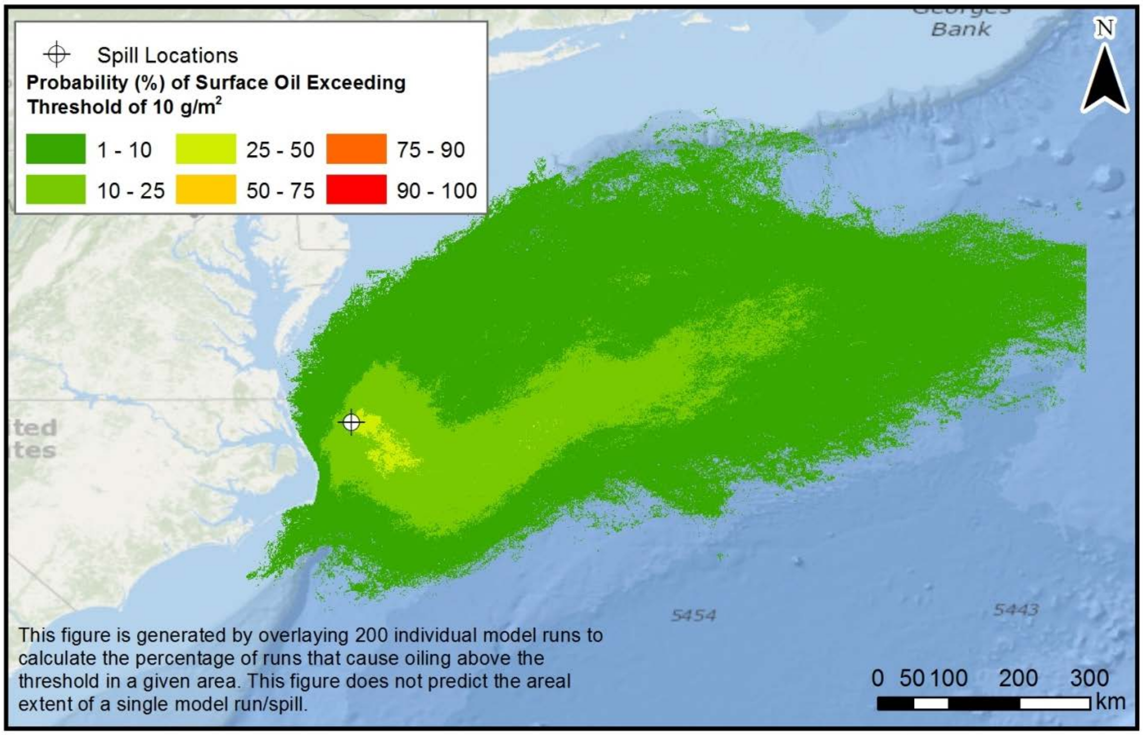
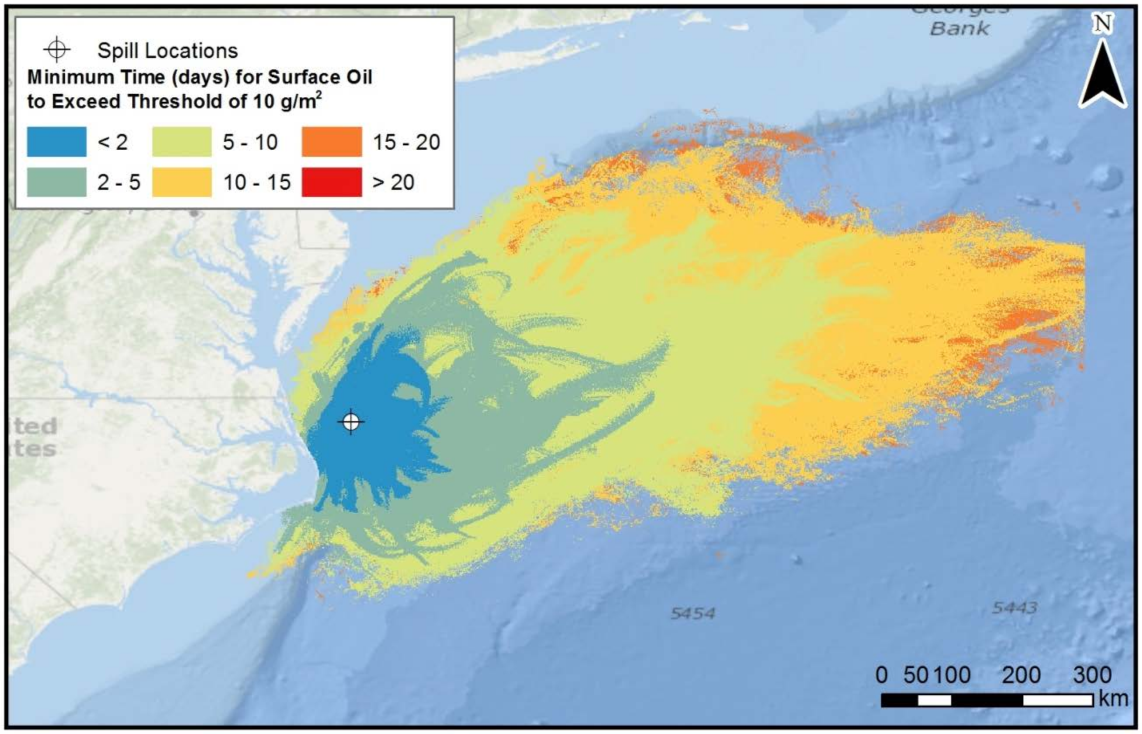


Figure C.71 Model scenario: 5WTG-MIX1-3400. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



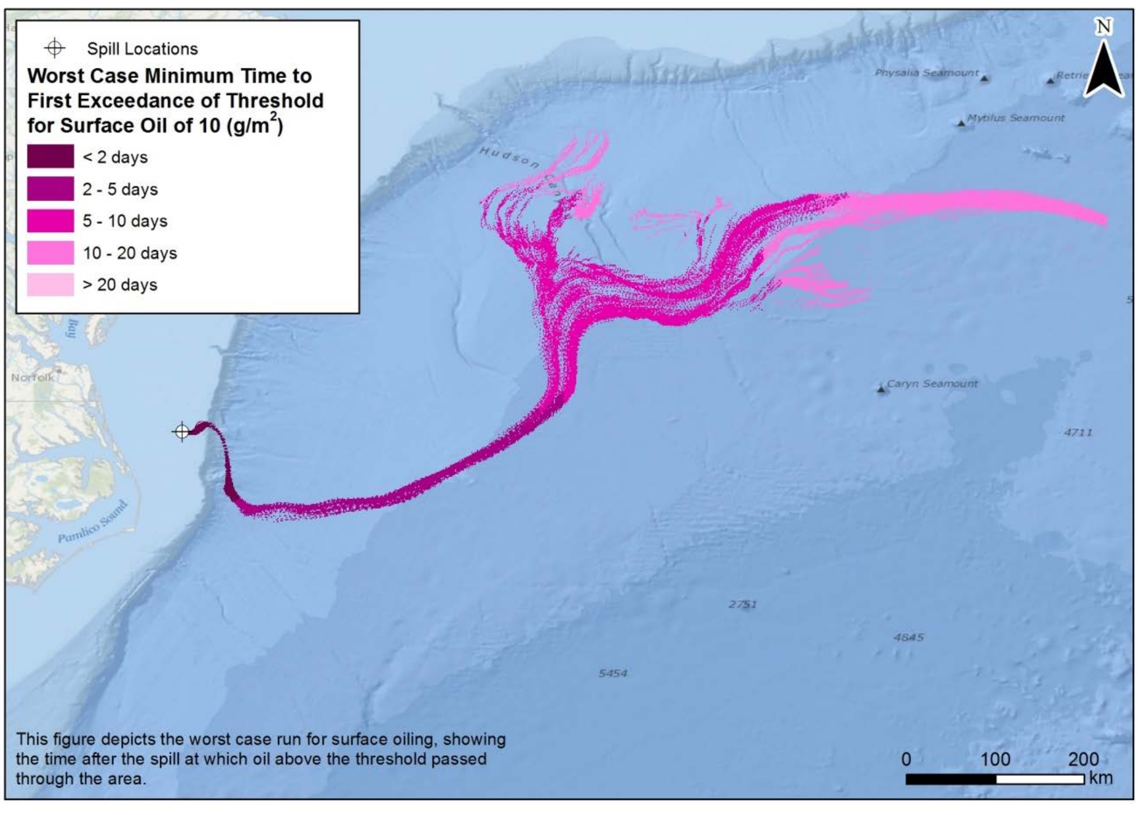
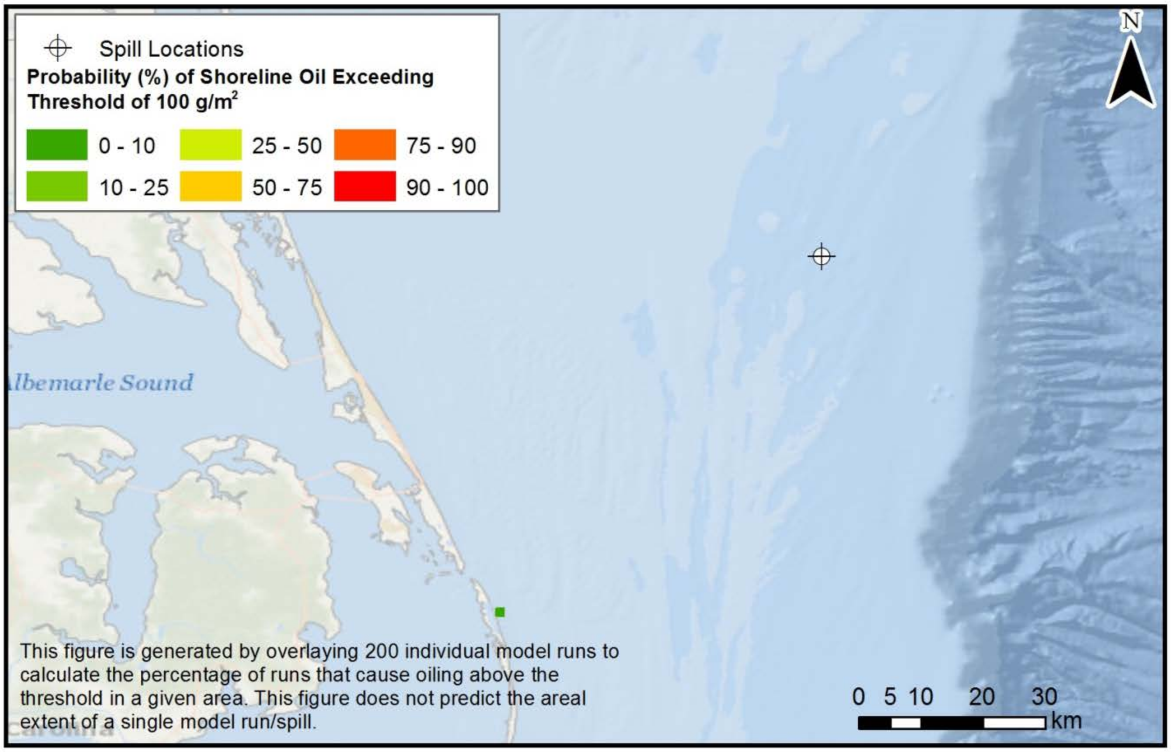


Figure C.72 Model scenario: 5WTG-MIX1-3400. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



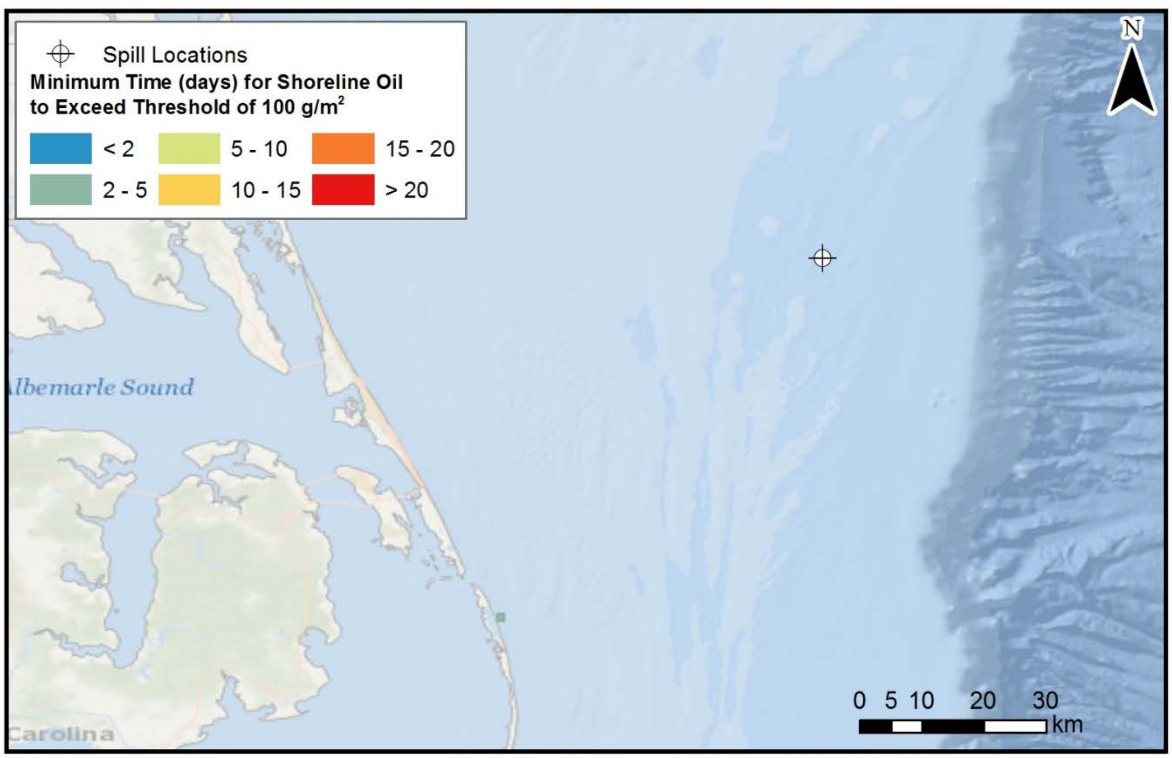


Figure C.73 Model scenario: 5WTG-MIX1-3400. Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the NC Call Area. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

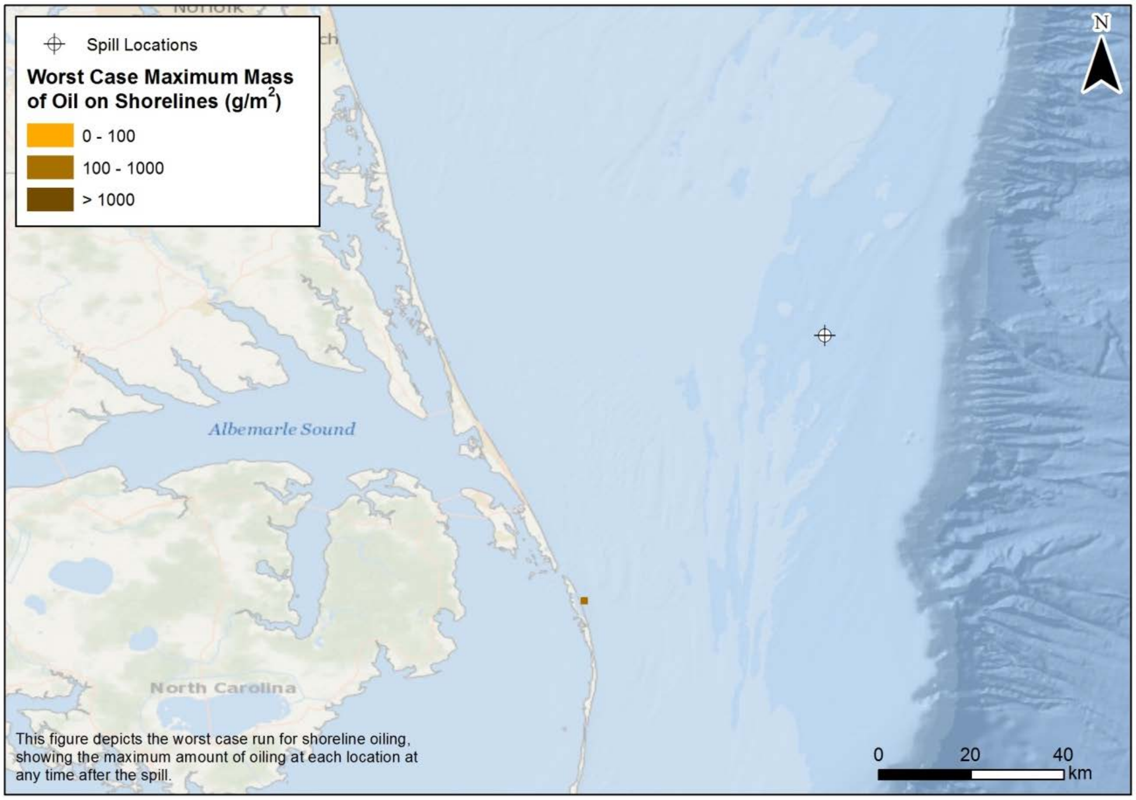


Figure C.74 Model scenario: 5WTG-MIX1-3400. Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the NC Call Area. Map represents a single simulation.

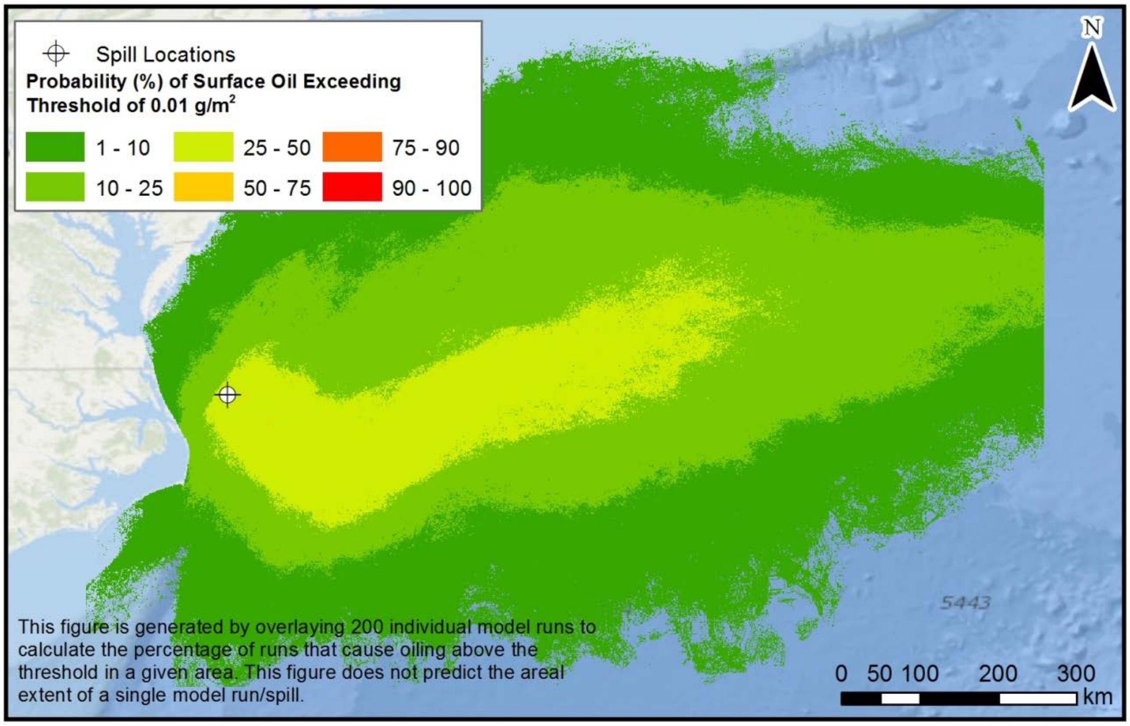
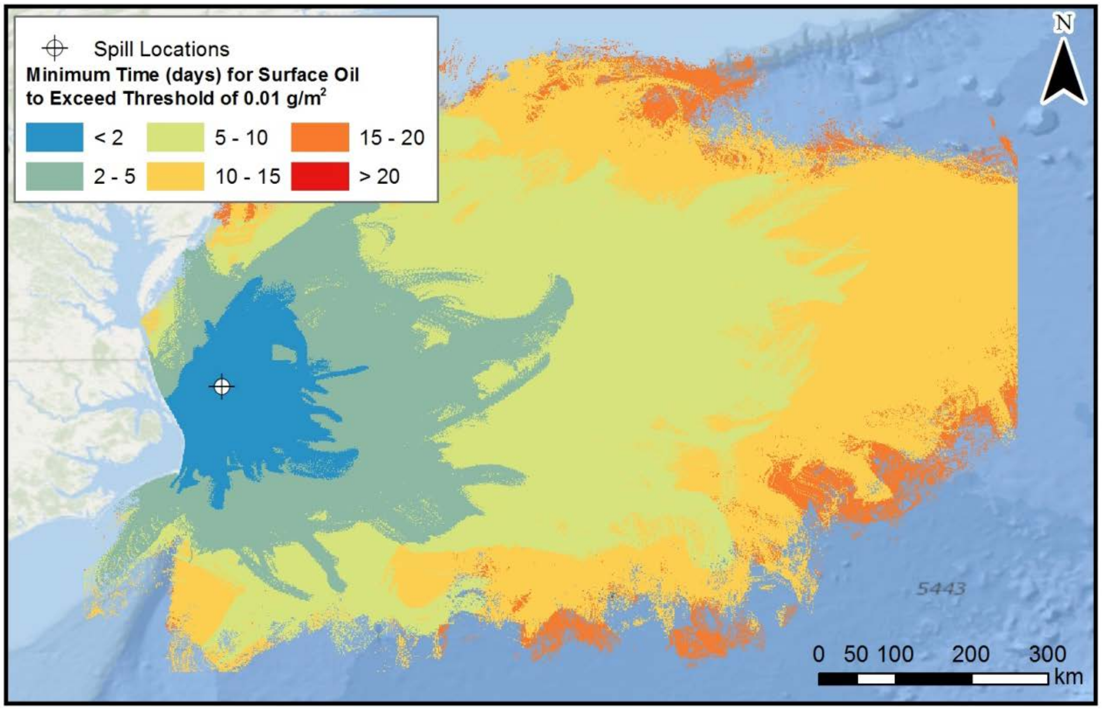


Figure C.75 Model scenario: 5WTG-MIX1-3400. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



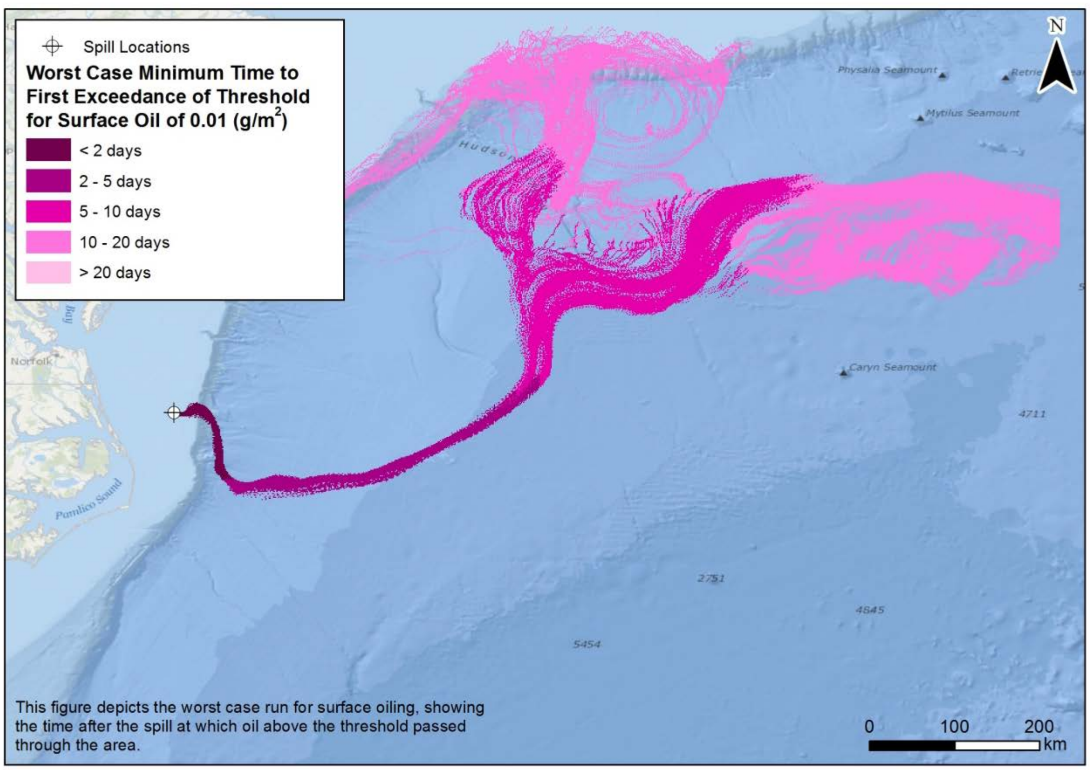


Figure C.76 Model scenario: 5WTG-MIX1-3400. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

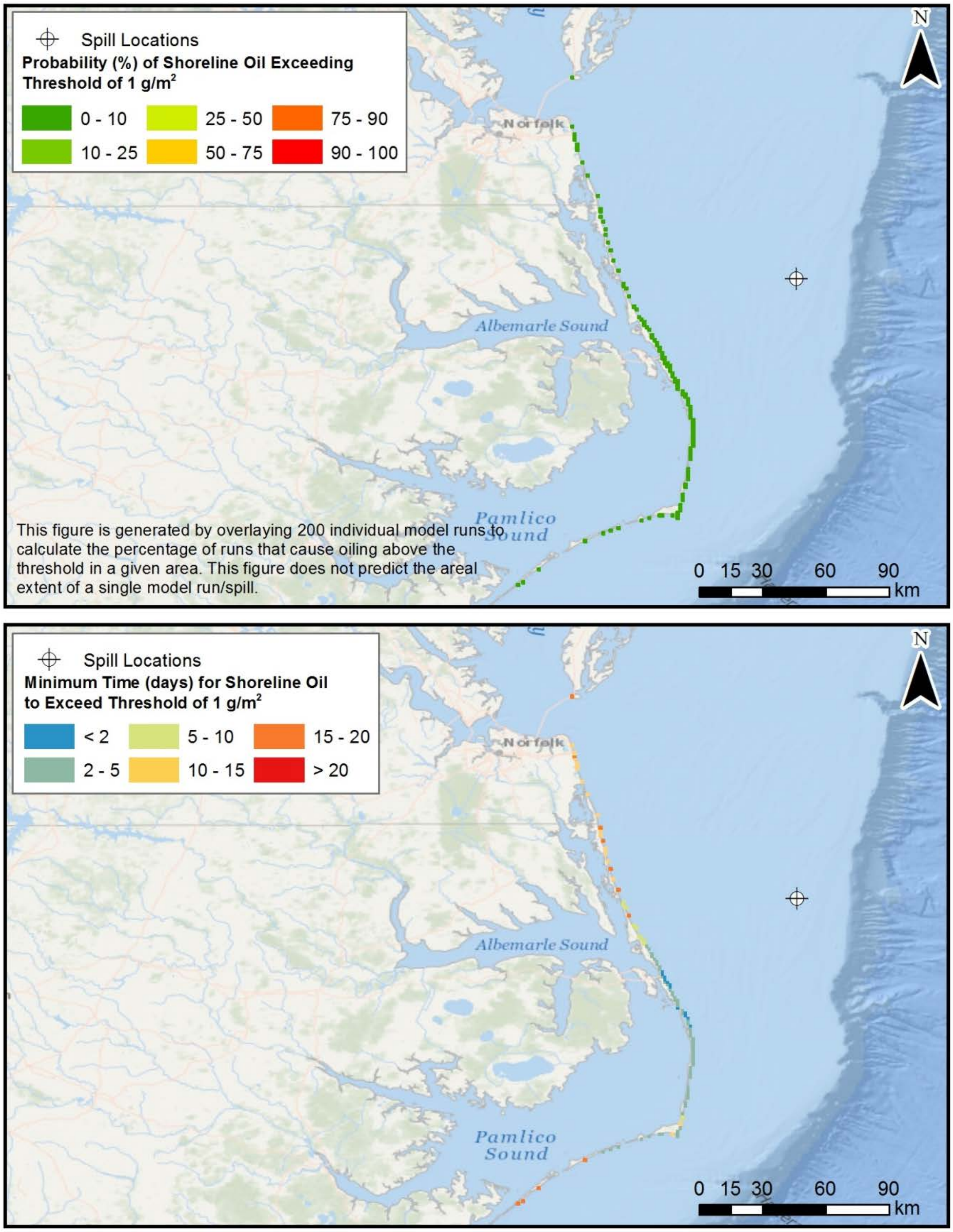


Figure C.77 Model scenario: 5WTG-MIX1-3400. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the NC Call Area. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

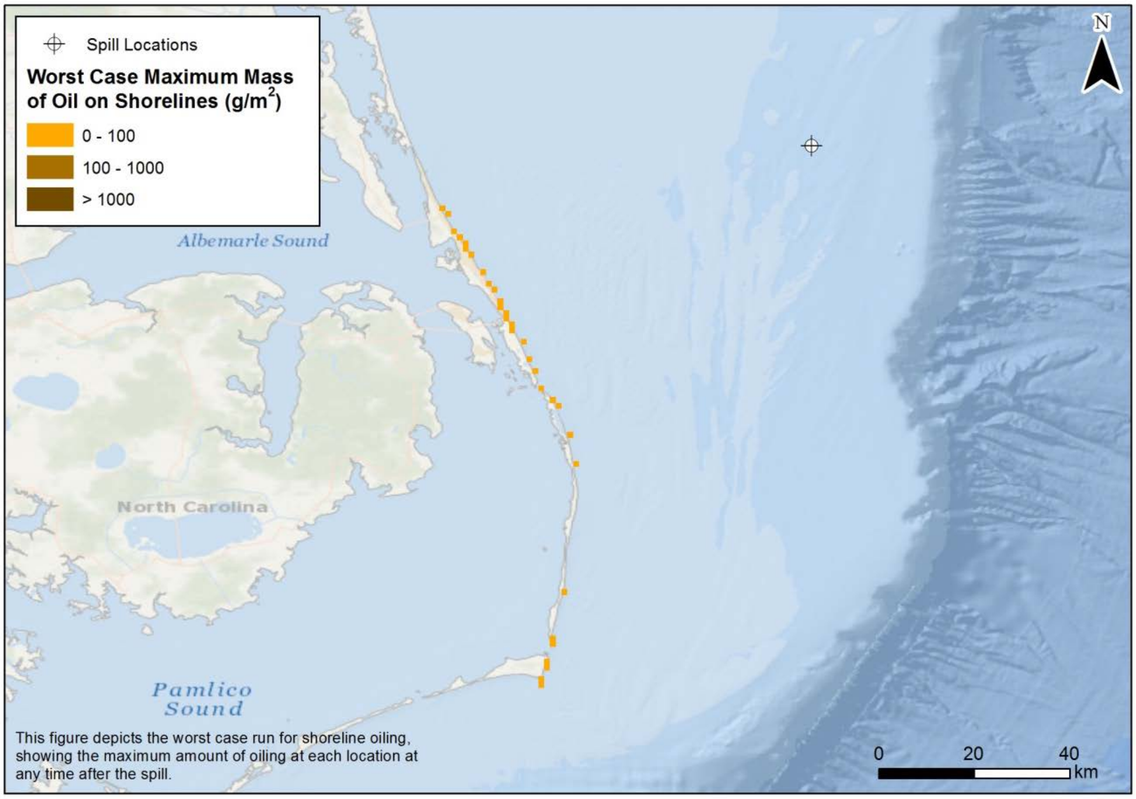


Figure C.78 Model scenario: 5WTG-MIX1-3400. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 3,400 gallons of oil mixture from a wind turbine in the NC Call Area. Map represents a single simulation.

C.4.2 ESP Naphthenic Mineral Oil Scenarios (1K and 40K Gallons)

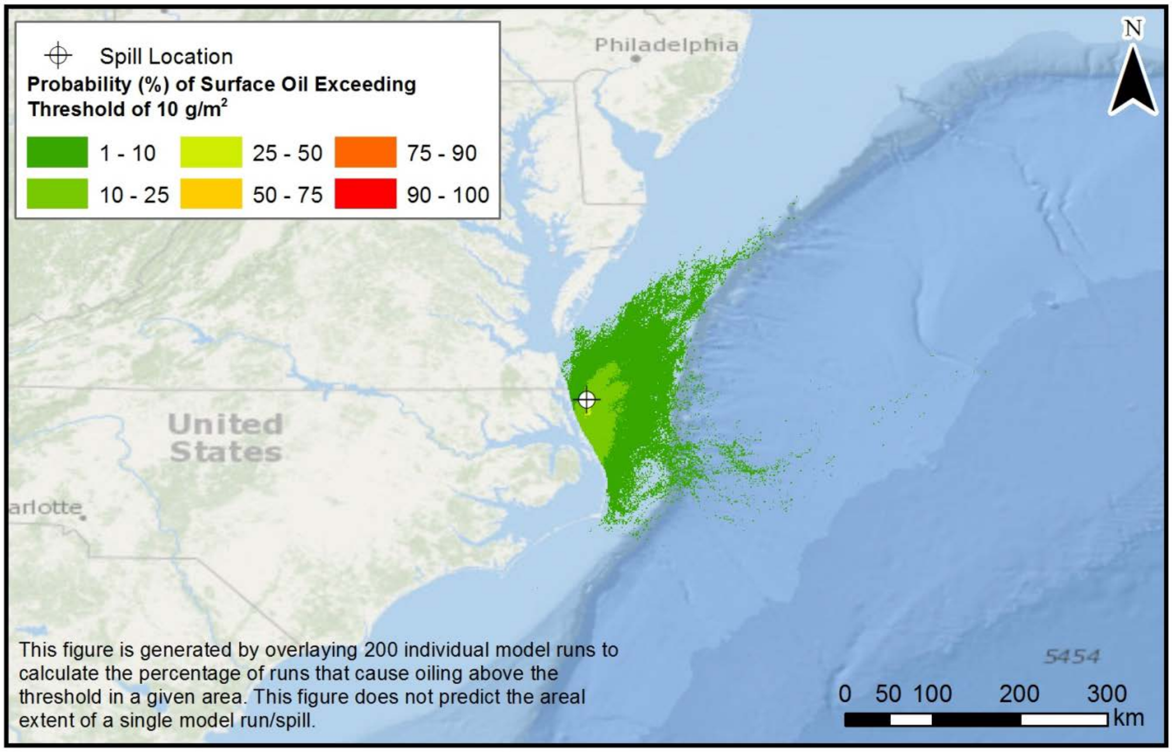
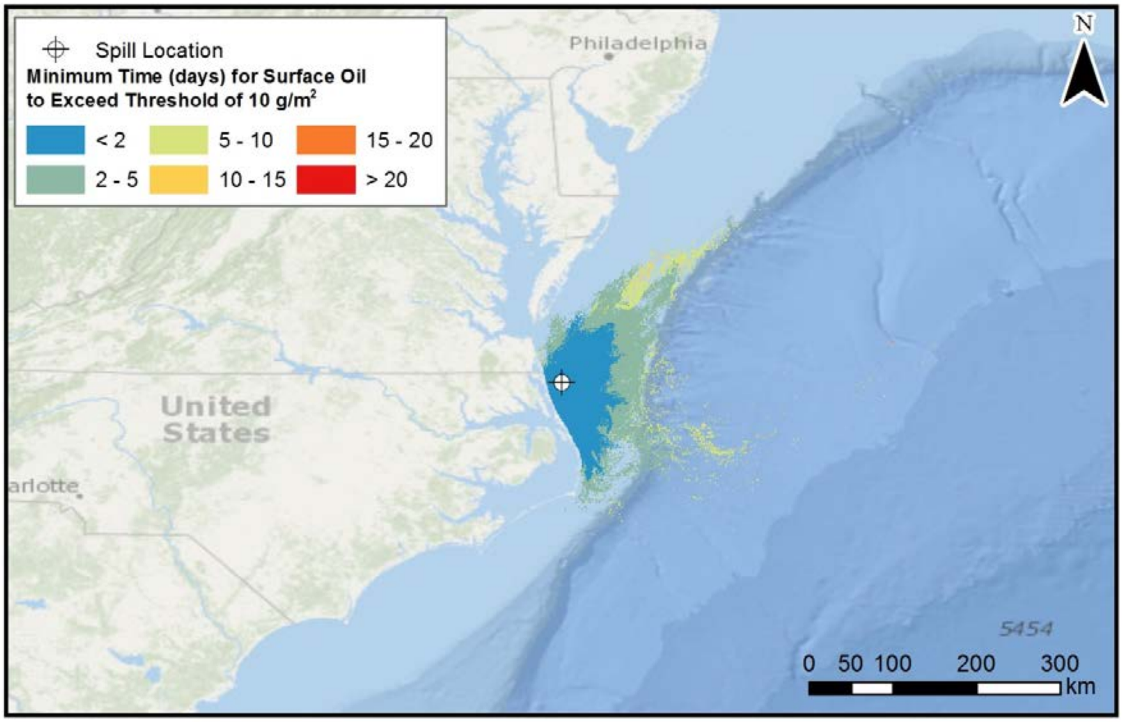


Figure C.79 Model scenario: ESP-NAP-E-1K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



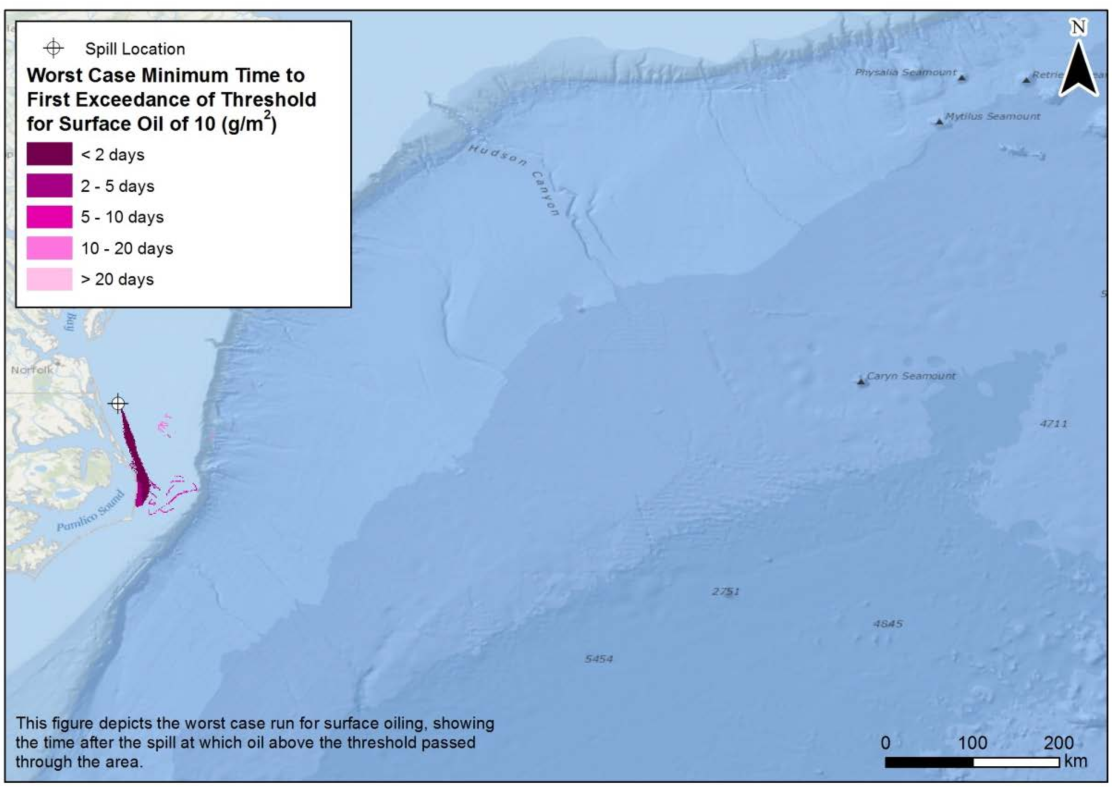


Figure C.80 Model scenario: ESP-NAP-E-1K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

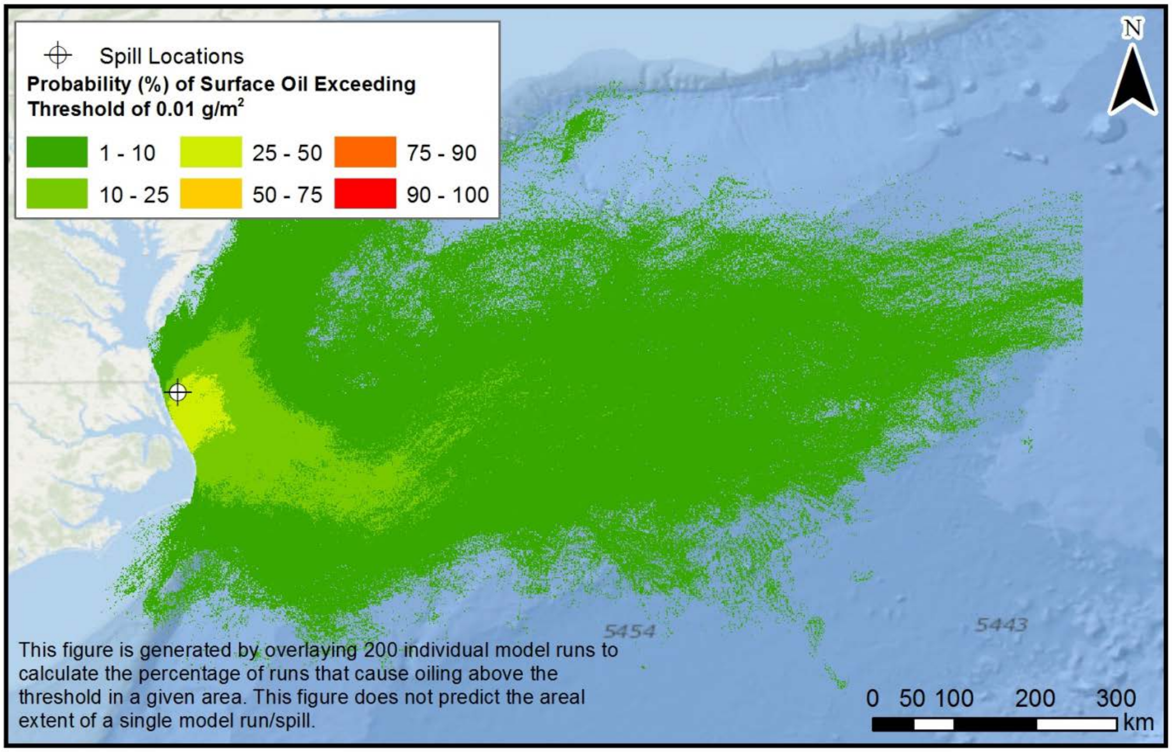


Figure C.81 Model scenario: ESP-NAP-S-1K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

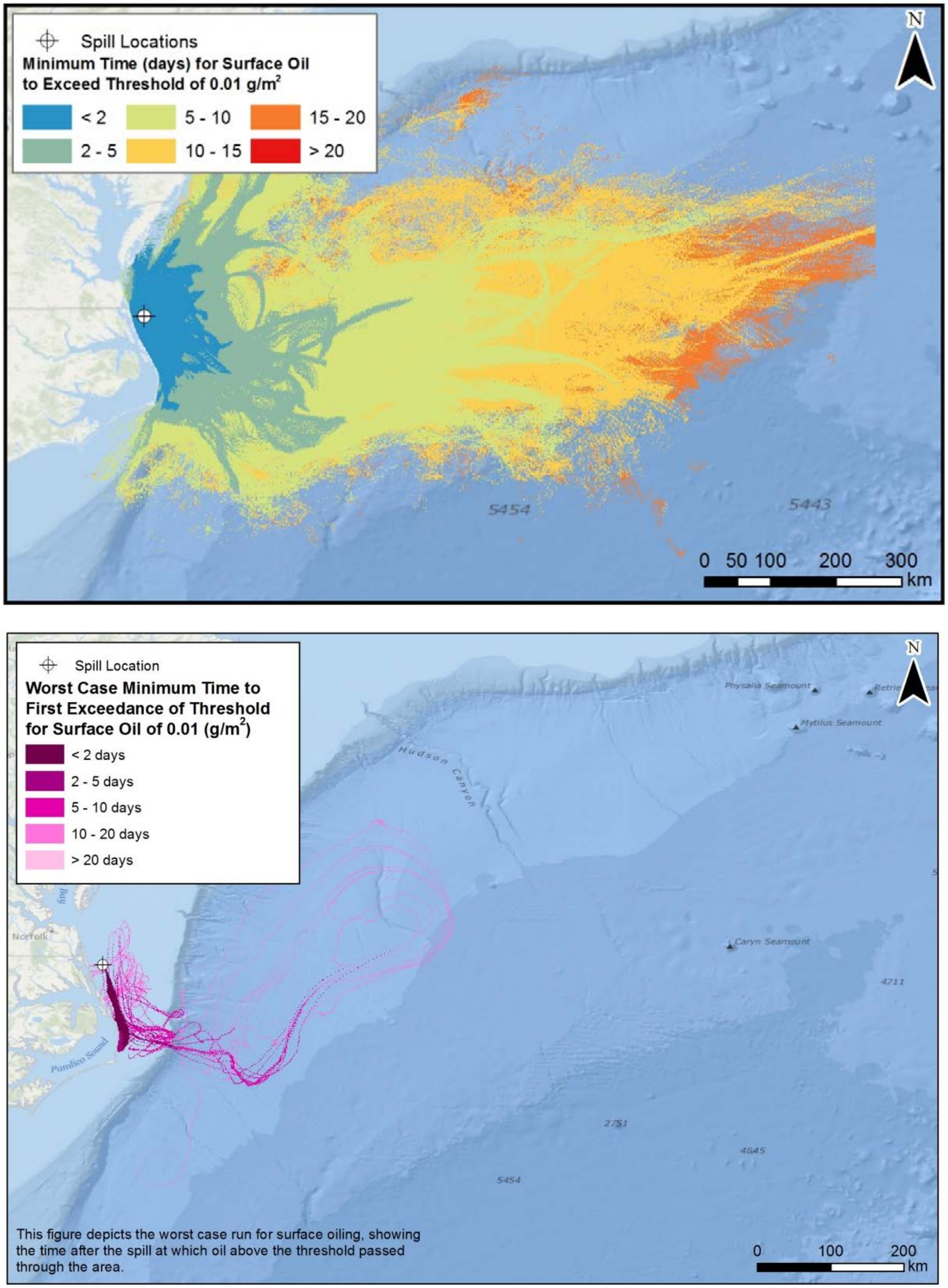
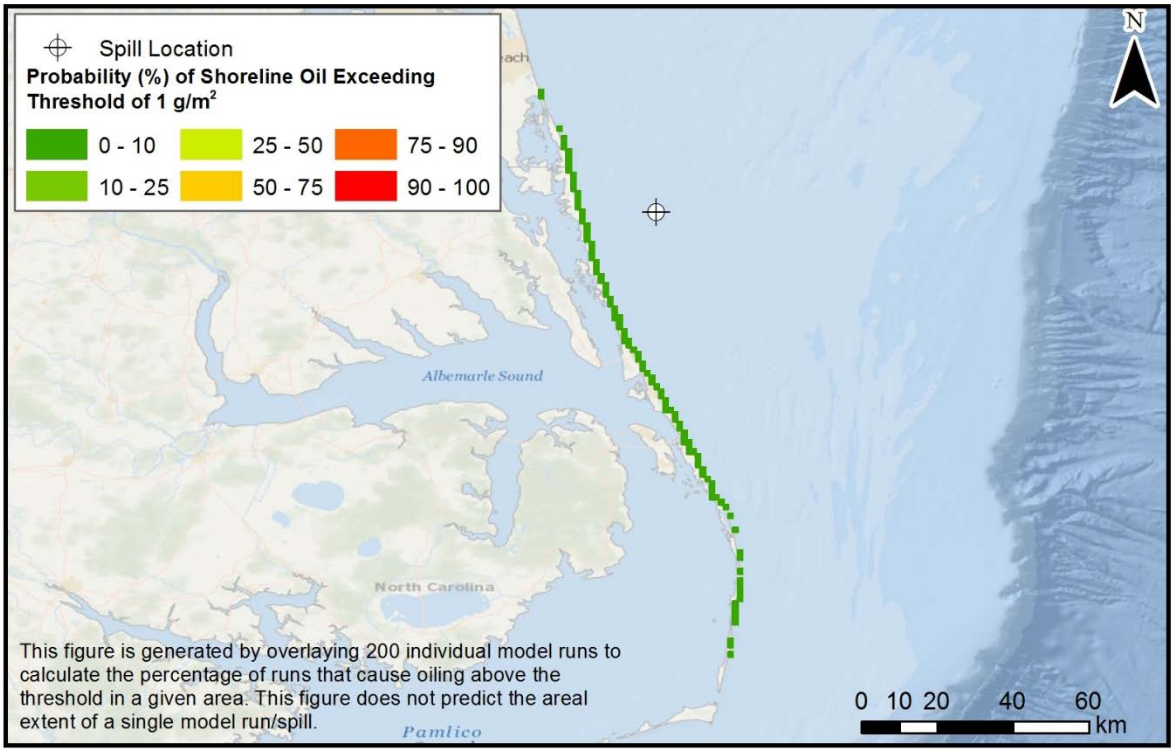


Figure C.82 Model scenario: ESP-NAP-S-1K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



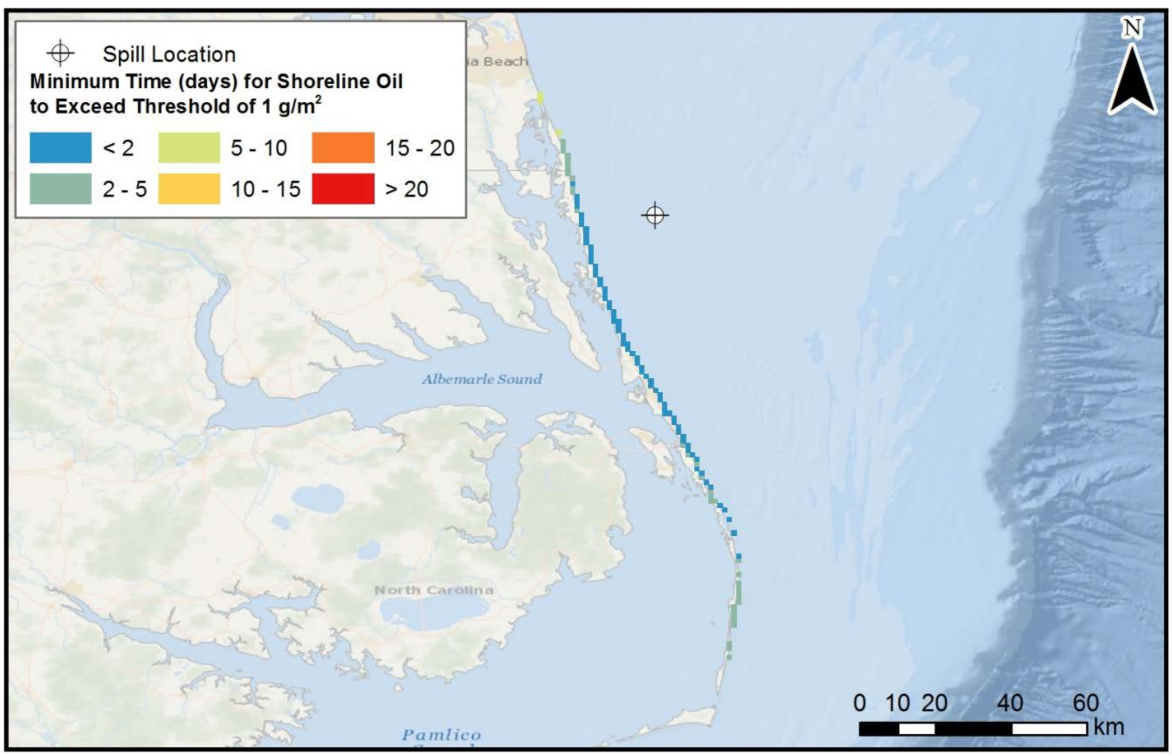


Figure C.83 Model scenario: ESP-NAP-S-1K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

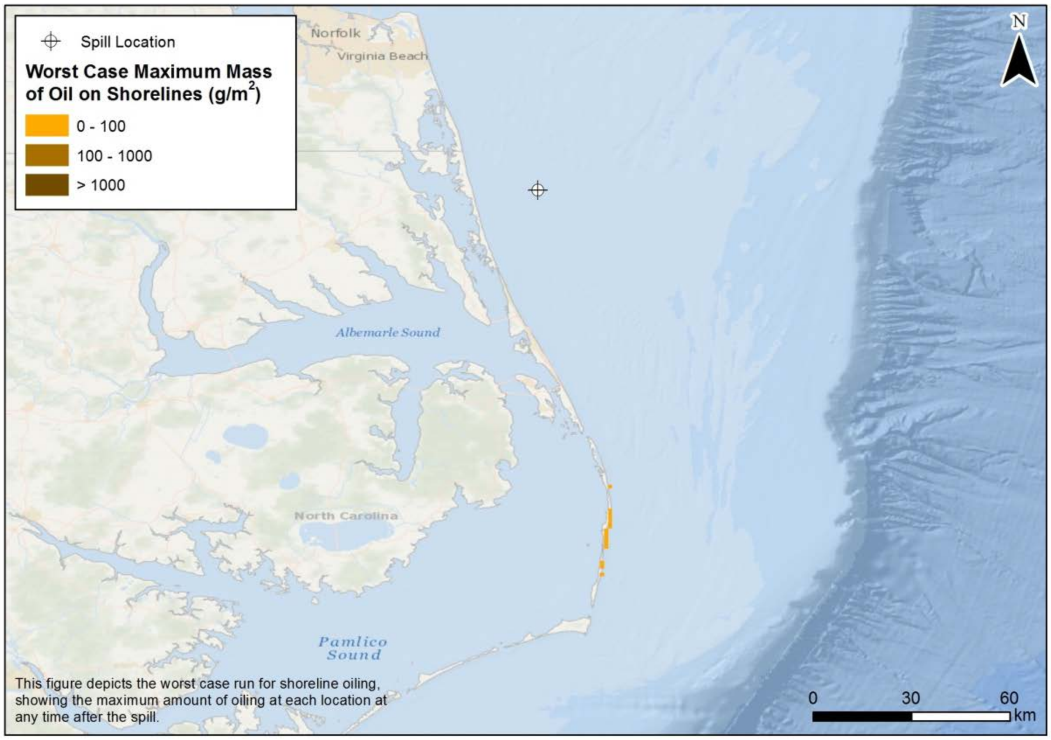


Figure C.84 Model scenario: ESP-NAP-S-1K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 1,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Map represents a single simulation.

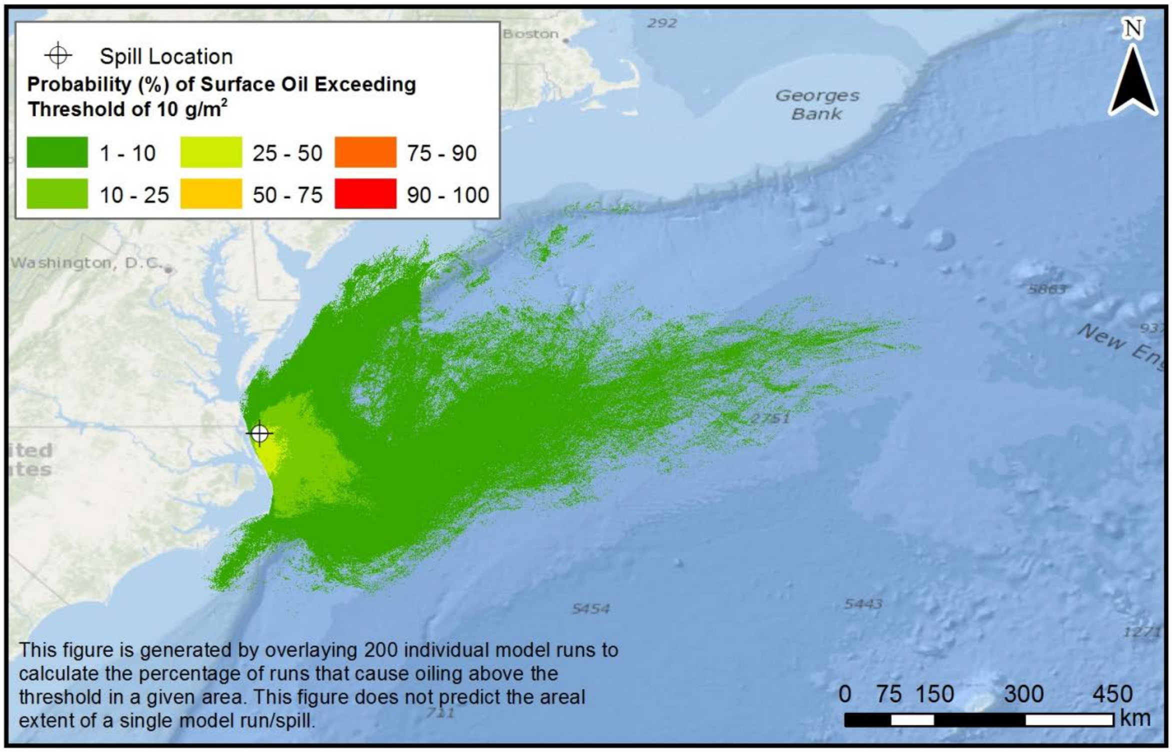
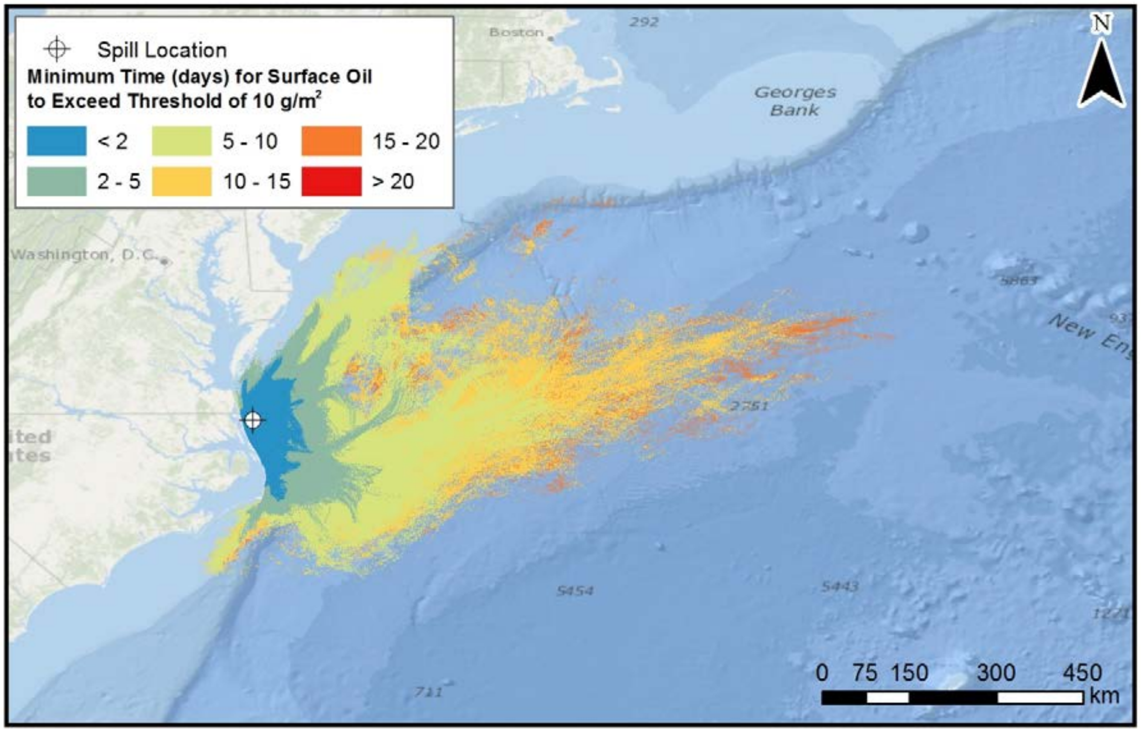


Figure C.85 Model scenario: ESP-NAP-E-40K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



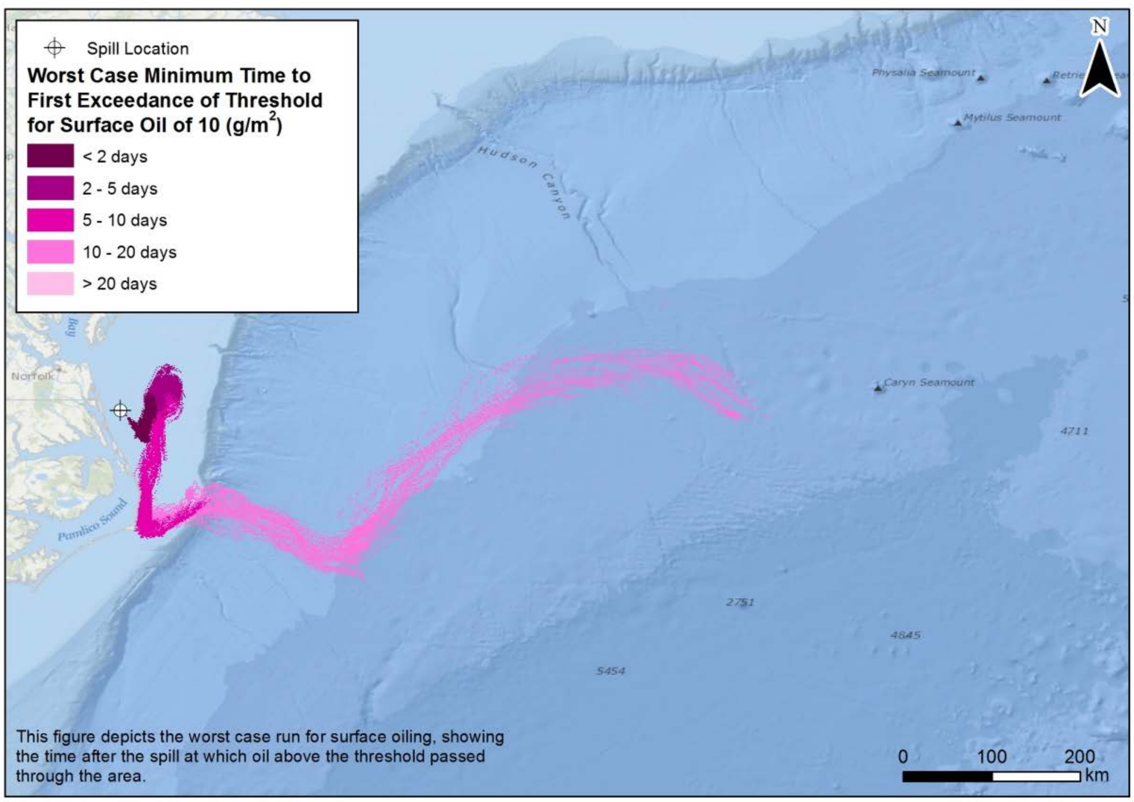
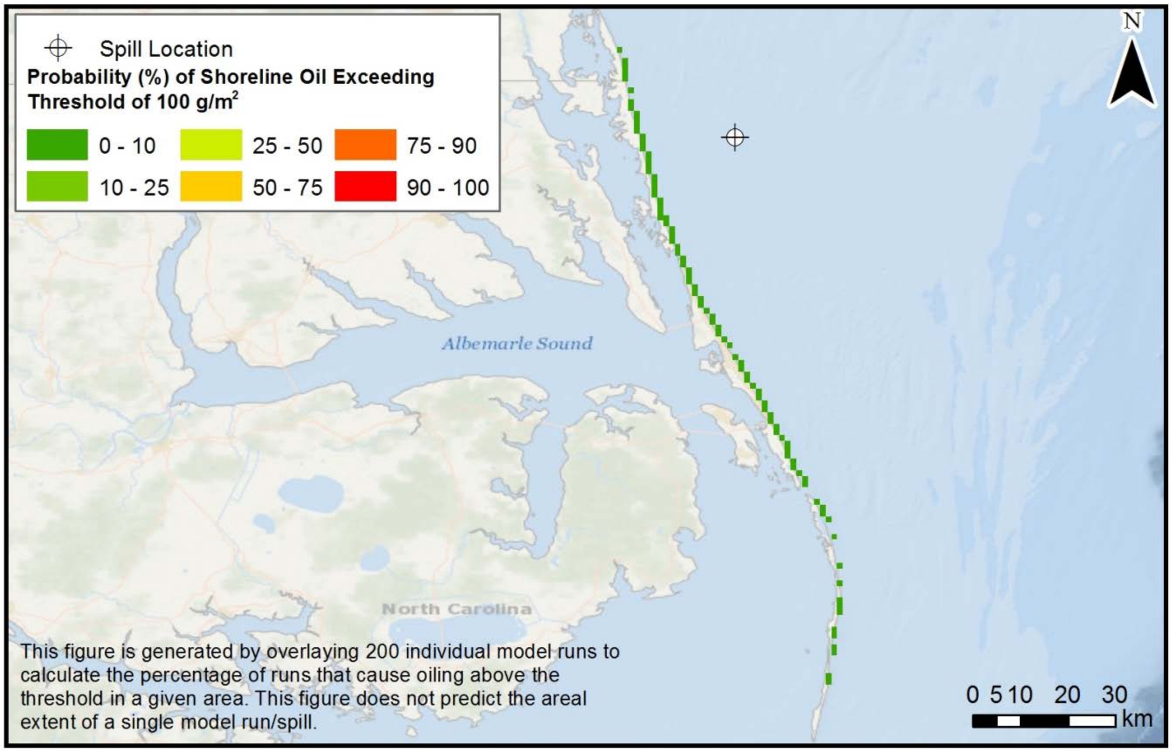


Figure C.86 Model scenario: ESP-NAP-E-40K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



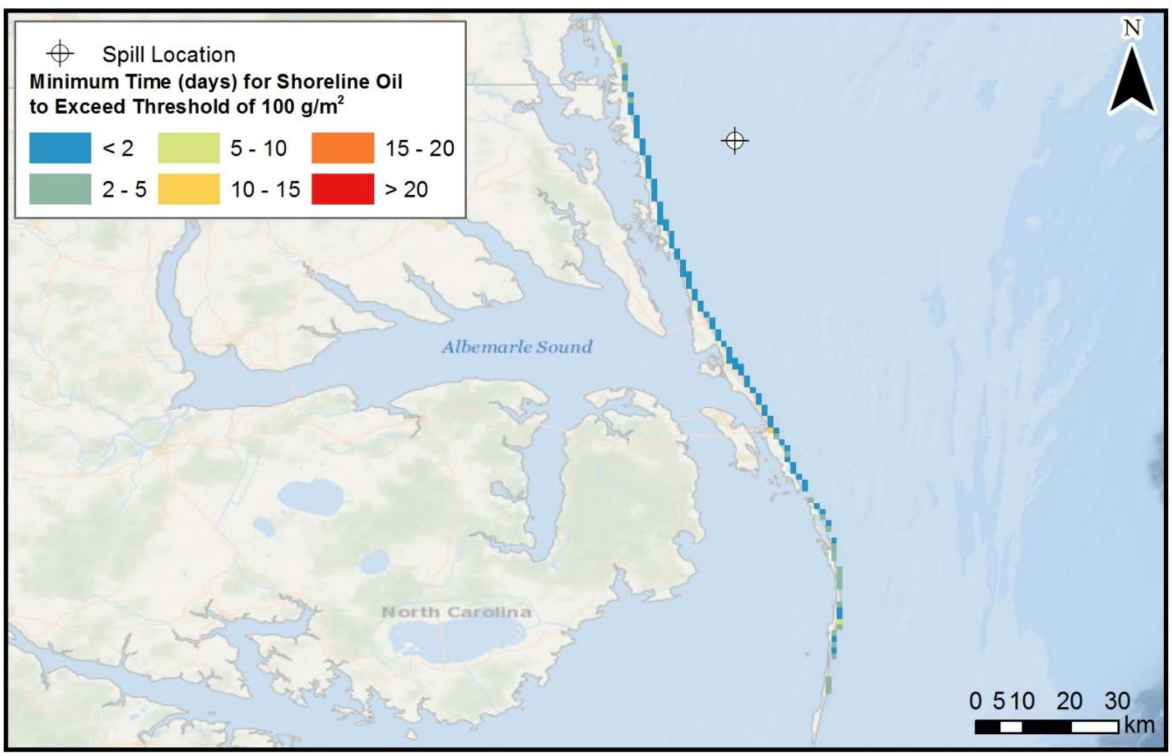


Figure C.87 Model scenario: ESP-NAP-E-40K. Probability of shoreline oiling exceeding 100 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 100 g/m^2 (bottom) for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

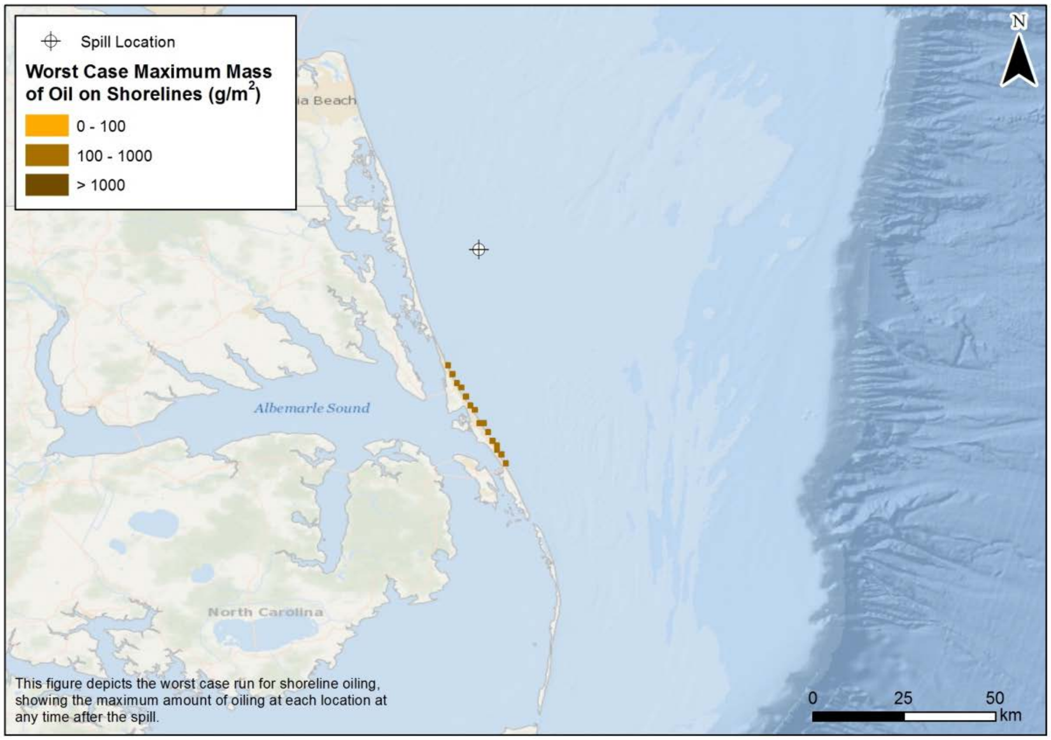


Figure C.88 Model scenario: ESP-NAP-E-40K. Worst case run for shoreline exposure using threshold of 100 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Map represents a single simulation.

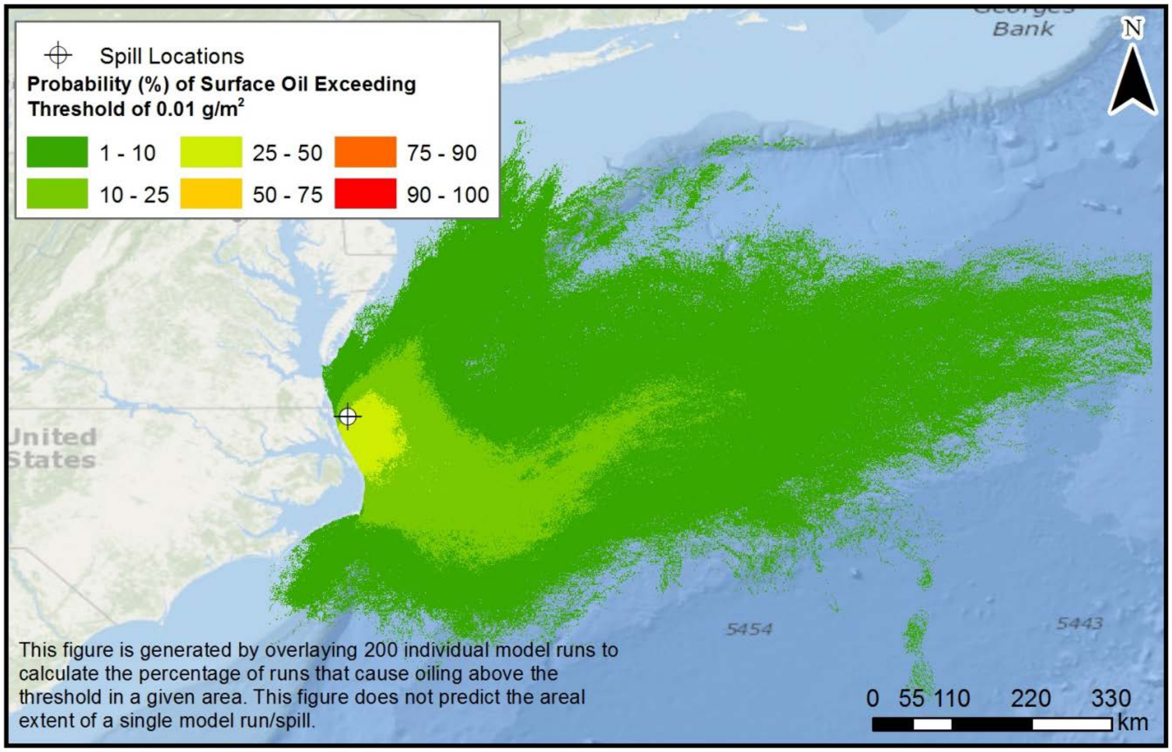
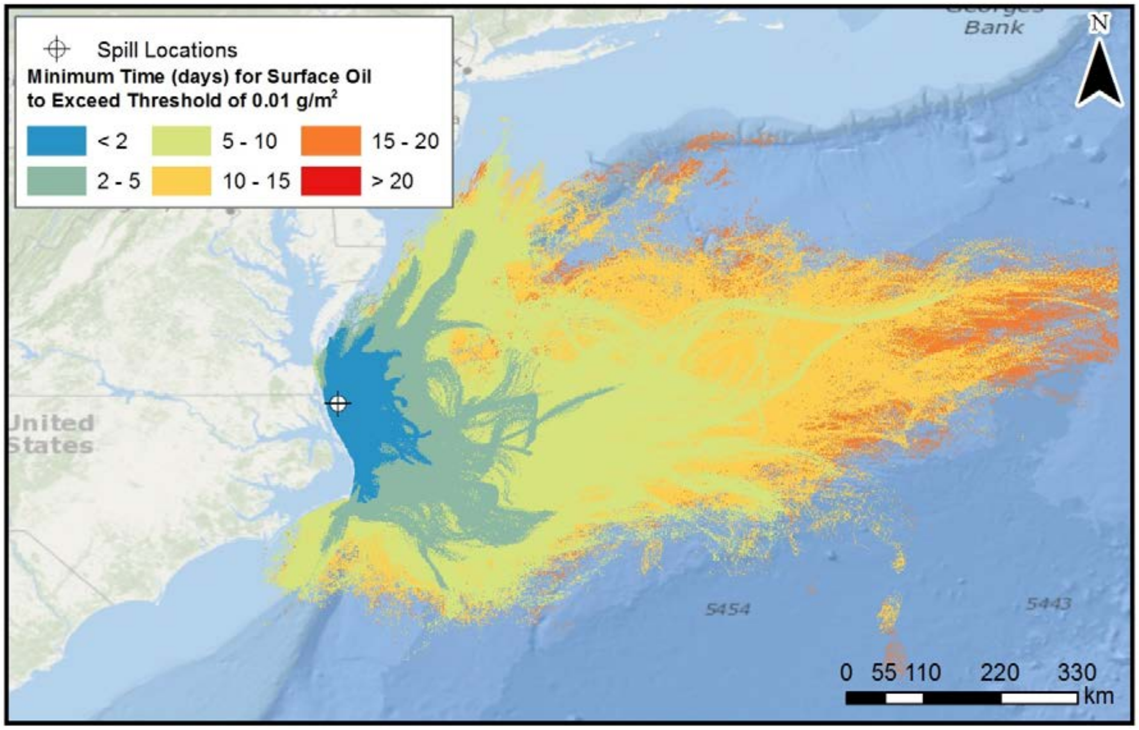


Figure C.89 Model scenario: ESP-NAP-S-40K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



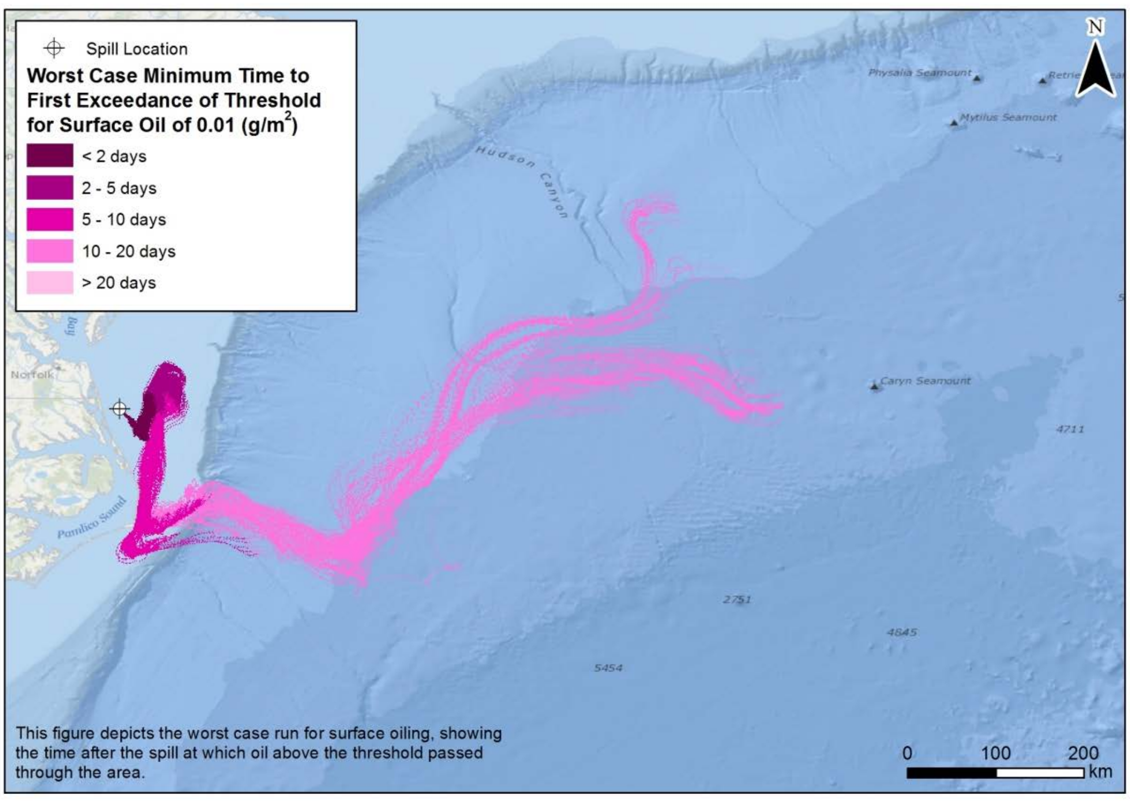
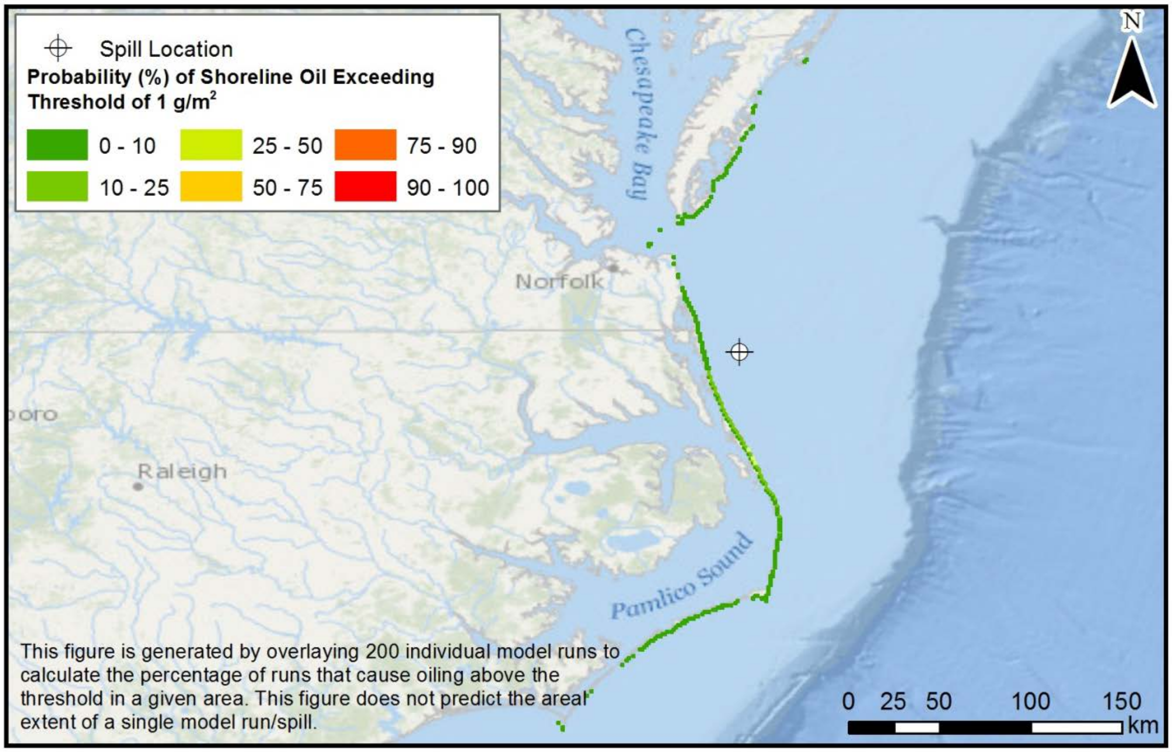


Figure C.90 Model scenario: ESP-NAP-S-40K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



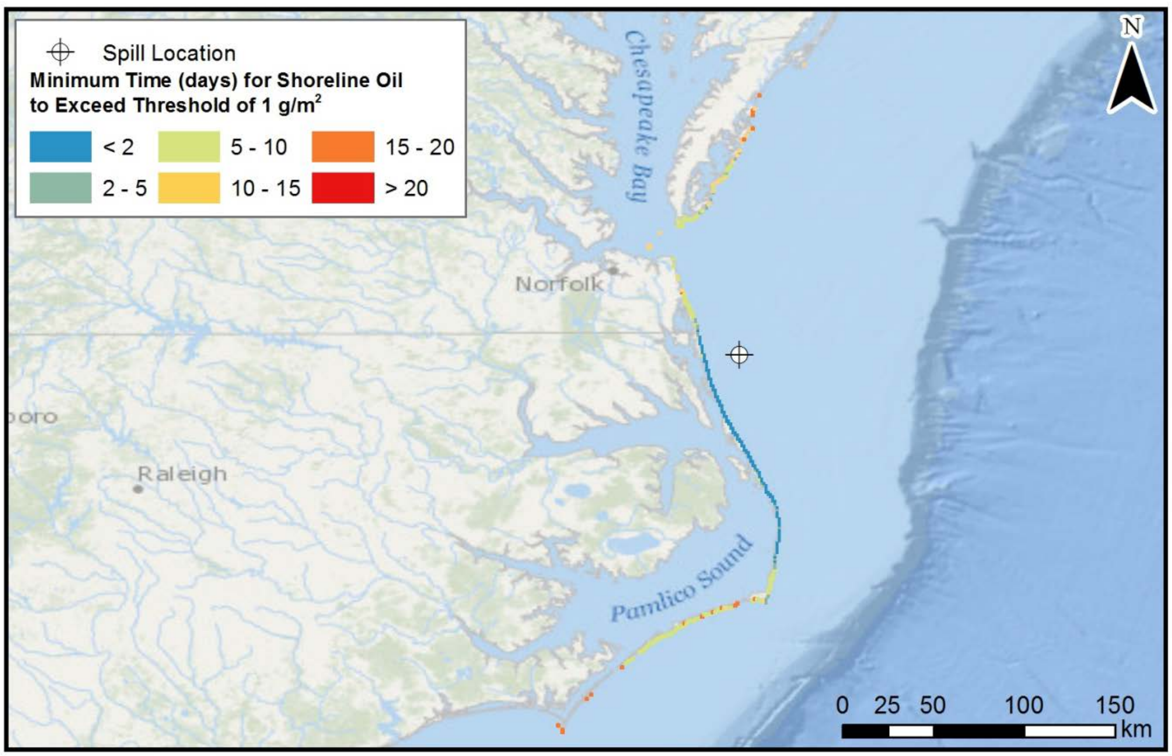


Figure C.91 Model scenario: ESP-NAP-S-40K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

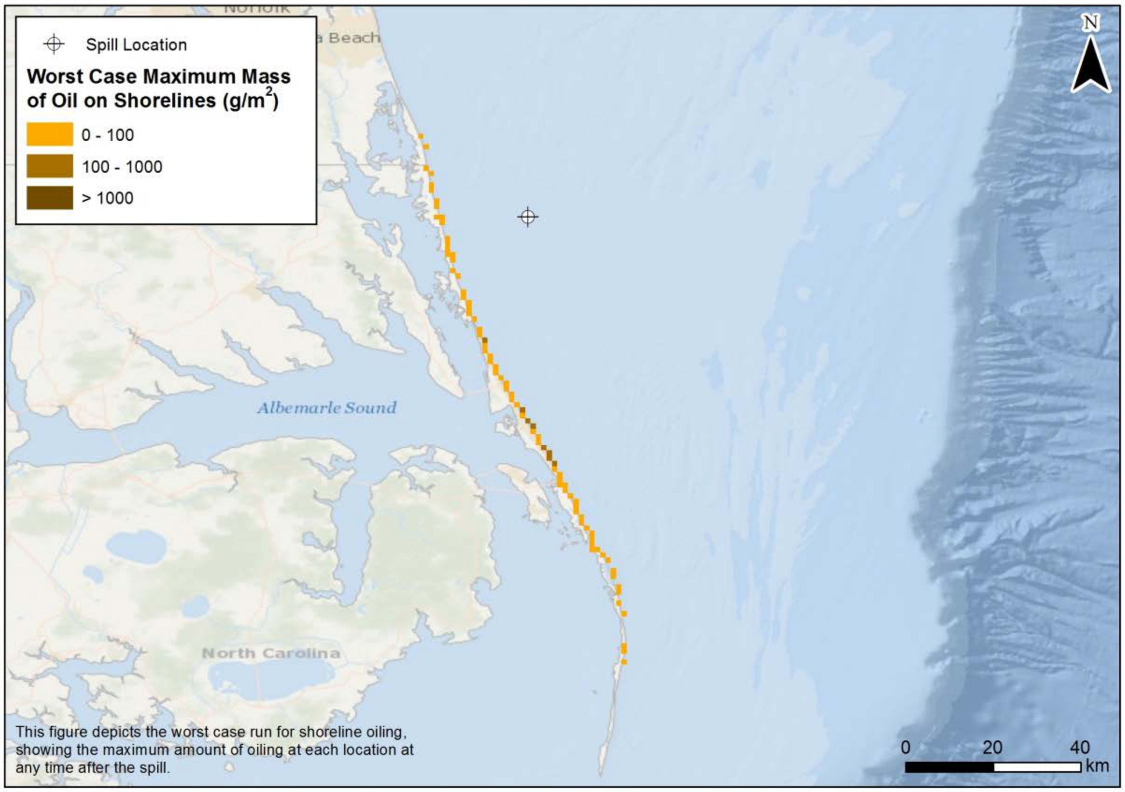


Figure C.92 Model scenario: ESP-NAP-S-40K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 40,000 gallons of naphthenic mineral oil from a wind turbine in the NC Call Area. Map represents a single simulation.

C.4.3 ESP DIESEL SCENARIOS

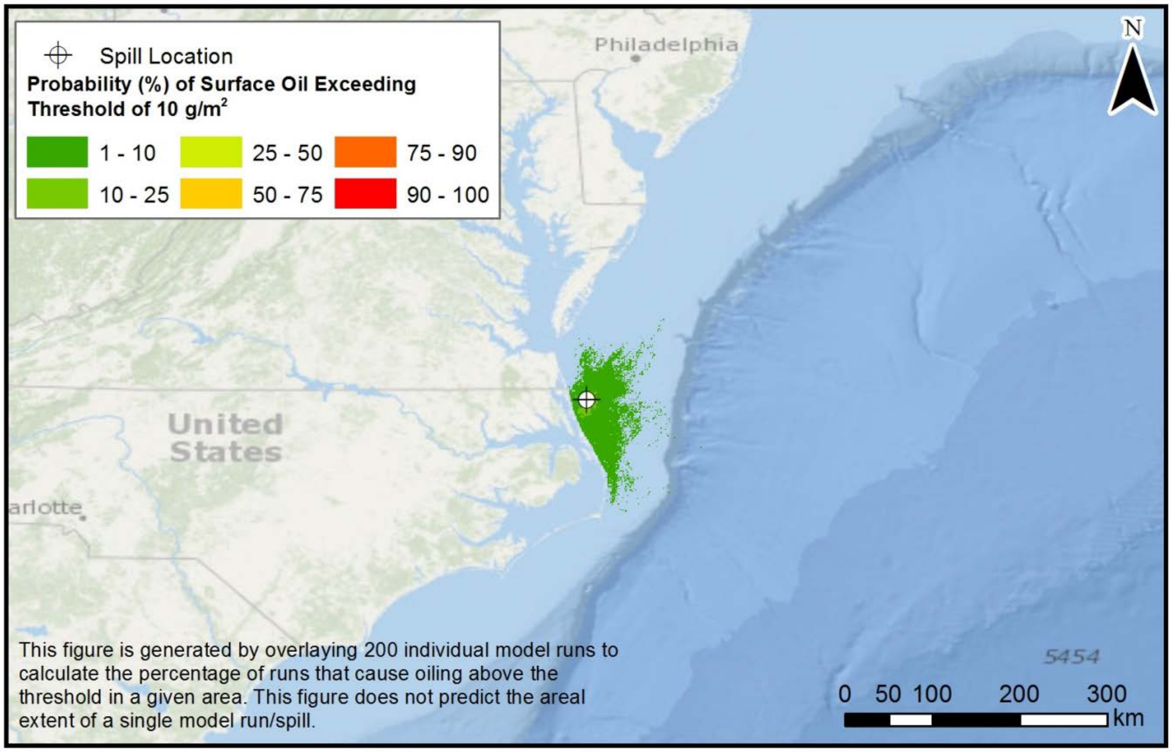
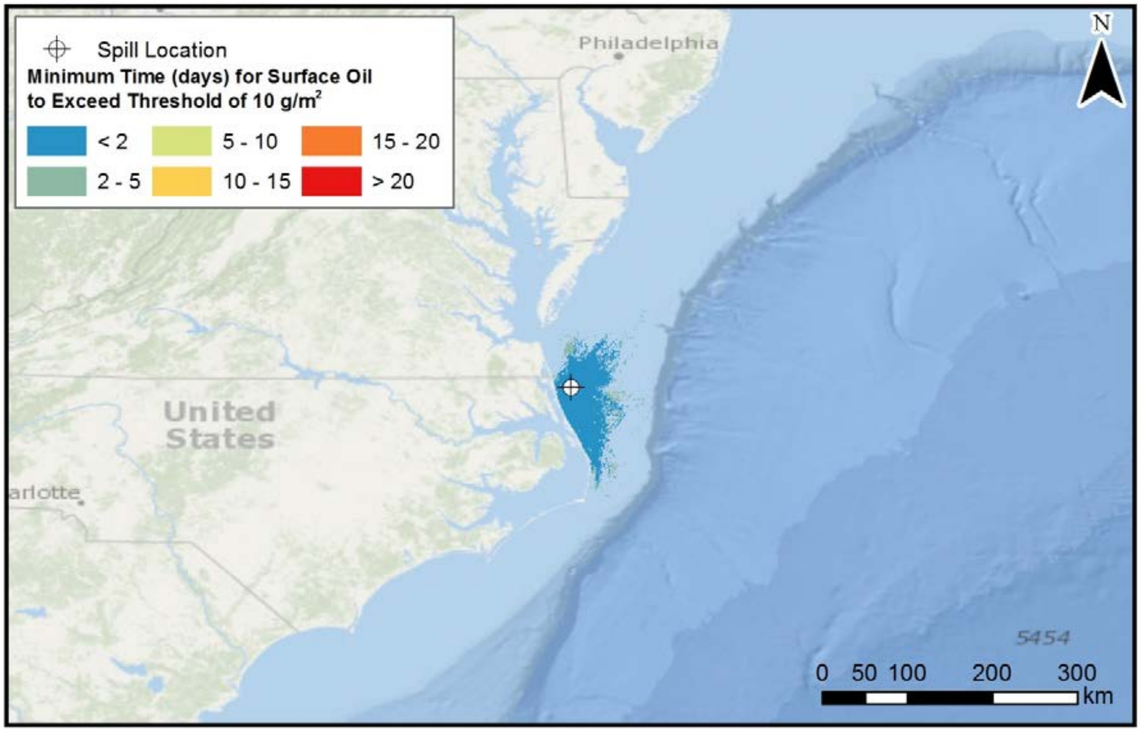


Figure C.93 Model scenario: ESP-DIESEL-E-2K. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



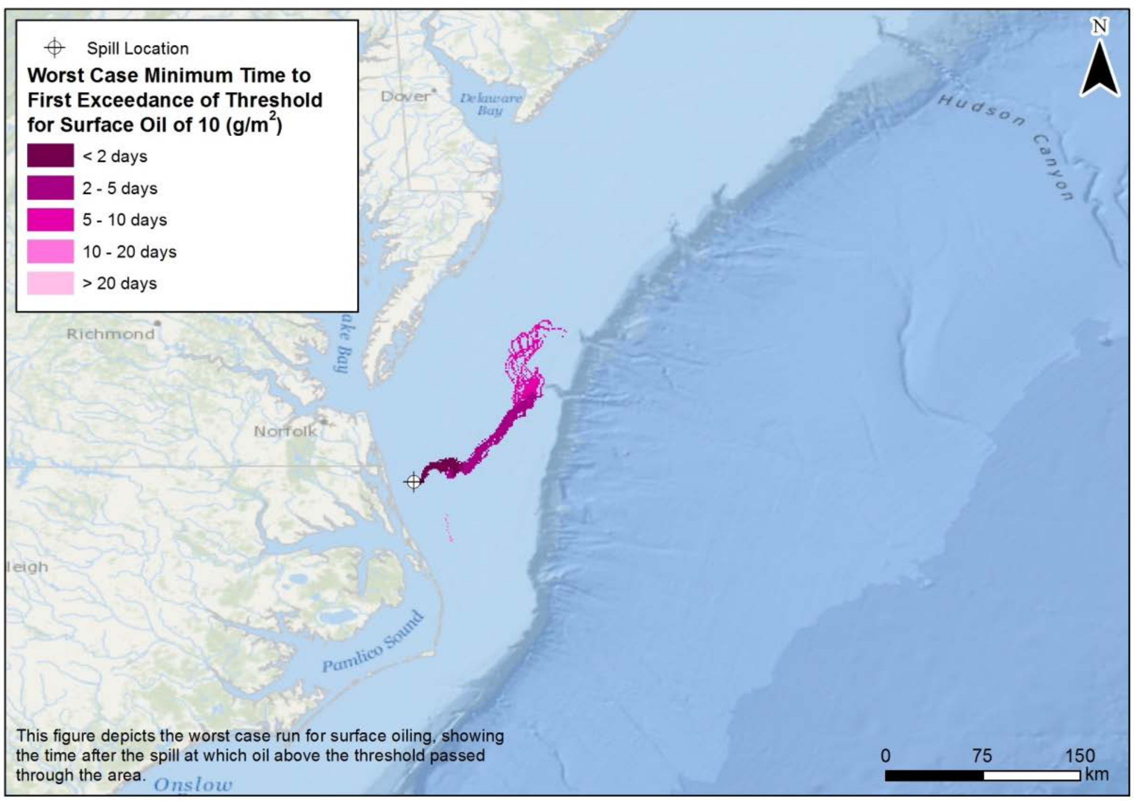


Figure C.94 Model scenario: ESP-DIESEL-E-2K. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

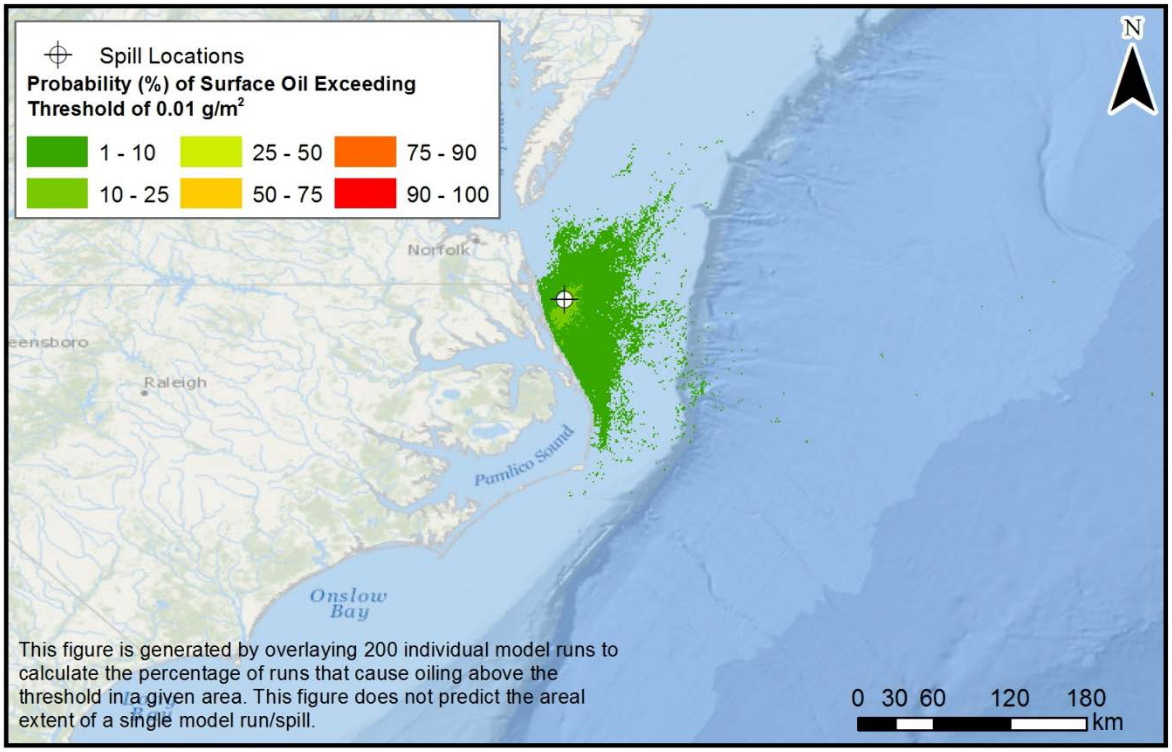
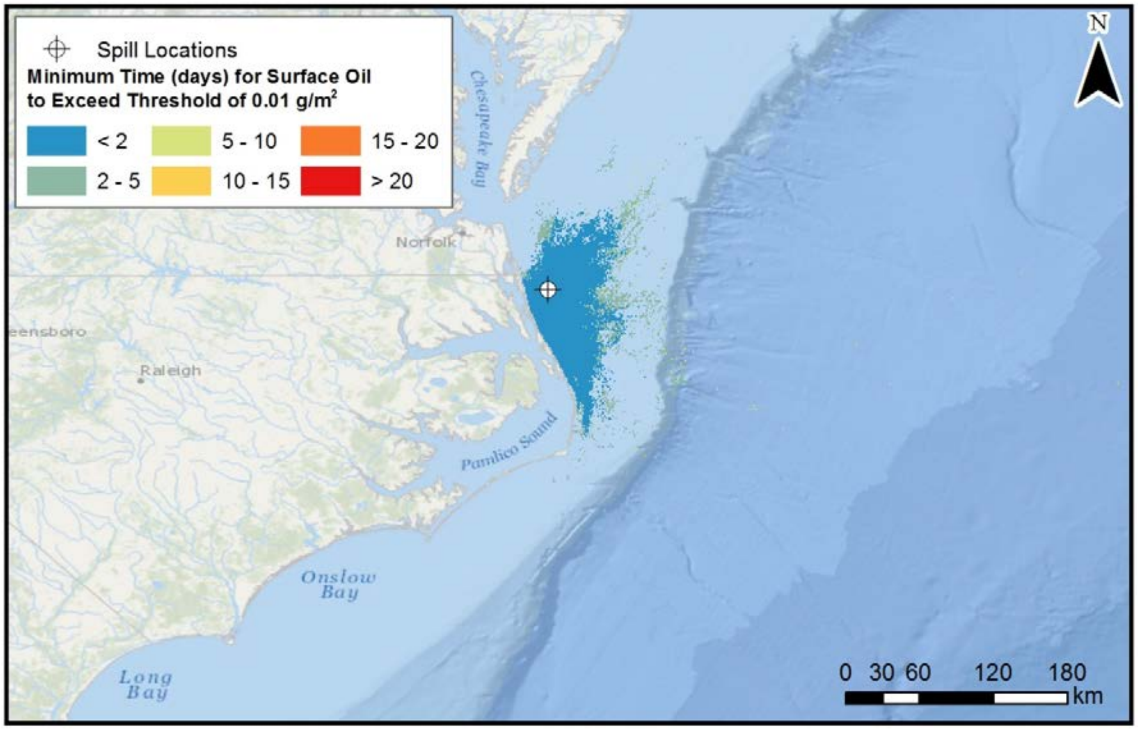


Figure C.95 Model scenario: ESP-DIESEL-S-2K. Probability of surface oil exceeding 0.01 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.



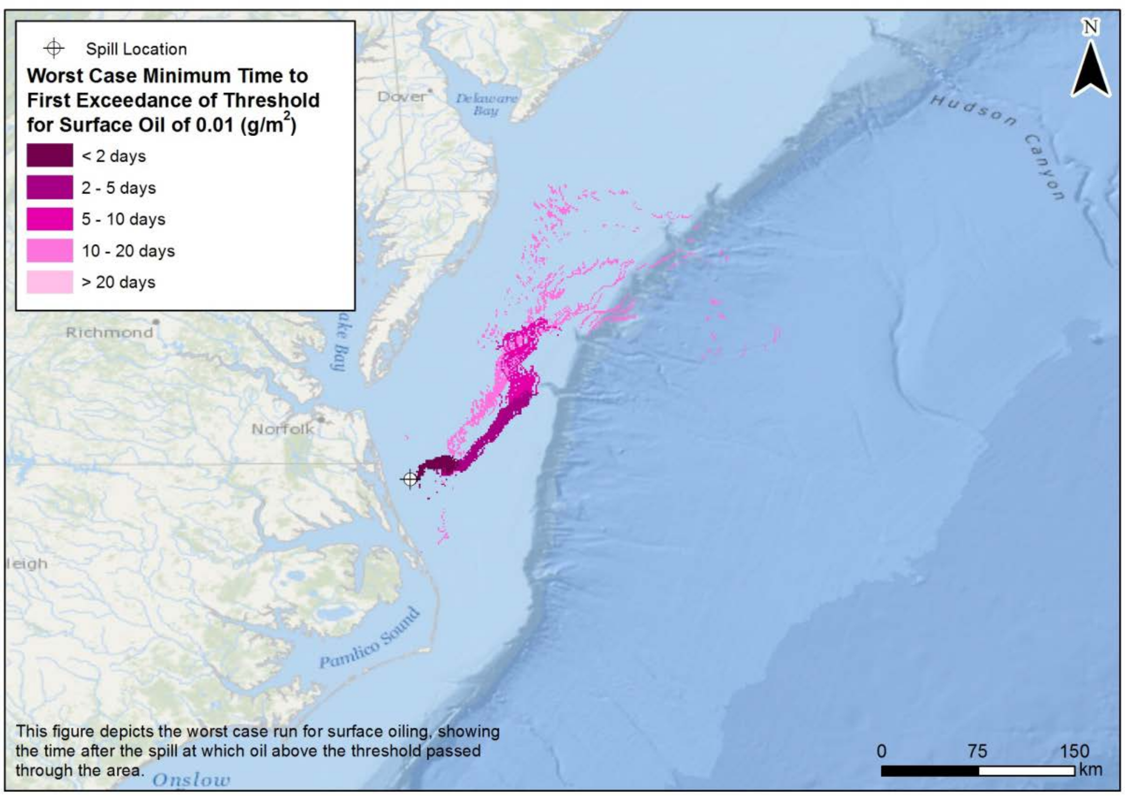
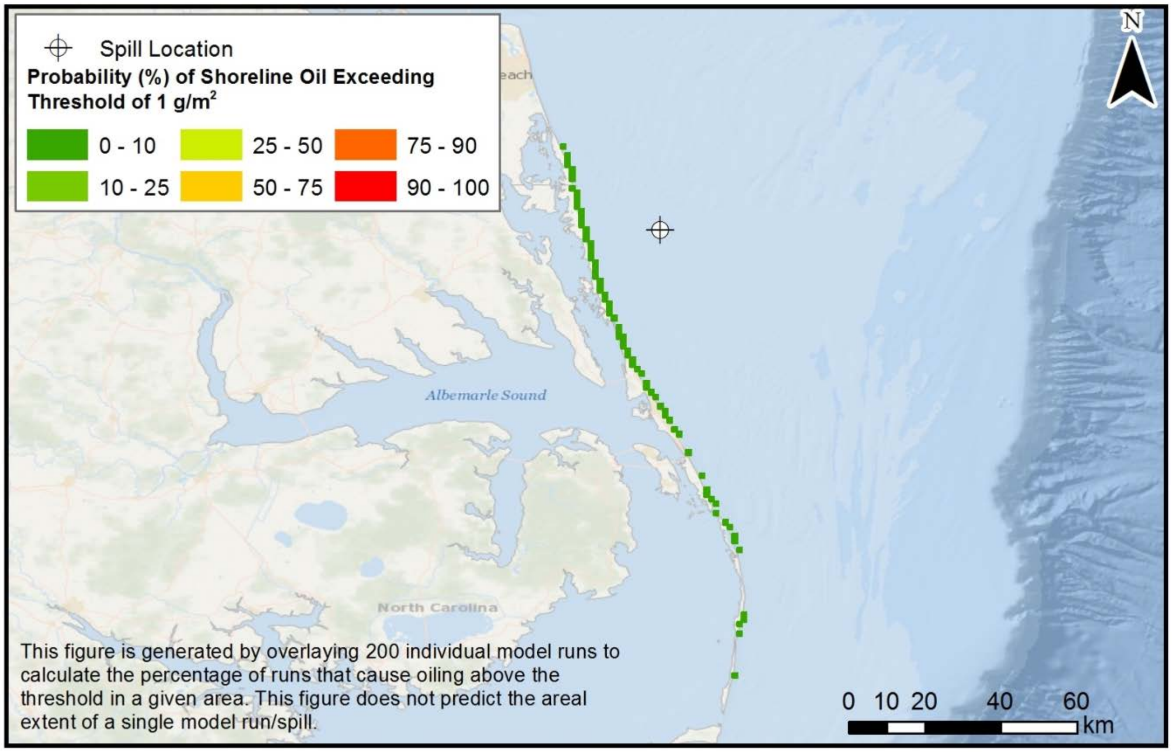


Figure C.96 Model scenario: ESP-DIESEL-S-2K. Minimum time (days) to first exceedance of a threshold of 0.01 g/m^2 for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.



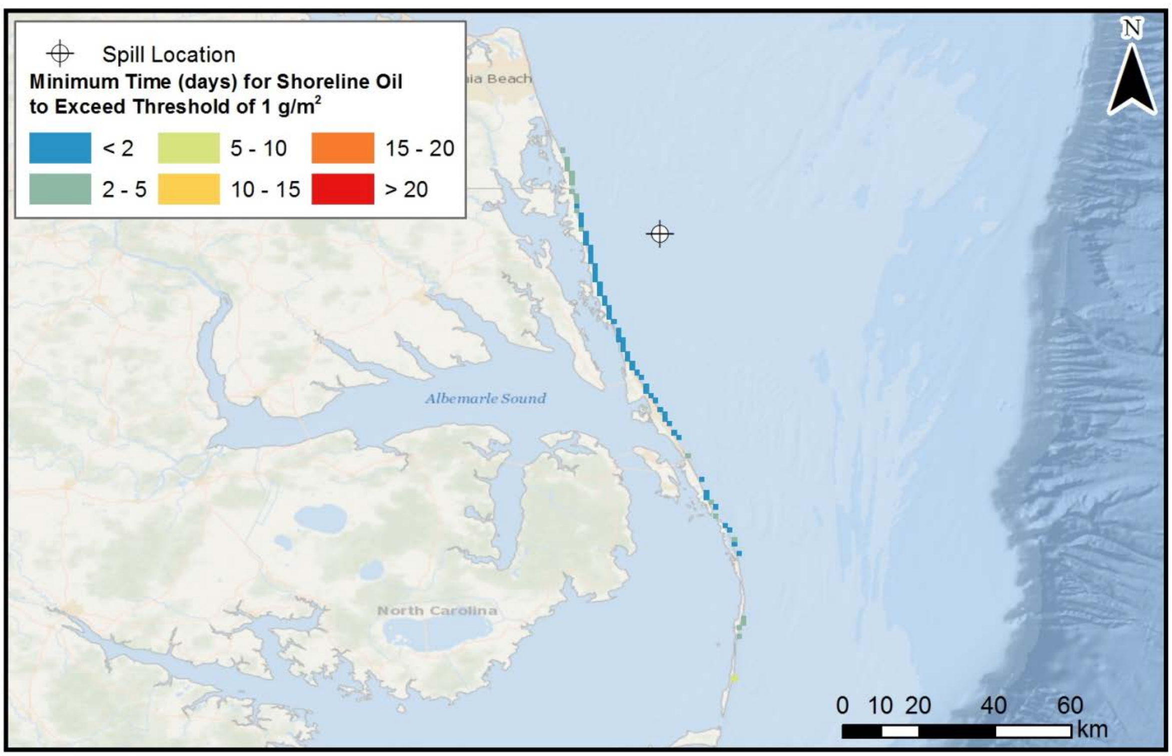


Figure C.97 Model scenario: ESP-DIESEL-S-2K. Probability of shoreline oiling exceeding 1 g/m^2 (top) and minimum time (days) to first exceedance of a threshold of 1 g/m^2 (bottom) for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the NC Call Area. Maps represent an overlay of 200 individual model simulations. Note that the 0-10% range in probability indicates a probability of shoreline oiling greater than and not equal to zero and less than 10.

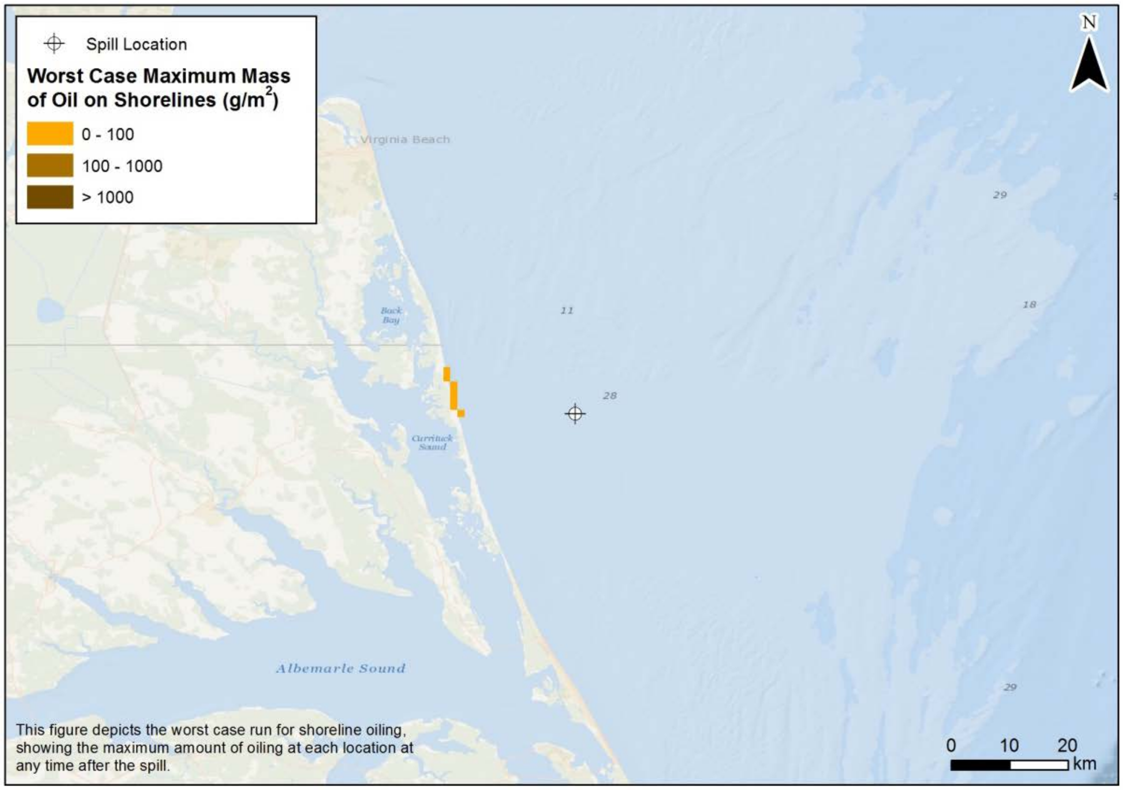


Figure C.98 Model scenario: ESP-DIESEL-S-2K. Worst case run for shoreline exposure using threshold of 1 g/m^2. Maximum mass (g/m^2) of oil on shorelines for a catastrophic spill of 2,000 gallons of diesel oil from a wind turbine in the NC Call Area. Map represents a single simulation.

C.4.4 WTG HYDRAULIC OIL SCENARIO

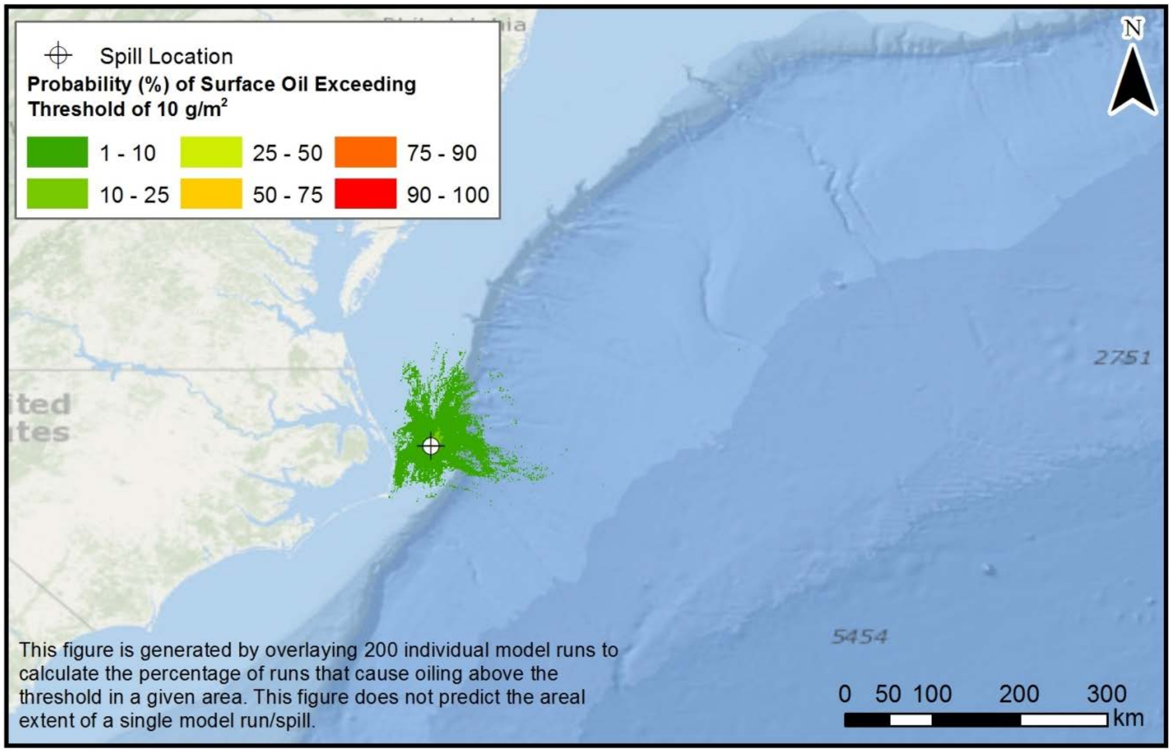


Figure C.99 Model scenario: WTG-HYD-E-90. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 90 gallons of hydraulic oil from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

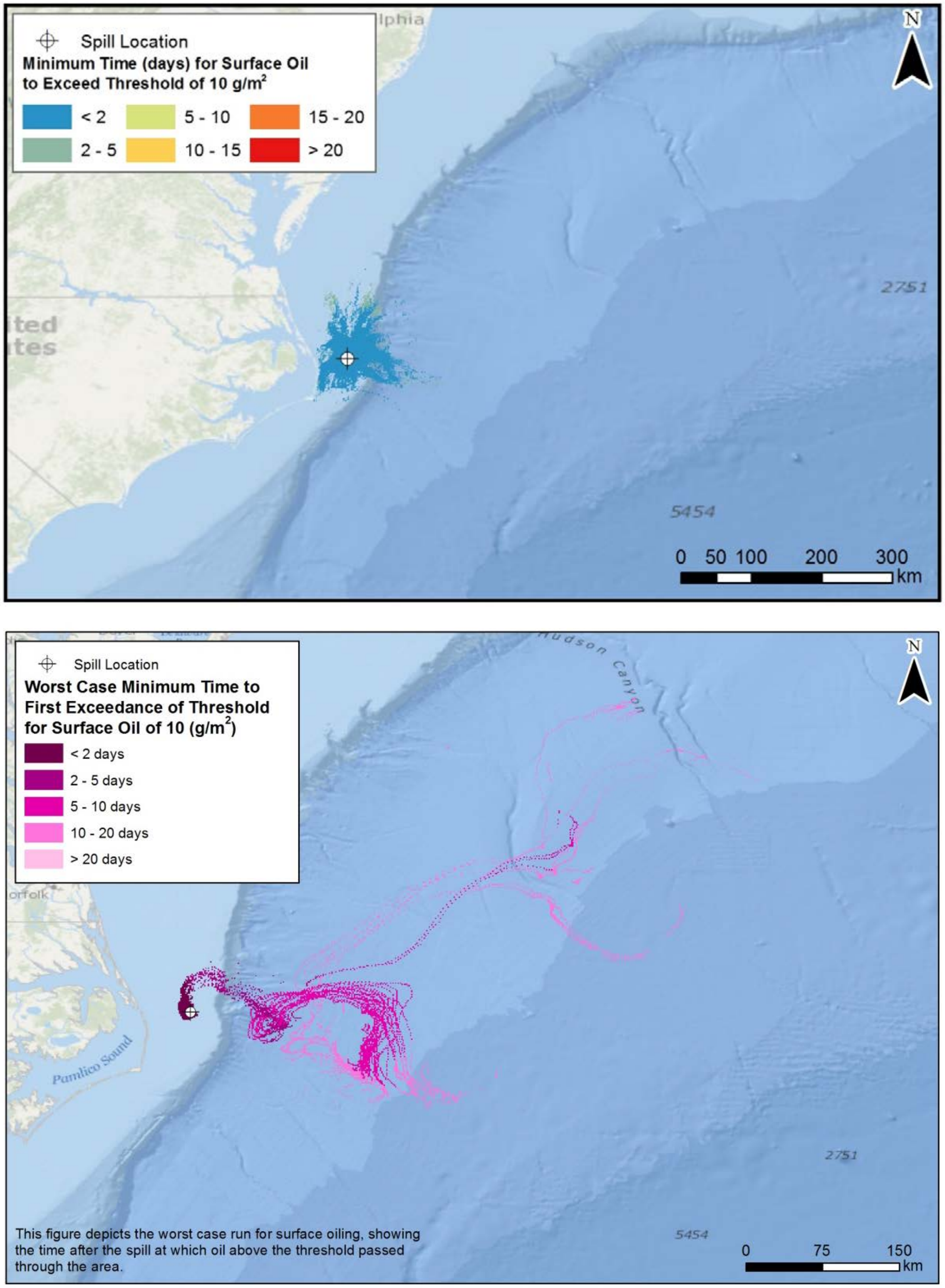


Figure C.100 Model scenario: WTG-HYD-E-90. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 90 gallons of hydraulic oil from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

C.4.5 WTG LUBRICATING OIL SCENARIO

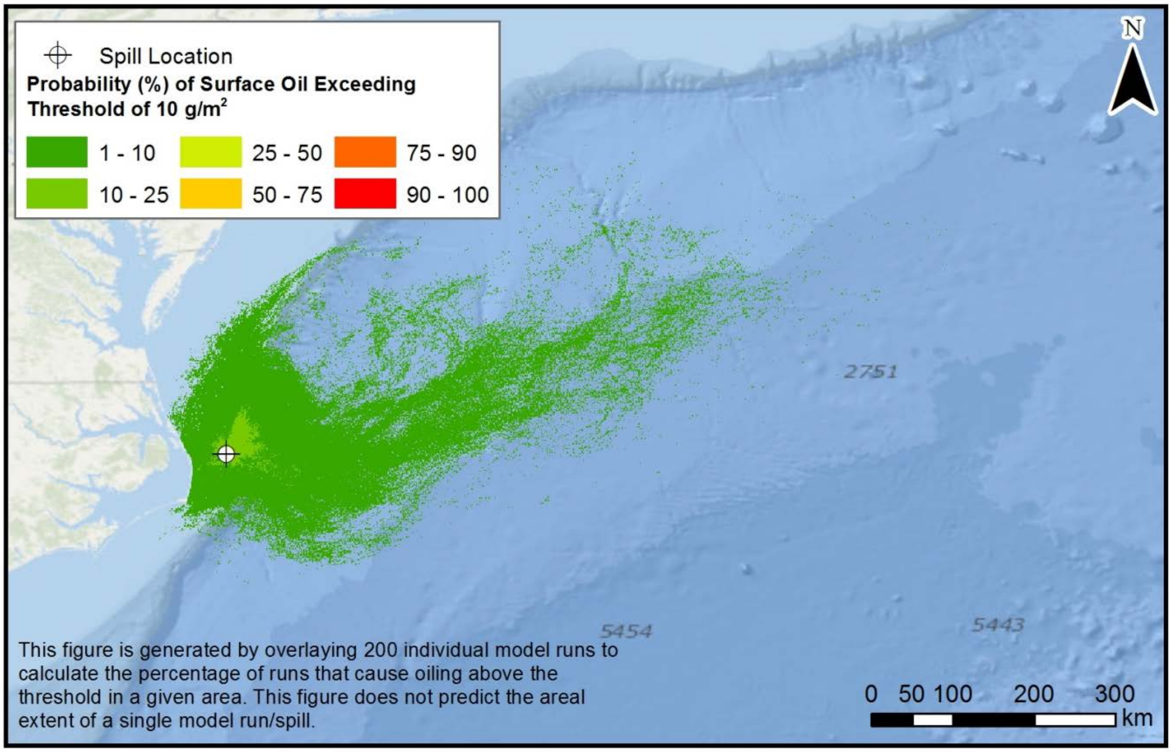


Figure C.101 Model scenario: WTG-LUB-E-220. Probability of surface oil exceeding 10 g/m^2 for a catastrophic spill of 220 gallons of lubricating oil from a wind turbine in the NC Call Area. This figure overlays 200 individual model runs to calculate the percentage of runs that caused oiling above the threshold in a given area. This figure does not depict the areal extent of a single model run/spill.

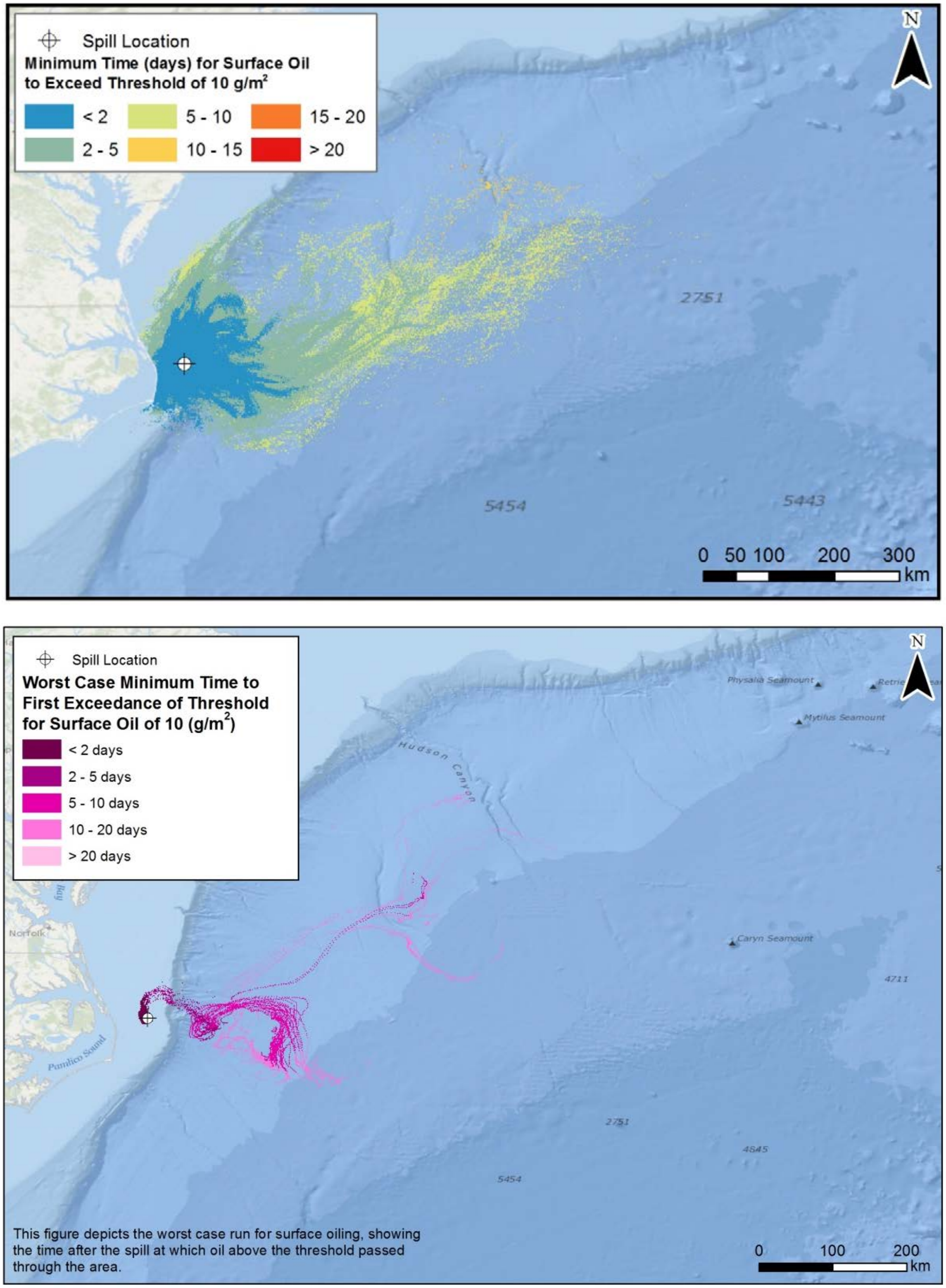


Figure C.102 Model scenario: WTG-LUB-E-220. Minimum time (days) to first exceedance of a threshold of 10 g/m^2 for a catastrophic spill of 220 gallons of lubricating oil from a wind turbine in the NC Call Area. Top map represents an overlay of 200 individual model simulations, while bottom map represents a single worst case simulation.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.

The BOEM Environmental Studies Program

The mission of the Environmental Studies Program (ESP) is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.