Hudson River Oil Spill Risk Assessment

Volume 4:
Spill Consequences: Trajectory, Fate and Resource Exposure

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The HROSRA research team acknowledges the invaluable inputs and discussions with Scenic Hudson over the course of the study period (September 2017 through May 2018), including the selection and development of the hypothetical spill scenarios. The contents of the report, data, analyses, findings, and conclusions are solely the responsibility of the research team and do not constitute any official position by Scenic Hudson. The Hudson River Oil Spill Risk Assessment was conducted as an independent, objective, technical analysis without any particular agenda or viewpoint except to provide quantitative and qualitative information that could be used to work to a common goal of spill prevention and preparedness. The study is intended to inform officials, decision-makers, stakeholders, and the general public about oil spill risk in the Hudson River.

The diligent efforts of the RPS SIMAP modeling team of Deborah Crowley, Jenna Ducharme, Matt Frediani, Emily Skeehan, and Matt Bernardo provided the necessary data, results, maps, and graphics that formed the foundation of much of the analysis in the HROSRA.

The research team also acknowledges the Launch 5 Foundation of Ossining who provided the team with transportation on a two-day river cruise between the Tappan Zee Bridge in Tarrytown and the Port of Albany, New York, on the *Patrolman Henry A. Walburger No. 5* (“Launch 5”) on 15-16 September 2017. The Launch 5 was piloted by Greg Porteus and Steve Kardian. The 26-hour two-way trip allowed the research team to personally see, photograph, evaluate, and measure the features of both banks of the Hudson River, as well as observe vessel traffic and river conditions.

Cover Photograph Credits

The photographs on the report cover were taken by Dagmar Schmidt Etkin (Esopus Meadows Lighthouse and articulated tank barge) and Steve Kardian (bald eagle) on the Hudson River.

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Hudson River Oil Spill Risk Assessment Report Volumes

The Hudson River Oil Spill Risk Assessment (HROSRA) is composed of seven separate volumes that cover separate aspects of the study.

Executive Summary (HROSRA Volume 1)
The first volume provides an overall summary of results in relatively *non-technical* terms, including:

- Purpose of study;
- Brief explanation of risk as "probability times consequences" and the way in which the study addresses these different factors;
- Brief discussion of oil spill basics;
- Results – the "story" of each spill scenario, including the oil trajectory/fate/exposure, fire/explosion brief story (if applicable), and a verbal description of the consequence mitigation (response – spill and fire emergency); and
- Brief summary of spill mitigation measures with respect to response preparedness and prevention.

HROSRA Volume 2
The second volume provides an overview of the study approach and general introduction to unique features of the Hudson River.

HROSRA Volume 3
The third volume reviews the potential sources of oil spillage. It also presents the analyses of the probability of occurrences of spills of varying sizes from the potential sources under different conditions of traffic and oil transport.

HROSRA Volume 4
The fourth volume presents the analyses of the potential consequences or impacts of hypothetical spills, including the trajectory and fate of spills to the water, and the potential exposure of resources above thresholds of concern, based on oil modeling (including Appendices with detailed figures, etc.).

HROSRA Volume 5
The fifth volume presents the analyses of potential consequences or impacts of hypothetical fire and explosion events that may occur in addition to oil spills.

HROSRA Volume 6
The sixth volume presents the analyses of spill mitigation measures to reduce the risk of spills through prevention, preparedness, and response. The volume includes response and preparedness considerations for the specific modeled scenarios, as well as overall response issues for the Hudson River. It also includes more generic descriptions of prevention measures (vessels, trains, facilities, etc.).

HROSRA Volume 7
The seventh volume presents the summary tables with data – including probabilities, spill modeling, fire/explosion analysis, and response considerations for each of the 72 modeled spill scenarios. This volume pulls together everything from HROSRA Volumes 3, 4, 5, and 6.

Research Team

Dagmar Schmidt Etkin, PhD (Environmental Research Consulting)

Dr. Etkin has 42 years of experience in environmental analysis–14 years investigating issues in population biology and ecological systems, and 28 years specializing in the analysis of oil spills. Since 1999, she has been president of Environmental Research Consulting (ERC) specializing in environmental risk assessment, and spill response and cost analyses. She has been an oil spill consultant to the US Coast Guard, EPA, NOAA, Army Corps of Engineers, the Bureau of Ocean Energy Management, the Bureau of Safety and Environmental Enforcement, various state governments, the Canadian government, the oil and shipping industries, and non-governmental organizations. She is internationally recognized as a spill expert and has been a member of the UN/IMO/UNEP/UNESCO Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) since 1997. She has a BA in Biology from University of Rochester, and received MA and PhD degrees from Harvard University in Organismic/Evolutionary Biology, specializing in ecological modeling and statistics.

Deborah French McCay, PhD (RPS Ocean Science)

Dr. French McCay (formerly Dr. French) specializes in quantitative assessments and modeling of aquatic ecosystems and populations, oil and chemical transport and fates, and biological response to pollutants. She has developed water quality, food web and ecosystem models for freshwater, marine and wetland ecosystems. She is an expert in modeling of oil and chemical fates and effects, toxicity, exposure and the bioaccumulation of pollutants by biota, along with the effects of this contamination. Her population modeling work includes models for plankton, benthic invertebrates, fisheries, birds and mammals. These models have been used for impact, risk, and natural resource damage assessments, as well as for studies of the biological systems. She has provided expert testimony in hearings regarding environmental risk and impact assessments. She has over 30 years of experience in analyzing oil spills and is considered one of the leading international experts on the fate and effects of oil spills. She has a BA in Zoology from Rutgers College, and a PhD in Biological Oceanography from the Graduate School of Oceanography, University of Rhode Island.

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Jill Rowe specializes in biological and environmental data gathering, analysis and management; natural resource damage assessment (NRDA) modeling and analysis of pollutant fates and effects; ecological risk assessment; impact assessment of dredging and development projects, preparing sections of Environmental Impacts Statements; providing NEPA support, and GIS mapping and analysis. Ms. Rowe has applied her marine biological and GIS expertise to biological data set development, as well as mapping habitats and biological resource distributions that could ultimately be affected by oil/chemical spills and development projects. She performs quantitative assessments and modeling of aquatic ecosystems and populations, pollutant transport and fates, and biological response to pollutants. The populations to which she applies these models include plankton, benthic invertebrates, fisheries, birds and mammals. She has analyzed data and has applied water quality, food web and ecosystem models to case studies in freshwater, marine and wetland ecosystems. She has a BA in Biology from DePauw University, and an MS in Marine Biology from the College of Charleston.

Deborah Crowley (RPS Ocean Science)
Deborah Crowley is a senior consulting environmental scientist and project manager at RPS. She has experience working on issues and projects related to various aspects of environmental science such as environmental data analysis, hydrodynamic and water quality modeling and analysis, coastal processes, oil and gas fate and transport assessment in the environment, operational discharge modeling and assessment, renewable energy project development assessment support, environmental impact assessment in coastal and marine environments and permitting and regulatory compliance analysis and support. Ms. Crowley's experience with renewable energy projects includes cable burial studies, wind resource assessment, climatology assessment including extremal analysis, wind turbine siting, turbine power production and site capacity analysis, turbine impacts assessment, turbine visualizations, regulatory, permitting and zoning review, planning and management of terrestrial met tower deployment and associated data management and analysis. Areas of experience include numerical modeling, model development and application, field program design and support, data analysis and visualization in Matlab™ and geospatial analysis in ArcGIS™. She has a BS in Mechanical Engineering from Worcester Polytechnic Institute and an MS in Civil & Environmental Engineering from University of Rhode Island.

John W. Joeckel (SEAConsult LLC)
Mr. Joeckel is an executive management professional with a broad-based background in multi-modal transportation, oil, chemical and gas industry sectors, and manufacturing and production. He has extensive experience in legislative advocacy and regulatory compliance, crisis and consequence management, emergency preparedness and response, including hands-on response as an Incident Commander on multiple major emergency incidents and development of all hazard response/crisis management programs and plans including training and exercises. He has experience in ports, waterways and facility maritime security vulnerability analysis and security plan development including personnel training and exercise. Mr. Joeckel has a BS in Maritime Transportation from SUNY Maritime College, as well as many years of training in oil spill response. He has been involved in response research and development and supervising many spill response operations, including the BP Gulf of Mexico Deepwater Horizon incident, the Enbridge Pipeline Michigan oil tar sands crude oil spill in the Kalamazoo River, and the Exxon Valdez spill in Alaska.

Andrew J. Wolford, PhD (Risknology, Inc.)
Dr. Wolford is founder and President of Risknology, Inc., a company specializing in risk analysis of hazardous facilities. He is an expert risk engineer with 29 years of experience. He has directed risk assessments on a diverse range of engineered systems including; offshore and onshore oil and gas installations, mobile offshore drilling units, marine and land-based transportation systems, chemical and nuclear fuel processing plants, nuclear power and test reactors, and the Space Shuttle program. He has a BA in Physics from Wittenberg University, a BA in Nuclear Engineering from Georgia Institute of Technology, and a ScD from Massachusetts Institute of Technology.

Acronyms and Abbreviations

ACP: Area Contingency Plan

ATB: articulated tank barge

bbl/hr: barrels per hour

bbl: barrels of oil (equivalent of 42 gallons)

BFHYDRO: boundary-fitted coordinate hydrodynamic model

BTEX: benzene, toluene, ethylbenzene and xylene

C: degrees Celsius

CBR: crude-by-rail

cP: centipoise

ERC: Environmental Research Consulting

ETC: Environmental Technology Center

F: degrees Fahrenheit

ft: feet

g/m^2: grams per square meter

g/m^3: grams per cubic meter

gal: gallons

GIS: geographic information system

HFO: heavy fuel oil

HHO: home heating oil

hr: hours

HRECOS: Hudson River Environmental Conditions Observing System

IFO: Intermediate Fuel Oil

kts: knots

M2: principal Lunar semidiurnal tidal constituent

MAHs: monoaromatics

mi: miles

mi^2: square miles

mil: million

mm: millimeter

NHD: National Hydrological Dataset

NOAA: National Oceanic and Atmospheric Administration

NRC: National Research Council

NYSDEC: New York State Department of Environmental Conservation

OILMAP: RPS Ocean Science's oil spill mapping model

PAHs: polycyclic aromatic hydrocarbons

ppt: parts per thousand

psu: practical salinity unit

SAV: submerged aquatic vegetation

SIMAP: RPS Ocean Science's Spill Impact Model Application Package

SPM: suspended particulate matter

USGS: US Geological Survey

WCD: worst-case discharge

µm: micron

Terminology

Oil Mass Balance

The oil spill model calculates a mass balance for the spill oil over the time of the simulation, which quantifies the time history of oil weathering and its fate over the duration of the spill. The mass balance is expressed as the percentage or amount of spilled oil on the water surface, on the shoreline, evaporated, entrained in the water column, degraded, settled to the sediments or that has exited the model domain (i.e., into New York Harbor).

Executive Summary

As part of an oil spill risk assessment for the Hudson River (New York, USA), oil spill consequence modeling was performed for hypothetical spills at twelve locations along the river from Albany to the entrance of New York Harbor. The scenarios represent a range of potential and reasonably plausible spill cases within the study area, based on the type of oil transport that is currently occurring or may occur in the future. Spill scenarios include worst case and smaller discharges from crude oil or fuel carrying tankers, vessel fuel spills, and train accidents involving spills of crude oil cargo from railcars. Potential spills of five oil types were modeled: Bakken crude, diluted bitumen, heavy fuel oil, home heating oil, and gasoline. For each of the twelve location-oil type-volume combinations, modeling was conducted for spills at high or low tide at the spill location in three different seasons: spring with high flow, summer with low flow, and winter with medium flow and ice cover.

Model results describe the mass balance or fate of the spilled oil over the duration of the model run of 30 days. The mass balances for the hypothetical spills reflect the general oil fate processes as well as the composition and bulk properties of the oil. Evaporation is faster with higher temperature (i.e., in summer than other seasons) and with higher wind speed (typical of spring), while evaporation is slowed in winter by the low temperatures and partial ice cover that restricts spreading. The spill cases from vessels examined are assumed to discharge from 1-2 m below the surface, so the initial condition is that the oil is entirely in the water column. In these cases, most of the oil surfaces immediately (by the next model time step). The floating oil is transported downstream and entrained into the water when and where there are high winds and waves. Oil in the water column dissolves and combines with suspended particulate matter (SPM), with some of the oil-SPM settling to the sediments. Oil strands on shorelines when the local winds are onshore.

Potential spills of five oil types were modeled:

- Bakken crude
- Diluted bitumen
- Heavy fuel oil
- Home heating oil
- Gasoline

Bakken crude is a very light, low viscosity crude oil with about 73% of the oil mass being volatile. As such, much of the oil evaporates quickly and the remainder easily disperses into the water column. The residual hydrocarbons that do not evaporate or dissolve strand on shorelines or are carried to the sediments by interaction with sediments suspended in the water that subsequently settle.

Diluted bitumen (dilbit) is a mixture of a highly weathered heavy oil diluted with a hydrocarbon solvent (diluent) to make it flow and behave more like a liquid crude oil. The blend ratio may consist of 25 to 55% diluent by volume, depending on characteristics of the bitumen and diluent, pipeline specifications, operating conditions, and refinery requirements. The dilbit composition used for this modeling study contained about 40% volatile (light) hydrocarbons; the remainder being comprised of very recalcitrant compounds that do not dissolve or easily degrade. Thus, when spilled into water, the light volatile hydrocarbons readily evaporate or dissolve, and the non-volatile bitumen fraction remains floating until it

goes ashore or settles to the bottom after combining with SPM. The dissolved components degrade in time, but the floating and stranded bitumen is slow to degrade.

Heavy fuel oil (HFO, also described as Bunker C fuel or Intermediate Fuel Oil, IFO) is primarily used to power vessels. It is comprised mainly of high molecular weight hydrocarbons that do not readily evaporate or dissolve. Of the typical heavy fuel oil used for this modeling study, less than 20% of the oil mass is volatile. Some of the volatiles evaporate, while the remaining volatile mass dissolves and degrades in the water column. The high viscosity of heavy fuel oil reduces the rate at which the oil entrains into the water column via breaking waves. Thus, heavy fuel oil primarily remains floating until it is washed ashore. The oil degrades very slowly over time.

Home heating oil (HHO) is a refined oil product, similar to diesel fuel, comprised primarily of volatile hydrocarbons. Thus, most (other than a few percent) of the oil mass evaporates or dissolves into the water column. The dissolved hydrocarbons readily degrade. The floating oil evaporates or enters the water column rapidly and little oil goes ashore.

Gasoline is comprised almost entirely (>99%) of highly volatile hydrocarbons, which evaporate or dissolve into the water column rapidly after a spill. Less than 1% of the mass is comprised of residual components that form sheens or contaminate the shoreline.

In spring, the river flow rate is at its highest of the year, and over much of the Hudson's river flow is much stronger than the tidal flow. Thus, spilled oil is rapidly carried downstream. In contrast, in summer the river flow is at its annual low and relatively slow compared to the tidal flow. Thus, oil spilled in summer is primarily carried by the tides and moves up and down river with the tidal cycle. In winter, the river flow rate is intermediate of the spring and summer flow rates.

Dispersion (entrainment) of the oil into the water column is highest in spring and slowest in winter. In winter, presence of ice slows spreading of the oil and entrainment into the water. Because of the ice cover, as well as low temperatures, evaporation and dissolution of spilled oil is considerably slower in winter than in the other seasons. Degradation is correspondingly slow. Because these processes are slow in winter, floating oil tends to be transported long distances down river from the spill site and more of it strands on shorelines than for the other seasons.

If oil is spilled at the time of (the local) high tide, it is first transported downstream, and then upstream at the change of the tide. If oil is spilled at the time of (the local) low tide, it is first transported upstream. After several tidal cycles, the floating oil is spread up- and down-stream, as well as carried down river. In spring, the movement down river is rapid, whereas in summer it is slow. After several days, the trajectories of spills occurring at high or at low tide are very similar (other inputs such as season being held constant), except for cases where for one tidal cycle the freshly spilled oil is trapped in inlets and behind islands.

Summary tables herein and in HROSRA Volume 7 list the amount of oil on the water surface and in the water at 30 days post-spill. Typically, the maximum amount in these two environmental compartments occurs earlier in the spill simulation, such that little to none might be in these compartments after 30 days. The amounts in the atmosphere (i.e., evaporated), on shorelines and sediments, and degraded (by microbes and light-induced photo-degradation) increase in time as the processes leading to these fates ensue. In some cases, some of the oil exists the modeled domain into New York Harbor.

The oil spill modeling summaries include the extent of oiling over specified thresholds. There are different thresholds for potential ecological effects and socioeconomic (including cultural) impacts. The basis for the thresholds is explained in this volume (HROSRA Volume 4) in the description of the model approach. The thresholds for potential ecological effects are conservative levels (concentrations) below which adverse effects are not expected to result. It should be noted that not all biota in the area or volume exposed above the threshold would be adversely affected. Biological impacts resulting from the oil exposure would vary, depending upon: the pathways of exposure such as direct contact, ingestion or inhalation; the degree of actual contact with biota, duration and magnitude of exposure, sensitivity of the organisms (life stage, physical health), etc. The thresholds for potential socioeconomic impacts are much lower than those for ecological effects. There would be effects on tourism, property, etc. with even light amount of staining which occurs at much lower oil concentrations than would actually cause any ecological impact. Note that all of these potential impacts assume that there has been no mitigation by spill response or protective booming strategies. In an actual spill situation, some of the oiled areas may be protected by timely and effective deployment of booms, assuming weather and current conditions are not counteracting the effectiveness. In addition, there may be some oil removal on the water surface that may reduce some of the spread and stranding of oil.

The oil spill modeling demonstrates typical trajectories for the spill scenarios and environmental conditions (i.e., seasonal river flow and ice cover, as well as tide stages) examined. The results describe expected oil fate and potential oil exposure, including length and duration of floating oil exposure along the river; length, locations and types of shoreline oiled; water column exposure to whole oil and dissolved hydrocarbons, oil contamination in sediments, and the habitat types and areas affected. The length of river contaminated was greatest in spring under high flow conditions and least in summer when river flow was low. Mass balance graphs demonstrate oil behavior and fate for various oil types, ranging from highly volatile gasoline, to easily dispersed home heating oil and light Bakken crude, and to heavy fuel that persists on shorelines. Diluted bitumen (dilbit) is a mixture of a highly weathered heavy oil and a light hydrocarbon solvent (diluent) to make it flow like a liquid crude oil. Thus, when modeled as spilled into water, the light volatile hydrocarbons readily evaporated or dissolved, and the non-volatile bitumen fraction remained floating until it went ashore or settled to the bottom after combining with suspended particulate matter.

The model results support analyses of spill mitigation measures to reduce the risk of spills through prevention, preparedness, and response. (See HROSRA Volume 6).

Introduction

The Hudson River Oil Spill Risk Assessment (HROSRA) is a comprehensive study of the risks of oil spills into the Hudson River based on the various types of oils that are (or potentially would be) stored in facilities (e.g., terminals) and transported by tanker, tank barge (including articulated tank barges, or ATBs), rail, and pipeline at river-crossings. As part of the HROSRA, oil spill modeling was performed for hypothetical oil spills potentially related to the placement of anchorages along the Hudson River from Manhattan to Albany, NY. The model results may be used to evaluate the expected trajectory and fate of spilled oil, as well as the potential environmental and socioeconomic consequences of these and similar oil spills in the Hudson River.

The goals of the oil spill modeling included accessing and developing the best available environmental input data (e.g., currents and winds); projecting the behavior of spilled oil using a state-of-the-art three-dimensional transport and fate model, and producing model output describing oil exposure, such as length and location of shoreline oiled, habitat types affected, mass balance graphs showing oil fate, and visual representations for various scenarios. This volume describes the oil spill modeling approach, input data, assumptions, and results. The oil spill model results are summarized in HROSRA Volume 7, as part of the summary tables with data on spill probabilities, expected oil exposure (based on this oil spill modeling), fire/explosion analyses, and response considerations for each of the 72 modeled spills scenario.

Oil transport and fate on the surface and in the water column was modeled using RPS' oil spill modeling software to assess these releases. The model is described in the next section, followed by a description of the modeling approach. Model inputs, including geographical (shore type, habitat, depth), hydrodynamic (currents), winds, ice cover, water temperature, salinity, and oil property data, are described in following sections. Model results are first described in general terms, based on oil type, season and stage of the tide when spilled. The results of each of the 12 scenarios are then described, organized by spill location/volume/oil type.

Model Overview

Oil spill trajectory and fate modeling was performed using the SIMAP (Spill Impact Model Application Package) oil fate model[1] (Figure 1). SIMAP quantifies oil trajectory, concentrations of various oil hydrocarbon components (hydrocarbon groups of similar physical-chemical properties) in oil droplet and dissolved phases in the water column, areas swept by floating oil of varying mass concentrations and thicknesses, shorelines oiled to varying degrees, and amount of oil settling to sediments.

Processes simulated by SIMAP (Figure 2) include spreading (gravitational and by shearing), evaporation of six volatile oil components from surface oil, transport on the surface and in the water column, randomized dispersion from small-scale motions (mixing), emulsification, entrainment of oil as droplets into the water (natural and facilitated by dispersant application), dissolution of three soluble and semi-soluble hydrocarbon components, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended particulate matter (SPM), adsorption of semi-soluble hydrocarbons to SPM, sedimentation, stranding on shorelines, and degradation (based on component-specific first-order biodegradation and photo-oxidation rates).

The model tracks soluble and semi-soluble components of the oil (i.e., monoaromatics (MAHs, such as benzene, toluene, ethylbenzene and xylene, BTEX) and polycyclic aromatic hydrocarbons (PAHs), as well as insoluble volatile aliphatic hydrocarbons, separately from high-molecular weight non-volatile and insoluble components of the oil. Sublots of the discharged oil are represented by Lagrangian Elements ("spillets"), each characterized by location, state (floating, droplet in water, on the bottom sediments, ashore), mass of the various hydrocarbon components, water content, thickness, diameter, density, viscosity, and associated SPM mass. A separate set of Lagrangian Elements is used to track mass and movements of the dissolved hydrocarbons.

The assumptions and algorithms included in SIMAP have been developed over three decades (involving several in-depth peer reviews)[2]. French McCay et al. (2018a, c) describe analyses and modeling of the DWH spill undertaken to validate the SIMAP model. In addition to the DWH spill, the authors have validated the model with data from more than 20 large surface oil spills, including the *Exxon Valdez*[3], as well as test spills designed to verify the model[4].

[1] French McCay 2003, 2004; French McCay et al. 2015, 2018b
[2] Assumptions and algorithms of SIMAP are fully documented in French et al. 1996, French McCay 2002, 2003, 2004 and French McCay et al. 2015, 2018b.
[3] French and Rines 1997; French McCay 2003, 2004; French McCay and Rowe 2004
[4] French et al. 1997

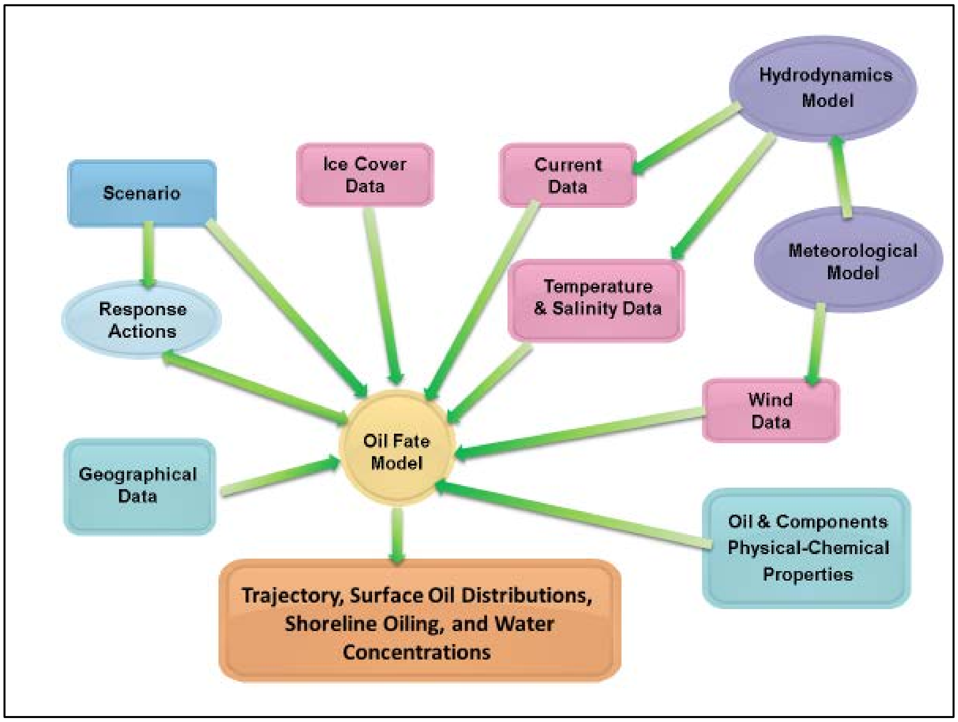

Figure 1: SIMAP 3-D Flow Diagram Oil Trajectory and Fate Model Components and Inputs

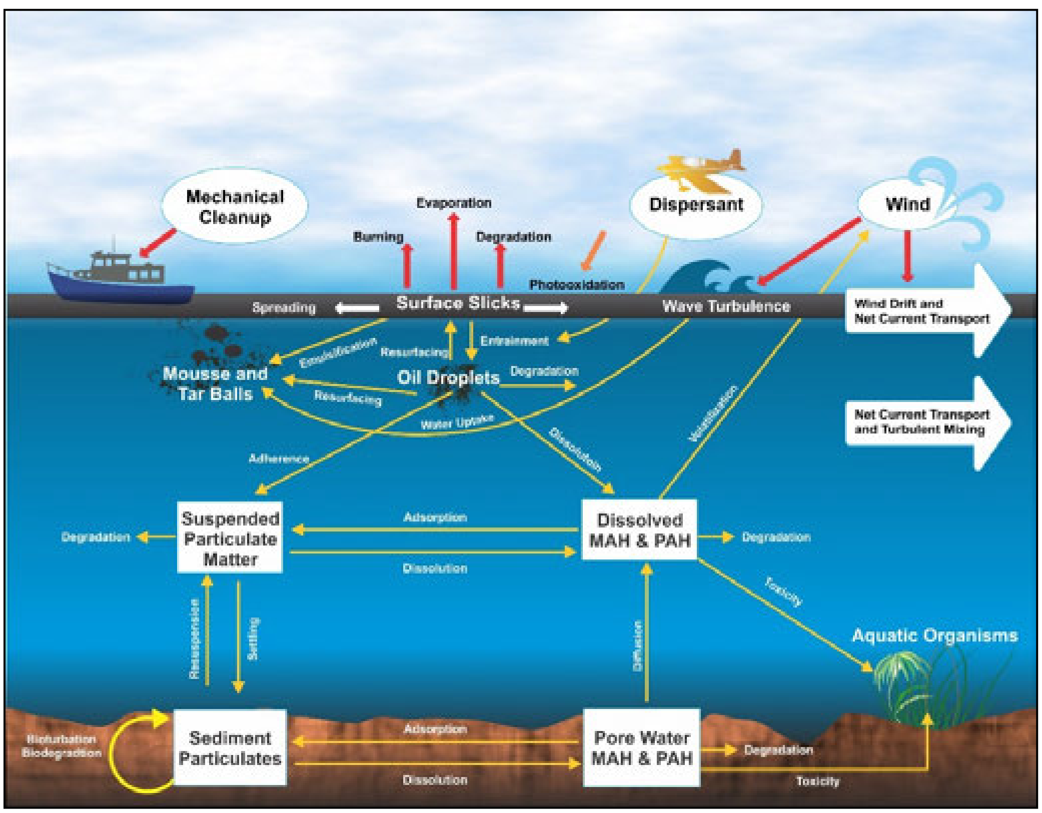

Figure 2: Open Water Oil Fate and Behavior Processed Simulated SIMAP

Modeling Approach

This report section summarizes the modeling approach used, including a description of the study area, scenario matrix and thresholds of concern.

Study Area and Resources of Interest

Figure 3 shows the Hudson River study area and the spill sites for the scenarios. Figure 4 and Figure 5 show habitats and other resources of interest in the Hudson River study area, as well as socioeconomic features of interest.

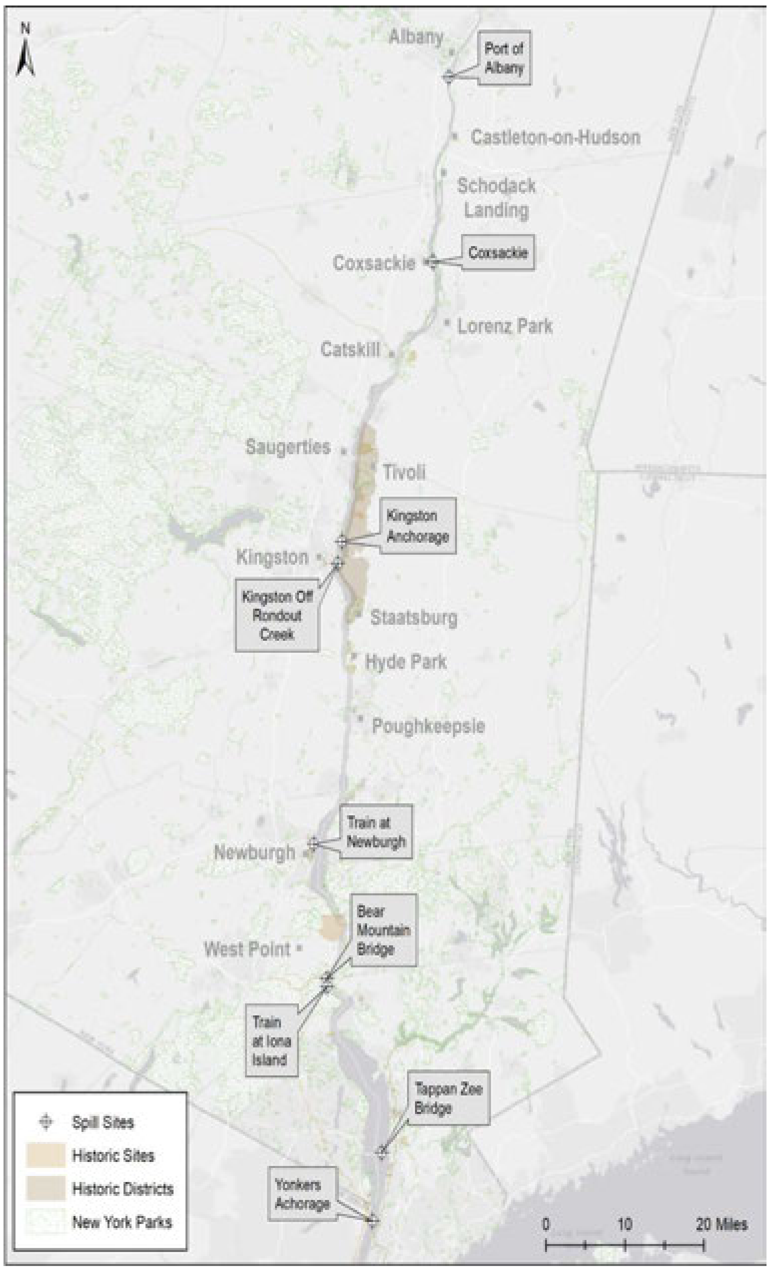

Figure 3: Place Name and Water Body Map with Spill Sites

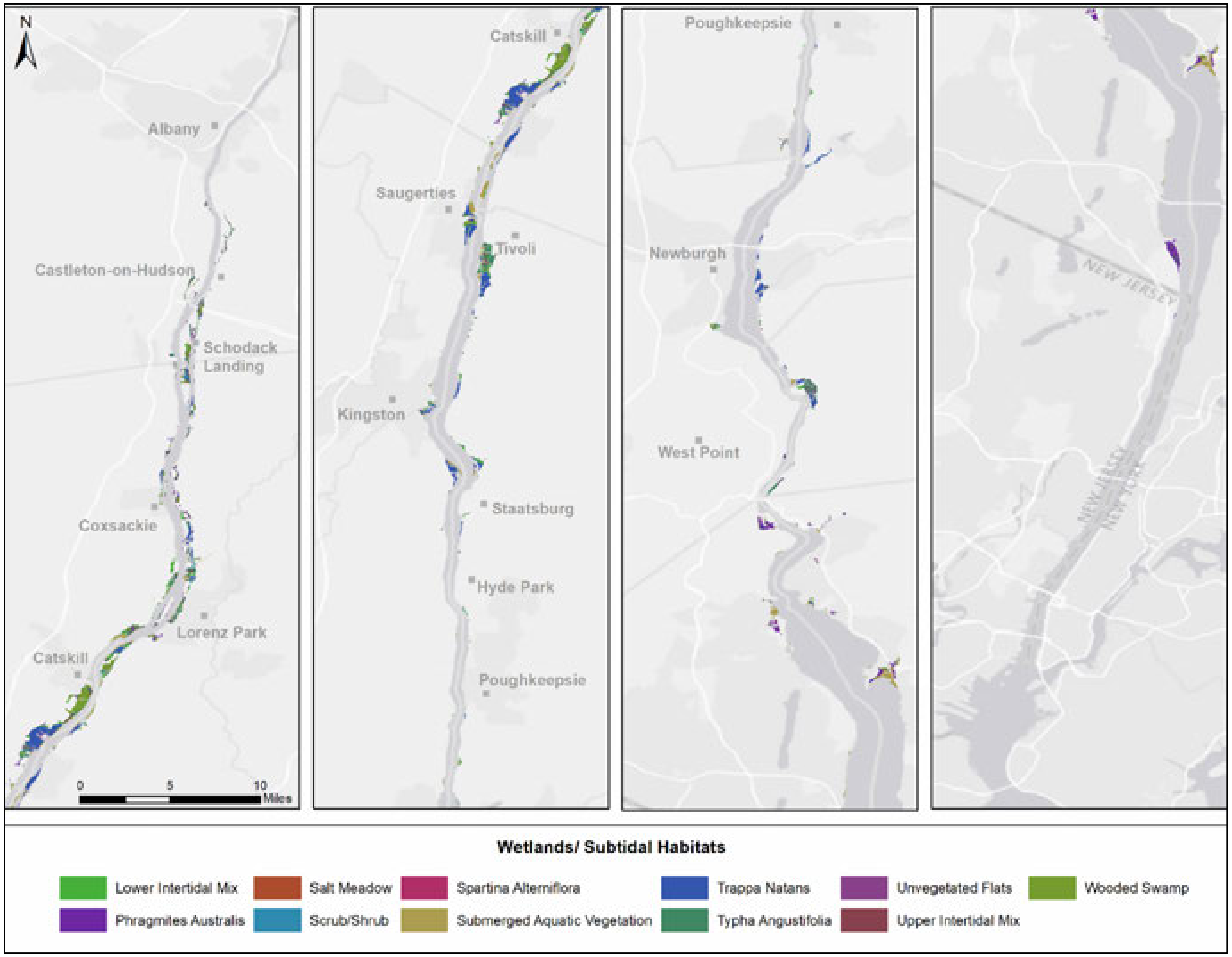

Figure 4: Maps of Hudson River Wetland Habitats (Albany to Upper New York Harbor)

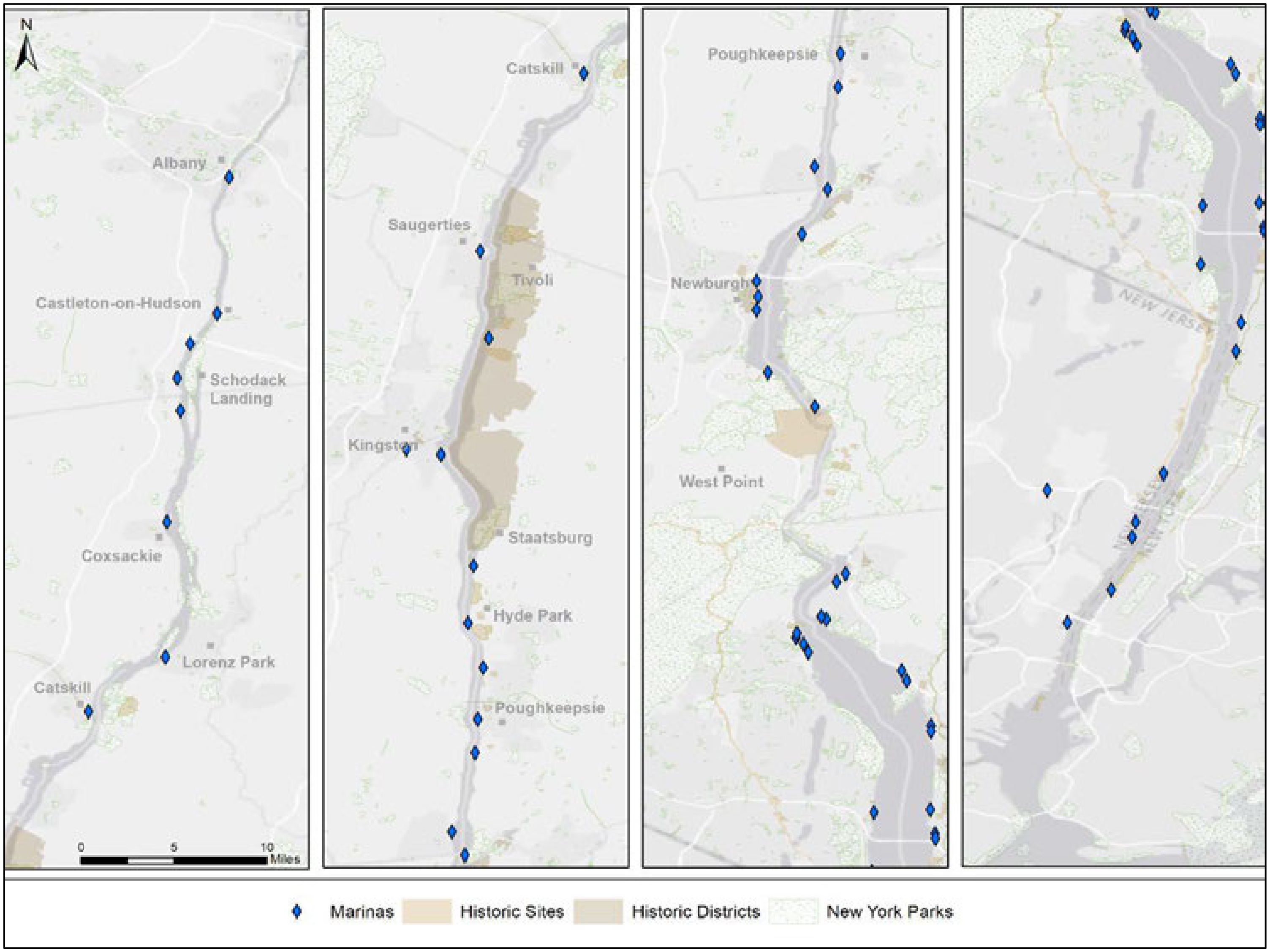

Figure 5: Maps of Hudson River Marinas, Historic Sites/Districts, and Parks (Albany to Entrance to New York Harbor)

Maps of habitats and shoreline types along the Hudson River have been compiled by the NYSDEC Hudson River Estuary Program in collaboration with numerous partners, including the Benthic Mapping Project that has mapped the physical environment and the Submerged Aquatic Vegetation Mapping Project that has mapped the extent of submerged aquatic vegetation. Data in the format used by Geographical Information Systems (GIS, i.e., "shape files") were downloaded from the New York State GIS data portal[5]. Parks, historic sites and districts and marinas were mapped based on composited data obtained from the New York State GIS data portal[6].

Scenario Matrix and Environmental Conditions

For spills in the Hudson River, river flow and ice conditions will be the dominant factors determining oil transport. Because winds are relatively light most of the time, winds will generally be of lesser importance to floating oil transport. However, high winds will entrain (mix) oil into the water column, where it will be carried by the tide and down river. Three hydraulic conditions were used to typify river conditions in various seasons of the year: high river flow (spring), low river flow (summer-fall), and medium flow with ice cover (winter). For each season, spills were assumed to begin at local high tide (initially moving down-river with the ebbing tide) and at local low tide (initially moving up-river with the flooding tide). Thus, six model runs were performed for each spill scenario. For three of the spring (high river flow) scenarios, the model runs were performed assuming storm conditions.

Table 1 describes the 12 spill scenarios modeled. For each scenario, model runs were performed for spills assumed to occur in each of the 3 seasons and 2 stages of the tide.

The results of the model simulations include: a time history of oil weathering and fate over the duration of the spill (mass balance), expressed as the percentage of spilled oil on the water surface, on the shoreline, evaporated, entrained in the water column, and degraded; tabular exposure information; and maps of individual trajectories showing mass of floating surface oil, water column concentrations, sediment contamination and shoreline oiling. Results from SIMAP are available in ArcGIS™ format. All model outputs can be overlaid on shoreline and habitat maps, as well as GIS data layers mapping resources of interest.

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[5] Shoreline and sediment types: http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1136; tidal wetlands: https://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1210; submerged aquatic vegetation: https://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1350

[6] https://gis.ny.gov/gisdata/inventories/index.cfm?AlphaIndex=N

Table 1: Modeled Oil Spill Scenarios in the Hudson River						
Location	**Latitude Longitude**	**Source**	**Volume**	**Oil Type**	**Flow**	**Tide Stages**
Port of Albany	42.61673 -73.76020	Tanker loading accident at dock	155,000 bbl	Bakken Crude	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
Coxsackie	42.35119 -73.78982	Grounding or collision of tanker	25,000 bbl	Home Heating Oil	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
Kingston Anchorage	41.93017 -73.95700	Articulated tank barge (ATB) in collision or allision with another vessel at the anchorage	150,000 bbl	Home Heating Oil	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
				Diluted Bitumen	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
ACP Off Rondout	41.91833 -73.96333	Tank barge spill	75,421 bbl	Bakken Crude	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
		Cargo vessel spill	14,000 bbl	Heavy Fuel Oil	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
Newburgh Waterfront	41.51523 -74.00694 41.50517 -74.00572	CBR train spill	11,000 bbl	Bakken Crude	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
Bear Mountain Bridge	41.32198 -73.98311	Tanker collision with vessel near bridge	2,500 bbl	Home Heating Oil	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
Iona Island	41.31363 -73.98598 41.30628 -73.98100	CBR train spill	11,000 bbl	Bakken Crude	Spring (high river flow) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
Tappan Zee	41.07195 -73.88333	Tanker allision with bridge abutment	2,500 bbl	Home Heating Oil	Spring (high river flow in storm) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
Tappan Zee	41.07195 -73.88333	Tanker allision with bridge abutment	50 bbl	Heavy Fuel Oil	Spring (high river flow in storm) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide
Yonkers Anchorage	40.97341 -73.90003	Collision/allision with tanker at anchorage	155,000 bbl	Gasoline	Spring (high river flow in storm) Summer (medium river flow) Winter (medium river flow w/ice)	At high and at low tide

Potential Environmental Impacts of Spilled Oil

Potential and documented impacts of oil in aquatic environments have been reviewed by the National Research Council,[7] among other studies. The following is a brief summary. A wide variety of natural resources and biota (e.g., water, shorelines, sediments, habitats such as wetlands, fish, shellfish and other invertebrates, reptiles, mammals, and birds) may be exposed to oil through various pathways, including direct exposure with oil and contact with contaminated water, air, vegetation, and sediments. Oil affects organisms and habitats in the environment by adherence and coating, by toxicity upon uptake via skin, inhalation or ingestion, and by behavioral changes affecting exposure. Floating oil can move through habitats and intercept surface-dwelling organisms such as birds, mammals, reptiles and vegetation, whereupon adverse effects may result from adherence and coating. Oil and chemical components may be mixed into or dissolve in the water column, exposing fish, invertebrates, and aquatic plants to hydrocarbons. The air above floating oil may experience elevated concentrations of volatile compounds that evaporate from the surface oil. Small droplets (aerosols) containing these chemicals and reaction products may also form in the air. Air-breathing animals are exposed to both evaporated compounds and aerosols. Animals may be exposed to oil hydrocarbons by drinking or ingesting contaminated water, food, and sediments; and this may be a pathway of exposure to their predators.

Oil is comprised of thousands of different chemicals, many of which are known to be toxic to exposed biota. Some of the more toxic compounds in oil are the aromatic hydrocarbons, i.e., BTEX and PAHs. PAHs from oil often remain long enough in the environment to cause effects on aquatic biota and their consumers. Aquatic biota (fish, invertebrates and aquatic plants) may suffer acute effects and direct impacts (lethal and sublethal) in the short-term; sublethal effects of chronic contamination; behavioral changes resulting in reduced growth, survival or reproductive success; indirect effects via reduction in food supply, habitat, or other changes in the ecosystem; impacts of spill response activities; and population level impacts caused by mortality and sublethal effects. When birds, mammals and reptiles are directly exposed to or ingest food contaminated with oil, they may suffer from a variety of adverse health effects, including hemolytic anemia, liver dysfunction, kidney damage, hypothermia, weight loss, lethargy, abnormal feces, moribundity (near death), and death. External oiling of birds causes feather damage and reduced flight performance. Oiled birds have demonstrated more erratic and less-efficient flying, shorter flight times, and higher energetic costs. Overall, disruption of organ physiology and function can have negative consequences for an animal’s fitness and survival.

Quantification of biological impacts of oil exposure should consider the degree and duration of exposure to oil and component hydrocarbons (i.e., dose), accounting for the movements and amounts of both oil and biota.[8] Such an impact analysis is beyond the scope of this study. Rather the approach for this risk assessment was to evaluate areas of water surface, lengths of shoreline and volumes of water exposed at some time after the spill to concentrations above thresholds of concern for potential effects on biota. This provides quantitative measures of areas/volumes where there is the potential for adverse impacts. Thus, it is a conservative analysis of ecological risk, whereby the objective is to be protective of the resources.

[7] NRC 1985; NRC 2002.
[8] French McCay 2003; French McCay 2009.

Thresholds of Concern

A review and analysis was performed[9] to develop defensible thresholds for potential effects that have been used in oil spill impact analyses and risk assessments. The review focused on literature that provided quantitative information from which thresholds were developed to apply to oil spill modeling results. The following is based on that review and related information.

Table 2 gives approximate thickness and mass loading ranges for surface oil of varying appearance. Floating oil mass loading is expressed as g/m^2, where 1 g/m^2 corresponds to an oil layer approximately 1 micron (µm) thick on average. Dull brown sheens are about 1 µm thick. Rainbow sheen is about 0.2-0.8 g/m^2 (0.2-0.8 µm thick) and silver sheens are 0.05-0.8 g/m^2 (0.05-0.8 µm thick)[10]. Crude and heavy fuel oil that is greater than 1 mm thick appears as black oil. Light fuels and diesel that are greater than 1 mm thick are not black in appearance, but appear brown or reddish. Floating oil will not always have these appearances, however, as weathered oil would be in the form of scattered floating tar balls and tar mats where currents converge. Guidance, based on some commonly used thresholds, is provided for surface oil thickness (Table 3), shoreline oil thickness (Table 4), and for subsurface oil concentration (Table 5).

The thresholds for potential ecological effects are conservative levels (concentrations) below which adverse effects are not expected to result. It should be noted that not all biota in the area or volume exposed above the threshold would be adversely affected. Biological impacts resulting from the oil exposure would vary, depending upon: the pathways of exposure such as direct contact, ingestion or inhalation; the degree of actual contact with biota, duration and magnitude of exposure, sensitivity of the organisms (life stage, physical health), etc. Similarly, the socioeconomic thresholds are conservatively low levels above which some effects on human activities, such as fishery closures or cleanup response, might occur. Further details are provided in Table 3 through Table 5.

Table 2: Oil Thickness/Equivalent Mass Loading and Appearance on Water Surface[11]

Minimum (µm or g/m^2)	Maximum (µm or g/m^2)	Appearance
0.01	**0.1**	Colorless and silver sheen
0.1	**1**	Rainbow sheen
1	**10**	Dull brown sheen
10	**100**	Dark brown or metallic
100	**1,000**	Translucent to opaque (black)
1,000	**10,000**	Opaque (black) or emulsified (mousse) oil
10,000	**100,000**	Emulsified oil (mousse)

[9] French McCay 2016.
[10] NRC 1985.
[11] Based on: NRC 1985; Allen and Dale 1997. µm = oil thickness; g/m^2 = equivalent mass loading.

Table 3: Oil Thresholds for Surface Oil Contamination

Threshold		Rationale	Visual Appearance	References
Mass/Unit Area	**Thickness**			
0.01 g/m²	**0.01 µm, 0.00001 mm**	**Socioeconomic:** A conservative threshold used in several risk assessments to determine where socioeconomic resources and uses might be affected (e.g., fishing may be prohibited when sheens are visible on the sea surface). Socio-economic resources and uses that would be affected by floating oil include commercial, recreational and subsistence fishing; aquaculture; recreational boating, port concerns such as shipping, recreation, transportation, and military uses; energy production (e.g., power plant intakes, wind farms, offshore oil and gas); water supply intakes; and aesthetics.	Fresh oil at this thickness corresponds to sheen, scattered tarballs, or widely scattered patches of thicker oil.	French McCay et al. 2011; French McCay et al. 2012; French McCay 2016
1.0 g/m2	**1.0 µm, 0.001 mm**	**Ecological:** A conservative threshold for consideration of sublethal effects on birds, marine mammals, and sea turtles from floating oil.	Fresh oil at this thickness corresponds to a slick being a dark brown or metallic sheen.	French McCay 2016
8.0 g/m²	**8.0 µm, 0.008 mm**	**Response:** Minimum thickness at which response equipment can skim/remove oil from the surface, surface dispersants are effectively applied, or oil can be boomed/collected for in situ burning.	Fresh oil at this thickness corresponds to a slick being a dark brown or metallic sheen.	NOAA 2010
10 g/m²	**10 µm, 0.01 mm**	**Ecological:** Mortality of birds on water has been observed at and above this threshold. Sublethal effects on marine mammals, sea turtles, and floating *Sargassum* communities are of concern.	Fresh oil at this thickness corresponds to a slick being a dark brown or metallic sheen.	French et al. 1996; French McCay 2009 (based on review of Engelhardt 1983, Clark 1984, Geraci and St. Aubin 1988, and Jenssen 1994 on oil effects on aquatic birds and marine mammals); French McCay et al. 2011; French McCay et al. 2012; French McCay 2016

Table 3: Oil Thresholds for Surface Oil Contamination

Threshold		Rationale	Visual Appearance	References
Mass/Unit Area	Thickness			
100 g/m^2	**100 µm, 0.1 mm**	**Ecological:** Risk of mortality for birds on water, marine mammals, sea turtles, and floating *Sargassum* communities.	May appear as black opaque oil.	French McCay 2016

Table 4: Oil Thresholds for Shoreline Oil Contamination

Threshold		Rationale	Visual Appearance	References
Mass/Unit Area	Thickness			
1.0 g/m^2	**1.0 µm, 0.001 mm**	**Socioeconomic/Response:** A conservative threshold used in several risk assessments. This is a threshold for potential effects on socio-economic resource uses, as this amount of oil may trigger the need for shoreline cleanup on amenity beaches, and affect shoreline recreation and tourism. Socio-economic resources and uses that would be affected by shoreline oil include recreational beach and shore use, wildlife viewing, nearshore recreational boating, tribal lands and subsistence uses, public parks and protected areas, tourism, coastal dependent businesses, and aesthetics.	May appear as a coat, patches or scattered tar balls, stain	French-McCay et al. 2011; French McCay et al. 2012; French McCay 2016
10 g/m^2	**10 µm, 0.01 mm**	**Ecological:** A conservative screening threshold used for potential ecological effects on shoreline fauna. Assumed as a sublethal effects threshold for birds on the shoreline.	May appear as dark brown coat or opaque/black oil.	French et al. 1996; French McCay 2009; French McCay 2016
100 g/m^2	**100 µm, 0.1 mm**	**Ecological:** This is a screening threshold for potential ecological effects on shoreline flora and fauna, based upon a synthesis of the literature showing that shoreline life has been affected by this degree of oiling. Sublethal effects on epifaunal intertidal invertebrates on hard substrates and on sediments have been observed where oiling exceeds this threshold.	May appear as black opaque oil.	French et al. 1996; French McCay 2009; French McCay et al. 2011; French McCay et al. 2012; French McCay 2016

Table 4: Oil Thresholds for Shoreline Oil Contamination				
Threshold		Rationale	Visual Appearance	References
Mass/Unit Area	Thickness			
200 g/m^2	**200 µm, 0.2 mm**	**Ecological:** A threshold for risk assessments considering potential effects on intertidal or subtidal infaunal invertebrates (living in the sediments). Threshold for oil penetration initially assumed 1 cm deep into the sediment.	Black opaque oil	French McCay 2016
1,000 g/m^2	**1,000 µm, 1 mm**	**Ecological:** Sublethal effects threshold for wetland vegetation (marsh or mangrove).	Black opaque oil or mousse	French McCay 2016
5,000 g/m^2	**5,000 µm, 5 mm**	**Ecological:** Lethal effects threshold for wetland vegetation (marsh or mangrove).	Black opaque oil or mousse	French McCay 2016
>10,000 g/m^2	**>10,000 µm, 10 mm, >1 cm**	**Response:** Shoreline Cleanup and Assessment Technique (SCAT) descriptor for pooled or thick oil (PO or TO).	Fresh oil or mousse	NOAA 2013; Owens and Sergy 2000
>1,000 g/m^2 to ≤10,000 g/m^2	**>1,000 µm to ≤10,000 µm, >1 mm to ≤10 mm, >0.1 cm to ≤1 cm**	**Response:** SCAT descriptor for cover (CV).	Oil or mousse on any surface	NOAA 2013; Owens and Sergy 2000
>100 g/m^2 to ≤1000 g/m^2	**>100 µm to ≤1000 µm, >0.1 mm to ≤1 mm, >0.01 cm to ≤0.1 cm**	**Response:** SCAT descriptor for coat (CT).	Visible oil that can be scratched off with fingernail on coarse sediment or bedrock	NOAA 2013; Owens and Sergy 2000
≤100 g/m^2	**≤100 µm, ≤0.1 mm, ≤0.01 cm**	**Response:** SCAT descriptor for stain (ST).	Visible oil which cannot be easily scraped off coarse sediments or bedrock with fingernail	NOAA 2013; Owens and Sergy 2000

Table 5: Oil Water Column Concentration Thresholds			
Threshold Type	**Threshold (Concentration)**	**Rationale**	**References**
In-Water Concentration	1.0 ppb of dissolved PAHs or 1 µg/L of dissolved PAHs, (for fresh unweathered crude oil types this roughly corresponds to 100 µg/L of Total Hydrocarbons (THC) in the water column, as the soluble PAHs are approximately 1% of the total mass)	**Ecological/Socio-economic**: Water column effects for both ecological and socioeconomic (e.g., seafood) resources could potentially occur at concentrations exceeding 1 ppb. A threshold of 1 ppb is typically used as a screening threshold for potential effects on sensitive organisms and early life stages (e.g., ichthyoplankton). This would be a conservative screening threshold for most adult and juvenile pelagic and demersal fish and invertebrates. Exposure concentration below which no significant ecological effects are expected for sensitive marine resources, based on S.L. Ross 2011 modeling for Old Harry in Gulf of St. Lawrence. This value was found to be a conservative threshold for early contact on herring larvae.	Trudel 1989; French-McCay 2004; French McCay 2002; French McCay et al. 2012; French McCay 2016
	10 ppb of dissolved PAHs or 10 µg/L of dissolved PAHs	**Ecological**: Threshold above which there is a potential for sublethal or lethal effects on water column biota generally (adult, juvenile fish and invertebrates).	French McCay 2016

Model Inputs

This report section provides a description of the various inputs to the model, including habitat mapping and bathymetry (water depths); hydrodynamics (currents), winds (speed and direction), ice cover, water temperature and salinity, and properties of the modeled oil types.

Habitats and Depth

For geographical reference, SIMAP uses a rectilinear grid to designate the location of the shoreline, the water depth, and the shore or habitat type. The grid is generated from a digital coastline using the ESRI Arc/Info compatible Spatial Analyst program. The cells are then coded for depth and habitat type. The digital shoreline, shore type, and habitat mapping data were obtained from the Lamont-Doherty Earth Observatory of Columbia University and the New York State Department of Environmental Conservation (NYSDEC) Hudson River Estuary Program.[12]

Depth data were obtained from hydrographic survey data supplied as a 30-meter grid from the NYSDEC Hudson River Estuary Program. Hydrographic survey data were based on large numbers of individual depth soundings. Data sources for the habitat and depth grid (Figure 6 and Figure 7) are summarized in Table 6.

Table 6: Data Sources for Habitat and Depth Grids

Layer Name	Data Source	Publication Date	Download/ Metadata Link	Date Downloaded
Hudson River Shoreline	Lamont-Doherthy Earth Observatory of Columbia University	2004	http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1136	August 21, 2017
Hudson River Shoreline Type	NYSDEC Hudson River Estuary Program	2008		August 28, 2017
Hudson River Sediment Type	Lamont-Doherthy Earth Observatory of Columbia University	2006		August 28, 2017
Submerged Aquatic Vegetation	NYSDEC Hudson River Estuary Program	2014 (Revised, July 2017)	https://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1350	August 28, 2017
Tidal Wetlands	Cornell Institute for Resource Information Sciences (Cornell IRIS)	2011 (Mapped from 2007 aerial imagery, includes SAV layer from 2007)	https://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1210	August 29, 2017
Hudson River Bathymetry 30m Grid	NYSDEC Hudson River Estuary Program	2008	http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1136	August 28, 2017

[12] Habitats were coded as described in French McCay 2009.

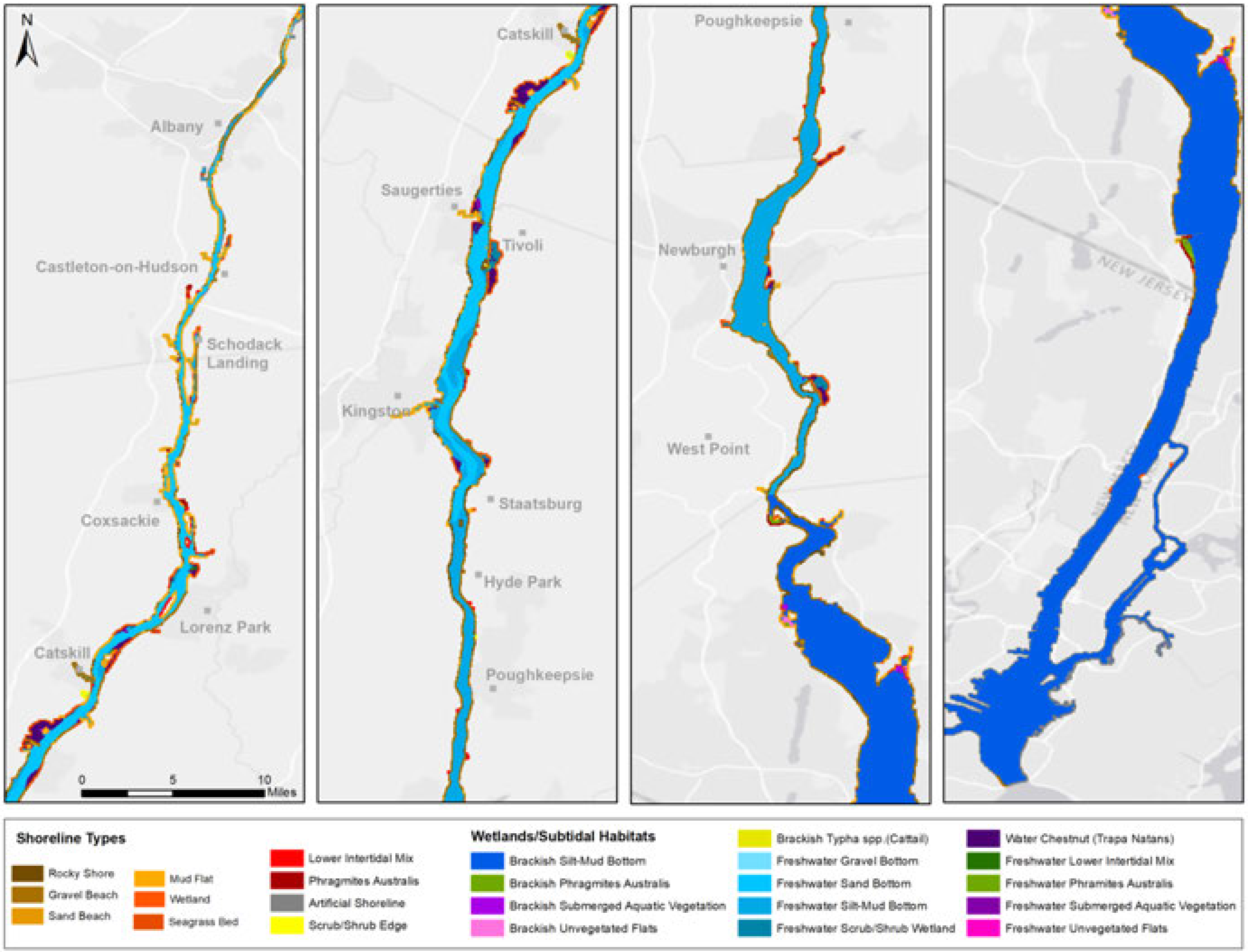

Figure 6: Habitat Grid

Figure 7: Depth Grid

Hydrodynamics

Currents have significant influence on the oil trajectory and fate, and are critical data inputs. Hydrodynamic models driven by winds, tides, freshwater inflows and ocean boundary forcing provide needed current data. The resulting currents are input to the fates and exposure models from a current file prepared for this purpose.

Current data was generated using RPS's boundary-fitted coordinate hydrodynamic model (BFHYDRO), which produces applicable hydrodynamic data sets suitable for use in oil spill modeling. The boundary-fitted grid is a mesh of quadrilateral cells of varying size and included angles, which is capable of handling variable geometry and flow regimes. The boundary fitted coordinate system in BFHYDRO uses general curvilinear coordinates to map the model grid to the shoreline of the water body being studied. It also allows enormous versatility in grid sizing so that many of the smaller features may be resolved, along with the larger, without being penalized by an excessive grid size (number of cells). In addition, a sigma stretching system is used in the vertical to map the free surface and bottom onto coordinate surfaces to resolve bathymetric variations. The model grid is developed to capture all important features at the appropriate resolution and the grid is assigned depths based on interpolation of available soundings.

Known physical conditions are input to the model grid at the edges, termed "open boundaries". These inputs are described as "forcing factors". The model forcing may include tides (i.e., water height, available from tidal height data), river flows, and surface winds. Salinity driven (i.e., density driven) flows, were not considered for the present analysis. Forcing factors due to wind stress on the water surface were included in the wind drift calculation in the oil fates model. The local surface wind drift was assumed 3.5% of wind speed and downwind, typical for inland waters and rivers. For this work, model forcing included tides and river flow.

For this study, the model grid and forcing was based on a previous model grid and application that had been validated[13], though the grid was modified to incorporate higher resolution in the study area and to incorporate the tributary flow from some of the minor tributaries that were local to the area of interest in the oil spill simulations. The model grid for this application is as shown in Figure 8. The locations of the various tidal forcing and river forcing are shown in this figure. Tidal forcing was applied at the open boundary in the Ambrose Channel and at Willets Point (See Figure 8), with values consistent with the previously validated study (presented in Table 7).

Forcing is accomplished by defining the harmonic characteristics of amplitude and phase of each constituent. There are many tidal constituents though the majority of the energy is produced by a limited number of semi-diurnal (twice daily) and diurnal (once daily) constituents. In this area, tides and tidal currents are predominately semi-diurnal, although the diurnal contributions modulate the total amplitude of the tide at any given time. The semi-diurnal nature causes two high tides and two low tides each day, meaning the water rises and falls in a periodic nature twice daily. This causes the currents to flow in and out twice daily, meaning the current magnitude and direction changes as a function of time throughout any given day. Further the tidal range varies from day to day and the tide range varies for the two tides on any given day. Most of the tidal characteristics are captured in a two-week period which includes spring

[13] Sankaranarayanan 2005.

(largest tide range) and neap (smallest tidal range) tides. The variation in tidal amplitude causes variation in the peak tidal speeds.

Table 7: Summary of Tidal Forcing

Constituent	Ambrose Channel		Willets Point	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
M2	0.650	208.1	1.103	331.2
N2	0.156	193.8	0.224	312.1
S2	0.135	228.0	0.183	352.2
K1	0.103	100.8	0.099	117.8
O1	0.063	88.3	0.064	150.9

Freshwater river and tributary forcing was also included in the model application. The river flow contributes to the current based on the magnitude of river flow. The rivers included and associated monthly river flows are as summarized in Table 8. The values for the head of the river were derived based on values from the US Geological Survey (USGS[14]; monthly means for 1947-2010), while the remaining tributaries were based on the National Hydrological Dataset (NHD)[15], using monthly means for all available water years for each tributary.

[14] https://waterdata.usgs.gov/nwis/
[15] https://nhd.usgs.gov/

ID	Name	Source	Average River Flow (m^3/s)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Green Island	USGS	402.1	402.1	640.0	872.2	526.7	303.0	203.9	178.4	184.1	271.9	393.6	450.3
2	Raritan River	NHD	60.7	51.6	68.2	71.2	68.8	30.5	35.7	24.7	25.7	24.5	43.2	61.9
3	Passaic River	NHD	35.3	34.2	63.1	72.6	52.1	40.4	30.3	18.8	21.0	21.2	35.7	48.3
4	Hackensack River	NHD	12.0	11.9	15.0	13.7	8.6	6.2	5.1	4.4	4.5	3.6	6.5	11.3
5	Catskill Creek	NHD	10.5	8.0	22.0	46.1	28.1	16.9	7.8	6.1	6.1	9.7	16.3	16.2
6	Hannacrois Creek	NHD	2.1	2.1	5.4	8.0	4.6	3.0	1.5	1.1	1.1	2.3	3.1	2.6
7	Rondout Creek	NHD	58.9	62.5	95.1	96.2	97.0	57.3	34.4	19.5	24.0	38.9	57.0	62.6
8	Sawmill River	NHD	1.4	1.5	2.0	2.1	1.5	1.0	0.8	0.6	0.6	0.7	1.1	1.3
9	Kinderhook/Claverack Creek	NHD	13.3	9.5	29.5	59.4	33.7	19.3	8.9	7.9	8.7	13.7	19.7	21.1
10	Normans Kill	NHD	4.4	3.8	12.3	19.0	9.6	6.0	2.9	2.4	2.0	3.3	6.1	6.0
11	Wappinger Creek	NHD	10.9	11.5	19.4	17.0	12.2	7.3	4.8	3.0	3.2	5.2	7.1	11.0
12	Canopus Creek Mouth	NHD	1.3	2.1	3.7	1.9	1.2	0.8	0.4	0.3	0.5	1.2	1.2	1.3
13	Peekskill Hollow Creek	NHD	3.3	4.6	9.1	5.6	3.2	2.1	1.1	0.9	1.2	2.8	3.1	3.9
14	Croton River	NHD	13.9	14.8	22.9	24.2	16.0	9.1	4.7	3.4	4.9	7.2	9.3	14.1
15	Esopus Creek	NHD	14.0	14.3	23.1	33.8	21.5	12.1	5.6	2.8	3.8	6.1	10.8	14.8
16	Moordener Kill	NHD	1.4	1.6	2.7	2.5	1.6	0.7	0.4	0.4	0.3	0.8	1.1	1.4
17	Coxsackie Creek	NHD	1.1	1.2	3.5	3.3	1.8	1.2	0.6	0.5	0.5	0.8	1.4	1.3
18	Popolopen Creek	NHD	2.1	2.8	6.1	4.5	2.7	1.8	0.9	0.7	1.5	2.4	2.4	2.5
19	Dickey Brook	NHD	0.4	0.9	1.2	0.3	0.2	0.2	0.1	0.1	0.1	0.3	0.3	0.3
20	Roeliff Jansen Kill	NHD	7.4	5.9	17.8	29.0	16.2	9.7	4.7	4.0	4.3	8.0	10.0	10.8
21	Binnen Kill	NHD	0.03	0.02	0.4	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1
22	Mill Creek	NHD	0.5	0.6	1.6	0.9	0.6	0.4	0.2	0.2	0.2	0.4	0.5	0.5
23	Vloman Kill	NHD	1.0	1.2	3.6	3.0	1.6	1.1	0.6	0.5	0.5	0.5	1.1	1.2
24	Coeymans Creek	NHD	1.8	1.8	5.1	6.3	3.5	2.3	1.2	0.9	0.9	1.5	2.4	2.1
25	Moodna Creek	NHD	8.3	9.9	23.9	18.8	9.9	6.1	3.1	2.5	2.6	5.6	8.1	12.0
26	Doodletown Brook	NHD	0.3	0.6	1.0	0.4	0.3	0.2	0.1	0.1	0.2	0.4	0.3	0.3
27	Fishkill Creek	NHD	8.5	8.2	23.8	24.0	11.8	7.2	3.6	2.9	3.5	7.2	9.3	12.7

Table 8: Summary of Monthly Average River Flow Used as Modeling Forcing

Table 8: Summary of Monthly Average River Flow Used as Modeling Forcing														
ID	**Name**	**Source**	**Average River Flow (m^3/s)**											
			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
28	**Lattintown Creek**	NHD	1.2	1.6	3.8	2.3	1.5	1.0	0.5	0.4	0.5	1.2	1.2	1.3
29	**Cedar Brook Pond**	NHD	1.7	2.5	4.6	2.7	1.7	1.2	0.6	0.5	1.0	1.7	1.6	1.7
30	**Schodack Creek**	NHD	1.0	1.1	3.1	2.4	1.5	1.0	0.5	0.4	0.4	0.9	1.1	1.1

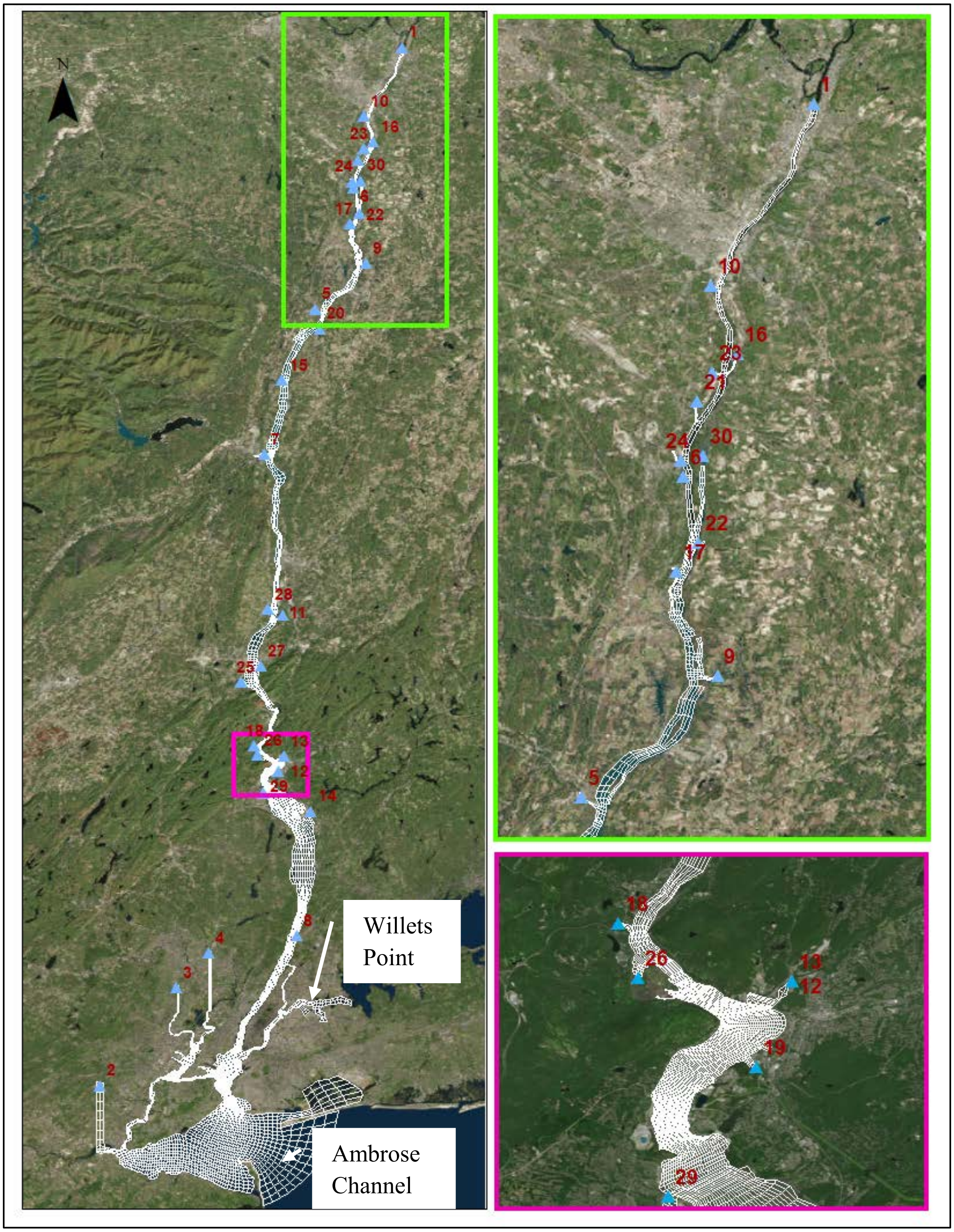

Figure 8: Model Grid and Forcing[16]

[16] Blue triangles denote location of river/tributary flow input; labeled number corresponds to description in Table 7.

The boundary fitted method uses a set of coupled quasi-linear elliptic transformation equations to map an arbitrary horizontal multi-connected region from physical space to a rectangular mesh structure in the transformed horizontal plane. The 3-dimensional conservation of mass and momentum equations, with approximations suitable for estuaries[17] that form the basis of the model, are then solved in this transformed space. In addition, an algebraic transformation is used in the vertical to map the free surface and bottom onto coordinate surfaces. The resulting equations are solved using an efficient semi-implicit finite difference algorithm. The model output contains spatially and temporally varying current fields that are easily utilized by RPS spill modeling systems such as OILMAP and SIMAP.

The hydrodynamic model's governing equations and validation are described in detail in several publications[18]. The hydrodynamic model (BFHYDRO) has been validated in numerous applications[19], including in, where the governing equations are described. Applications that have been validated include: for Mt. Hope Bay, Massachusetts[20]; for the Providence River, Rhode Island[21]; for San Francisco Bay[22]; for the Narragansett Bay system[23]; for Bay of Fundy[24]; the Savannah River[25], and Charleston Harbor, South Carolina[26].

The oil spill model then used a combination of the tidal currents and river flow currents to produce the total current. The resulting current varies in space and time, though current speeds typically peak less than 1 m/s within the majority of the study domain. Snapshots of speed contours of the M2 constituent at a time-step close to peak ebb and peak flood in New York Harbor are shown in Figure 9 and Figure 10, respectively. Due to the size of the domain, the currents may vary in direction throughout the domain at any given moment. The currents are relatively rectilinear and reverse in a shore-parallel orientation throughout the majority of the domain.

[17] Muin and Spaulding 1997a
[18] Spaulding 1984; Muin 1993; Muin and Spaulding 1997a; Huang and Spaulding 1995a, 1996; Spaulding et al. 1999a, and Sankaranarayanan and Spaulding 2003
[19] e.g., Spaulding et al. 1999a; Sankaranarayanan and Spaulding 2003
[20] Huang and Spaulding 1995b
[21] Muin and Spaulding 1997b
[22] Sankaranarayanan and French McCay 2003a
[23] Swanson et al. 1998, Spaulding et al. 1999b
[24] Sankaranarayanan and French McCay 2003b
[25] Mendelsohn et al. 1999
[26] Yassuda et al., 2000

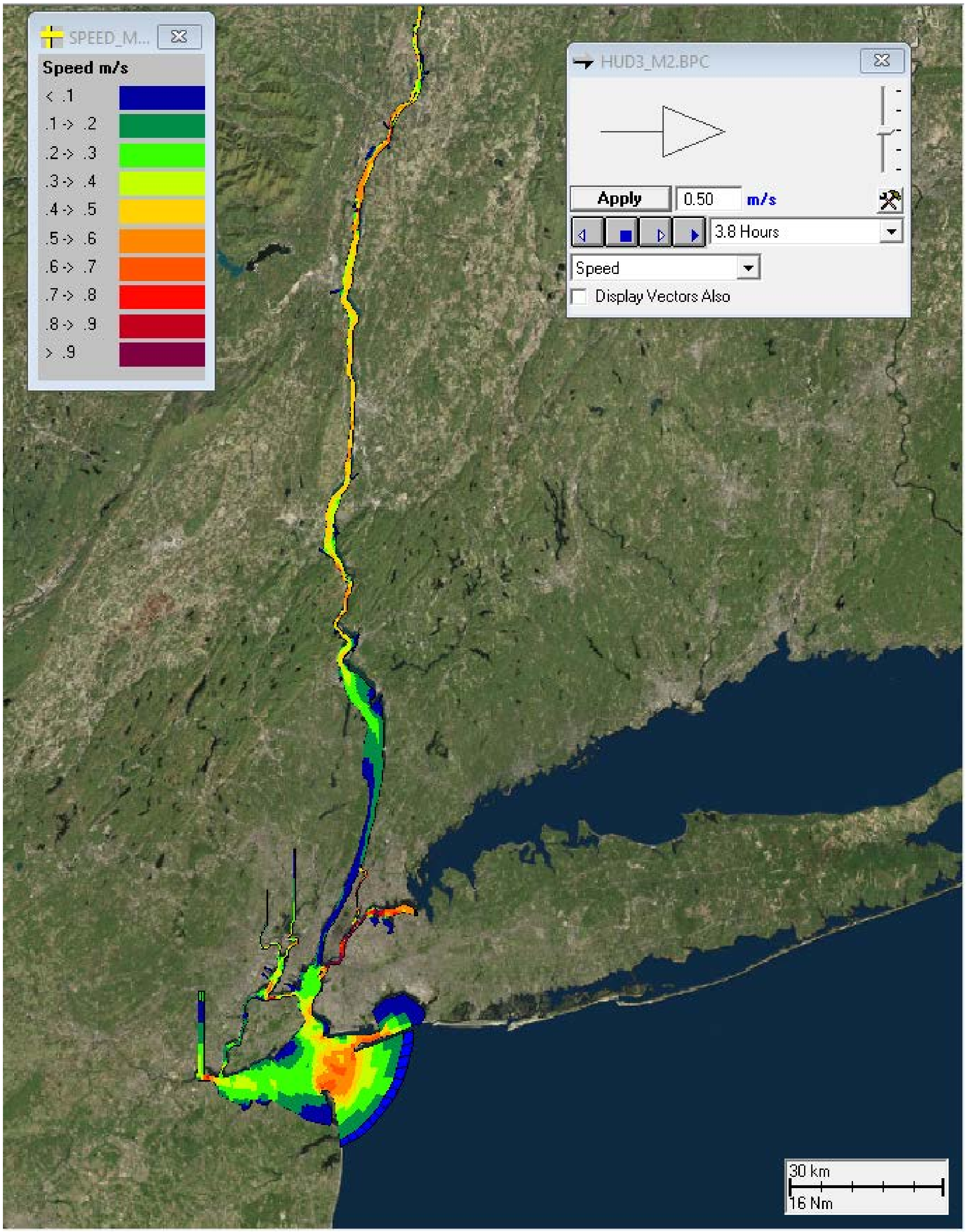

Figure 9: Example of M2 Speed Contours during Ebb Tide at New York Harbor

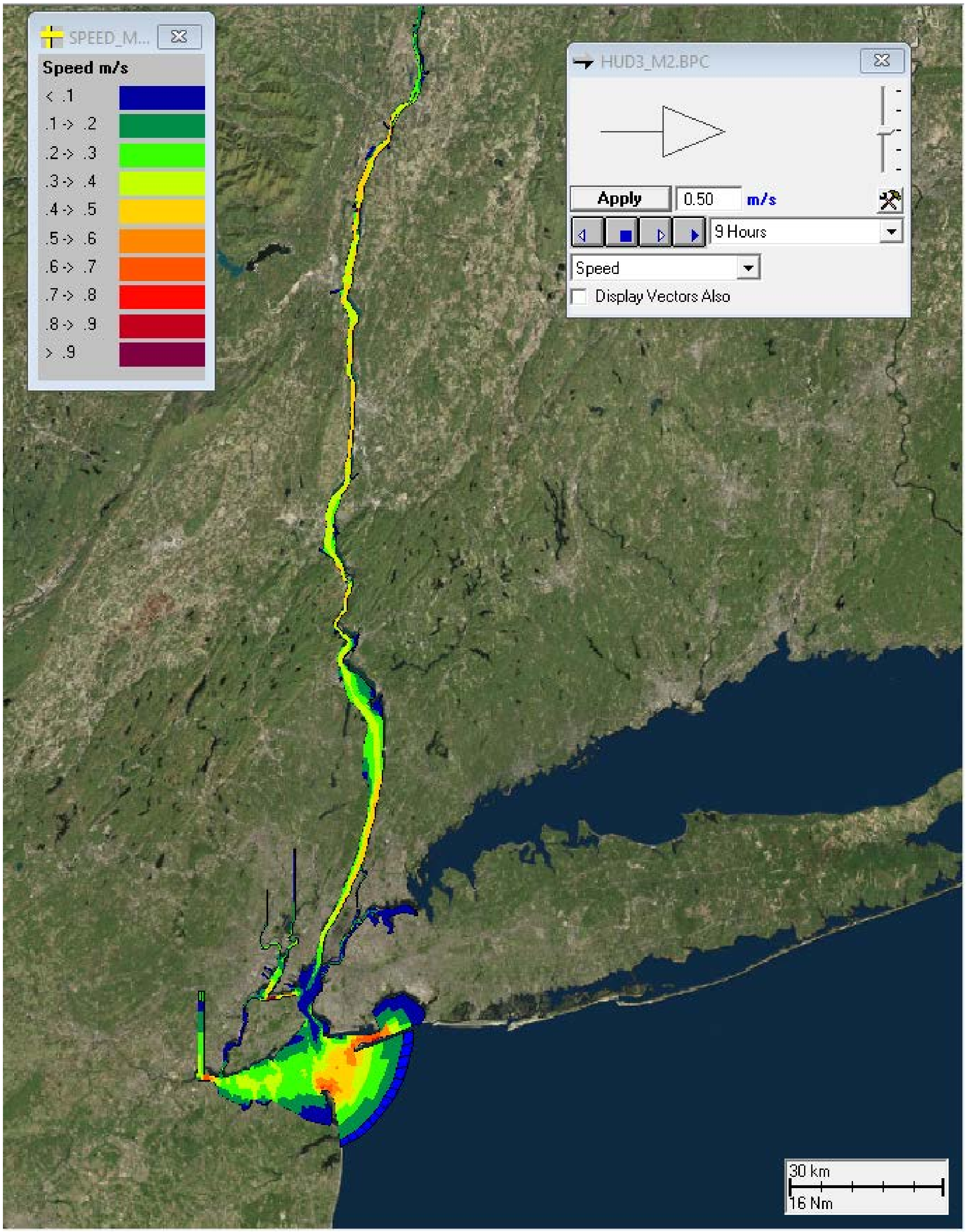

Figure 10: Example of M2 Speed Contours during Flood Tide at New York Harbor

Winds

A long-term wind data time series is used for model input. Hourly wind records from the Hudson River Environmental Conditions Observing System (HRECOS)[27] were obtained. The specific stations from which data were retrieved were Port of Albany, Schodack Island, Norrie Point and Piermont Pier. Table 9 provides a summary of the specific wind records used per scenario for each spill site location.

Table 9: HRECOS Wind Data Record Location Used for Each Spill Site Location

Spill Site Location	Wind Record Location
Port of Albany	Port of Albany
Coxsackie	Schodack Island
Kingston Flats South Anchorage	Norrie Point
Kingston Flats South Anchorage	Norrie Point
Kingston Rondout Creek	Norrie Point
Kingston Rondout Creek	Norrie Point
Newburgh Train	Norrie Point
Train tracks at Iona Island	Piermont Pier
Bear Mountain Bridge	Piermont Pier
Tappan Zee	Piermont Pier
Tappan Zee	Piermont Pier
Yonkers Anchorage Extension	Piermont Pier

Ice

Observed ice data statistics along the tidal Hudson River during the ice season (December to March) were compiled from the US Coast Guard[28] daily ice reports with geospatial data obtained from the Stevens Institute of Technology[29]. The analysis of ice data statistics indicated that, during the ice season (December to March), ice cover was 50% on average north of Bear Mountain Bridge and 20% on average south of Bear Mountain Bridge. These average ice cover amounts were assumed in all model runs for the winter season.

Temperature, Salinity and Suspended Particulate Matter

Average monthly temperature and salinity data were retrieved from the HRECOS[19] and Riverkeeper[30] and used as input to the model. Table 10 provides the temperature and salinity data for each spill site location and the HRECOS and Riverkeeper stations from which the data were obtained.

SPM data are also input to the oil spill modeling. Oil and dissolved hydrocarbons may adhere to SPM and then settle to the river bottom. In the Hudson River, oil settling could be considerable because of the high SPM loads in the river, particularly during storms due to runoff and under high flow conditions (e.g.,

[27] http://www.hrecos.org/index.php?option=com_content&view=article&id=143&Itemid=54
[28] Daily ice conditions and any special advisory notices concerning ice operations are available under Ice Operations in US Coast Guard Waterways Management page (http://homeport.uscg.mil/newyork).
[29] http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1136
[30] https://www.riverkeeper.org/water-quality/hudson-river/orange-putnam/

winter-spring). SPM concentration data were derived from published literature[31] and are summarized per river flow condition in Table 11.

Table 10: Average Temperature and Salinity Data Used as Input to Modeling

Spill Site Location	Average Temperature (°F)			Salinity (psu)	Data Source
	January	April	August		
Port of Albany	33	46	77	0	HRECOS Port of Albany
Coxsackie	32	46	77	0	HRECOS Schodack Island
Kingston Flats South Anchorage	32	48	75	0	HRECOS Norrie Point
Kingston Rondout Creek	32	48	75	0	HRECOS Norrie Point
Newburgh Train	32	43	81	0	Riverkeeper (Newburgh)
Train Tracks at Iona Island	34	45	81	1	Riverkeeper (West Pt, Peekskill)
Bear Mountain Bridge	34	45	81	1	Riverkeeper (West Pt, Peekskill)
Tappan Zee	35	50	81	4	HRECOS Piermont Pier
Tappan Zee	35	50	81	4	HRECOS Piermont Pier
Yonkers Anchorage Extension	35	50	81	4	HRECOS Piermont Pier

Table 11: Suspended Particulate Matter (SPM) Data Used as Input to Modeling

River Flow Condition	Month	SPM (g/L)
High Flow, Spring	April	300
Low Flow, Summer	August	100
Low Flow, Winter with Ice Cover	January	300

Oil Types

A total of five oil types were used in the oil spill modeling scenarios. These oils included the following:

- Bakken crude
- Home heating oil
- Diluted bitumen
- Heavy fuel oil
- Gasoline

Specific physical and chemical properties of each of the oil types modeled are provided in Appendix A.

[31] Geyer et al. 2000 and Geyer et al. 2001.

Overall Modeling Results

General Spilled Oil Behavior

All oils contain some fraction of light hydrocarbons that are volatile and readily evaporate. Some of the volatile hydrocarbons, mostly low molecular weight aromatic hydrocarbons (e.g., the MAHs, including BTEX, and the PAHs), are soluble and therefore to some extent dissolve into the water column. Dissolution is enhanced by wind-driven waves breaking over floating oil and entraining the oil into the water column in the form of small droplets. This process increases the surface area exposed to the water and enhances dissolution. Dissolved hydrocarbons are more readily utilized by microbes and therefore biodegradation is enhanced when more oil is dispersed under more turbulent environmental conditions as small droplets, and, as a consequence, more soluble hydrocarbons dissolve.

Figure 57 through Figure 128 in Appendix B show the mass balance of the spilled oil over time, that is the amount of oil floating on the water surface, volatilized (evaporated) to the atmosphere, in the water column, on shorelines, on the sediments and degraded over time. The mass balances for the hypothetical spills reflect these general processes as well as the composition and bulk properties of the oil. Evaporation is faster with higher temperature (i.e., in summer than other seasons) and with higher wind speed (typical of spring), while evaporation is slowed in winter by the low temperatures and partial ice cover that restricts spreading. Note that the spills from vessels are assumed to discharge from 1-2 m below the surface, so the initial condition is that the oil is entirely in the water column. In these cases, most of the oil surfaces immediately (by the next model time step). The floating oil is transported downstream and entrained into the water when and where there are high winds and waves. Oil in the water column dissolves and combines with SPM, with some of the oil-SPM settling to the sediments. Oil strands on shorelines when the local winds are onshore.

Oil Type

Potential spills of five oil types were modeled:

- Bakken crude
- Diluted bitumen
- Heavy fuel oil
- Home heating oil
- Gasoline

Bakken crude is a very light, low viscosity crude oil with about 73% of the oil mass being volatile. As such, much of the oil evaporates quickly and the remainder easily disperses into the water column. The residual hydrocarbons that do not evaporate or dissolve strand on shorelines or are carried to the sediments by interaction with sediments suspended in the water that subsequently settle. Figure 11 shows a typical mass balance for spilled Bakken crude. In the spring spill off Rondout Creek, 47% of the oil evaporated, 50% dispersed into the water column where it ultimately settled to the sediments or degraded, and the remaining 3% went ashore. Of the oil entrained in the water column 44% of it (22% of the spilled oil) entered New York Harbor, exiting the modeled domain.

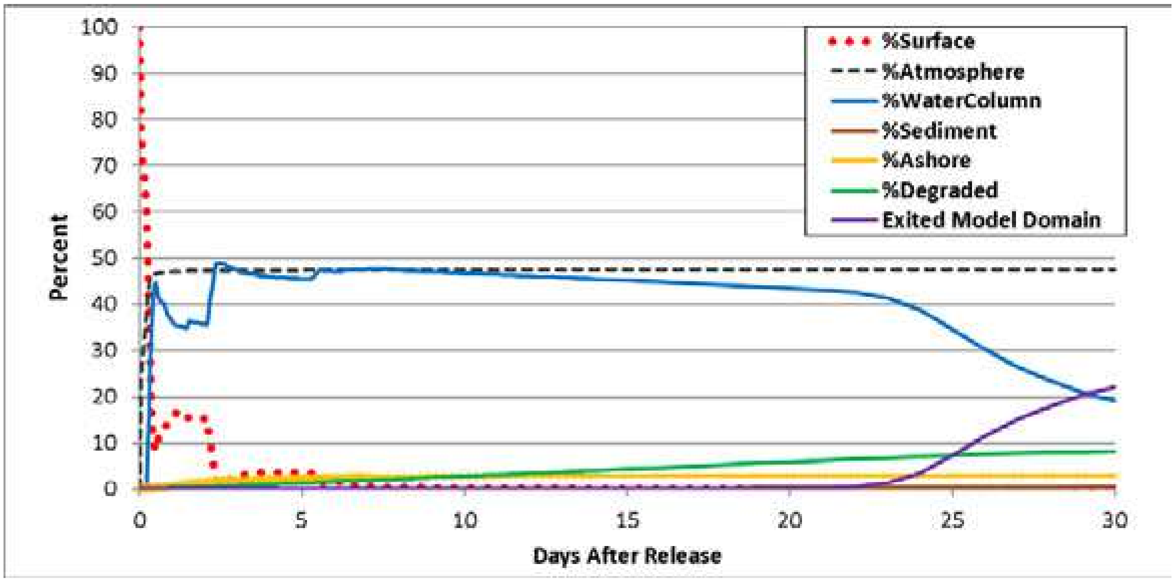

Figure 11: Percent Oil in Different Environmental Compartments over Time: Rondout Creek–75,421 bbl Bakken Crude–Spring–High Tide

Diluted bitumen (dilbit) is a mixture of a highly weathered heavy oil diluted with a hydrocarbon solvent (diluent) to make it flow and behave more like a liquid crude oil. The blend ratio may consist of 25 to 55% diluent by volume, depending on characteristics of the bitumen and diluent, pipeline specifications, operating conditions, and refinery requirements. The dilbit composition used for this modeling study contained about 40% volatile (light) hydrocarbons; the remainder being comprised of very recalcitrant compounds that do not dissolve or easily degrade. Thus, when spilled into water, the light volatile hydrocarbons readily evaporate or dissolve, and the non-volatile bitumen fraction remains floating until it goes ashore or settles to the bottom after combining with SPM. Some of the floating oil was transported to New York Harbor and exited the model domain. The dissolved components degrade in time, but the floating and stranded bitumen is slow to degrade. Figure 12 shows a typical mass balance for spilled dilbit.

Heavy fuel oil (HFO, also described as Bunker C fuel or Intermediate Fuel Oil, IFO) is primarily used to power vessels. It is comprised mainly of high molecular weight hydrocarbons that do not readily evaporate or dissolve. Of the typical heavy fuel oil used for this modeling study, less than 20% of the oil mass is volatile. Some of the volatiles evaporate, while the remaining volatile mass dissolves and degrades in the water column. The high viscosity of heavy fuel oil reduces the rate at which the oil entrains into the water column via breaking waves. Thus, heavy fuel oil primarily remains floating until it is washed ashore. The oil degrades very slowly over time. Figure 13 shows a typical mass balance for spilled heavy fuel oil.

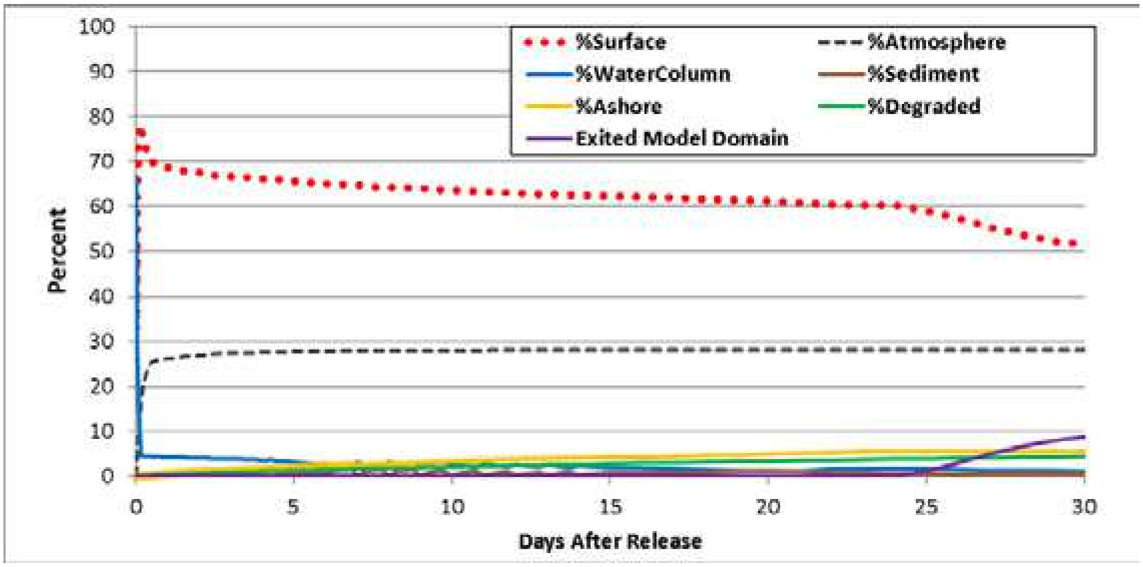

Figure 12: Percent Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Dilbit–Spring–High Tide

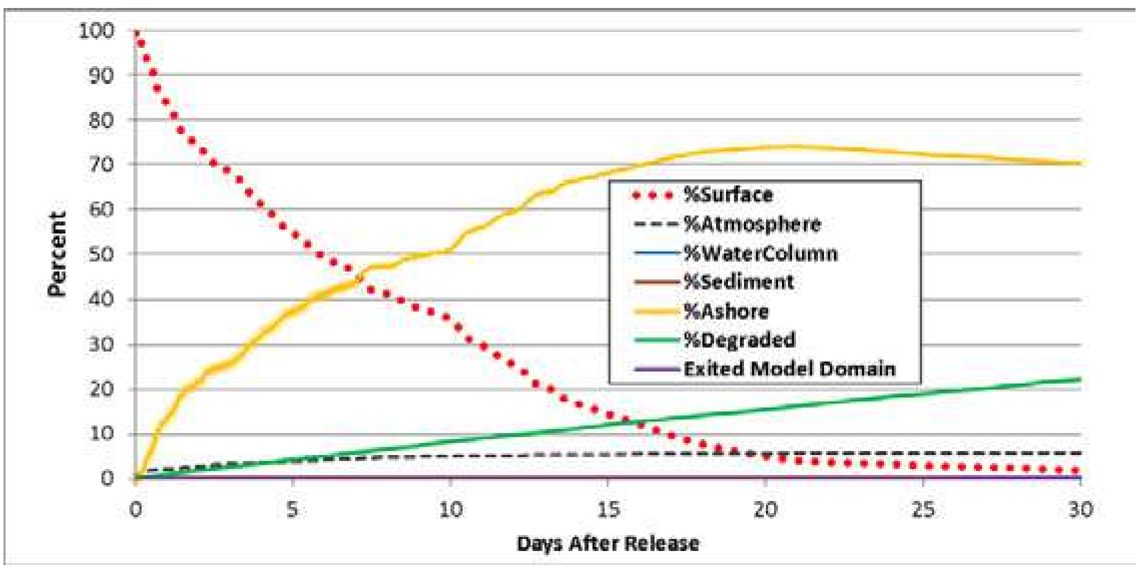

Figure 13: Percent Oil in Different Environmental Compartments over Time: Rondout Creek–14,000 bbl Heavy Fuel Oil–Spring–High Tide

Home heating oil (HHO) is a refined oil product, similar to diesel fuel, comprised primarily of volatile hydrocarbons, including BTEX and PAHs. Thus, most (other than a few percent) of the oil mass evaporates or dissolves into the water column. The dissolved hydrocarbons readily degrade. The floating oil evaporates or enters the water column rapidly and little oil goes ashore. Figure 14 shows a typical mass balance for spilled home heating oil.

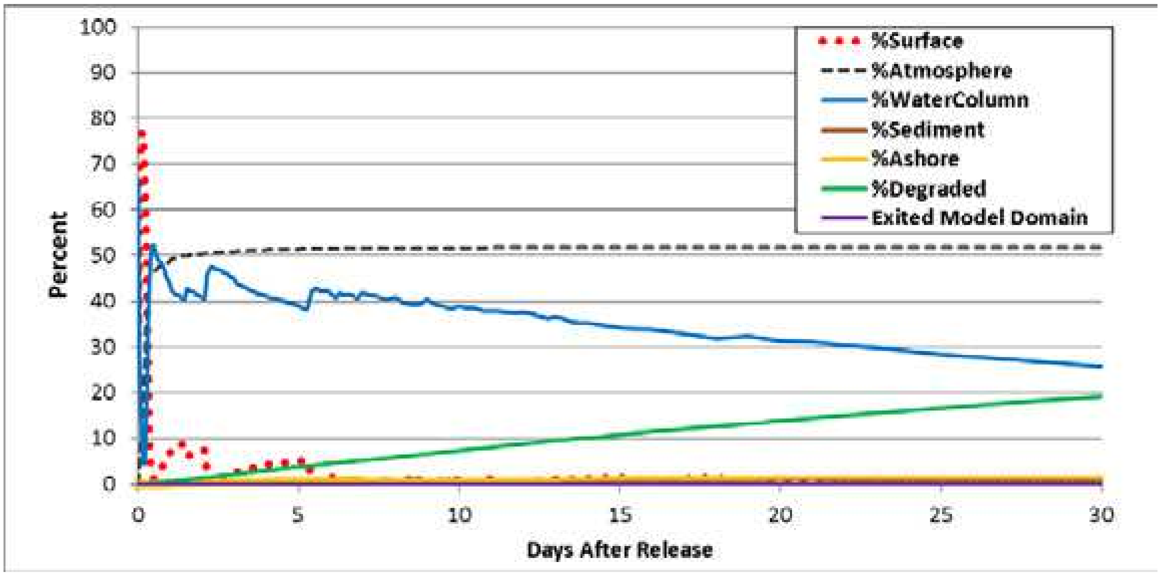

Figure 14: Percent Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Home Heating Oil–Spring–High Tide

Gasoline is comprised almost entirely (>99%) of highly volatile hydrocarbons, which evaporate or dissolve into the water column rapidly after a spill. Gasoline contains considerable BTEX but very little PAH. Less than 1% of the mass is comprised of residual components that form sheens or contaminate the shoreline. Figure 15 shows a typical mass balance for a large quantity of spilled gasoline (i.e., 155,000 bbl at the Yonkers Anchorage).

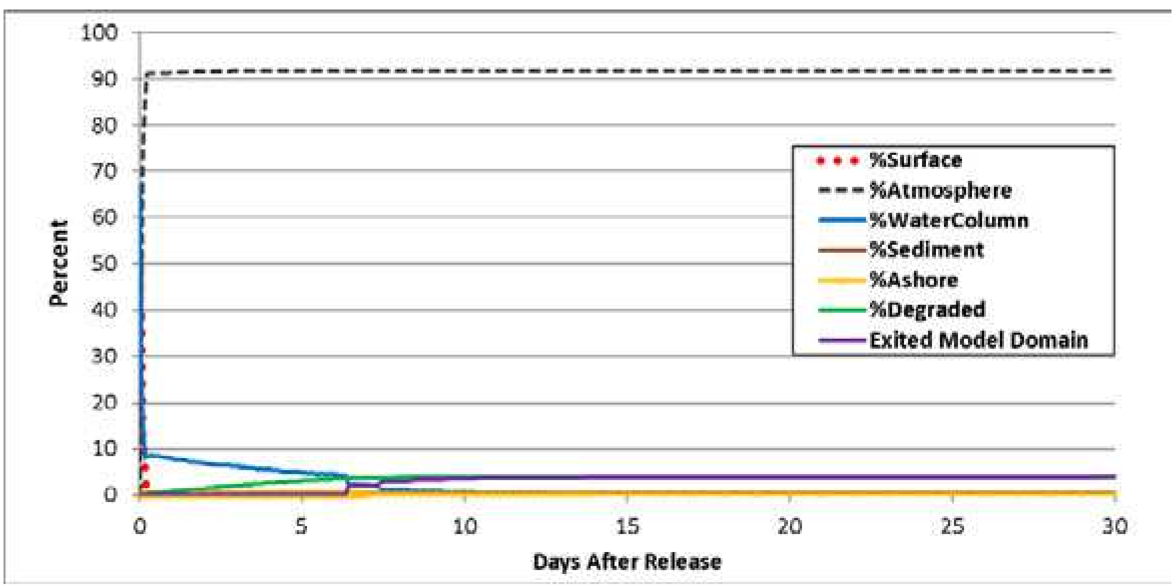

Figure 15: Percent Oil in Different Environmental Compartments over Time: Yonkers–155,000 bbl Gasoline–Spring–High Tide

Effect of Season

Potential spills in three seasons were modeled:

- Spring (April),
- Summer (August), and
- Winter, with ice cover (January).

In spring, the river flow rate is at its highest of the year, and over much of the Hudson's river flow is much stronger than the tidal flow. Thus, spilled oil is rapidly carried downstream. In contrast, in summer the river flow is at its annual low and relatively slow compared to the tidal flow. Thus, oil spilled in summer is primarily carried by the tides and moves up and down river with the tidal cycle. In winter, the river flow rate is intermediate of the spring and summer flow rates.

Dispersion (entrainment) of the oil into the water column is highest in spring and slowest in winter (compare Figures 15, 16 and 17). In these figures, discrete storm events that (naturally) disperse (mix) floating oil into the water column are evident. In winter, where ice cover averages about 50% above the Bear Mountain Bridge and about 20% below that bend in the river, presence of ice slows spreading of the oil and entrainment into the water. Because of the ice cover, as well as low temperatures, evaporation and dissolution of spilled oil is considerably slower in winter than in the other seasons. Degradation is correspondingly slow. Because these processes are slow in winter, floating oil tends to be transported long distances down river from the spill site and more of it strands on shorelines than for the other seasons.

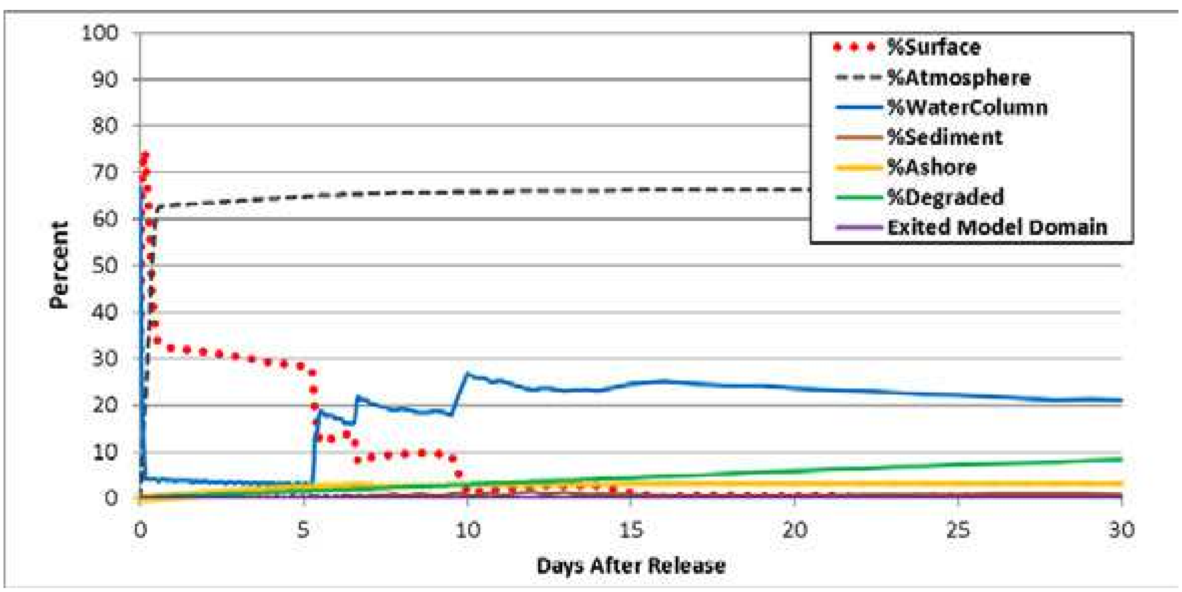

Figure 16: Percent Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Home Heating Oil–Summer–High Tide

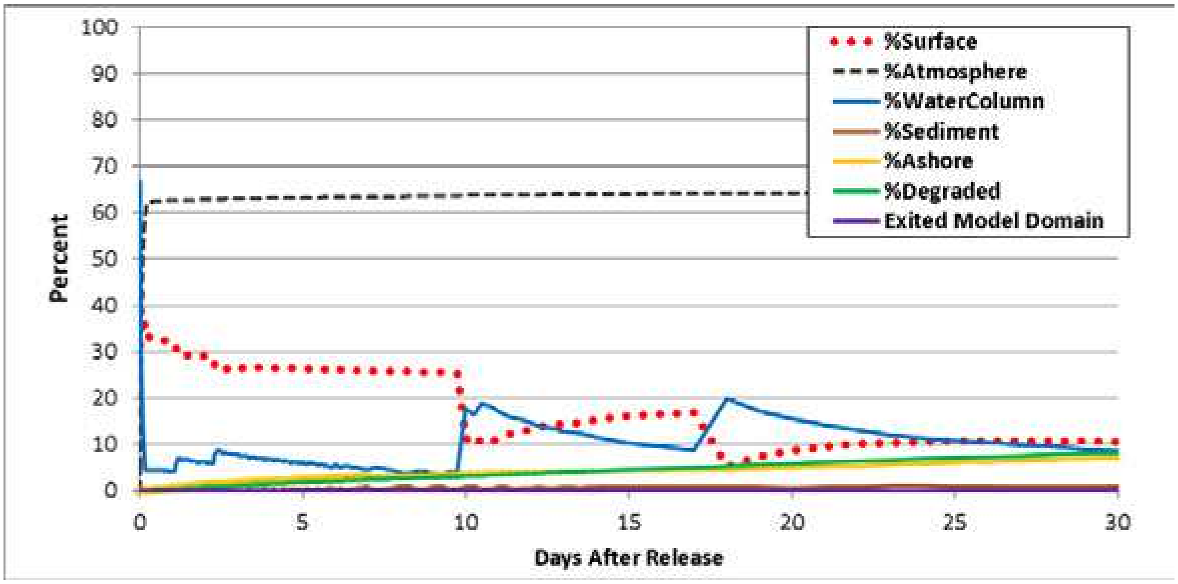

Figure 17: Percent Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Home Heating Oil–Winter–High Tide

Effect of Tide Stage

Spills were simulated as starting at a consistent stage of the tide, as measured at the specific location of the spill:

- At high tide
- At low tide

If oil is spilled at the time of (the local) high tide, it is first transported downstream, and then upstream at the change of the tide. If oil is spilled at the time of (the local) low tide, it is first transported upstream. After several tidal cycles, the floating oil is spread up- and down-stream, as well as carried down river. In spring, the movement down river is rapid, whereas in summer it is slow. After several days, the trajectories of spills occurring at high or at low tide are very similar (other inputs such as season being held constant), except for cases where for one tidal cycle the freshly spilled oil is trapped in inlets and behind islands (e.g., the Iona Island scenario).

See, for example, Figure 18 and Figure 19 for summer spills, the season where tidal transport is most influential, leading to the greatest difference in the oiling footprint. Similar figures for other scenarios (in Appendix C) show that in most cases the footprint of oiling is nearly the same for spills occurring at high versus at low tide.

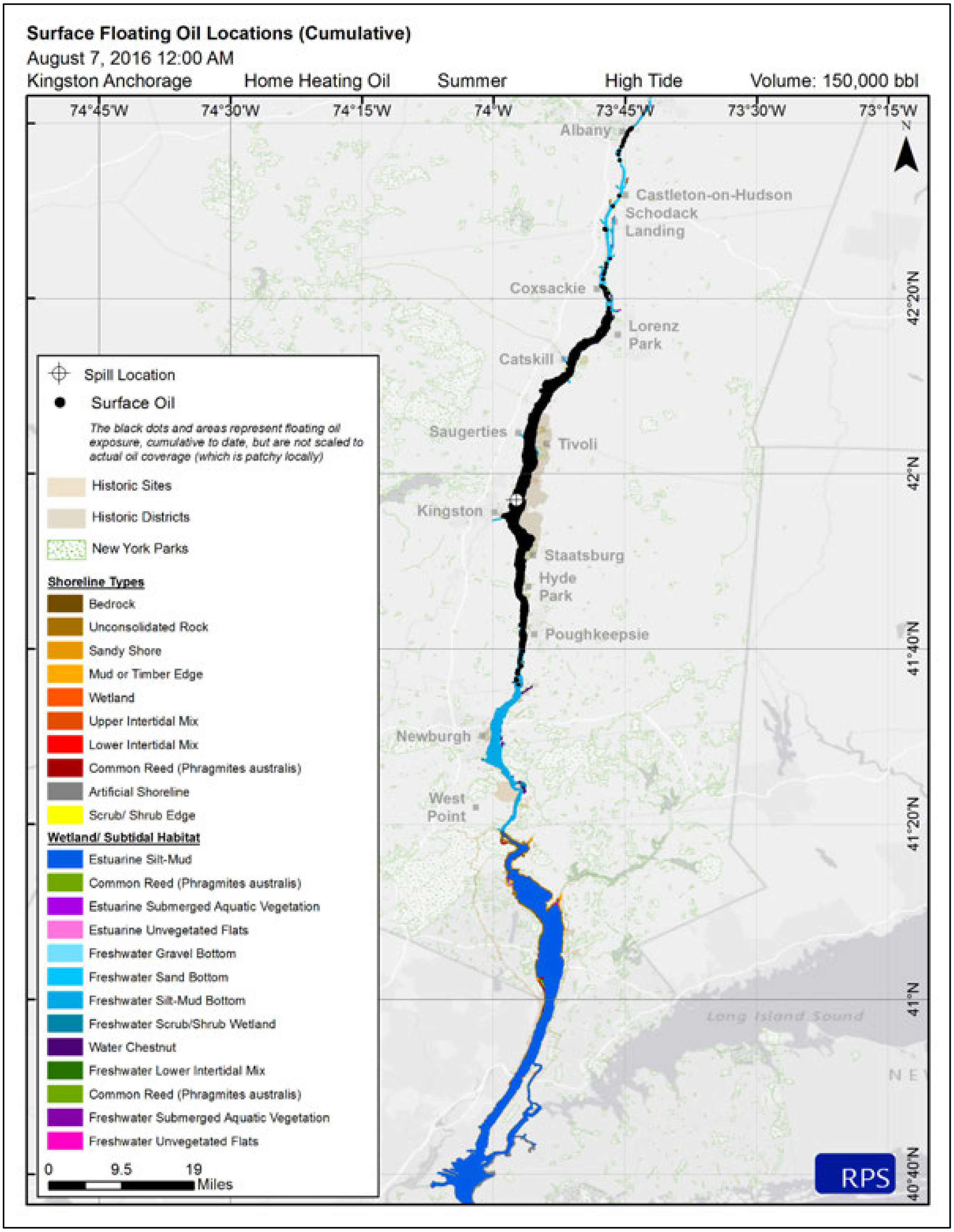

Figure 18: Areas Exposed to Oil at Some Time after Spill: Kingston–150,000 bbl Home Heating Oil–Summer–High Tide

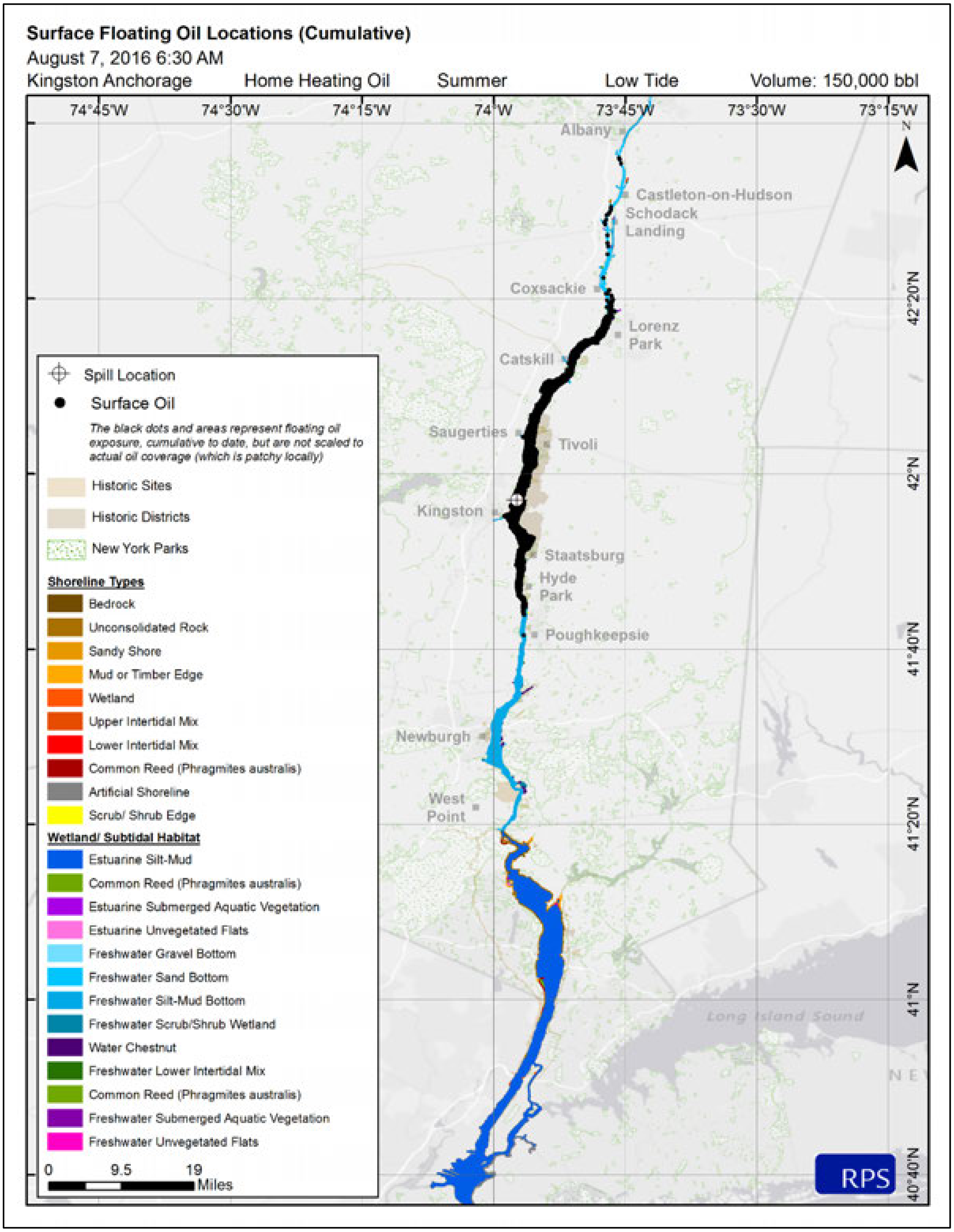

Figure 19: Areas Exposed to Oil at Some Time after Spill: Kingston–150,000 bbl Home Heating Oil–Summer–Low Tide

Effect of Spill Location

Spills were modeled for nine potential spill sites along the Hudson River:

- Port of Albany
- Coxsackie
- Kingston Anchorage
- Off Rondout Creek
- Newburgh Waterfront
- Bear Mountain Bridge
- Iona Island
- Tappan Zee
- Yonkers Anchorage

In general, spilled oil moved up- and down-stream with the tidal cycle and was flushed downstream with the river flow. The downstream extent was typically all the way to New York Harbor for the larger spills in spring or winter. In summer, and for small spills, the downstream extent of contamination was less.

Results for the 12 Hypothetical Spill Scenarios

The following sections summarize the results for each of the modeled scenarios (i.e., combination of spill location and oil type). Figure 20 through Figure 55 show the amount of oil in each environmental compartment (mass balance) over time for the spills in spring at high tide. The mass balance tables summarize the fate of the oil in the model simulation at the end of the 30-day simulation. In the figures and tables, "surface" represents the floating oil at day 30 after release that is still within the modeled domain (Troy Dam to the entrance of New York Harbor). "Atmosphere" is the amount evaporated, "water column includes both oil droplets and dissolved oil components in the water at 30 days after the spill, "sediment" is the amount of oil that settled within the modeled domain by 30 days after the spill, "ashore" is the amount of oil that went ashore within the modeled domain by 30 days after the spill, and "degraded" is the amount that was degraded by microbial activity by 30 days after the spill. Degradation is primarily of oil entering the water column, as floating oil, oil on shore and oil in the sediments degrades much more slowly (and little of this oil degrades in the first month after a spill). The oil that exited the modeled domain and entered New York Harbor may have done so while floating or entrained in the water column. In the sections below, these fates are discussed further.

Other tables summarize the length of shoreline oiled by > 1 g/m^2 (average thickness of 1 micron = 0.001 mm), by shore type, for each scenario. This threshold has been used as an indicator for an amount that may impact socioeconomic uses related to the shoreline. The extents of oiling over the ecological threshold of 10 g/m^2 (average thickness of 10 microns = 0.01 mm) are tabulated by shoreline habitat type in the summary tables in HROSRA Volume 7.

Port of Albany–155,000 bbl Bakken Crude

Table 12 and Figure 20 through Figure 22 summarize the mass balance for the Port of Albany Bakken crude spill scenario.

Table 12: Mass Balance Summary: Port of Albany 155,000-bbl Bakken Crude Spills[32]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	0.1%	45.0%	36.5%	1.0%	6.4%	10.9%	0.1%
Spring Low Tide	0.1%	46.9%	34.7%	1.2%	6.9%	10.2%	0.1%
Summer High Tide	0.1%	50.4%	32.9%	0.4%	1.0%	15.2%	0.0%
Summer Low Tide	0.0%	50.7%	31.3%	0.3%	0.9%	16.8%	0.0%
Winter High Tide	18.0%	48.9%	9.5%	1.1%	17.4%	5.1%	0.0%
Winter Low Tide	17.7%	50.5%	10.0%	0.5%	17.8%	3.4%	0.0%

Nearly 50% of the spilled Bakken crude evaporated, and the remaining light hydrocarbons dissolved and degraded in the water column. In the winter, when there is ice cover, less oil evaporated or entrained into the water than in spring or summer. In winter, approximately18% of the non-volatile fraction remained

[32] At the end of 30-day model simulation.

floating at the end of the 30-day simulation, whereas in spring and summer less than 1% remained on the surface. The amount of oil going ashore is highest in winter because of being retained on the surface longer and carried well down-stream, whereas in summer the floating oil moves the least distance from the spill site and therefore oils less shoreline. Degradation is fastest in summer and slowest in winter.

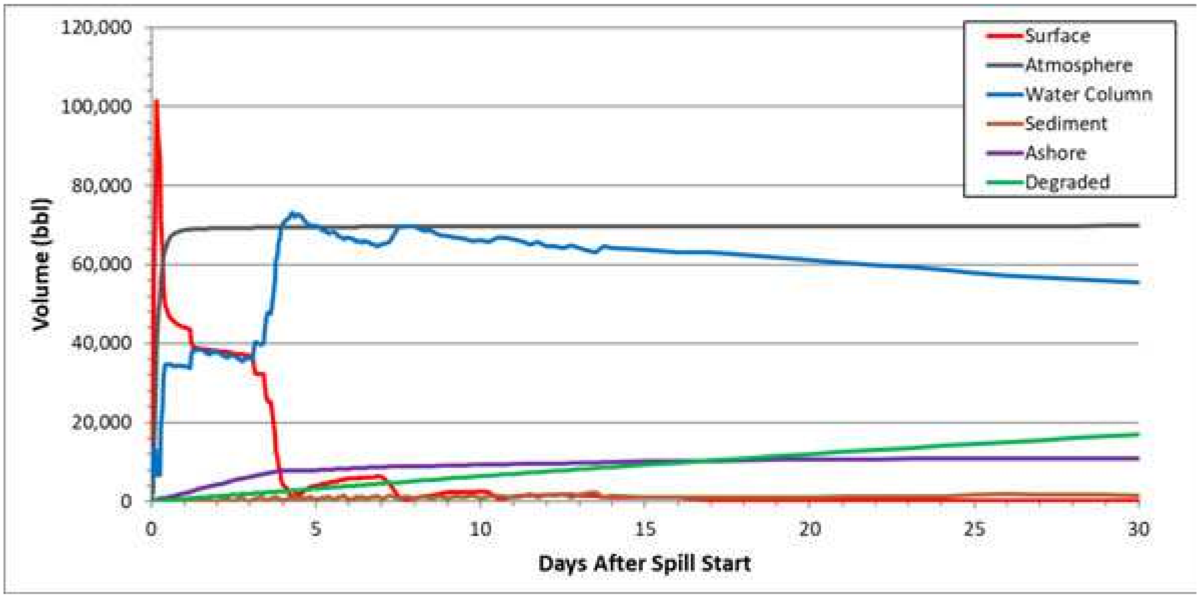

Figure 20: Amount of Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Spring–High Tide

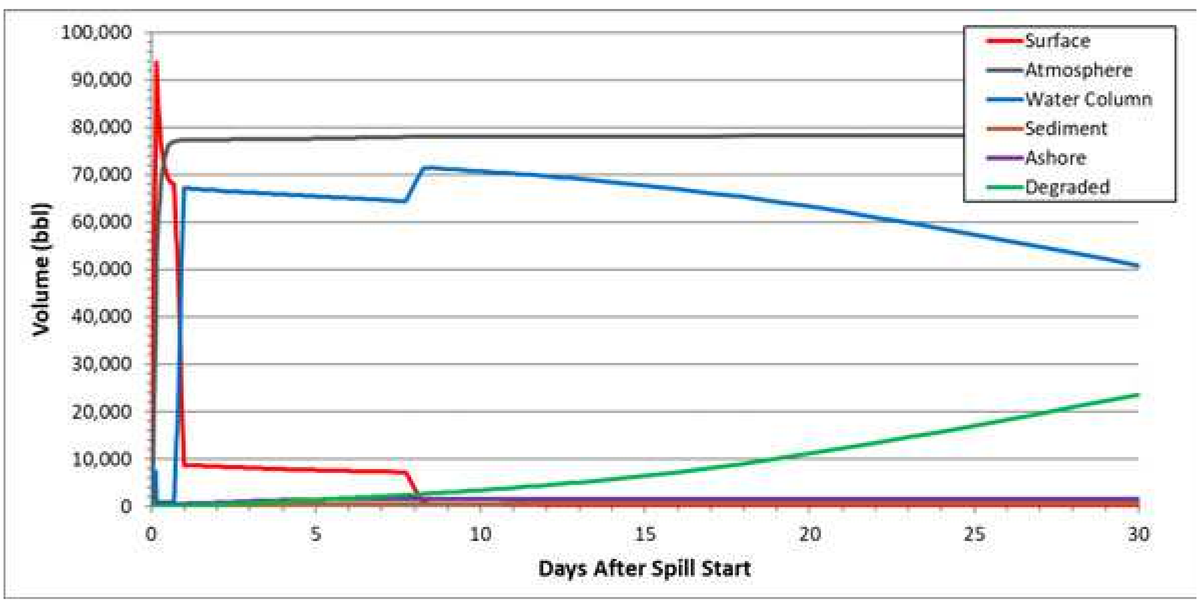

Figure 21: Amount of Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Summer–High Tide

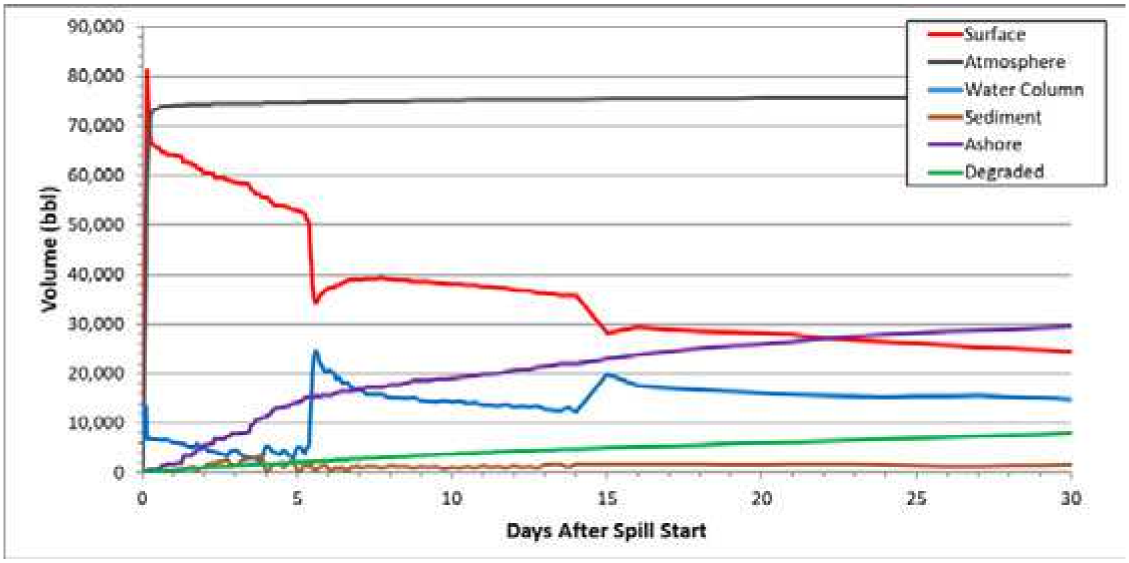

Figure 22: Amount of Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Winter–High Tide

Floating oil from the spring spills at both high and low tide were transported down river, reaching the Tappan Zee area by 28 days after the spill. In contrast, in the summer, the river flow is much weaker than the tidal flow, and the Bakken crude was not carried downstream appreciably, and most of the floating oil was blown upstream slightly by the prevailing southerly winds. In winter, oil spilled at either high or low tide was transported downstream as far as Newburgh in the 30-day simulations.

This scenario being for a very large spill, shoreline and sediment contamination extended over the areas exposed to floating oil (see Appendix C1). Table 13 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Because strong river flows carried floating oil a long distance downstream in spring and winter, the shore oiling is extensive (over 200 miles of shoreline oiled) in those seasons for spills at any stage of the tide. In summer, floating oil and shoreline exposures occur close to the spill site, both up and downstream.

Contamination in the sediments extended over similar portions of the river as the shoreline oiling. Concentrations of spilled oil in the sediment were low during seasons of high flow, where oil settling was spread out along the river. In the summer, when freshwater flow was relatively low, sedimented oil was spread by the tides under areas of floating oil contamination, which were localized around the spill site.

High concentrations of oil droplets in the water column were swept well downstream of the spill site except during the summer when river flow was weak and the subsurface oil remained concentrated near the spill site. There was some upstream movement of oil in the water column with the tide (both when released at high and at low tide). While subsurface oil reached New York Harbor in spring and winter, the oil was diluted in the lower river near the southern extent of the floating oil. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for effects on fish and invertebrates. These higher dissolved concentrations extended as far south as West Point in spring and as far as Kingston area in winter, but were localized near Albany and Troy in summer.

Table 13: Shoreline Length Oiled for Port of Albany 155,000-bbl Bakken Crude Spills						
Habitat Type	**Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)**					
	Spring		**Summer**		**Winter**	
	High Tide	**Low Tide**	**High Tide**	**Low Tide**	**High Tide**	**Low Tide**
Solid Bedrock	24.1	24.4	0.0	0.0	18.7	18.4
Unconsolidated Rock	107.0	112.3	9.7	9.7	71.4	70.2
Sand or Sand with Brick	1.8	2.0	0.0	0.0	2.2	2.1
Mud, Mixed Mud-Sand, Timber Edge	63.8	66.2	2.7	2.3	66.5	66.2
Saltmarsh (*Spartina* spp.)	3.3	3.3	0.0	0.0	3.6	4.0
Upper Intertidal Mix	17.7	15.6	0.0	0.0	24.6	24.1
Lower Intertidal Mix	6.1	6.2	0.0	0.0	6.6	6.8
Phragmites australis	2.6	2.6	0.0	0.0	1.4	1.5
Sheet Pile, Concrete or Other	13.6	15.5	5.4	4.7	12.4	11.3
Scrub/Shrub or Forested Wetland	0.4	0.5	0.0	0.0	0.4	0.6
Total Shoreline	**240.4**	**248.5**	**17.8**	**16.7**	**207.7**	**205.3**

Coxsackie–25,000 bbl Home Heating Oil

Table 14 and Figure 23 through Figure 25 summarize the mass balance for the Coxsackie home heating oil spill scenario. Much of the spilled home heating oil evaporated, and most of the remaining oil was entrained into the water column, where some of it dissolved and degraded by 30 days after the release. In all seasons, less than 1% of the oil remained on the surface by 30 days after the release. Higher wind speeds in spring caused more oil to become entrained and subsequently dissolve and degrade in the water column. In summer, there was less wind and thus less entrainment into the water column, and more of the oil evaporated owing to warmer temperatures. In winter, the 50% ice cover reduced entrainment into the water as well as evaporation, and therefore more oil came ashore.

Table 14: Mass Balance Summary: Coxsackie 25,000-bbl Home Heating Oil Spills[33]							
Scenario	**Surface**	**Atmosphere**	**Water Column**	**Sediment**	**Ashore**	**Degraded**	**Entered NY Harbor**
Spring High Tide	0.0%	44.5%	32.2%	0.8%	4.9%	17.6%	0.0%
Spring Low Tide	0.1%	46.3%	28.1%	0.8%	6.3%	18.5%	0.0%
Summer High Tide	0.0%	70.3%	7.4%	0.3%	18.6%	3.4%	0.0%

[33] At the end of 30-day model simulation.

Table 14: Mass Balance Summary: Coxsackie 25,000-bbl Home Heating Oil Spills[33]							
Scenario	**Surface**	**Atmosphere**	**Water Column**	**Sediment**	**Ashore**	**Degraded**	**Entered NY Harbor**
Summer Low Tide	0.0%	70.1%	6.8%	0.3%	19.4%	3.4%	0.0%
Winter High Tide	0.0%	66.3%	0.9%	0.3%	30.2%	2.4%	0.0%
Winter Low Tide	0.0%	66.2%	0.6%	0.3%	30.6%	2.3%	0.0%

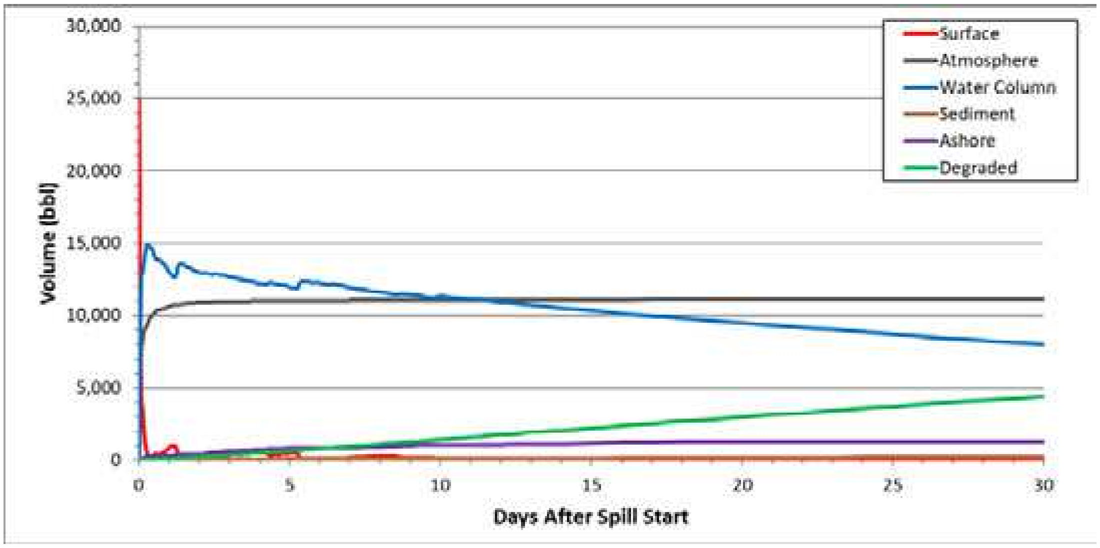

Figure 23: Amount of Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Spring–High Tide

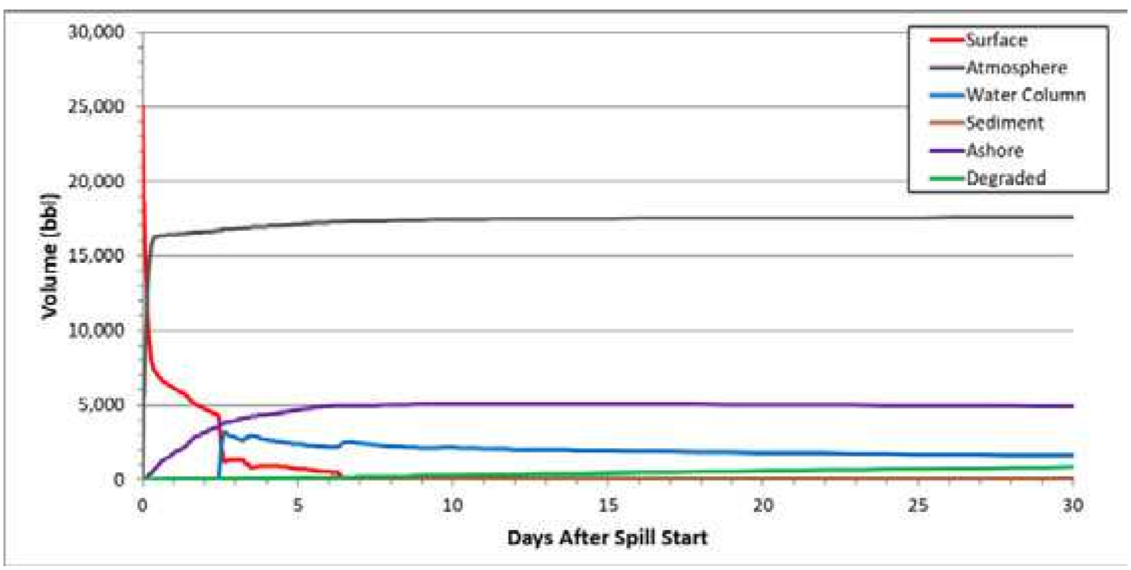

Figure 24: Amount of Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Summer–High Tide

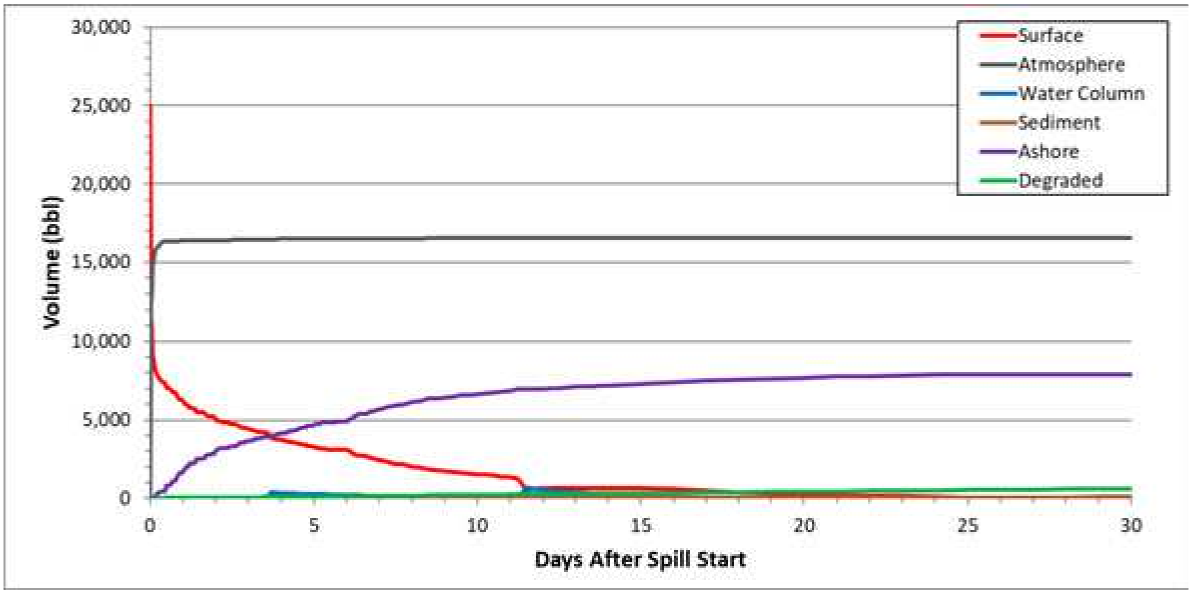

Figure 25: Amount of Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Winter–High Tide

Floating oil from the spring spills at both high and low tide were transported down river, reaching New York Harbor by 28 days after the spill. In contrast, in the summer, the river flow is much weaker than the tidal flow, and the floating home heating oil was blown upstream past Albany and downstream to Stockport Creek (just north of Lorenz Park). In winter, oil spilled was transported downstream as far as Kingston when spilled at low tide and Staatsburg when spilled at high tide in the 30-day simulations.

This scenario being for a very large spill, shoreline and sediment contamination extended over the areas exposed to floating oil (see Appendix C2). Table 15 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Because strong river flows carried floating oil a long distance downstream in spring and winter, the shore oiling is extensive in those seasons for spills at any stage of the tide. In summer, floating oil and shoreline exposures occur closer to the spill site, but still over a considerable distance both up and downstream.

Table 15: Shoreline Length Oiled for Coxsackie 25,000-bbl Home Heating Oil Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	21.9	24.4	1.7	1.6	13.9	9.2
Unconsolidated Rock	91.0	102.8	22.5	21.5	41.7	37.1
Sand or Sand with Brick	2.3	2.2	0.0	0.0	1.4	0.9
Mud, Mixed Mud-Sand, Timber Edge	25.1	29.0	52.9	50.1	32.1	35.2
Saltmarsh (*Spartina* spp.)	0.7	1.5	1.5	1.6	1.9	2.0

Table 15: Shoreline Length Oiled for Coxsackie 25,000-bbl Home Heating Oil Spills						
Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Upper Intertidal Mix	14.1	15.2	4.3	4.1	17.1	13.3
Lower Intertidal Mix	4.6	4.0	4.4	3.4	4.8	4.7
Phragmites australis	1.6	2.7	1.4	1.6	0.4	1.0
Sheet Pile, Concrete, or Other	13.8	19.8	10.9	11.3	3.2	2.6
Scrub/Shrub or Forested Wetland	0.2	0.2	0.1	0.1	0.1	0.3
Total Shoreline	**175.2**	**201.7**	**99.6**	**95.2**	**116.5**	**106.4**

Contamination in the sediments extended over similar portions of the river as exposed to floating oil. Concentrations of the spilled oil in the sediment were low during seasons of high flow, where oil settling was spread out along the river. In the summer, when freshwater flow was relatively low, the sedimented oil was under areas of floating oil contamination near and north of Coxsackie. The highest sediment contamination was in the wetlands and open water areas near Schodack Landing.

High concentrations of oil droplets in the water column were swept well downstream of the spill site except during the summer when the subsurface oil remained more concentrated just north and south of the spill site. There was some upstream movement of oil in the water column with the tide (both when released at high and at low tide). While subsurface oil reached New York Harbor in spring, it reached as far south as Newburgh in winter. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for effects on fish and invertebrates. These higher dissolved concentrations extended in patch distributions as far south as the Tappan Zee in spring and as far as Kingston area in winter, but were localized near Coxsackie in summer.

Proposed Kingston Anchorage–150,000 bbl Home Heating Oil

Table 16 and Figure 26 through Figure 28 summarize the mass balance for the proposed Kingston Anchorage home heating oil spill scenario. Nearly 50% of the spilled home heating oil evaporated, and most of the remaining oil was entrained into the water column, where some of it dissolved and degraded by 30 days after the release. In the winter, when it is cold and there is ice cover, and therefore less evaporation and entrainment into the water column, about 11% of the non-volatile fraction remained floating by the end of the 30-day simulation. In spring and summer less than 1% of the oil remained on the surface. Higher wind speeds in spring caused more oil to become entrained and subsequently dissolve and degrade in the water column. In summer, there was less wind and thus less entrainment into the water column, and more of the oil evaporated owing to warmer temperatures.

Floating oil from the spring spills at both high and low tide were transported down river, reaching New York Harbor by 21 days after the spill. In contrast, in the summer, the river flow is much weaker than the tidal flow, and the floating home heating oil was blown upstream past Lorenz Park and downstream to

Poughkeepsie when spilled at high tide. Likewise, in the summer, the floating home heating oil was blown upstream past Coxsackie and downstream to Staatsburg when spilled at low tide. In winter, oil spilled was transported downstream past Bear Mountain Bridge (at both high tide and low tide) in the 30-day simulations.

This scenario being for a very large spill, shoreline and sediment contamination extended over the areas exposed to floating oil (see Appendix C3). Table 17 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Because strong river flows carried floating oil a long distance downstream in spring and winter, the shore oiling is extensive in those seasons for spills at any stage of the tide. In summer, floating oil and shoreline exposures occur closer to the spill site, but still over a considerable distance both up and downstream.

Table 16: Mass Balance Summary: Kingston 150,000-bbl Home Heating Oil Spills[34]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	1.0%	51.9%	25.7%	0.8%	1.5%	19.1%	0.0%
Spring Low Tide	1.1%	45.9%	30.9%	1.0%	2.1%	19.1%	0.0%
Summer High Tide	0.3%	66.3%	21.1%	0.8%	3.2%	8.4%	0.0%
Summer Low Tide	0.2%	66.2%	21.2%	0.6%	3.2%	8.6%	0.0%
Winter High Tide	10.5%	64.6%	8.6%	0.9%	7.1%	8.2%	0.0%
Winter Low Tide	10.7%	64.4%	8.6%	0.7%	7.1%	8.5%	0.0%

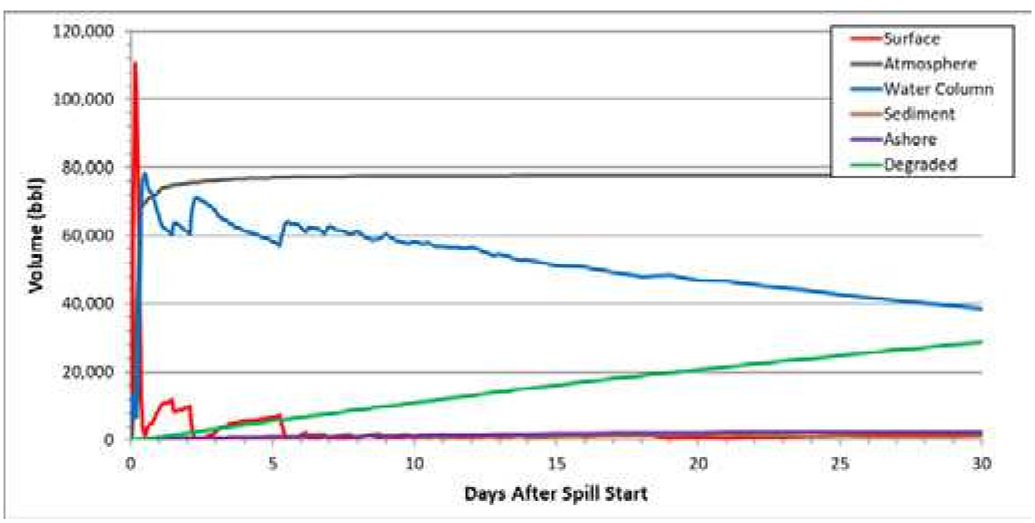

Figure 26: Amount of Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Home Heating Oil–Spring–High Tide

[34] At the end of 30-day model simulation.

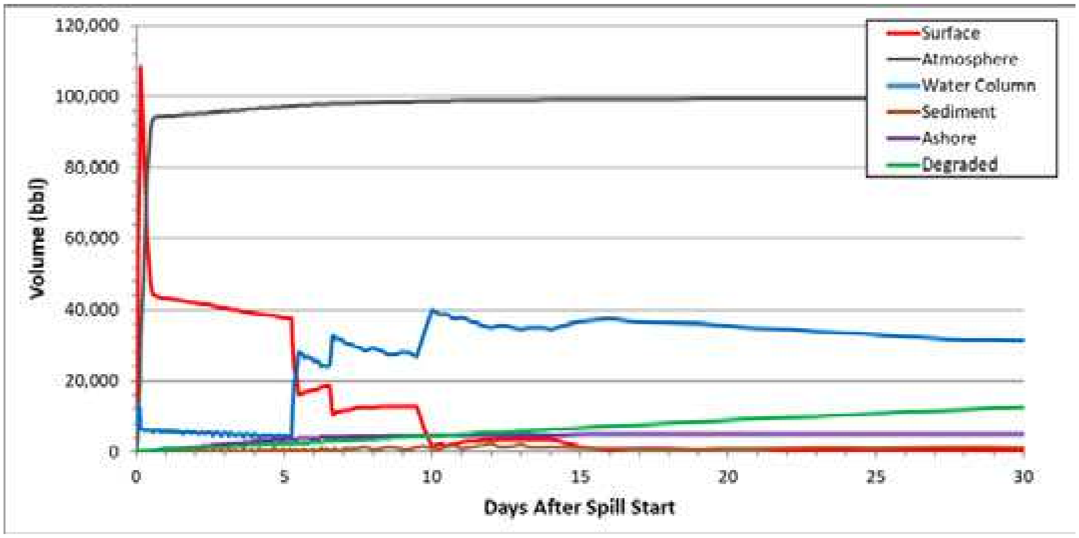

Figure 27: Amount of Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Home Heating Oil–Summer–High Tide

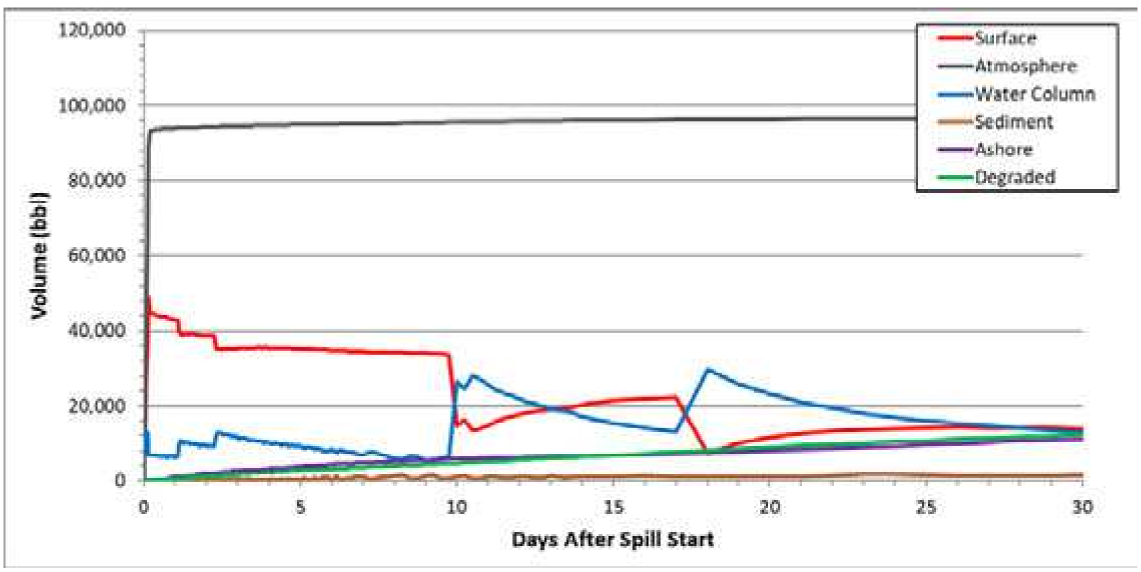

Figure 28: Amount of Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Home Heating Oil–Winter–High Tide

Contamination in the sediments extended over similar portions of the river as exposed to floating oil. Concentrations of the spilled oil in the sediment were relatively low during spring when there was high river flow, where oil settling was spread out along the river. However, contamination of sediments was relatively high in summer and winter, in part due to the very large spill and ease with which home heating oil entrains into the water column where it may combine with suspended particulate matter and settle. In the summer, when freshwater flow was relatively low, the sedimented oil was under areas of floating oil contamination near Kingston and north to Catskill, particularly in the wetlands near Kingston and Saugerties. In winter, sediment contamination extended downstream as far as West Point, but was highest between Kingston and Poughkeepsie.

Table 17: Shoreline Length Oiled for Kingston 150,000-bbl Home Heating Oil Spills						
Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	20.5	21.5	16.1	13.9	20.6	20.1
Unconsolidated Rock	89.6	96.1	45.7	40.1	88.1	86.9
Sand or Sand with Brick	0.1	0.3	2.2	2.1	0.9	1.1
Mud, Mixed Mud-Sand, Timber Edge	9.3	11.2	19.8	27.3	10.1	10.1
Saltmarsh (*Spartina* spp.)	1.0	1.2	3.4	4.0	0.9	1.0
Upper Intertidal Mix	6.3	7.2	14.5	18.0	8.0	8.2
Lower Intertidal Mix	1.6	1.9	2.5	2.8	1.9	2.3
Phragmites australis	1.4	1.8	0.2	0.7	0.0	0.0
Sheet Pile, Concrete, or Other	77.8	84.9	3.6	3.9	5.5	5.2
Scrub/Shrub or Forested Wetland	0.3	0.3	0.4	1.2	0.3	0.3
Total Shoreline	**207.8**	**226.4**	**108.4**	**114.1**	**136.4**	**135.3**

High concentrations of oil droplets in the water column were swept well downstream of the spill site except during the summer when the subsurface oil remained more concentrated just north and south of the spill site. There was some upstream movement of oil in the water column with the tide. While subsurface oil reached New York Harbor in spring, it reached as far south as the Tappan Zee in winter. The oil was well diluted in the lower river near the southern extent of the floating oil. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for effects on fish and invertebrates. These higher dissolved concentrations extended in patchy distributions as far south as New York Harbor in spring and as far as the Bear Mountain area in winter, but were localized near Kingston in summer.

Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen

Table 18 and Figure 29 through Figure 31 summarize the mass balance for the proposed Kingston Anchorage diluted bitumen spill scenario. Nearly 30% of the spilled diluted bitumen (dilbit) evaporated, and the remaining light hydrocarbons from the diluent dissolved and degraded in the water column. Most (>52%) of the non-volatile bitumen fraction remained floating over the 30-day simulation, with some of going ashore or settling to the sediments. After the spring spills, 7-9% of the floating oil exited the model domain into New York Harbor.

Floating oil from the spring spills (at both high and low tide) was transported down river, reaching New York Harbor by 21 days after the spill. Little oil was carried upstream in the spring. In contrast, in the summer, the river flow is much weaker than the tidal flow, and the oil was carried both up and down river, and only carried downstream as far south as Poughkeepsie. The floating oil was carried north by flood tides and blown upstream by the prevailing southerly winds as far north as Coxsackie. In winter, oil spilled at either high or low tide was transported downstream as far as Haverstraw Bay, and upstream towards Catskill.

This scenario being for a very large spill, shoreline and sediment contamination extended over the areas exposed to floating oil (see Appendix C4). Table 17 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Because strong river flows carried floating oil a long distance downstream in spring and winter, the shore oiling is extensive, particularly in spring, for spills at any stage of the tide. In summer, floating oil and shoreline impacts are also extensive, both up and downstream of the spill site. The sediment contamination from these dilbit spills was relatively low because the highly viscous bitumen remained floating and went ashore, as opposed to being mixed into the water where it could bind with suspended particulate matter and settle.

Table 18: Mass Balance Summary: Kingston 150,000-bbl Diluted Bitumen Oil Spills[35]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	51.5%	28.2%	1.2%	0.6%	5.6%	4.4%	8.7%
Spring Low Tide	51.9%	28.1%	1.2%	0.8%	6.1%	4.5%	7.4%
Summer High Tide	58.9%	28.9%	1.3%	0.8%	6.0%	4.1%	0.0%
Summer Low Tide	59.0%	28.9%	1.2%	0.8%	5.9%	4.2%	0.0%
Winter High Tide	57.6%	28.1%	1.4%	0.5%	7.9%	4.6%	0.0%
Winter Low Tide	57.8%	28.1%	1.6%	0.4%	7.6%	4.6%	0.0%

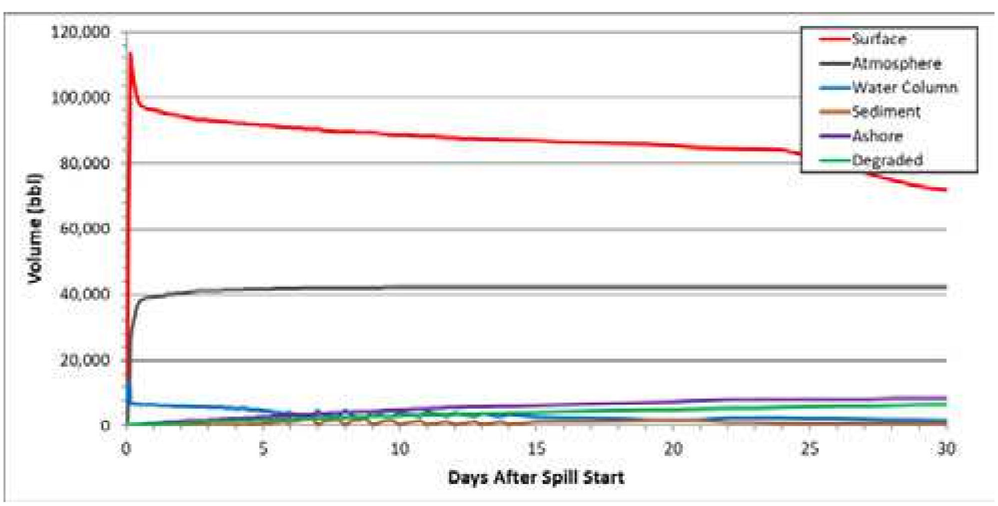

Figure 29: Amount of Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Diluted Bitumen–Spring–High Tide

[35] At the end of 30-day model simulation.

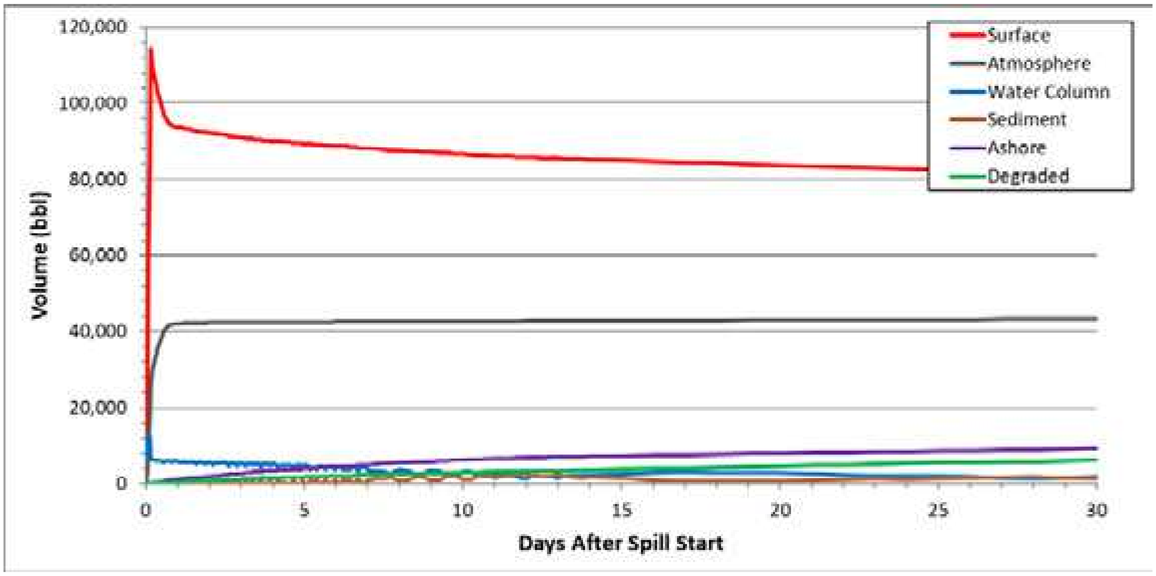

Figure 30: Amount of Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Diluted Bitumen–Summer–High Tide

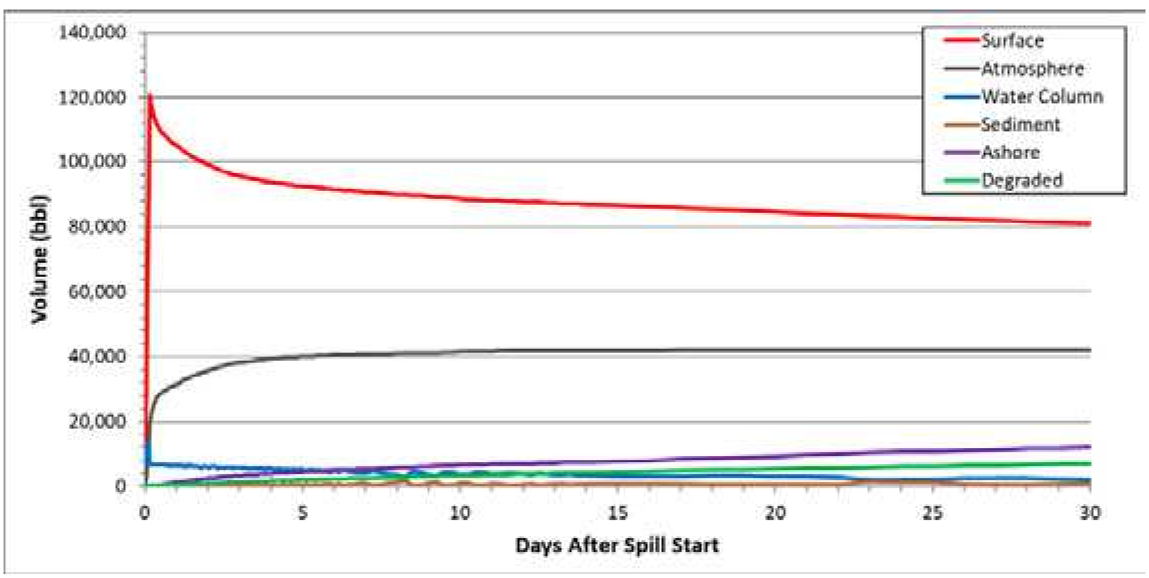

Figure 31: Amount of Oil in Different Environmental Compartments over Time: Kingston–150,000 bbl Diluted Bitumen–Winter–High Tide

High concentrations of oil droplets in the water column were primarily near the spill site and immediately downstream. The oil was well diluted in the lower river near the southern extent of the floating oil. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m^3) for effects on fish and invertebrates.

Table 19: Shoreline Length Oiled for Kingston 150,000-bbl Diluted Bitumen Oil Spills						
Habitat Type	**Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)**					
	Spring		**Summer**		**Winter**	
	High Tide	**Low Tide**	**High Tide**	**Low Tide**	**High Tide**	**Low Tide**
Solid Bedrock	21.8	22.9	16.4	14.6	22.8	22.6
Unconsolidated Rock	120.3	125.8	50.2	45.7	98.4	95.7
Sand or Sand with Brick	0.4	0.6	2.2	2.2	1.1	1.4
Mud, Mixed Mud-Sand, Timber Edge	18.7	19.7	32.1	32.9	13.4	12.5
Saltmarsh (*Spartina* spp.)	3.7	4.1	5.6	6.2	1.9	1.9
Upper Intertidal Mix	12.8	14.0	23.1	23.8	9.9	10.0
Lower Intertidal Mix	2.2	2.7	4.0	4.3	2.3	2.2
Phragmites australis	3.7	2.8	0.2	0.2	0.5	0.0
Sheet Pile, Concrete, or Other	119.7	128.4	3.6	3.5	6.1	6.2
Scrub/Shrub or Forested Wetland	0.3	0.3	1.7	0.7	0.3	0.3
Total Shoreline	**303.6**	**321.3**	**139.0**	**134.2**	**156.6**	**152.8**

Off Rondout Creek–75,421 bbl Bakken Crude

Table 20 and Figure 32 through Figure 34 summarize the mass balance for the Kingston Rondout Creek Bakken crude spill scenario. Nearly 50% of the spilled Bakken crude evaporated, and most of the remaining oil was entrained into the water column, where some of it dissolved and degraded by 30 days after the release. In the winter, when there is less evaporation because of ice cover and cold temperatures, about 22% of the non-volatile fraction remained floating over the 30-day simulation whereas in spring and summer no floating oil is predicted to remain on the surface. About 22-23% of the oil spilled in spring reached New York Harbor after being entrained into the water column. The percentage of oil going ashore varies from 3 to 14% based on the season.

Floating oil from the spring spills at both high and low tide were transported down river, reaching New York Harbor by 21 days after the spill. In contrast, in the summer, Bakken oil was blown upstream past Lorenz Park after 14 days (at both high and low tide) but after 21+ days the floating oil was pushed back downstream closer to the Catskills. In winter, spilled oil was initially (in the first few days) transported upstream and downstream but after 14 days, the floating oil was past Bear Mountain Bridge (at both high tide and low tide) in the 30-day simulations.

This scenario being for a very large spill, shoreline contamination extended over the areas exposed to floating oil (see Appendix C5). Table 21 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Because strong river flows carried floating oil a long distance downstream in spring and winter, the shore oiling is extensive in those seasons for spills at any stage of the tide. In summer, floating oil and shoreline exposures also occur over a considerable distance both up and downstream.

Table 20: Mass Balance Summary: Rondout 75,421-bbl Bakken Crude Spills[36]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	0.0%	47.5%	19.1%	0.3%	2.9%	8.3%	22.0%
Spring Low Tide	0.0%	38.6%	24.1%	0.3%	2.4%	11.3%	23.3%
Summer High Tide	0.1%	52.8%	37.3%	0.1%	6.6%	3.1%	0.0%
Summer Low Tide	0.1%	52.7%	37.4%	0.1%	6.5%	3.2%	0.0%
Winter High Tide	21.6%	51.1%	10.6%	0.1%	14.1%	2.5%	0.0%
Winter Low Tide	21.2%	51.1%	10.8%	0.1%	14.3%	2.5%	0.0%

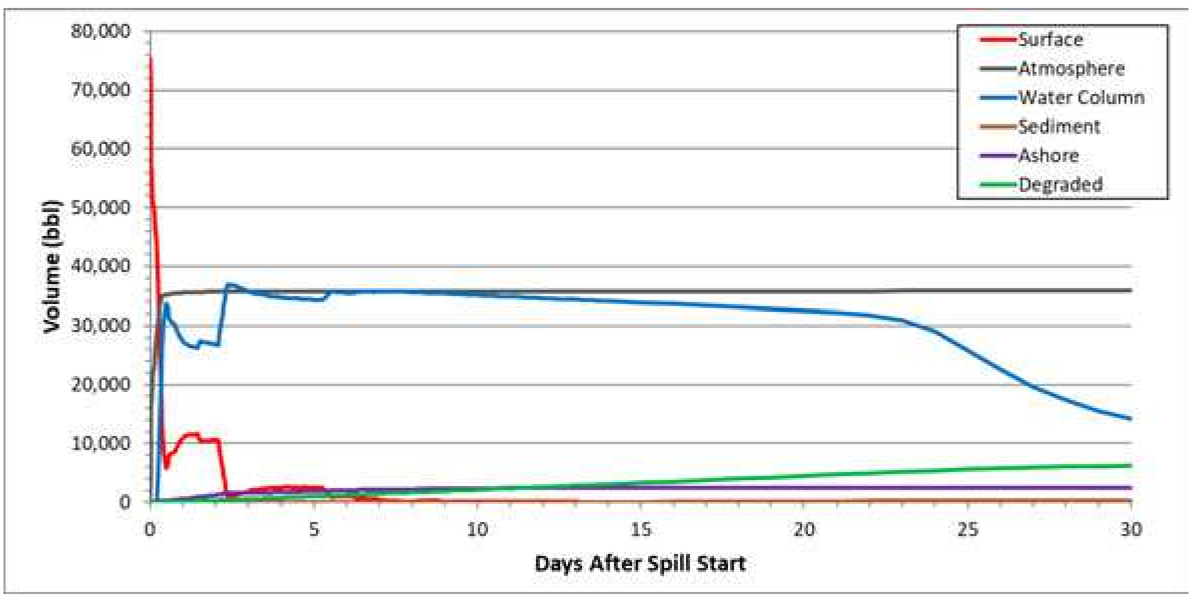

Figure 32: Amount of Oil in Different Environmental Compartments over Time: Rondout–75,421 bbl Bakken Crude–Spring–High Tide

[36] At the end of 30-day model simulation.

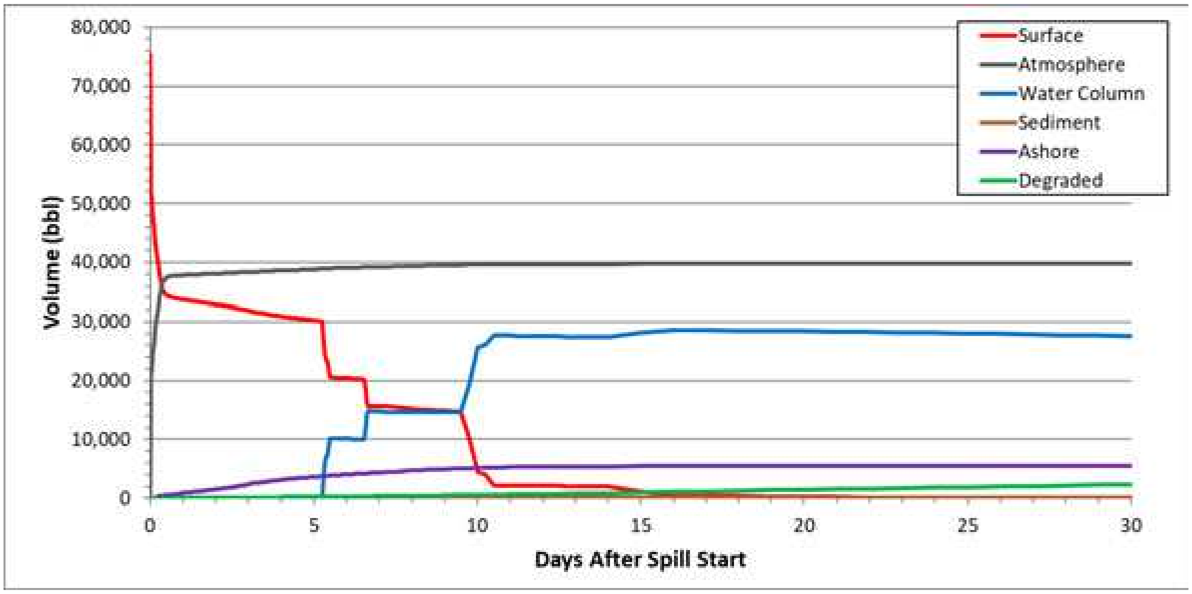

Figure 33: Amount of Oil in Different Environmental Compartments over Time: Rondout–75,421 bbl Bakken Crude–Summer–High Tide

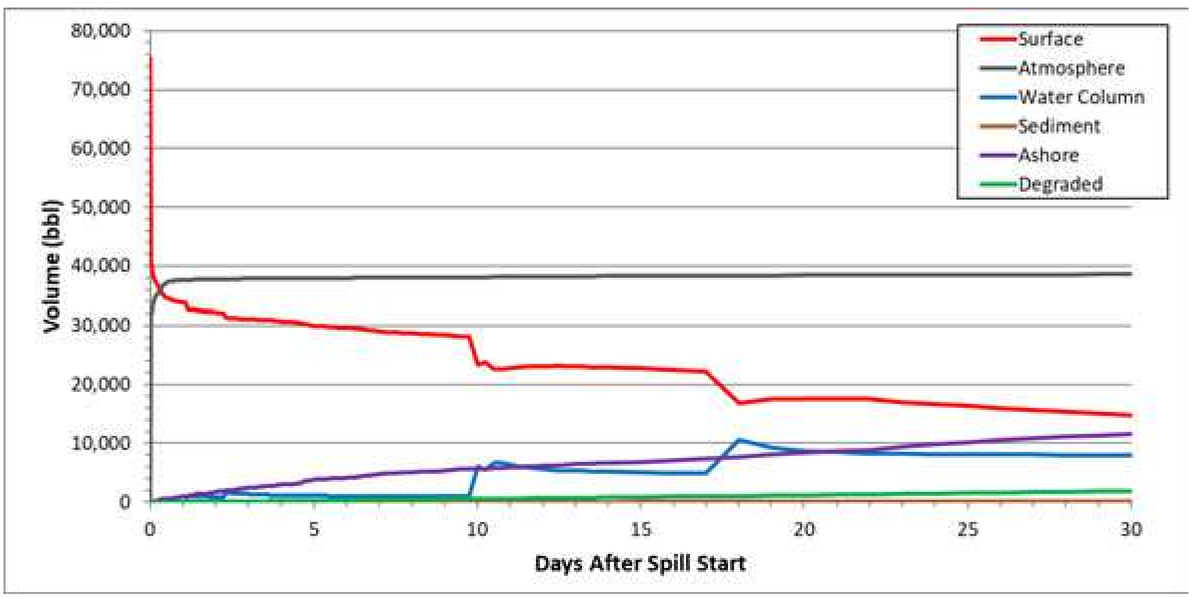

Figure 34: Amount of Oil in Different Environmental Compartments over Time: Rondout–75,421 bbl Bakken Crude–Winter–High Tide

Contamination in the sediments extended over similar portions of the river as exposed to floating oil. Concentrations of the spilled oil in the sediment were low during spring when there was high river flow, where oil settling was spread out along the river. In the summer, when freshwater flow was relatively low, the sedimented oil was under areas of floating oil contamination near Kingston and north towards Catskill. In winter, sediment contamination extended downstream as far as West Point, and was highest between Kingston and Poughkeepsie. However, the concentrations of the spilled oil in the sediments were low overall.

High concentrations of oil droplets in the water column were swept well downstream of the spill site except during the summer when the subsurface oil remained more concentrated just north and south of the spill site. There was some upstream movement of oil in the water column with the tide. The subsurface oil reached New York Harbor in spring and winter. The oil was well diluted in the lower river near the southern extent of the floating oil. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for effects on fish and invertebrates. These higher dissolved concentrations extended in patchy distributions as far south as New York Harbor in spring and as far as the Newburgh area in winter, but were localized near Kingston in summer.

Table 21: Shoreline Length Oiled for Rondout 75,421-bbl Bakken Crude Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	18.4	17.3	16.1	15.9	20.8	21.1
Unconsolidated Rock	71.6	67.9	45.7	49.7	88.3	86.9
Sand or Sand with Brick	0.0	0.1	2.2	2.2	0.8	1.3
Mud, Mixed Mud-Sand, Timber Edge	6.4	6.7	19.8	23.1	11.5	10.9
Saltmarsh (*Spartina* spp.)	0.1	0.3	3.4	4.0	1.1	1.0
Upper Intertidal Mix	7.7	7.5	14.5	14.8	8.4	8.3
Lower Intertidal Mix	1.8	1.8	2.5	3.0	2.2	2.0
Phragmites australis	0.6	0.7	0.2	0.2	0.5	0.0
Sheet Pile, Concrete, or Other	16.0	13.3	3.6	3.9	5.4	5.6
Scrub/Shrub or Forested Wetland	0.3	0.3	0.4	0.4	0.3	0.3
Total Shoreline	**122.9**	**115.8**	**108.4**	**117.1**	**139.3**	**137.3**

Off Rondout Creek–14,000 bbl Heavy Fuel Oil

Table 22 and Figure 35 through Figure 37 summarize the mass balance for the Kingston Rondout Creek heavy fuel oil spill scenario. As only a small percentage of heavy fuel oil is comprised of volatile or soluble hydrocarbons, most of the oil remains floating until it goes ashore. A small percentage of the heavy fuel oil evaporates, and some of the stranded oil degrades by 30 days after the spill. Little oil reaches the sediments because it is too viscous to be entrained into the water where it might combine with suspended particulate matter and subsequently settle.

Map figures showing floating, water column, sediment and shoreline oil exposures are in Appendix C6. Floating oil from the spring spills were transported down river, reaching the farthest (New York Harbor) when spilled at high tide and just north of the George Washington Bridge after 28 days when spilled at low tide. In contrast, in the summer, Heavy fuel oil was blown upstream past Saugerties after 28 days when spilled at high tide, but transported even farther upstream (closer to the Catskills) when spilled at low tide. In winter, oil spilled was initially (in the first few days) transported upstream and downstream but after 28 days, the floating oil was past Newburgh when spilled at high tide and even further downstream (closer to West Point) when spilled at low tide in the 30-day simulations.

The sediment contamination from these heavy fuel oil spills was very low because for the most part the highly viscous fuel oil remained floating and went ashore, as opposed to being mixed into the water where it could bind with suspended particulate matter and settle. Water column concentrations were very low, because any oil not surfacing and remaining in the water column combined with SPM and settled. In spring and winter, the sediment oil contamination was spread out along the river and patchy. In summer, the sediment oil contamination was more localized, but very low in concentration.

Table 23 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Most of the spilled heavy fuel oil goes ashore in this scenario. Shoreline oiling is similar in summer and winter, and more extensive in spring where the higher flow carries the oil downstream farther.

Table 22: Mass Balance Summary: Rondout 14,000-bbl Heavy Fuel Oil Spills[37]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	1.8%	5.7%	0.0%	0.0%	70.3%	22.2%	0.0%
Spring Low Tide	1.2%	5.7%	0.0%	0.0%	70.8%	22.2%	0.0%
Summer High Tide	17.1%	6.4%	0.0%	0.0%	54.4%	22.2%	0.0%
Summer Low Tide	18.2%	6.4%	0.0%	0.0%	53.2%	22.2%	0.0%
Winter High Tide	5.1%	3.6%	0.0%	0.0%	68.9%	22.4%	0.0%
Winter Low Tide	4.8%	3.6%	0.0%	0.0%	69.2%	22.4%	0.0%

[37] At the end of 30-day model simulation.

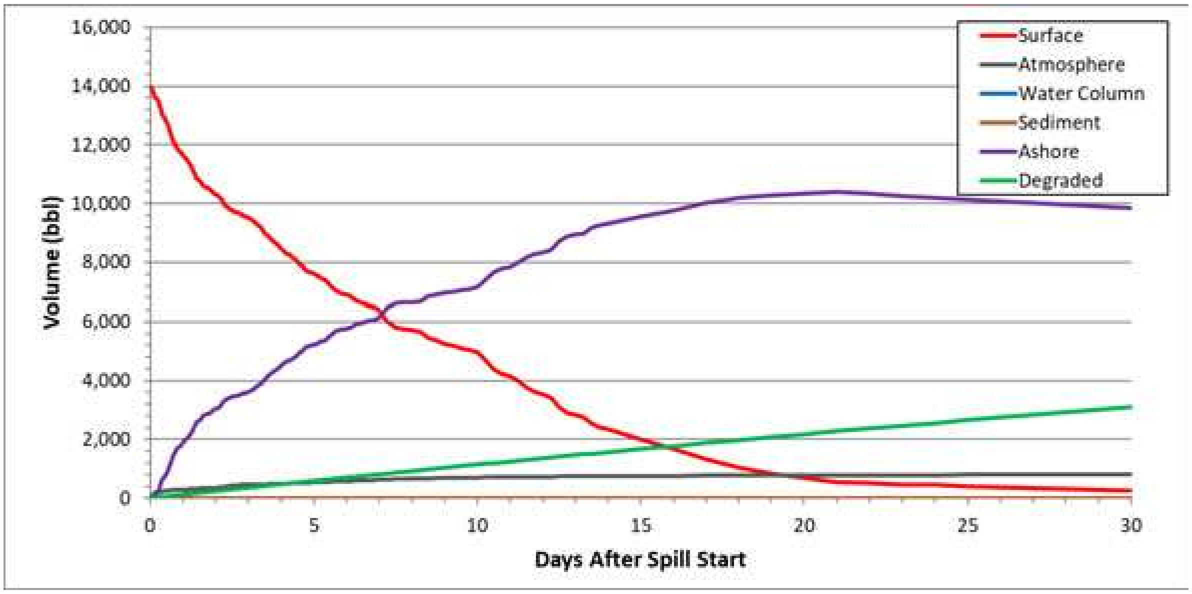

Figure 35: Amount of Oil in Different Environmental Compartments over Time: Rondout–14,000 bbl Heavy Fuel Oil–Spring–High Tide

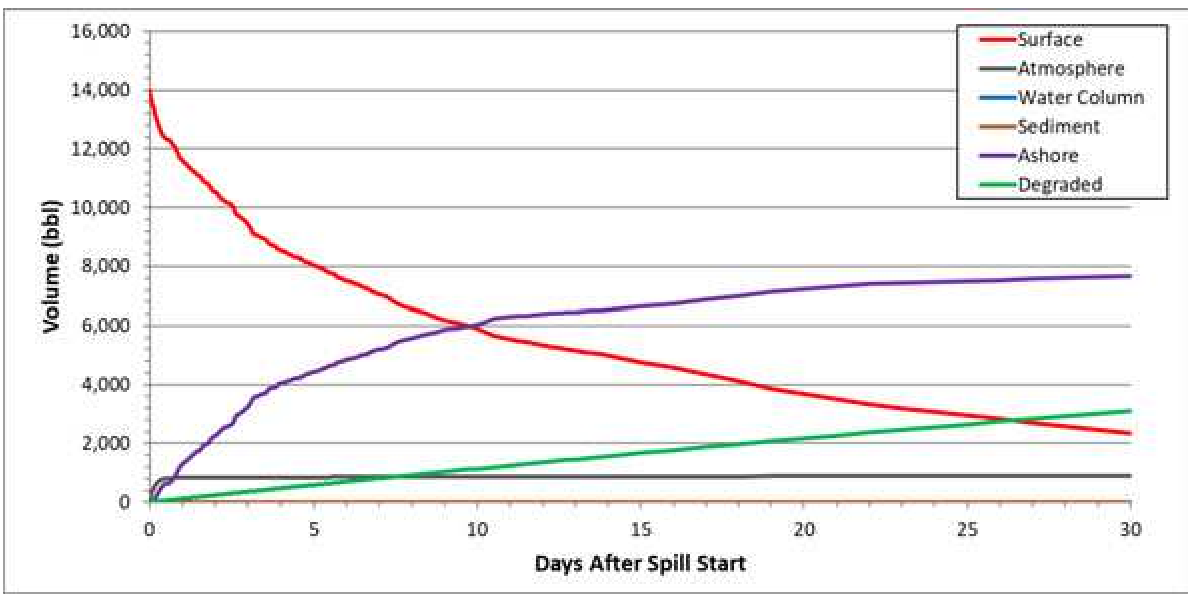

Figure 36: Amount of Oil in Different Environmental Compartments over Time: Rondout–14,000 bbl Heavy Fuel Oil–Summer–High Tide

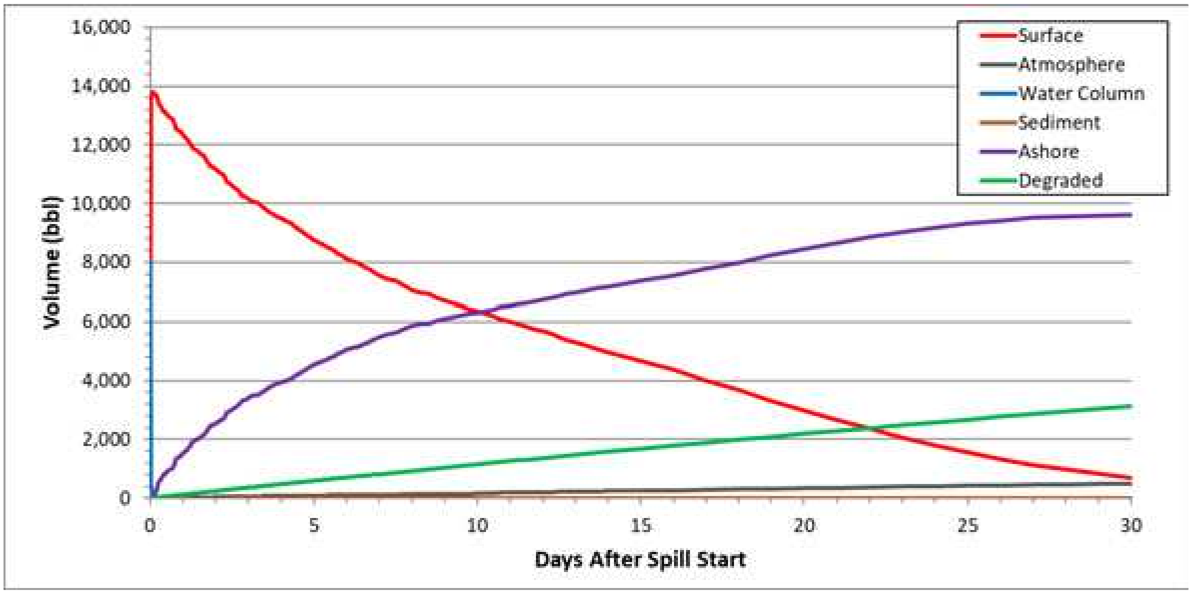

Figure 37: Amount of Oil in Different Environmental Compartments over Time: Rondout–14,000 bbl Heavy Fuel Oil–Winter–High Tide

Table 23: Shoreline Length Oiled for Rondout 14,000-bbl Heavy Fuel Oil Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	18.7	19.4	14.1	12.9	12.1	12.3
Unconsolidated Rock	77.9	78.3	32.3	31.4	50.0	48.8
Sand or Sand with Brick	0.0	0.1	2.2	2.2	0.5	1.0
Mud, Mixed Mud-Sand, Timber Edge	6.8	7.5	10.7	11.6	6.5	7.4
Saltmarsh (*Spartina* spp.)	0.4	0.5	2.2	1.7	0.2	0.3
Upper Intertidal Mix	7.0	7.3	8.5	8.7	3.8	4.0
Lower Intertidal Mix	2.1	2.2	0.5	0.5	1.5	1.5
Phragmites australis	0.0	0.0	0.0	0.0	0.0	0.0
Sheet Pile, Concrete, or Other	11.5	9.4	2.6	2.6	3.7	3.8
Scrub/Shrub or Forested Wetland	0.3	0.3	0.3	0.3	0.3	0.3
Total Shoreline	**124.6**	**124.9**	**73.4**	**71.8**	**78.5**	**79.4**

Newburgh Waterfront–11,000 bbl Bakken Crude

Table 24 and Figure 38 through Figure 40 summarize the mass balance for the Newburgh waterfront Bakken crude spill scenario. Except for the spring-low tide scenario, ~40-50% of the spilled Bakken crude evaporated, and most of the remaining oil was entrained into the water column, where some of it dissolved and degraded by 30 days after the release. For spring spills, much of the oil was transported within the water column into New York Harbor and, because of this and especially when spilled at low tide, a smaller percentage evaporated or came ashore compared to the other seasons. None of the non-volatile fraction remained floating over the 30-day simulation and less than 1% reached the sediment across all seasons. The percentage going ashore ranged from 4 to 40%, partially the result of variable wind conditions.

Map figures showing floating, water column, sediment and shoreline oil exposures are in Appendix C7. Floating oil from the spring spills was transported down river, reaching New York Harbor as early as 14 days after the spill for both high and low tide spills. In contrast, in the summer, when spilled at high tide Bakken oil was contained close to Newburgh (in the northern extent) but floated downstream to Bear Mountain Bridge after 7 days; whereas when spilled at low tide the oil was transported even farther upstream (closer to Hyde Park) but only downstream to West Point. In winter, spilled oil was initially (in the first few days) transported upstream and downstream but after 28 days, the floating oil reached the Tappan Zee, when spilled at high tide, but not quite as far downstream, when spilled at low tide, in the 30-day simulations.

Table 25 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Because strong river flows carried floating oil a long distance downstream in spring and winter, the shore oiling is extensive in those seasons for spills at any stage of the tide. In summer, floating oil and shoreline exposures also occur over a considerable distance both up and downstream.

Table 24: Mass Balance Summary: Newburgh 11,000-bbl Bakken Crude Spills[38]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	0.1%	42.3%	6.3%	0.2%	8.6%	7.6%	35.0%
Spring Low Tide	0.0%	25.9%	7.5%	0.4%	4.2%	13.5%	48.4%
Summer High Tide	0.0%	50.7%	23.9%	0.0%	22.5%	2.8%	0.0%
Summer Low Tide	0.0%	50.7%	26.2%	0.1%	20.1%	3.0%	0.0%
Winter High Tide	0.0%	44.2%	11.9%	0.2%	39.3%	4.4%	0.0%
Winter Low Tide	0.0%	43.9%	12.2%	0.0%	39.0%	4.9%	0.0%

[38] At the end of 30-day model simulation.

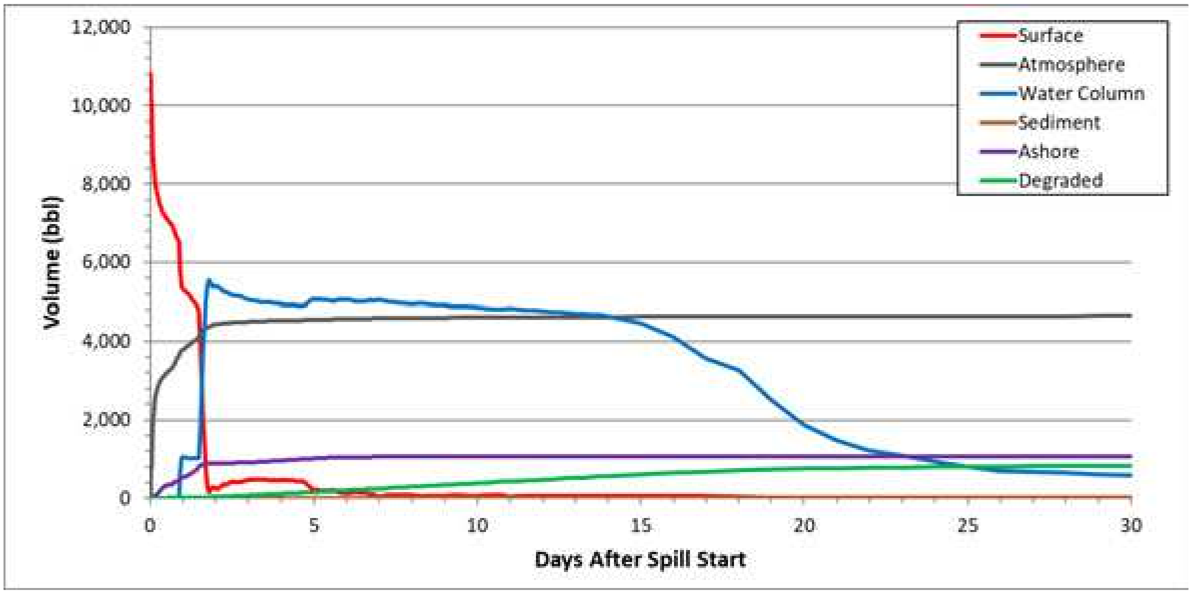

Figure 38: Amount of Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Spring–High Tide

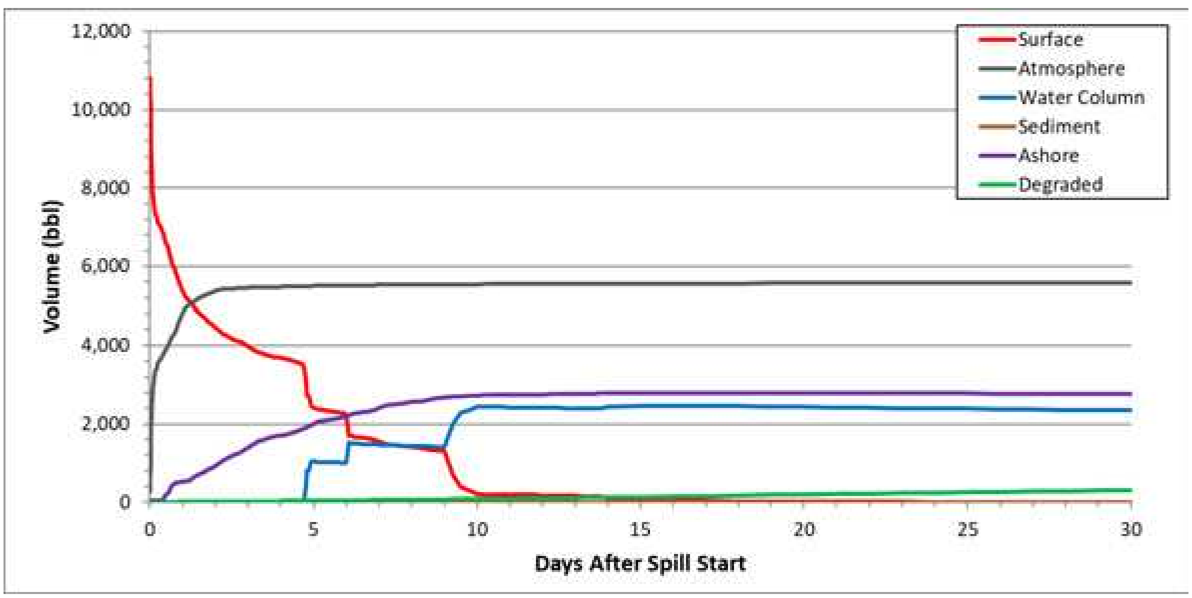

Figure 39: Amount of Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Summer–High Tide

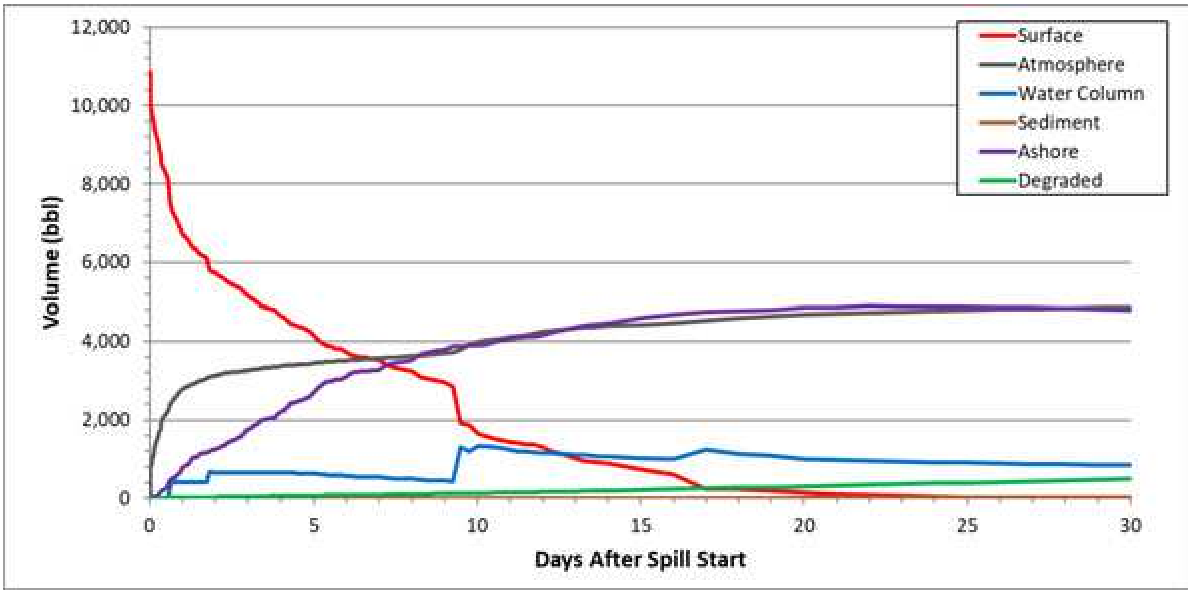

Figure 40: Amount of Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Winter–High Tide

Table 25: Shoreline Length Oiled for Newburgh 11,000-bbl Bakken Crude Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	8.7	6.8	5.2	2.8	9.3	9.3
Unconsolidated Rock	36.4	31.4	39.6	39.7	44.7	43.7
Sand or Sand with Brick	0.0	0.0	0.0	0.0	0.0	0.0
Mud, Mixed Mud-Sand, Timber Edge	3.4	5.3	3.2	2.7	5.4	4.1
Saltmarsh (*Spartina* spp.)	0.3	0.1	0.1	0.0	0.1	0.1
Upper Intertidal Mix	0.8	0.4	3.4	3.2	1.2	1.7
Lower Intertidal Mix	0.0	0.1	0.3	1.0	0.0	0.0
Phragmites australis	0.7	0.2	0.0	0.0	0.0	0.0
Sheet Pile, Concrete, or Other	42.8	28.3	2.3	2.2	3.0	2.9
Scrub/Shrub or Forested Wetland	0.0	0.0	0.0	0.1	0.0	0.0
Total Shoreline	**93.2**	**72.5**	**54.0**	**51.6**	**63.8**	**61.7**

Contamination in the sediments extended over similar portions of the river as exposed to floating oil. Concentrations of the spilled oil in the sediment were low, as its settling was spread out along the river.

Moderate concentrations of oil droplets in the water column were swept well downstream of the spill site to New York Harbor, except during the summer when the subsurface oil extended north to Kingston and south to the Tappan Zee area. There was some upstream movement of oil in the water column with the tide. The oil was well diluted in the lower river near the southern extent of the floating oil. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for potential effects on fish and invertebrates. These higher dissolved concentrations were patchy in distribution, and primarily in the Newburgh area. In summer, dissolved concentrations were very low, owing to the smaller spill size (than other spills examined herein) and low turbulence with which to mix oil into the water column.

Bear Mountain Bridge–2,500 bbl Home Heating Oil

Table 26 and Figure 41 through Figure 43 summarize the mass balance for the Bear Mountain Bridge home heating oil spill scenario. The majority (>56%) of the spilled home heating oil evaporated, and most of the remaining oil was entrained into the water column, where some of it dissolved and degraded by 30 days after the release. In spring, more oil mass entered the water column than in other seasons, but much of this entrained oil was swept downstream into New York Harbor. What remained in the water column in the river readily degraded (between 4 to 11% of the spilled oil). With the exception of the spring scenario at low tide, where little shoreline oiling occurred because the oil was rapidly swept downstream, 16-20% of the home heating oil washed ashore.

Table 26: Mass Balance Summary: Bear Mountain 2,500-bbl Home Heating Oil Spills[39]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	0.0%	67.8%	1.3%	0.7%	15.7%	4.3%	10.2%
Spring Low Tide	0.0%	55.7%	5.4%	2.4%	1.3%	10.8%	24.3%
Summer High Tide	0.002%	73.8%	3.6%	0.1%	20.0%	2.6%	0.0%
Summer Low Tide	0.0004%	70.1%	7.2%	0.1%	18.9%	3.6%	0.0%
Winter High Tide	0.005%	65.9%	6.8%	0.5%	19.4%	6.9%	0.6%
Winter Low Tide	0.1%	66.0%	7.4%	0.6%	17.6%	7.4%	1.0%

[39] At the end of 30-day model simulation.

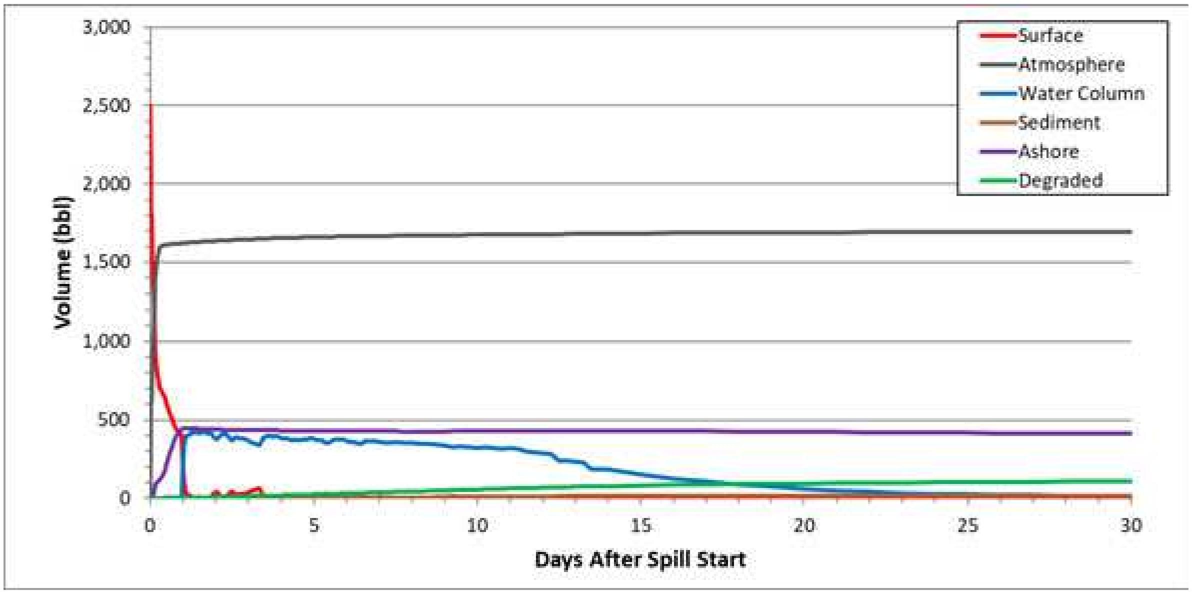

Figure 41: Amount of Oil in Different Environmental Compartments over Time: Bear Mountain–2,500 bbl Home Heating Oil–Spring–High Tide

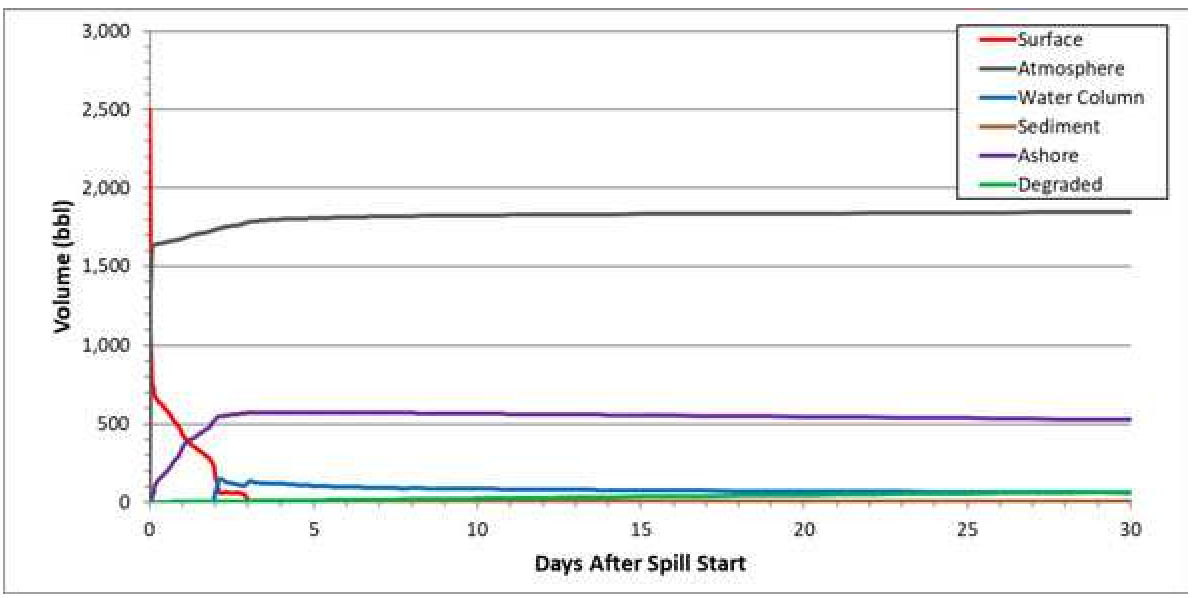

Figure 42: Amount of Oil in Different Environmental Compartments over Time: Bear Mountain–2,500 bbl Home Heating Oil–Summer–High Tide

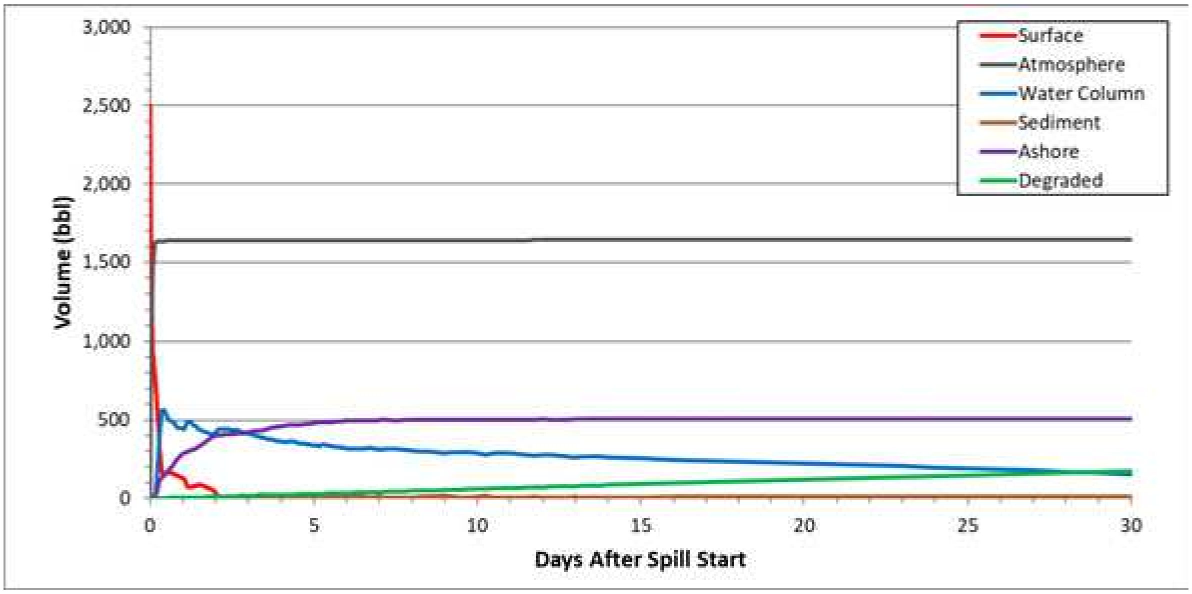

Figure 43: Amount of Oil in Different Environmental Compartments over Time: Bear Mountain–2,500 bbl Home Heating Oil–Winter–High Tide

Map figures showing floating, water column, sediment and shoreline oil exposures are in Appendix C8. Floating oil from the spring spills at both high and low tide was transported down river, reaching New York Harbor by 14 days after the spill. Considerable oil was trapped in the marsh behind Iona Island. In summer, down-river transport was slower and less oil was trapped in the Iona Island marsh because the inflow was slower. The winter spill trajectories appear similar to the spring trajectories, the river flow being almost as strong.

Table 27 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Because the tides and river flows carried floating oil a considerable distance, the shore oiling extends 34-56 miles, regardless of season. Due the strong curves in the river, as well as the presence of the Iona marsh, just south of the bridge, the shoreline oiling depended on the particular timing of the spill relative to the tidal flows.

Table 27: Shoreline Length Oiled for Bear Mountain 2,500-bbl Home Heating Oil Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	4.9	3.2	6.1	8.3	6.3	6.0
Unconsolidated Rock	16.6	8.5	31.9	27.4	22.1	24.5
Sand or Sand with Brick	0.0	0.2	0.4	0.0	0.0	0.0
Mud, Mixed Mud-Sand, Timber Edge	2.2	1.2	7.1	3.2	2.1	3.6
Saltmarsh (*Spartina* spp.)	0.4	0.5	0.0	0.0	0.3	0.3
Upper Intertidal Mix	0.3	0.0	0.7	0.2	0.2	0.3

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Lower Intertidal Mix	0.0	0.0	0.2	0.2	0.0	0.1
Phragmites australis	0.0	1.1	0.0	0.0	0.2	0.1
Sheet Pile, Concrete, or Other	30.7	19.2	2.9	1.7	17.1	21.1
Scrub/Shrub or Forested Wetland	0.0	0.0	0.0	0.0	0.0	0.0
Total Shoreline	**55.1**	**33.9**	**49.3**	**41.1**	**48.3**	**56.0**

Table 27: Shoreline Length Oiled for Bear Mountain 2,500-bbl Home Heating Oil Spills

Contamination in the sediments extended over similar portions of the river as exposed to floating oil. Concentrations of the spilled oil in the sediment were low in most areas, as its settling was spread out along the river. However, in spring, oil entered Iona marsh, leading to considerable contamination in the sediments of that wetland complex. After the summer spill at high tide, oil entered Annsville Creek and considerable sedimentation occurred in that inlet. Similarly, after the winter spills, oil entered Dicky Brook and other wetlands just north of Indian Point, contaminating the sediments in those inlets.

Moderate concentrations of oil droplets in the water column were swept well downstream of the spill site to New York Harbor, except during the summer when the subsurface oil extended southward to the Tappan Zee. The oil was well diluted in the lower river near the southern extent of the floating oil. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for potential effects on fish and invertebrates. In all seasons, these higher dissolved concentrations were patchy in distribution, and primarily in and just south of the Bear Mountain area.

Iona Island–11,000 bbl Bakken Crude

Table 28 and Figure 44 through Figure 46 summarize the mass balance for the Newburgh waterfront Bakken crude spill scenario. About half of the spilled Bakken crude evaporated, and much of the remaining oil was entrained into the water column, where some of it dissolved and degraded by 30 days after the release (Table 28). For the high tide spill in the spring (Figure 44), some of the oil that entered the water column was swept downstream into New York Harbor. Much of the oil spilled at low tide in the spring entered Iona marsh and settled to the sediments (Figure 45). Less of the oil was entrained into the water column in winter than in summer, due to the ice cover (Figure 46 and Figure 47). The percentage of oil going ashore varies from 1 to 17% based on the season, reflecting the amount of oil that had remained floating in the river.

Table 28: Mass Balance Summary: Iona Island 11,000-bbl Bakken Crude Spills[40]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	0.0%	50.6%	6.8%	5.4%	8.2%	4.5%	24.5%
Spring Low Tide	0.0%	42.3%	6.1%	39.2%	1.3%	4.4%	6.6%
Summer High Tide	0.0%	53.0%	31.5%	0.3%	12.1%	3.0%	0.0%
Summer Low Tide	0.0%	52.5%	32.9%	0.6%	10.6%	3.3%	0.0%
Winter High Tide	0.0%	50.4%	21.7%	3.6%	16.7%	6.6%	1.1%
Winter Low Tide	0.0%	50.4%	21.1%	3.6%	17.2%	6.4%	1.3%

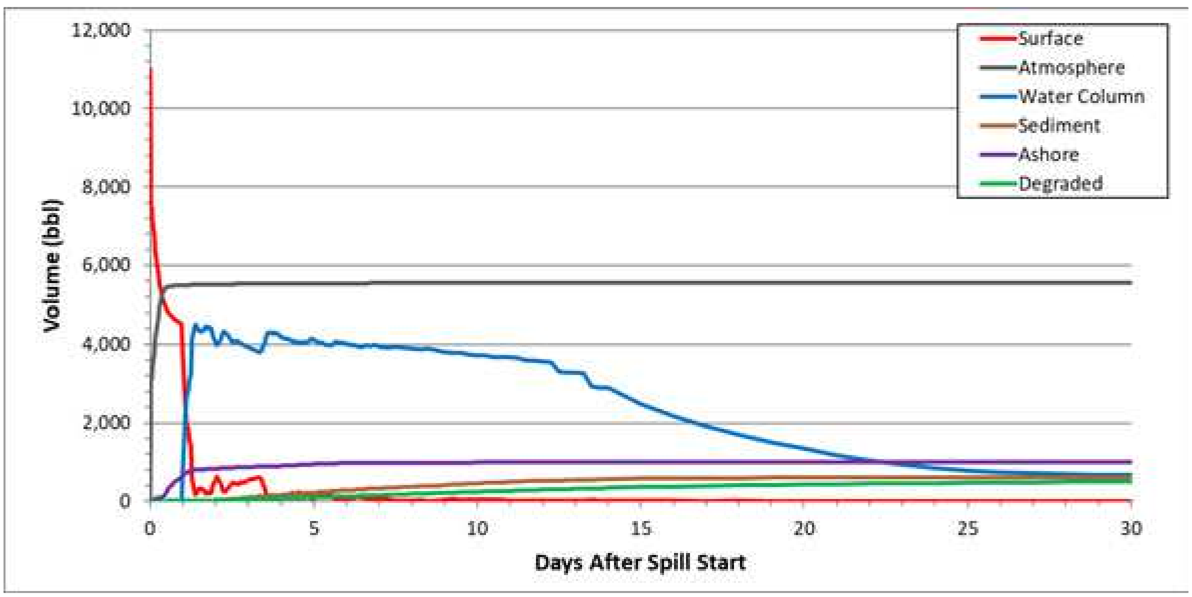

Figure 44: Amount of Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Spring–High Tide

[40] At the end of 30-day model simulation.

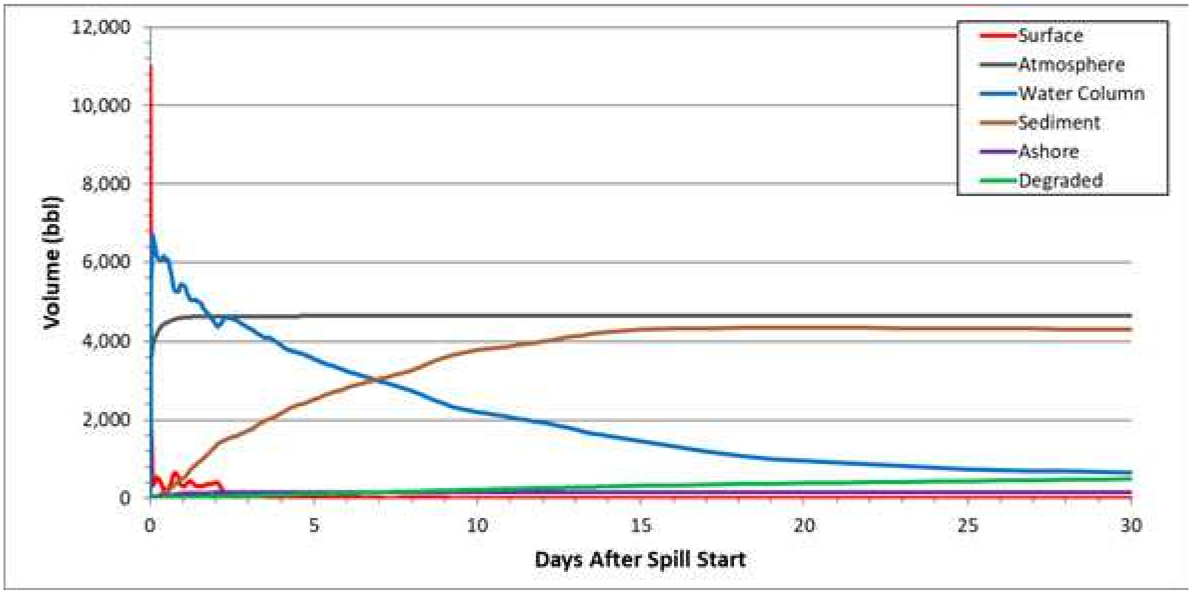

Figure 45: Amount of Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Spring–Low Tide

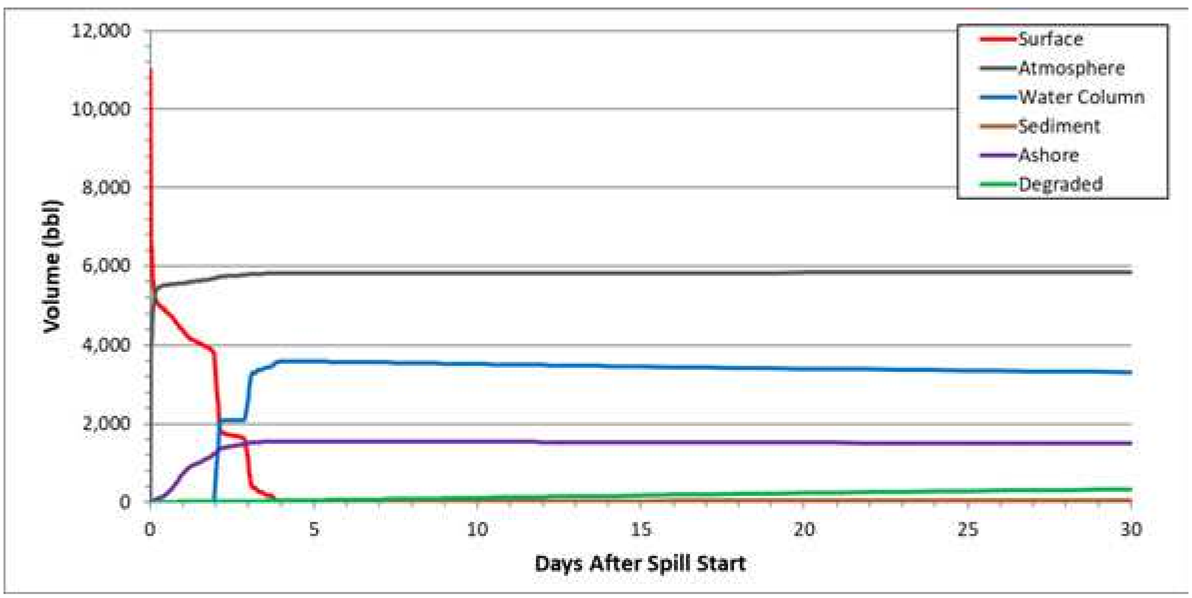

Figure 46: Amount of Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Summer–High Tide

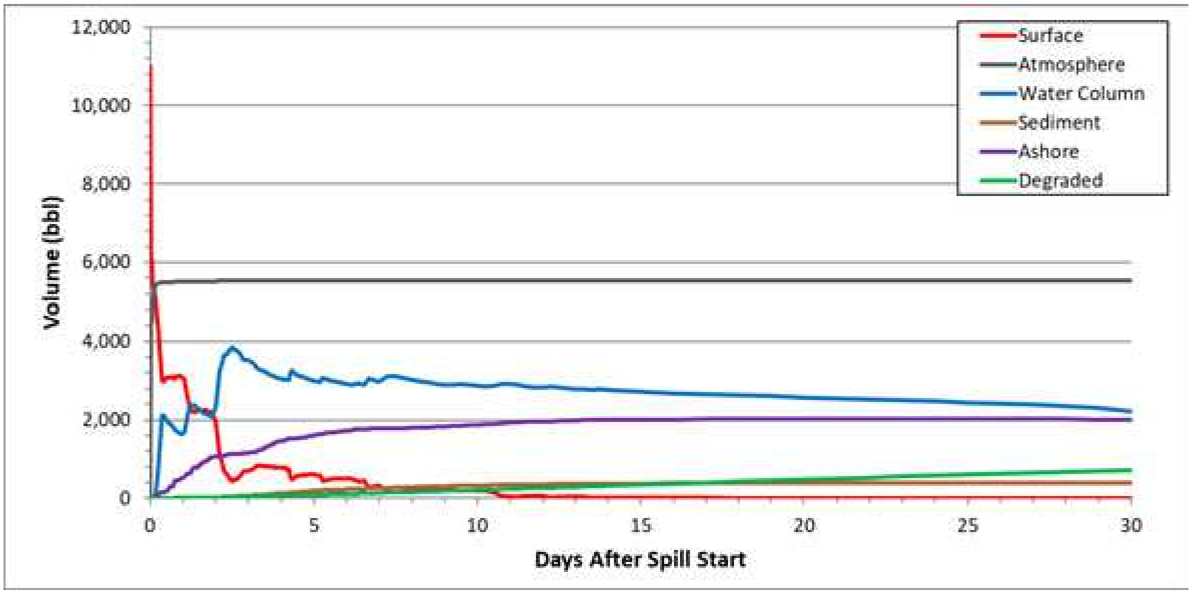

Figure 47: Amount of Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Winter–High Tide

Map figures showing floating, water column, sediment and shoreline oil exposures are in Appendix C9. Floating oil from the spring spill at high tide was transported down river, reaching New York Harbor by 14 days after the spill whereas when spilled at low tide floating oil was only transported downstream to the Tappan Zee after 14 days. By 21+ days after the spill at low tide, the majority of the floating oil entrained, resulting in floating oil only near Iona Island. In summer, down-river transport was much slower and less extensive. The down-river extents of the winter spill trajectories were intermediate to the spring and summer trajectories. In all seasons, much of the oil was trapped in the Iona Island marsh.

Contamination in the sediments extended over similar portions of the river as exposed to floating oil. Concentrations of the spilled oil in the sediment were low in most areas, as its settling was spread out along the river. In spring and in winter, large amounts of oil entered Iona marsh, leading to considerable contamination in the sediments of that wetland complex. However, after the summer spills there was little river flow into the Iona marsh area and therefore less oil reached the sediment in the wetlands there.

Table 29 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Due the strong curves in the river near the spill site, as well as the presence of the Iona marsh, the shoreline oiling depended on the particular timing of the spill relative to the tidal flows. Note that the shoreline oiling includes only the edge of the wetlands oiled. The majority of the area of Iona marsh that was oiled in winter and spring was flooded, and therefore not counted as "shoreline" length oiled. The oil in the flooded areas entered the sediments, as shown in the sediment contamination figure. A spill of 11,000 bbl of Bakken crude at Iona marsh would be expected to oil ~20 to over 100 miles of shoreline, depending upon the season, as well as the Iona marsh area.

Table 29: Shoreline Length Oiled for Iona Island 11,000-bbl Bakken Crude Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	5.9	3.2	7.1	7.6	9.2	8.9
Unconsolidated Rock	31.2	8.9	24.4	23.0	37.1	37.4
Sand or Sand with Brick	0.4	0.2	0.0	0.0	0.2	0.2
Mud, Mixed Mud-Sand, Timber Edge	4.7	1.0	6.4	6.4	6.7	6.1
Saltmarsh (*Spartina* spp.)	0.9	0.4	0.1	0.0	0.3	0.3
Upper Intertidal Mix	0.4	0.0	0.3	0.3	0.9	0.6
Lower Intertidal Mix	0.0	0.0	0.2	0.2	0.0	0.1
Phragmites australis	1.7	1.5	0.3	0.4	1.6	1.6
Sheet Pile, Concrete, or Other	66.8	9.1	1.4	1.5	13.9	14.3
Scrub/Shrub or Forested Wetland	0.0	0.0	0.0	0.0	0.0	0.0
Total Shoreline	**112.0**	**24.2**	**40.2**	**39.3**	**69.8**	**69.4**

Moderate concentrations of oil droplets in the water column were swept well downstream of the spill site to New York Harbor, except during the summer when the subsurface oil extended southward to the Tappan Zee. The oil was well diluted in the lower river near the southern extent of the floating oil. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for potential effects on fish and invertebrates. In all seasons, these higher dissolved concentrations were patchy in distribution, and primarily in and just south of the Bear Mountain area.

Tappan Zee–2,500 bbl Home Heating Oil

Table 30 and Figure 48 through Figure 50 summarize the mass balance for the Tappan Zee home heating oil spill scenario. The majority (>66%) of the spilled home heating oil evaporated, and most of the remaining oil was entrained into the water column, where some of it dissolved and degraded by 30 days after the release. In spring and winter, entrained and dissolved oil was transported into New York Harbor. In summer, evaporation is faster with higher temperature therefore the percentage evaporated and dissolved was higher than the other seasons. Also, river flow is lowest in summer and little of the oil reached New York Harbor.

Table 30: Mass Balance Summary: Tappan Zee 2,500-bbl Home Heating Oil Spills[41]							
Scenario	**Surface**	**Atmosphere**	**Water Column**	**Sediment**	**Ashore**	**Degraded**	**Entered NY Harbor**
Spring High Tide	0.0%	65.9%	2.6%	0.6%	0.9%	4.8%	25.1%
Spring Low Tide	0.0%	68.9%	1.4%	0.5%	1.2%	4.4%	23.5%
Summer High Tide	0.0%	79.0%	12.6%	0.2%	4.0%	4.2%	0.0%
Summer Low Tide	0.0%	75.9%	13.2%	0.2%	6.1%	4.7%	0.0%
Winter High Tide	0.0%	66.2%	5.3%	1.5%	5.4%	9.3%	12.2%
Winter Low Tide	0.0%	66.3%	5.0%	1.4%	7.0%	9.1%	11.2%

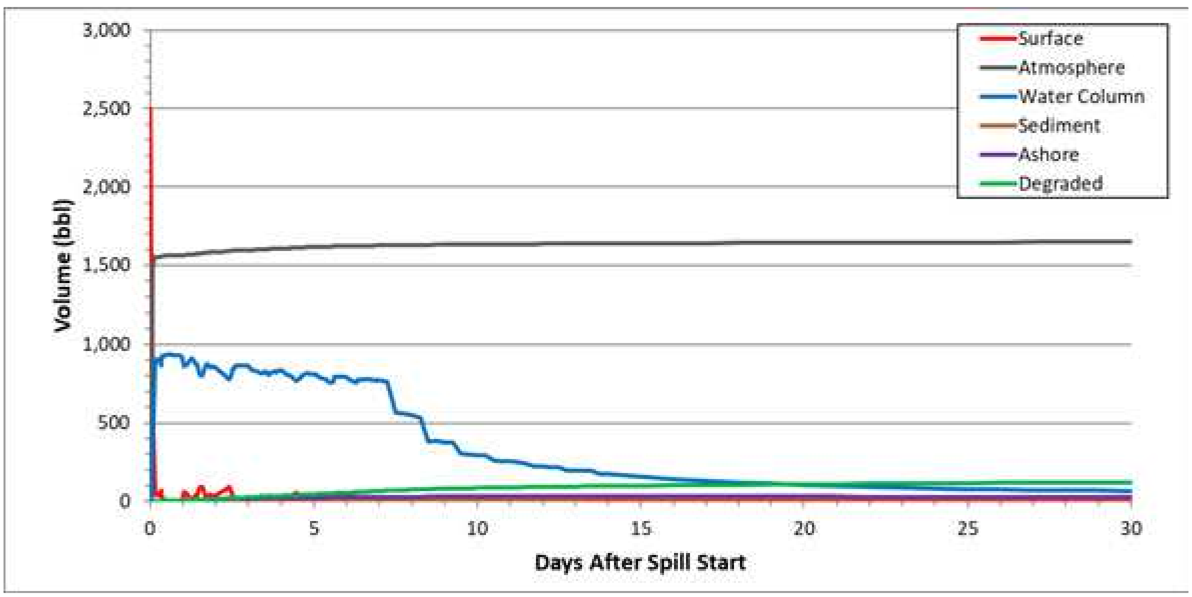

Figure 48: Amount of Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Spring–High Tide

[41] At the end of 30-day model simulation.

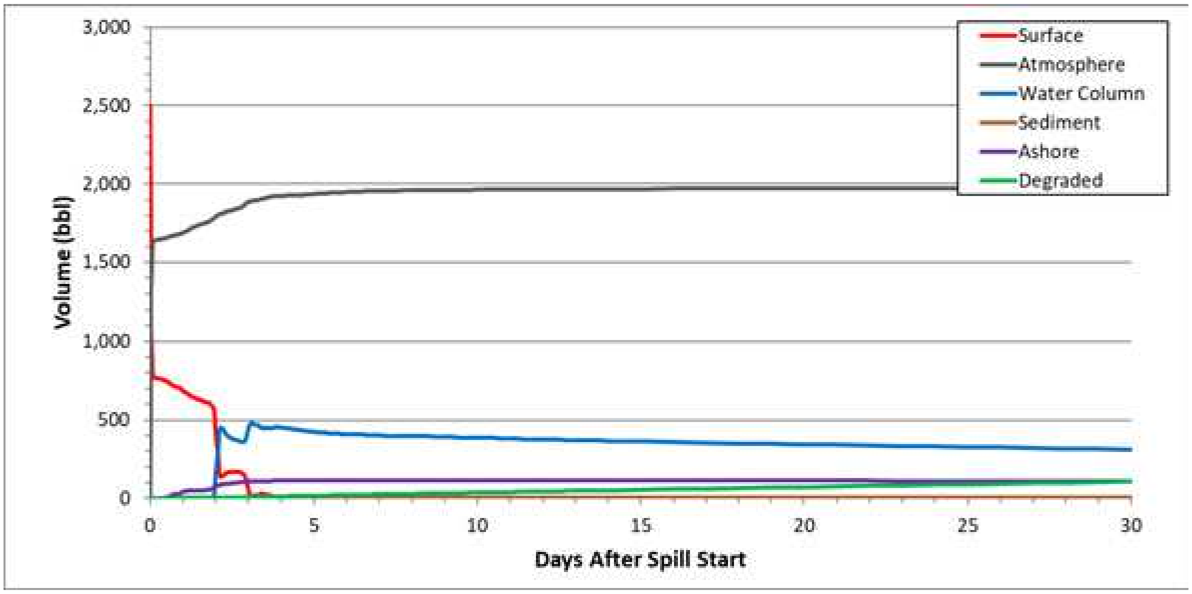

Figure 49: Amount of Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Summer–High Tide

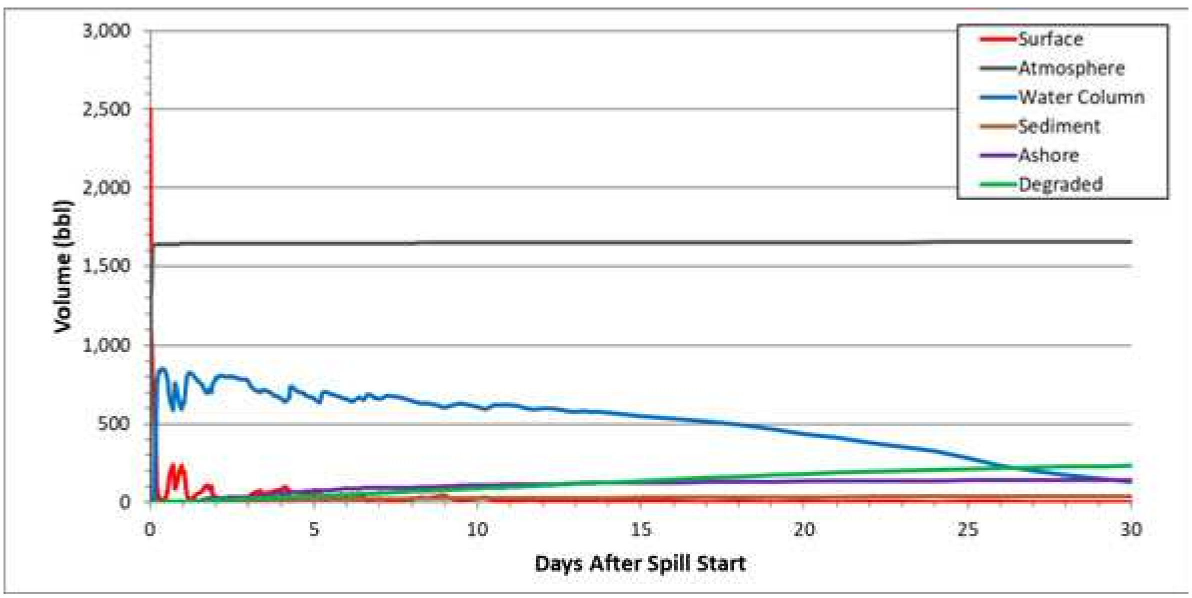

Figure 50: Amount of Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Winter–High Tide

Map figures showing floating, water column, sediment and shoreline oil exposures are in Appendix C10. Floating oil from the spring spills at both high and low tide were transported down river, reaching New York Harbor before 7 days. In summer, down-river transport was much slower and less extensive in fact after 28 days the oil was patchy and discontinuous north of the release site at both high and low tide. The down-river extents of the winter spill trajectories, at low tide, reached the New York Harbor by 7 days and 14 days (following the release) for both high tide and low tide, respectively.

Table 31 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Because strong river flows carried floating oil a considerable distance downstream in spring and winter, the shore oiling extends 45-60 miles in those seasons. In summer, floating oil and shoreline exposures also occur over a considerable distance (16-21 miles) both up and downstream.

Table 31: Shoreline Length Oiled for Tappan Zee 2,500-bbl Home Heating Oil Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	0.0	0.0	0.2	0.2	0.1	0.1
Unconsolidated Rock	0.2	0.2	8.7	9.1	2.4	3.1
Sand or Sand with Brick	0.0	0.0	0.0	0.0	0.0	0.0
Mud, Mixed Mud-Sand, Timber Edge	0.1	0.2	1.2	1.2	0.3	0.3
Saltmarsh (*Spartina* spp.)	0.5	0.8	0.0	0.0	0.6	0.6
Upper Intertidal Mix	0.0	0.0	0.1	0.6	0.0	0.0
Lower Intertidal Mix	0.0	0.0	0.0	0.0	0.0	0.0
Phragmites australis	0.0	0.0	0.0	0.0	0.0	0.0
Sheet Pile, Concrete, or Other	45.3	54.0	10.6	4.8	56.3	50.0
Scrub/Shrub or Forested Wetland	0.0	0.0	0.0	0.0	0.0	0.0
Total Shoreline	**46.0**	**55.2**	**20.7**	**15.8**	**59.6**	**54.1**

Contamination in the sediments extended over similar portions of the river as exposed to floating oil. Concentrations of the spilled oil in the sediment were low, as oil settling was spread out along the river. In winter, there was more sediment contamination near the east side of the river due to northwesterly winds mixing the fuel into shallow water where the oil combined with suspended particulate matter.

Moderate concentrations of oil droplets in the water column were swept well downstream of the spill site to New York Harbor, except during the summer when the subsurface oil remained closer to the Tappan Zee. The oil was well diluted in the lower river near the southern extent of the floating oil. Some of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for potential effects on fish and invertebrates. In all seasons, these higher dissolved concentrations were patchy in distribution, and primarily in and just north and south of the Tappan Zee area.

Tappan Zee–50 bbl Heavy Fuel Oil

Table 32 and Figure 51 through Figure 53summarize the mass balance for the Tappan Zee heavy fuel oil spill scenario. As only a small percentage of heavy fuel oil is comprised of volatile or soluble hydrocarbons, most of the oil remained floating until it went ashore. A small percentage of the heavy fuel oil evaporated, and some of the stranded oil degraded by 30 days after the spill. Little oil reached the sediments because the oil is too viscous to be entrained into the water where it might combine with suspended particulate matter and subsequently settle.

Table 32: Mass Balance Summary: Tappan Zee 50-bbl Home Heating Oil Spills[42]

Scenario	Surface	Atmosphere	Water Column	Sediment	Ashore	Degraded	Entered NY Harbor
Spring High Tide	0.0%	8.7%	0.0%	0.0%	69.2%	22.1%	0.0%
Spring Low Tide	0.0%	8.2%	0.0%	0.0%	69.6%	22.1%	0.0%
Summer High Tide	0.0%	8.6%	0.0%	0.0%	69.4%	22.1%	0.0%
Summer Low Tide	0.0%	8.1%	0.0%	0.0%	69.8%	22.1%	0.0%
Winter High Tide	0.0%	6.1%	0.0%	0.0%	71.7%	22.2%	0.0%
Winter Low Tide	0.0%	6.1%	0.0%	0.0%	71.7%	22.2%	0.0%

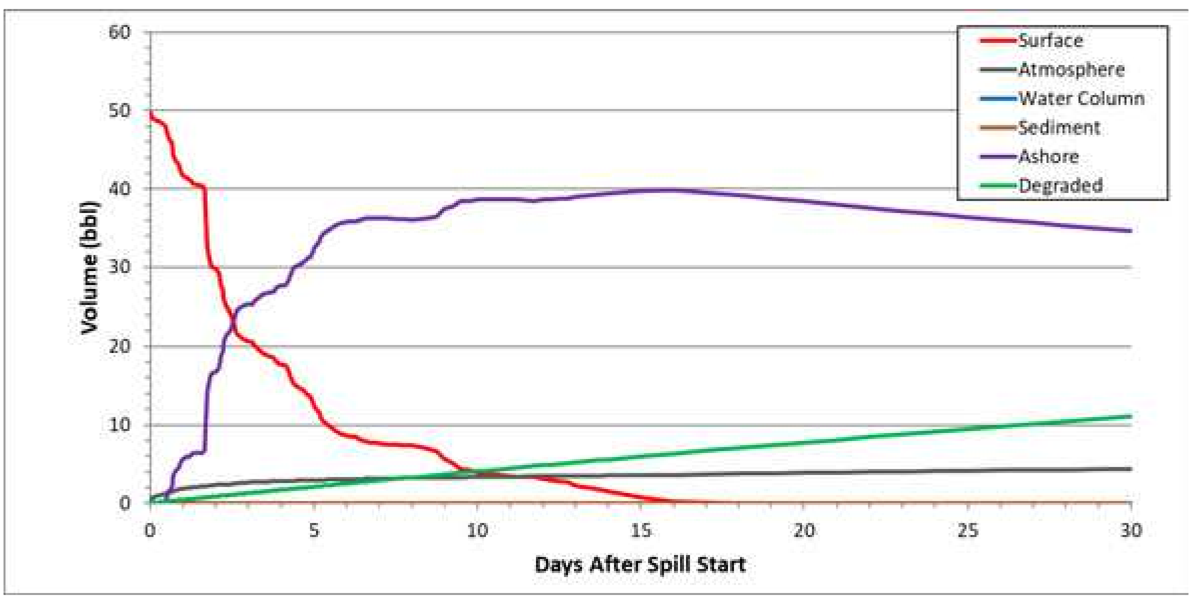

Figure 51: Amount of Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Spring–High Tide

[42] At the end of 30-day model simulation.

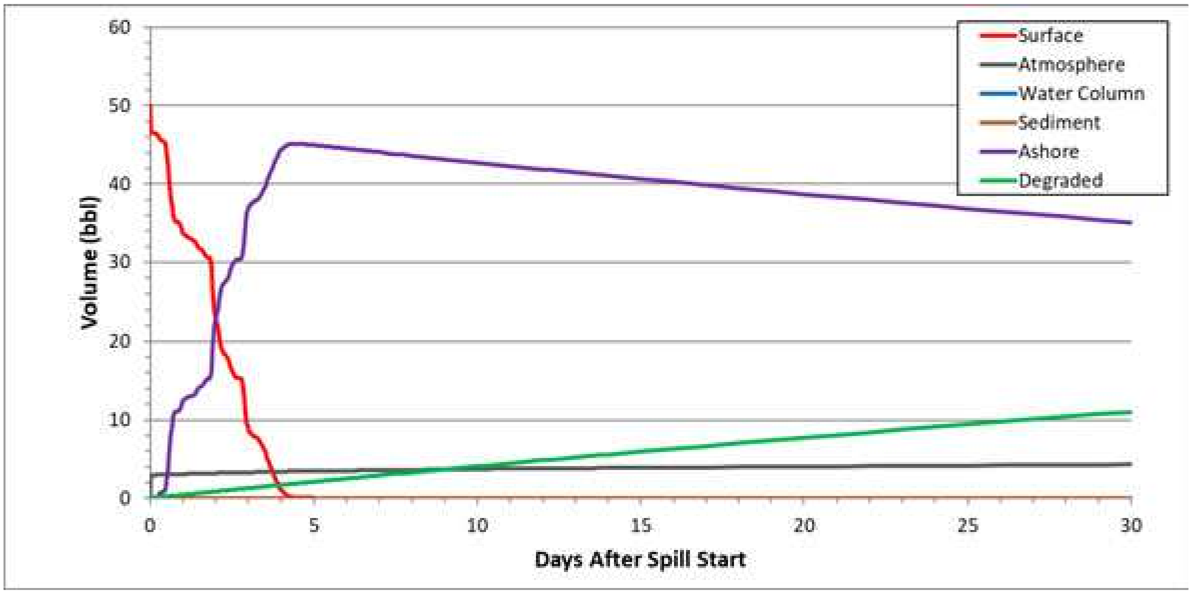

Figure 52: Amount of Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Summer–High Tide

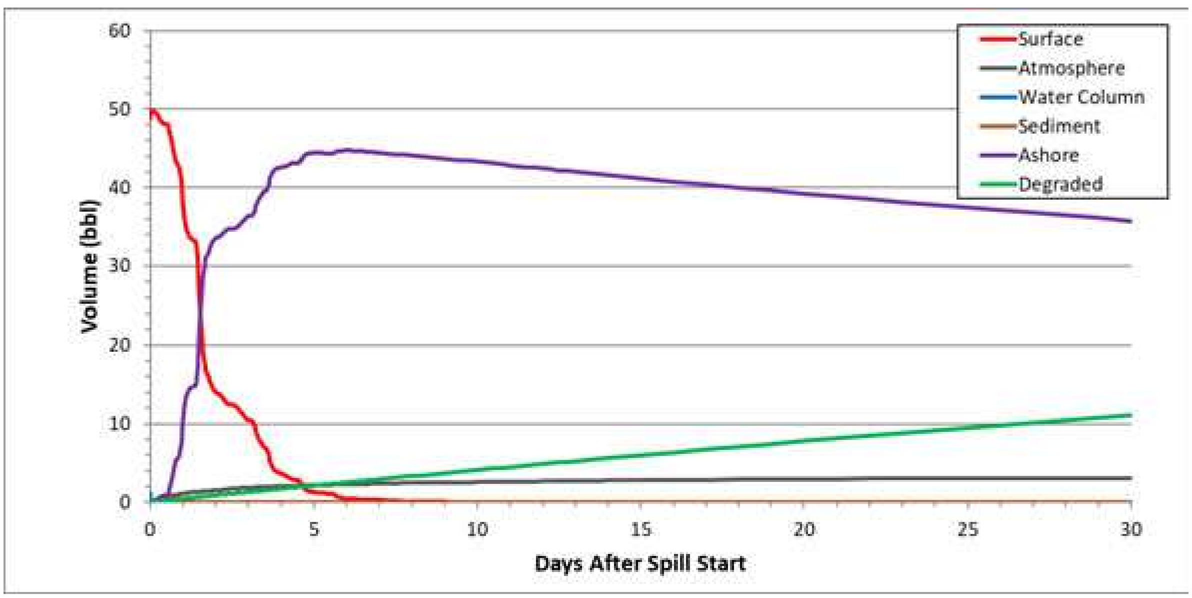

Figure 53: Amount of Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Winter–High Tide

Map figures showing floating, water column, sediment and shoreline oil exposures are in Appendix C11. Floating oil from the spring spills at both high and low tide were transported down river, reaching New York Harbor before 7 days. In summer, within the first three days, floating oil moved both upstream and downstream but after 14 days all traces of floating oil had disappeared at both high and low tide. The down-river extents of the winter spill trajectories reached just south of the Tappan Zee after 3 days when spilled at high tide and 60 hours when spilled at low tide but disappeared after 14 days for high tide spills and 3 days for low tide spills.

Table 33 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Most of the spilled heavy fuel oil goes ashore in this scenario. Shoreline oiling is similar in summer and winter, and extends further in spring where the higher flow carries the oil downstream farther.

Table 33: Shoreline Length Oiled for Tappan Zee 50-bbl Home Heating Oil Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	0.0	0.0	0.2	0.2	0.1	0.2
Unconsolidated Rock	0.1	1.0	4.4	5.7	1.1	2.6
Sand or Sand with Brick	0.0	0.0	0.0	0.0	0.0	0.0
Mud, Mixed Mud-Sand, Timber Edge	0.1	0.1	0.3	0.5	0.2	0.2
Saltmarsh (*Spartina* spp.)	0.5	0.4	0.0	0.0	0.0	0.0
Upper Intertidal Mix	0.0	0.0	0.0	0.5	0.0	0.0
Lower Intertidal Mix	0.0	0.0	0.0	0.0	0.0	0.0
Phragmites australis	0.0	0.0	0.0	0.0	0.0	0.0
Sheet Pile, Concrete, or Other	37.2	33.3	7.8	0.9	7.2	2.5
Scrub/Shrub or Forested Wetland	0.0	0.0	0.0	0.0	0.0	0.0
Total Shoreline	**37.8**	**34.7**	**12.6**	**7.8**	**8.5**	**5.4**

The sediment contamination from these heavy fuel oil spills was negligible because the highly viscous fuel oil remained floating and went ashore, as opposed to being mixed into the water where it could bind with suspended particulate matter and settle. Water column concentrations were also negligible.

Yonkers Anchorage–155,000 bbl Gasoline

Table 32 and Figures 53 to 55 summarize the mass balance for the Yonkers Anchorage gasoline spill scenario. The majority (>92%) of the spilled gasoline evaporated, and a very small percentage of the remaining oil dissolved and degraded in the water column. Less than 4% of the gasoline was transported downstream into New York Harbor.

Table 34: Mass Balance Summary: Yonkers 155,000-bbl Gasoline Spills[43]							
Scenario	**Surface**	**Atmosphere**	**Water Column**	**Sediment**	**Ashore**	**Degraded**	**Entered NY Harbor**
Spring High Tide	0.0%	91.8%	0.1%	0.1%	0.0%	3.9%	4.0%
Spring Low Tide	0.0%	93.4%	0.2%	0.1%	0.1%	3.2%	3.1%
Summer High Tide	0.0%	93.9%	1.4%	0.1%	0.0%	4.6%	0.0%
Summer Low Tide	0.0%	94.1%	1.4%	0.1%	0.0%	4.3%	0.0%
Winter High Tide	0.0%	93.8%	0.3%	0.2%	0.1%	4.1%	1.5%
Winter Low Tide	0.0%	93.1%	0.3%	0.2%	0.1%	5.0%	1.3%

Map figures showing floating, water column, sediment and shoreline gasoline exposures are in Appendix C12. Floating oil from the spring spills was transported down river, reaching New York Harbor after 54 hours when spilled at high tide and 3 days when spilled at low tide. In contrast, in the summer, the river flow carried the floating gasoline downstream to Manhattan (only when spilled at high tide), as well as upstream north of the Tappan Zee when spilled at both high and low tide. In winter, oil spilled was transported downstream to New York Harbor as soon as 7 days (at both high tide and low tide) in the 30-day simulations.

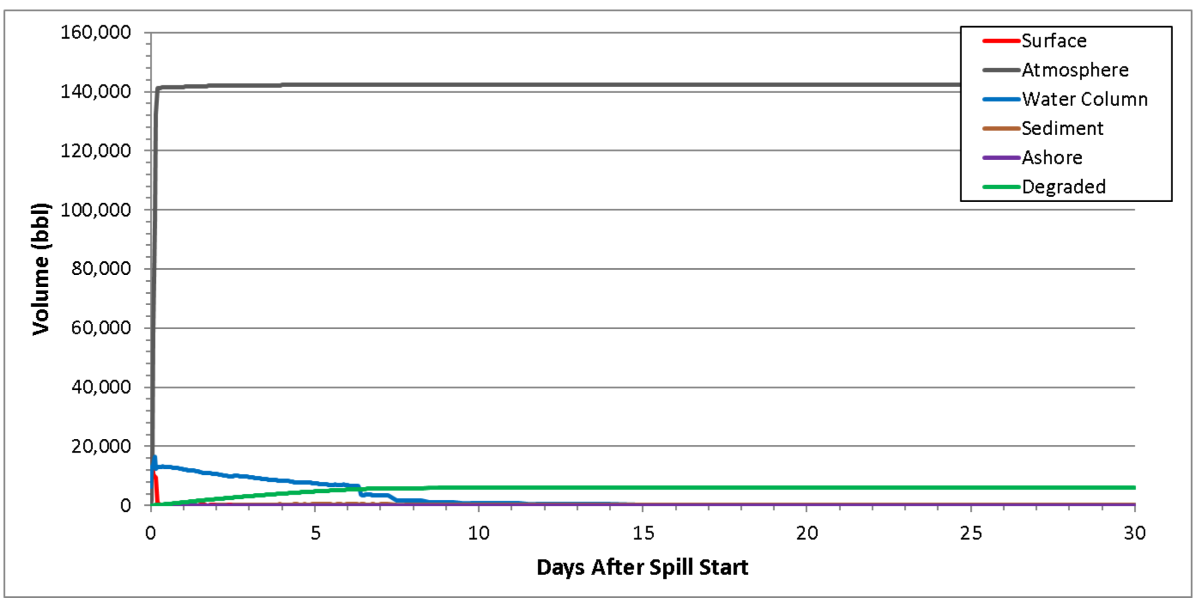

Figure 54: Amount of Oil in Different Environmental Compartments over Time: Yonkers–155,000 bbl Gasoline–Spring–High Tide

[43] At the end of 30-day model simulation.

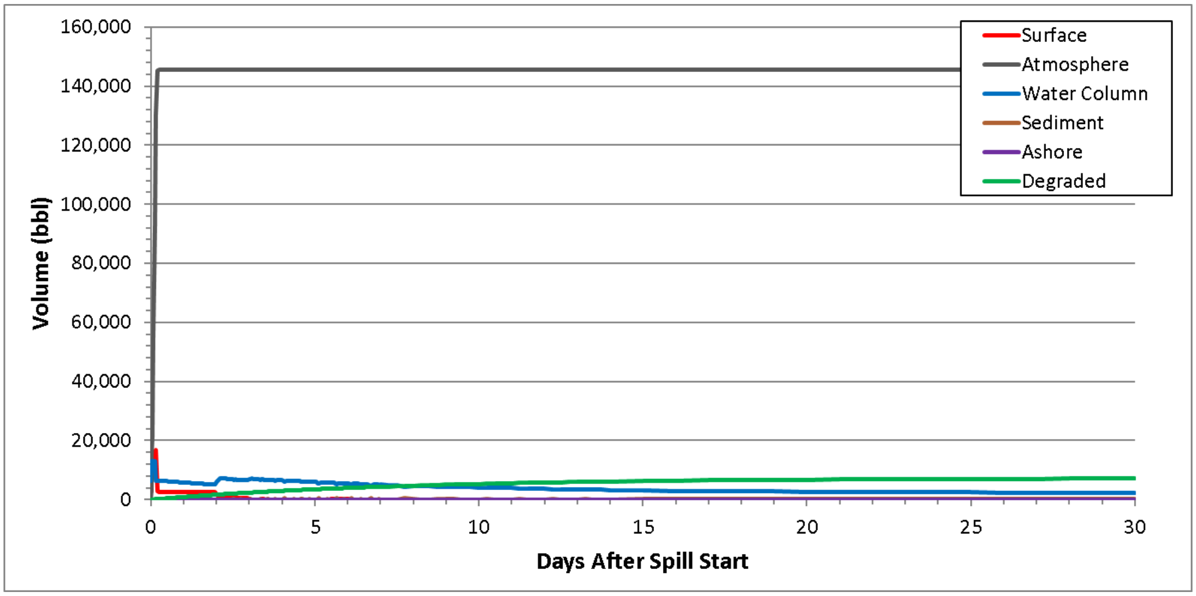

Figure 55: Amount of Oil in Different Environmental Compartments over Time: Yonkers–155,000 bbl Gasoline–Summer–High Tide

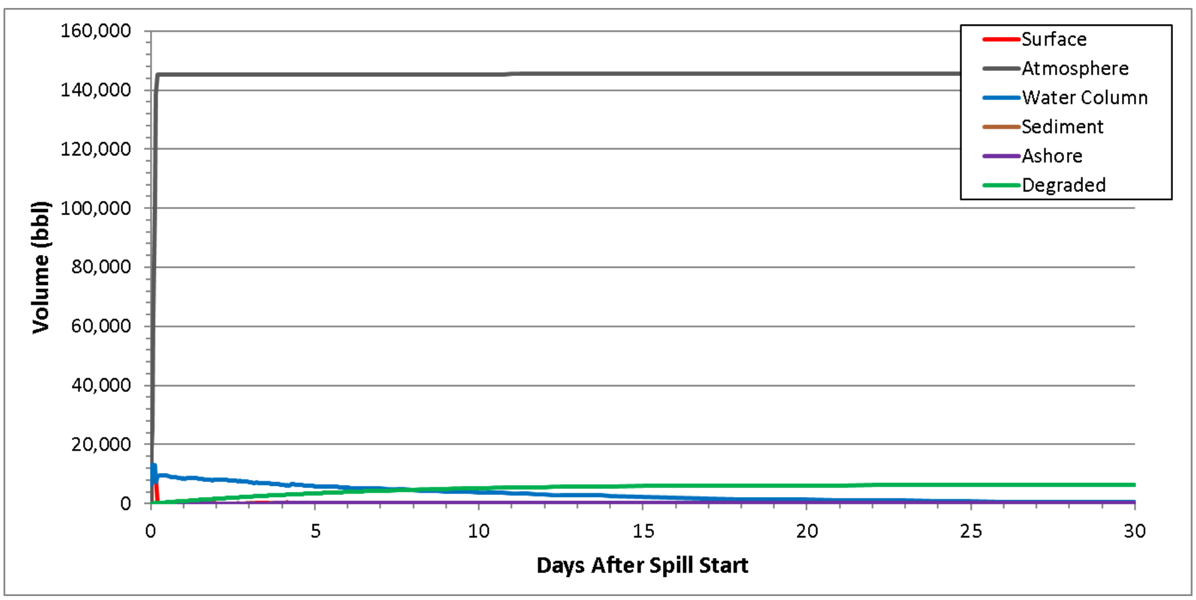

Figure 56: Amount of Oil in Different Environmental Compartments over Time: Yonkers–155,000 bbl Gasoline–Winter–High Tide

Table 33 summarizes the shoreline oiled by more than 1 g/m^2 of oil, by shore type. Most of the spilled gasoline evaporated, but since this is a very large spill the ~0.1% of the volume (155 bbl) left as residual is spread over a long shoreline. Less than 4 miles of shoreline is contaminated by > 100 g/m^2 of residual hydrocarbons for these spills. Shoreline oiling is least in summer and extends furthest in winter where the ice cover and low temperatures slow evaporation and moderate flow carries the residual hydrocarbons downstream.

Table 35: Shoreline Length Oiled for Yonkers 155,000-bbl Gasoline Spills

Habitat Type	Miles with Average Loading > 1 g/m^2 (Average Thickness > 0.001 mm)					
	Spring		Summer		Winter	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
Solid Bedrock	0.0	0.0	0.0	0.2	0.0	0.1
Unconsolidated Rock	0.1	0.4	5.3	5.3	2.2	2.3
Sand or Sand with Brick	0.0	0.0	0.0	0.0	0.0	0.0
Mud, Mixed Mud-Sand, Timber Edge	0.1	0.1	0.2	0.4	0.2	0.2
Saltmarsh (*Spartina* spp.)	0.5	0.8	0.4	0.1	1.0	0.7
Upper Intertidal Mix	0.0	0.0	0.0	0.0	0.0	0.0
Lower Intertidal Mix	0.0	0.0	0.0	0.0	0.0	0.0
Phragmites australis	0.0	0.0	0.8	0.4	0.0	0.0
Sheet Pile, Concrete, or Other	62.6	81.8	24.5	16.3	99.9	91.4
Scrub/Shrub or Forested Wetland	0.0	0.0	0.0	0.0	0.0	0.0
Total Shoreline	**63.2**	**83.1**	**31.1**	**22.6**	**103.3**	**94.7**

Contamination in the sediments extended over similar portions of the river as exposed to floating gasoline components. The substantial quantities of non-volatile residual components from the gasoline, given the very large spill volume, combined with suspended particulate matter and settled. However, the concentrations in the sediments were low overall.

High concentrations of oil (gasoline) droplets in the water column were swept downstream of the spill site to New York Harbor in all seasons. During the summer the subsurface droplets remained closer to the Yonkers area and extended north of the Tappan Zee. Much of the water contamination was of dissolved hydrocarbons, which were in high enough concentrations to be of concern (i.e., >1 mg/m3) for acutely toxic effects on fish and invertebrates. In winter and spring, these higher dissolved concentrations extended from the Tappan Zee area to New York Harbor, whereas in summer, the high concentrations were more focused near Yonkers and northward towards the Tappan Zee.

Conclusions

The oil spill consequence modeling performed in this study provides geographical and quantitative measures of oil fate and exposure that could result from each of the 12 hypothetical spills examined. The model results include summaries the percentage of the spilled oil in each environmental compartment of the Hudson River over time. In addition, the areas of water surface, lengths of shoreline and volumes of water exposed at some time after the spill to concentrations above thresholds of concern for potential effects on biota are tabulated and mapped.

Quantification of the actual biological impacts expected from oil exposure should consider the degree and duration of exposure to oil and component hydrocarbons, accounting for the movements and amounts of both oil and biota. Thus, summing the areas of water and shoreline surfaces or volumes of water contaminated above threshold concentrations, and multiplying by numbers of animals present at any instant in time, would not quantify numbers of animals expected to be killed or otherwise impacted. Animal behavior and movements in and out of the contaminated area would need to be considered, as would the ephemeral nature of the oil exposure and the sensitivity of the organisms that are exposed (e.g., life stage, physical health). However, the approach of summing areas/volumes exposed above a threshold of concern at any instant in time after a spill does provide quantitative measures of areas/volumes where there is the *potentia*l for adverse effects. Such a conservative analysis as this is appropriate to an ecological risk assessment, whereby the objective is to be protective of the resources of concern.

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Appendix A: Oil Properties

This appendix provides the properties of the oils used in the oil spill modeling.

Bakken Crude

Table 36: Oil Properties for Bakken Crude Used in Modeling

Oil Property	Value	Comments/References
Density at 16° C (g/cm^3)	0.82220	Yang et al. 2017
Viscosity at 15°C (cP)	3.8	Yang et al. 2017
API Gravity	40.6	Yang et al. 2017
Interfacial Tension (dyne/cm)	19.63	Assumed as for other light crude oils (Belore et al. 2011)
Pour Point (°C)	-28	Yang et al. 2017
Adsorption Rate to Suspended Sediment	0.010080	Default Value (Kolpack et al. 1977)
Adsorption Salinity Coefficient (/ppt)	0.023000	Default Value (Kolpack et al. 1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.025670	Yang et al. 2017
Fraction 2-ring aromatics	0.007061	Yang et al. 2017
Fraction 3-ring aromatics	0.007469	Yang et al. 2017
Fraction Non-Aromatics: boiling point < 180°C	0.246962	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Yang et al. (2017)
Fraction Non-Aromatics: boiling point 180-264°C	0.220218	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Yang et al. (2017)
Fraction Non-Aromatics: boiling point 264-380°C	0.219810	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Yang et al. (2017)
Maximum Mousse Water Content (%)	0	Assumed that this very light crude oil does not form mousse.
Degradation Rate (/day), Surface & Shore	0.010	French et al. (1996)
Degradation Rate (/day), Soluble/Semi-soluble Aromatic Hydrocarbons in Water	0.222-0.267	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Volatile Aliphatic Hydrocarbons in Water	0.042-0.240	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)

Home Heating Oil

Table 37: Oil Properties for Home Heating Oil Used in Modeling		
Oil Property	**Value**	**Comments/References**
Density at 25°C (g/cm^3)	0.83100	Environmental Technology Centre, Environment Canada 2007
Viscosity at 25°C (cP)	2.76	Environmental Technology Centre, Environment Canada 2007
API Gravity	38.8	Environmental Technology Centre, Environment Canada 2007
Interfacial Tension (dyne/cm)	19.63	Assumed as for other oils (Belore et al. 2011)
Pour Point (°C)	-50	Environmental Technology Centre, Environment Canada 2007
Adsorption Rate to Suspended Sediment	0.010080	Default Value (Kolpack et al. 1977)
Adsorption Salinity Coefficient (/ppt)	0.023000	Default Value (Kolpack et al. 1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.019333	Environmental Technology Centre, Environment Canada (ETC 2007)
Fraction 2-ring aromatics	0.011410	Environmental Technology Centre, Environment Canada (ETC 2007)
Fraction 3-ring aromatics	0.015605	Environmental Technology Centre, Environment Canada (ETC 2007)
Fraction Non-Aromatics: boiling point < 180°C	0.144667	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from ETC (2007)
Fraction Non-Aromatics: boiling point 180-264°C	0.478690	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from ETC (2007)
Fraction Non-Aromatics: boiling point 264-380°C	0.303295	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from ETC (2007)
Maximum Mousse Water Content (%)	0	(Not applicable, as this oil type does not form a mousse)
Degradation Rate (/day), Surface & Shore	0.010	French et al. (1996)
Degradation Rate (/day), Soluble/Semi-soluble Aromatic Hydrocarbons in Water	0.222-0.267	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Volatile Aliphatic Hydrocarbons in Water	0.042-0.240	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)

Diluted Bitumen

Table 38: Oil Properties for Cold Lake Diluted Bitumen Used in Modeling		
Oil Property	**Value**	**Comments/References**
Density at 16° C (g/cm^3)	0.91823	Yang et al. (2016)
Viscosity at 15°C (cP)	150.	Yang et al. (2016)
API Gravity	22.6	Yang et al. (2016)
Interfacial Tension (dyne/cm)	19.63	Assumed as for other oils (Belore et al. 2011)
Pour Point (°C)	-25	Yang et al. (2016)
Adsorption Rate to Suspended Sediment	0.010080	Default Value (Kolpack et al. 1977)
Adsorption Salinity Coefficient (/ppt)	0.023000	Default Value (Kolpack et al. 1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.010500	Yang et al. (2016)
Fraction 2-ring aromatics	0.001191	Yang et al. (2016)
Fraction 3-ring aromatics	0.006158	Yang et al. (2016)
Fraction Non-Aromatics: boiling point < 180°C	0.176755	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Yang et al. (2016)
Fraction Non-Aromatics: boiling point 180-264°C	0.105958	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Yang et al. (2016)
Fraction Non-Aromatics: boiling point 264-380°C	0.100991	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Yang et al. (2016)
Maximum Mousse Water Content (%)	72.	King 2013
Degradation Rate (/day), Surface & Shore	0.010	French et al. (1996)
Degradation Rate (/day), Soluble/Semi-soluble Aromatic Hydrocarbons in Water	0.222-0.267	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Volatile Aliphatic Hydrocarbons in Water	0.042-0.240	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)

Heavy Fuel Oil

Table 39: Oil Properties for Heavy Fuel Oil Used in Modeling

Oil Property	Value	Comments/References
Density at 25°C (g/cm^3)	0.97490	Jokuty et al. (1999)
Viscosity at 25°C (cP)	3180.	Jokuty et al. (1999)
API Gravity	12.3	Jokuty et al. (1999)
Interfacial Tension (dyne/cm)	19.63	Assumed as for other oils (Belore et al. 2011)
Pour Point (°C)	7	Mean of values in Whiticar et al. 1994
Adsorption Rate to Suspended Sediment	0.010080	Default Value (Kolpack et al. 1977)
Adsorption Salinity Coefficient (/ppt)	0.023000	Default Value (Kolpack et al. 1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.097433	Environmental Technology Centre, Environment Canada (ETC 2007)
Fraction 2-ring aromatics	0.022659	Environmental Technology Centre, Environment Canada (ETC 2007)
Fraction 3-ring aromatics	0.0147149	Environmental Technology Centre, Environment Canada (ETC 2007)
Fraction Non-Aromatics: boiling point < 180°C	0.6053969	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from ETC (2007)
Fraction Non-Aromatics: boiling point 180-264°C	0.1406876	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from ETC (2007)
Fraction Non-Aromatics: boiling point 264-380°C	0.0913626	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from ETC (2007)
Maximum Mousse Water Content (%)	30.	ADIOS (Automated Data Inquiry for Oil Spills) (NOAA 2000).
Degradation Rate (/day), Surface & Shore	0.010	French et al. (1996)
Degradation Rate (/day), Soluble/Semi-soluble Aromatic Hydrocarbons in Water	0.222-0.267	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Volatile Aliphatic Hydrocarbons in Water	0.042-0.240	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)

Gasoline

Table 40: Oil Properties for Gasoline Used in Modeling		
Oil Property	**Value**	**Comments/References**
Density at 25°C (g/cm^3)	0.80000	Jokuty et al. (1999)
Viscosity at 30 ° C (cP)	0.510	Whiticar et al. (1994)
API Gravity	45.400	Calculated API from density using the following equation: API = (141.5(density of water)/(density of oil))-131.5
Interfacial Tension (dyne/cm)	19.63	Assumed as for other oils (Belore et al. 2011)
Pour Point (°C)	< -50	-
Adsorption Rate to Suspended Sediment	0.010080	Default Value (Kolpack et al. 1977)
Adsorption Salinity Coefficient (/ppt)	0.023000	Default Value (Kolpack et al. 1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.247000	Cline et al. (1991)
Fraction 2-ring aromatics	0.003500	Cline et al. (1991)
Fraction 3-ring aromatics	0.000002	Cline et al. (1991)
Fraction Non-Aromatics: boiling point < 180°C	0.703000	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Jokuty et al. (1999)
Fraction Non-Aromatics: boiling point 180-264°C	0.026500	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Jokuty et al. (1999)
Fraction Non-Aromatics: boiling point 264-380°C	0	Subtracted the Aromatic Hydrocarbons from the Total Hydrocarbons to obtain the fraction of Aliphatic Hydrocarbons. Boiling fraction from Jokuty et al. (1999)
Maximum Mousse Water Content (%)	0	(Not applicable, as this oil type does not form a mousse)
Degradation Rate (/day), Surface & Shore	0.010	French et al. (1996)
Degradation Rate (/day), Soluble/Semi-soluble Aromatic Hydrocarbons in Water	0.222-0.267	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Volatile Aliphatic Hydrocarbons in Water	0.042-0.240	Varies by compound group, as developed by French-McCay et al. (2015)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)

Appendix A References

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Appendix B: Oil Mass Balance for Modeled Oil Spill Scenarios

This appendix contains mass balance graphs for all 72 modeled spill scenarios. Note that mass balance in volume terms is approximate because volumes are not appropriate for atmosphere, dissolved, degraded, and oil density varies in time and space.

Port of Albany–155,000 bbl Bakken Crude

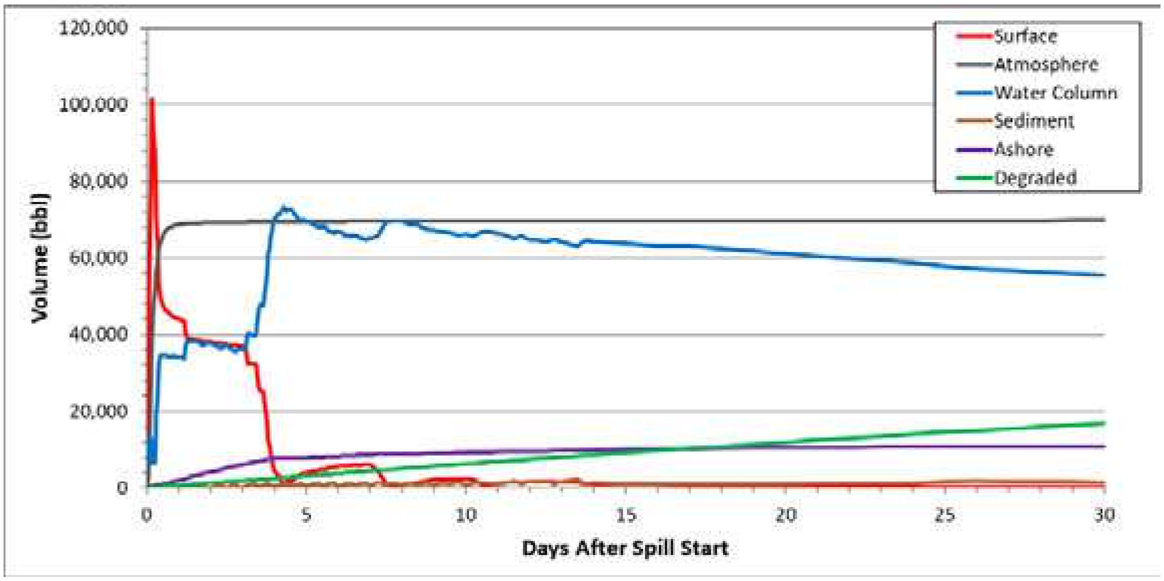

Figure 57: Percent Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Spring–High Tide

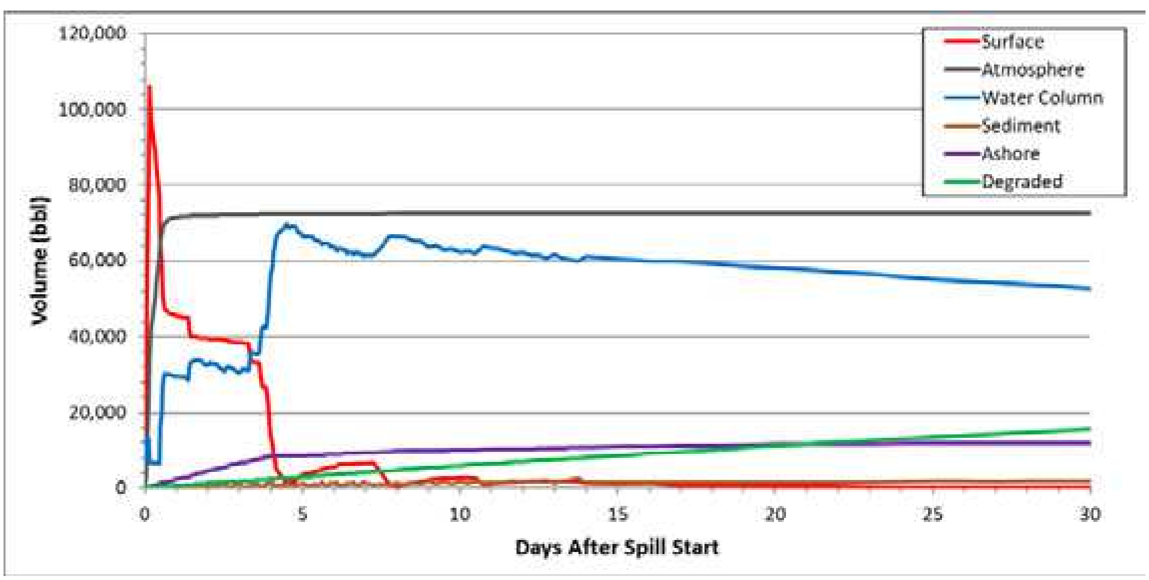

Figure 58: Percent Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Spring–Low Tide

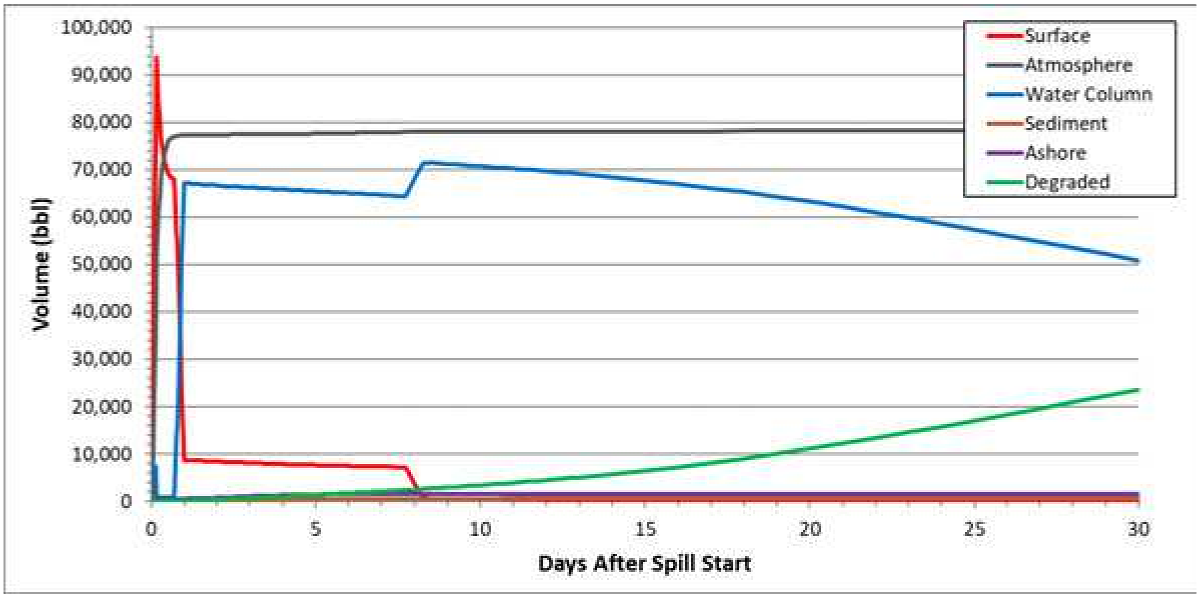

Figure 59: Percent Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Summer–High Tide

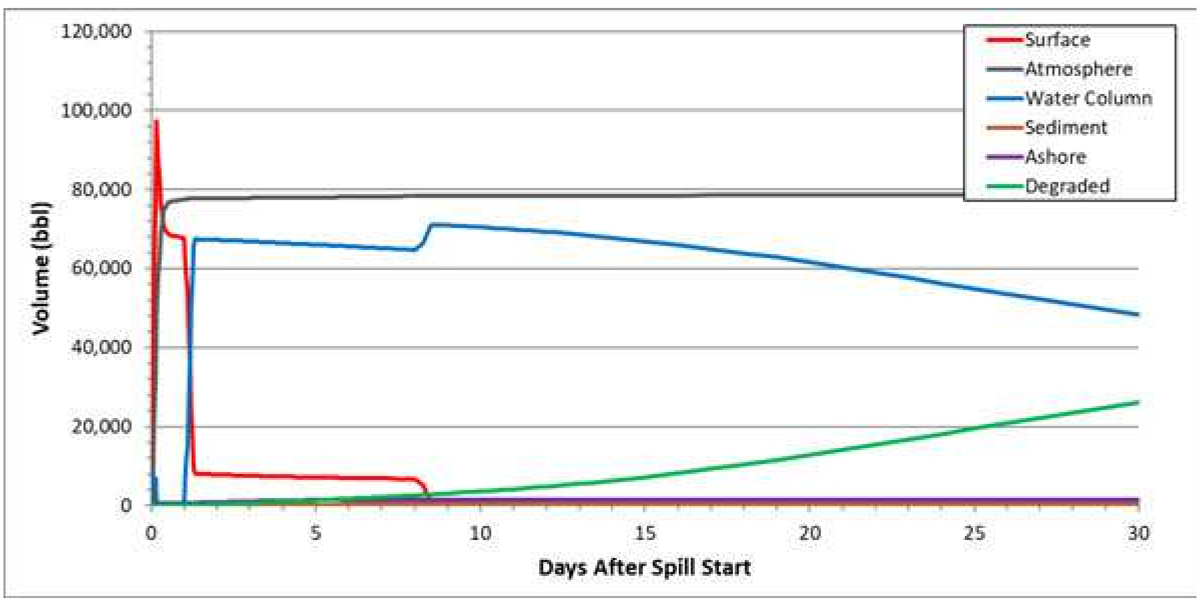

Figure 60: Percent Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Summer–Low Tide

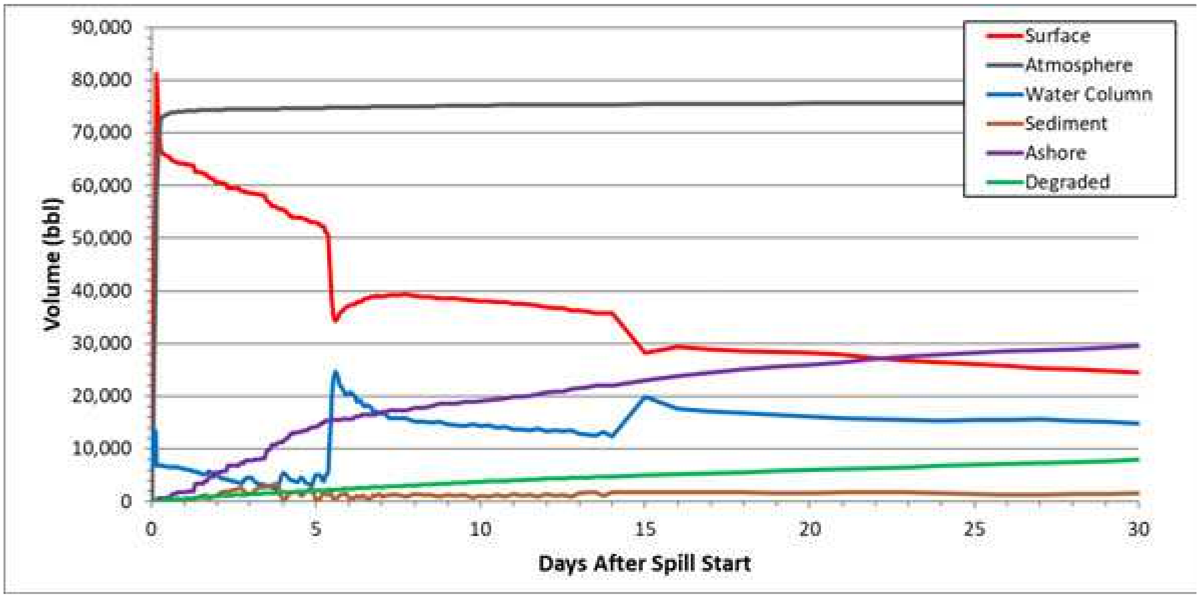

Figure 61: Percent Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Winter–High Tide

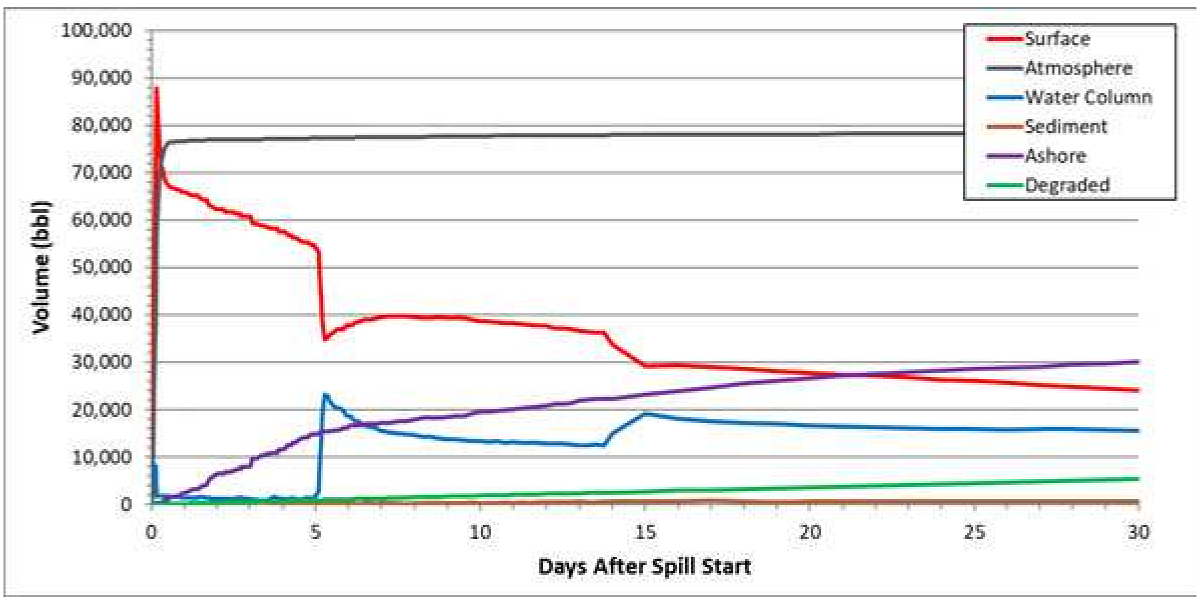

Figure 62: Percent Oil in Different Environmental Compartments over Time: Port of Albany–155,000 bbl Bakken Crude–Winter–Low Tide

Coxsackie–25,000 bbl Home Heating Oil

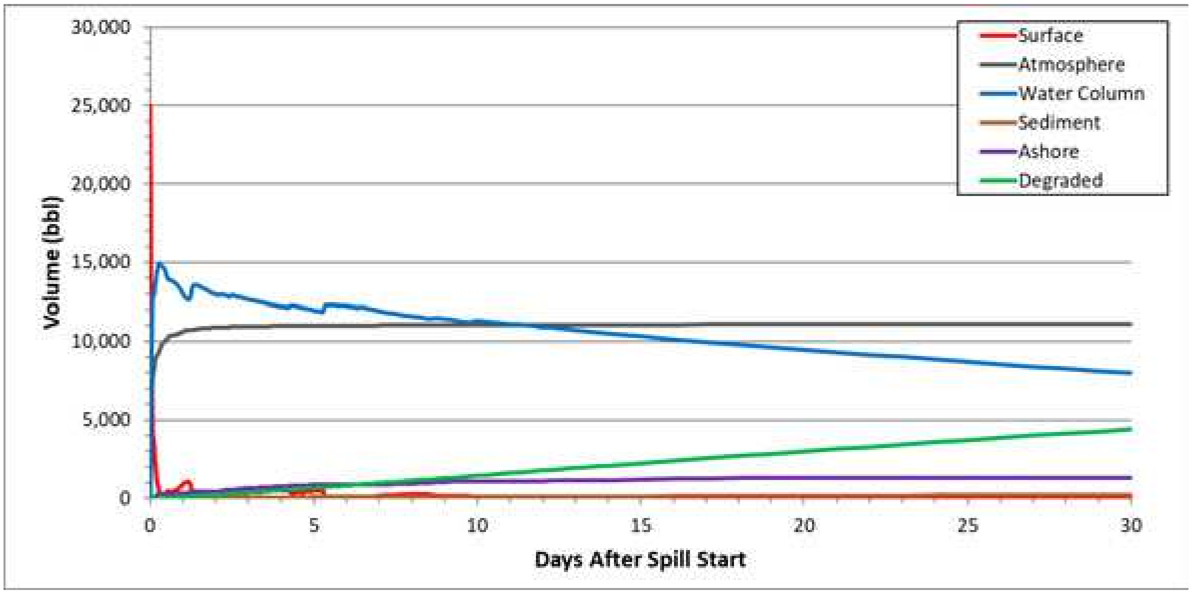

Figure 63: Percent Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Spring–High Tide

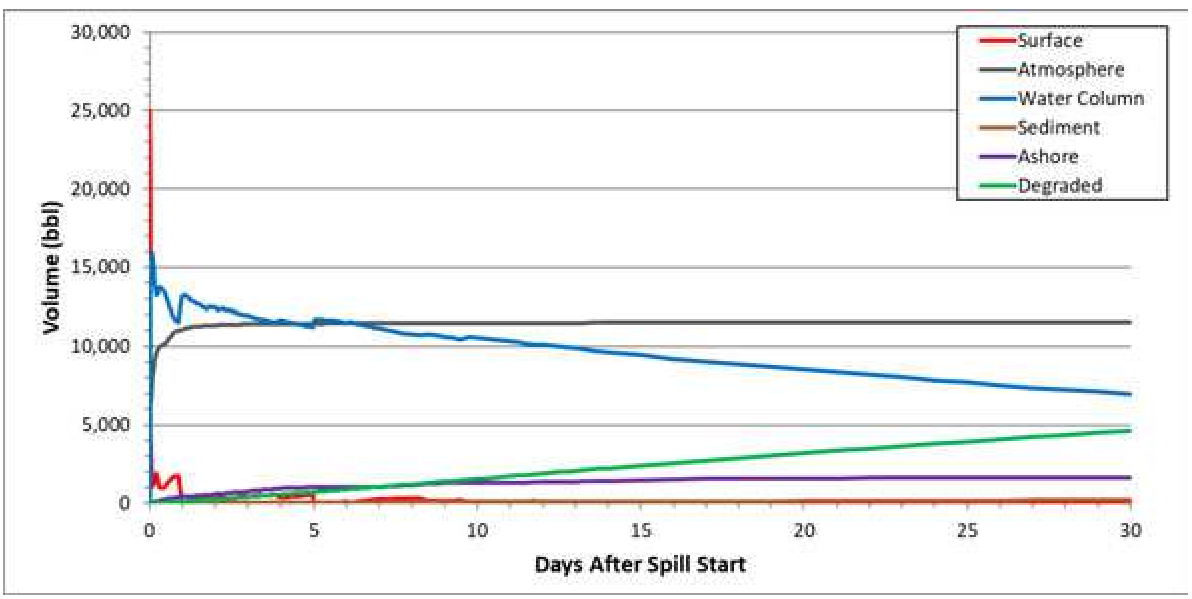

Figure 64: Percent Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Spring–Low Tide

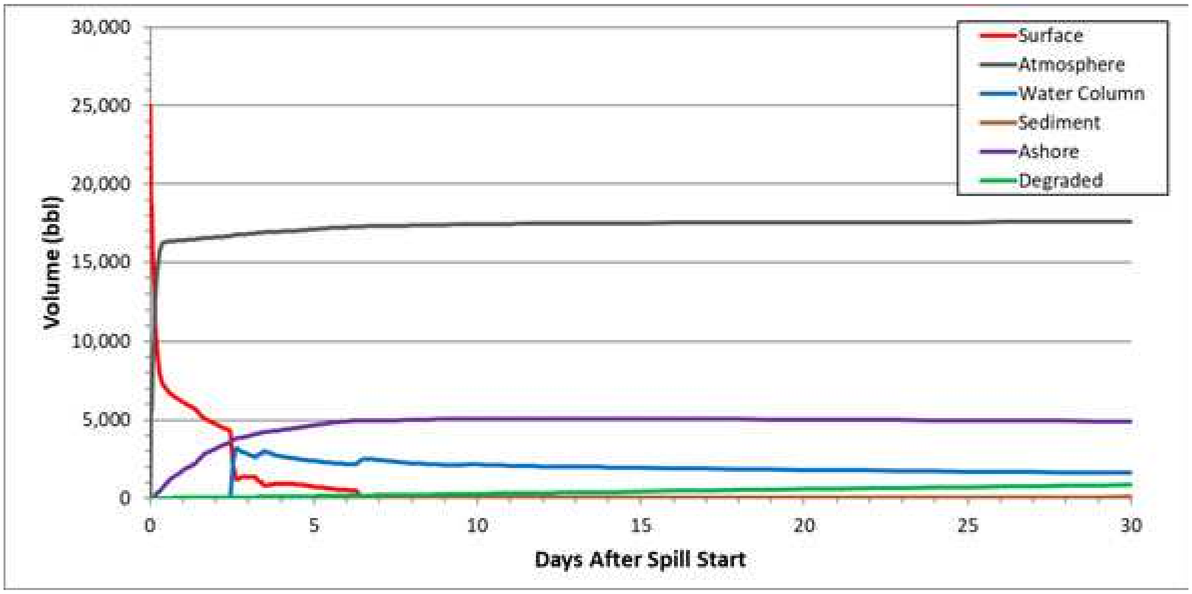

Figure 65: Percent Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Summer–High Tide

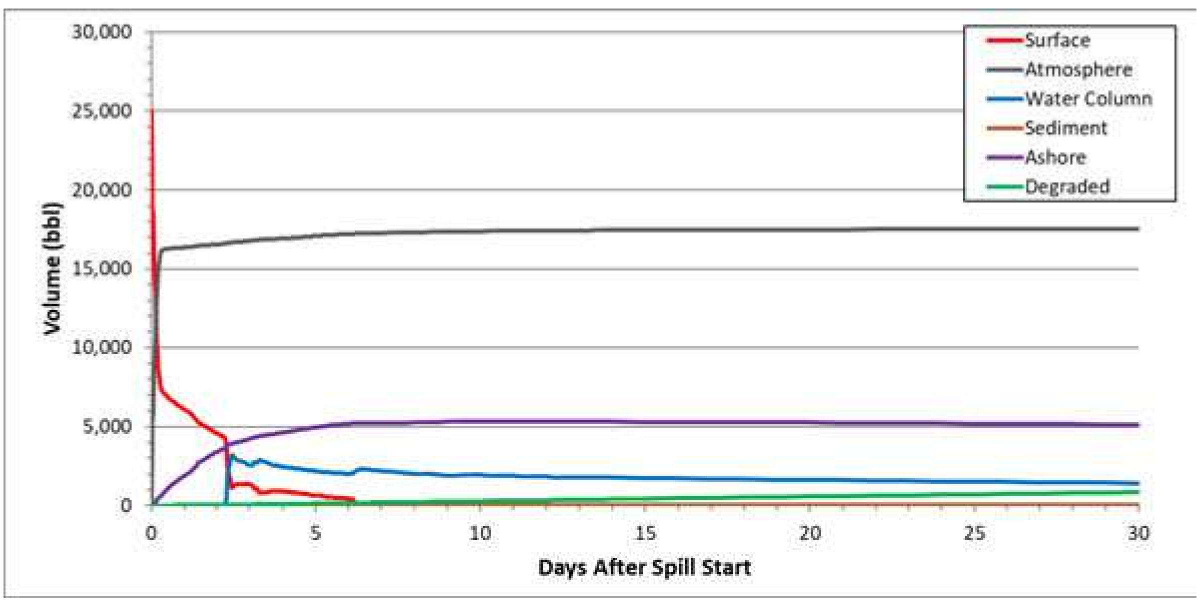

Figure 66: Percent Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Summer–Low Tide

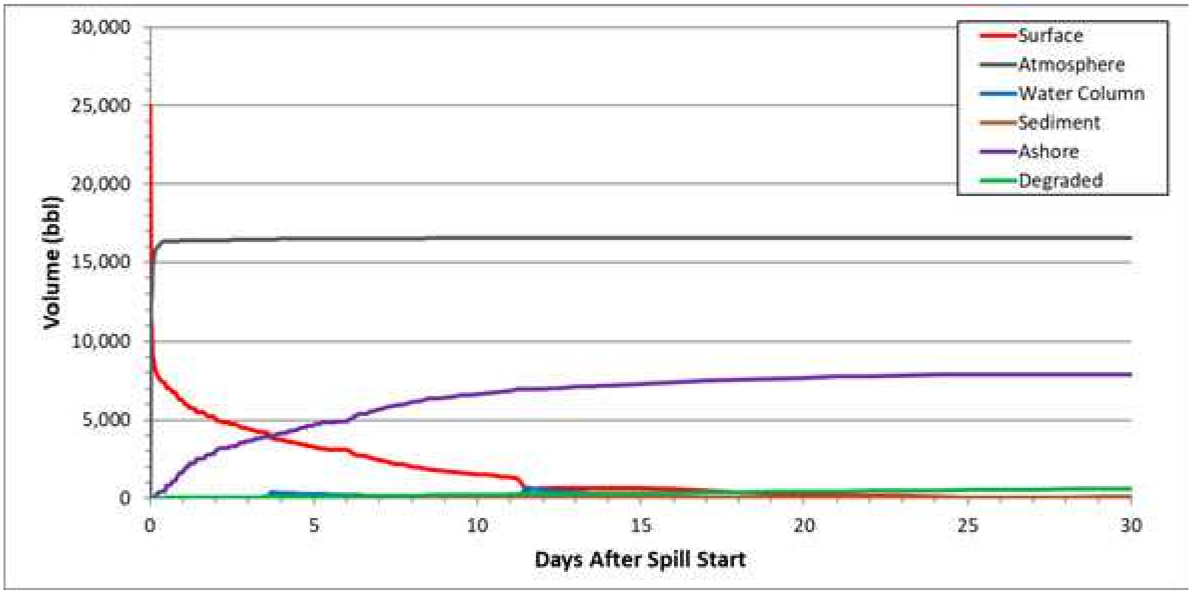

Figure 67: Percent Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Winter–High Tide

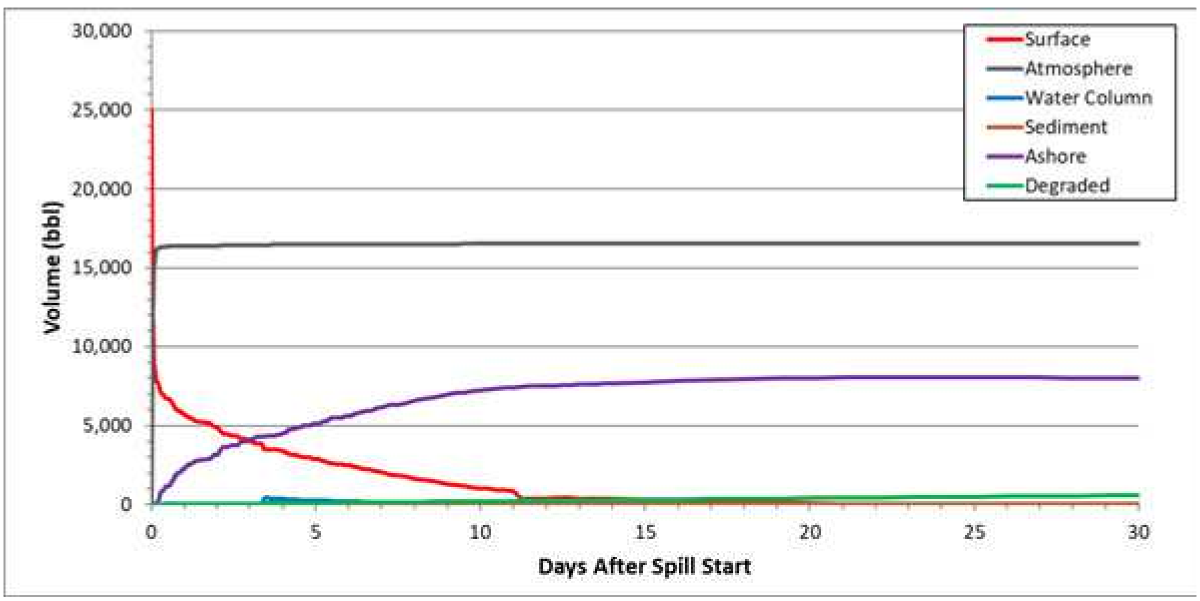

Figure 68: Percent Oil in Different Environmental Compartments over Time: Coxsackie–25,000 bbl Home Heating Oil–Winter–Low Tide

Proposed Kingston Anchorage–150,000 bbl Home Heating Oil

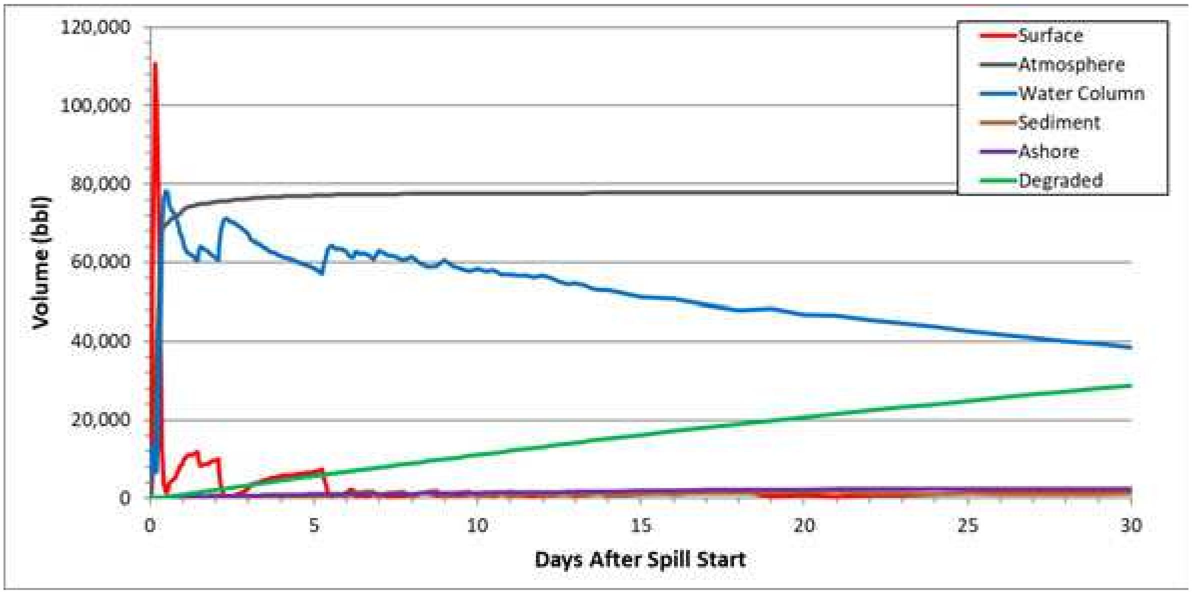

Figure 69: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Home Heating Oil–Spring–High Tide

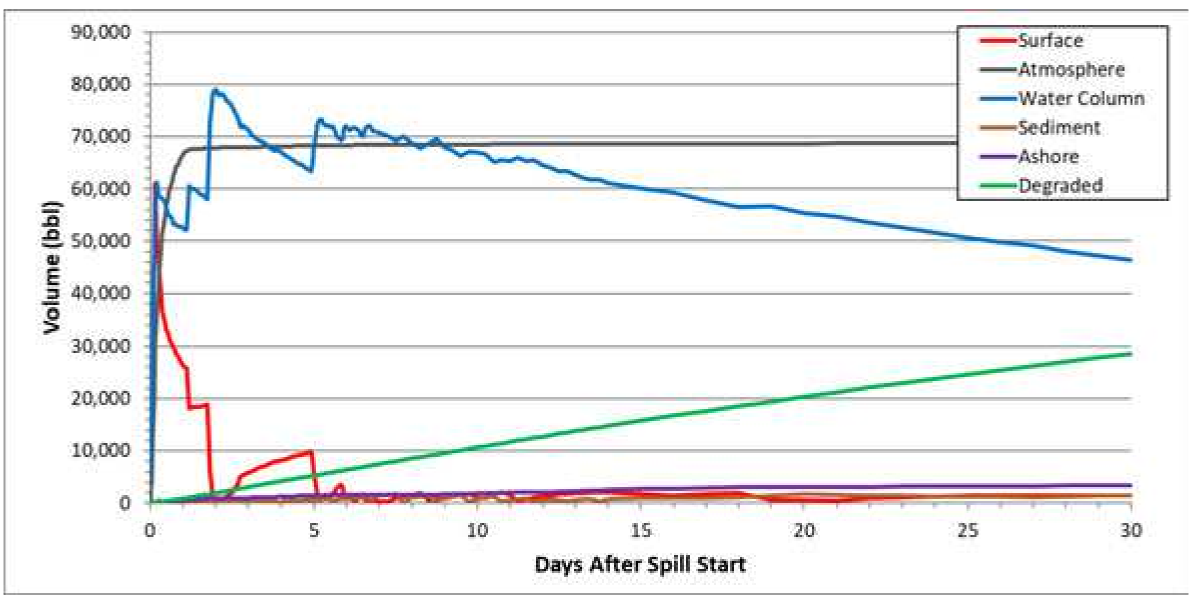

Figure 70: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Home Heating Oil–Spring–Low Tide

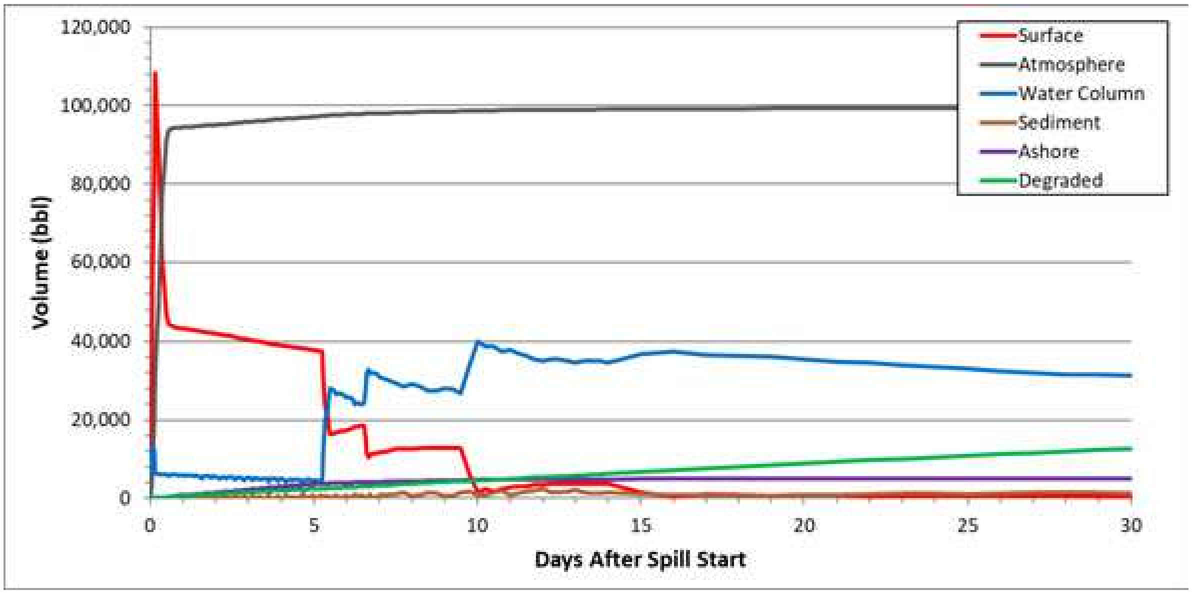

Figure 71: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Home Heating Oil–Summer–High Tide

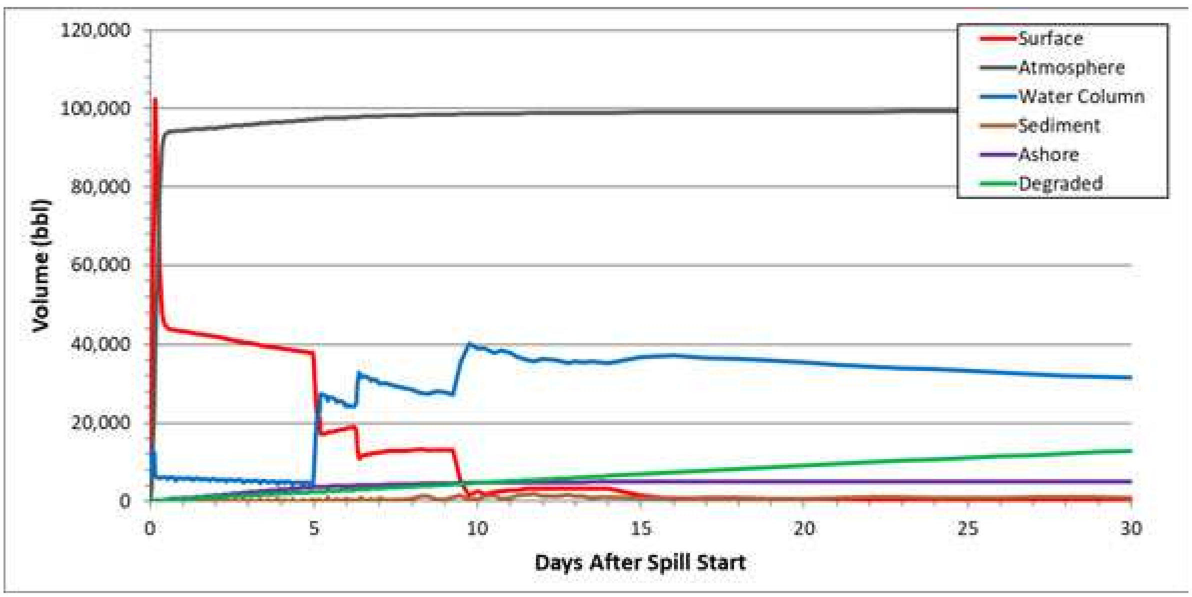

Figure 72: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Home Heating Oil–Summer–Low Tide

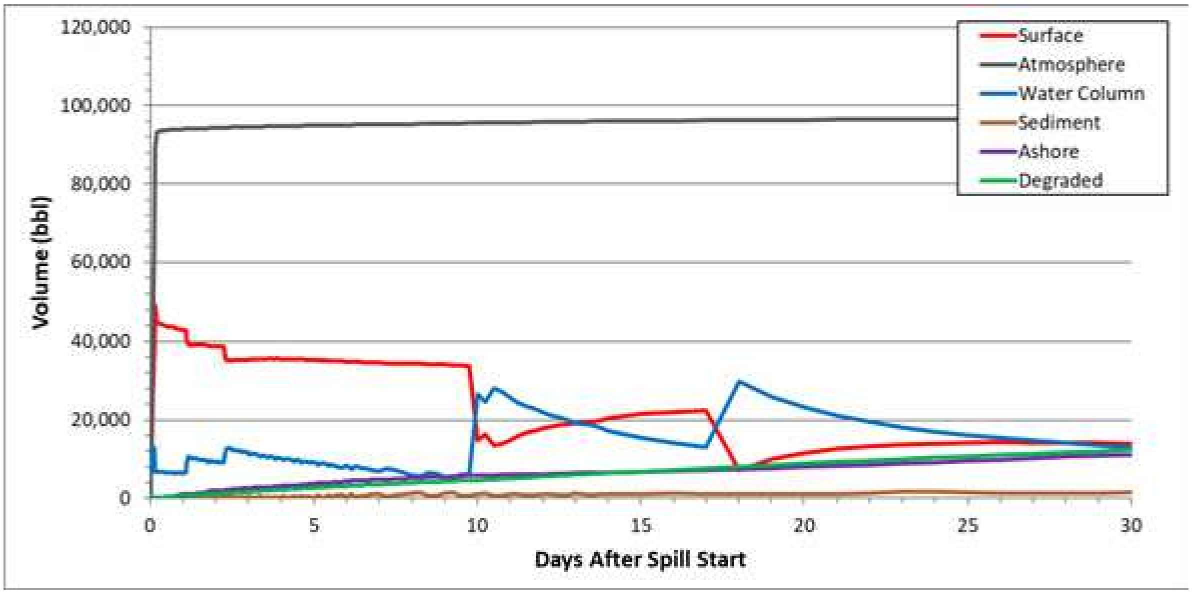

Figure 73: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Home Heating Oil–Winter–High Tide

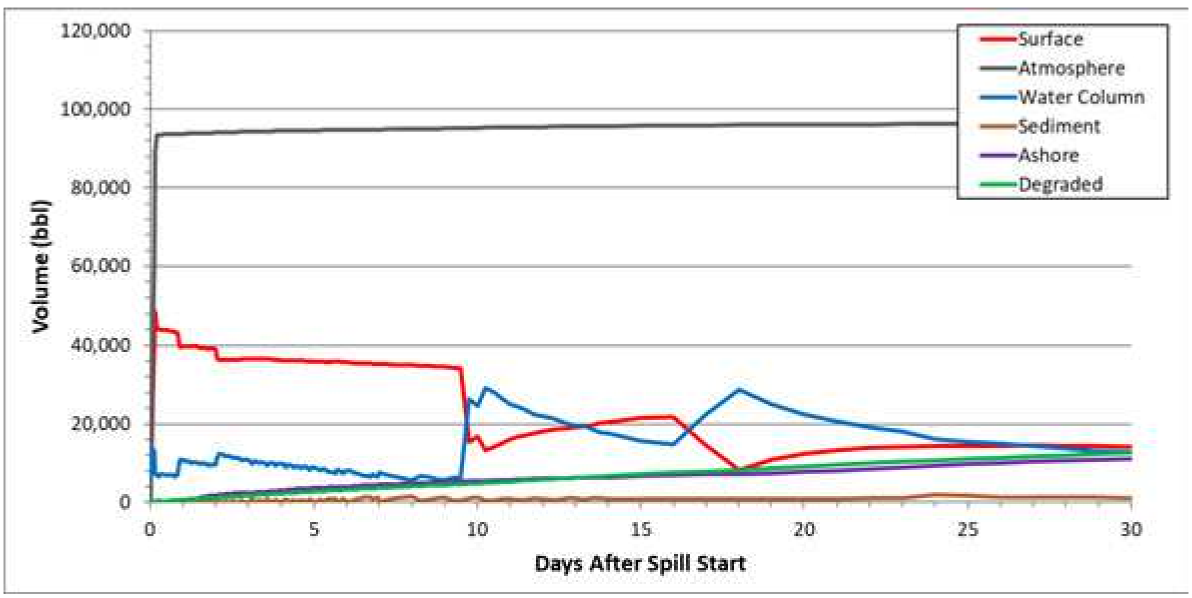

Figure 74: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Home Heating Oil–Winter–Low Tide

Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen

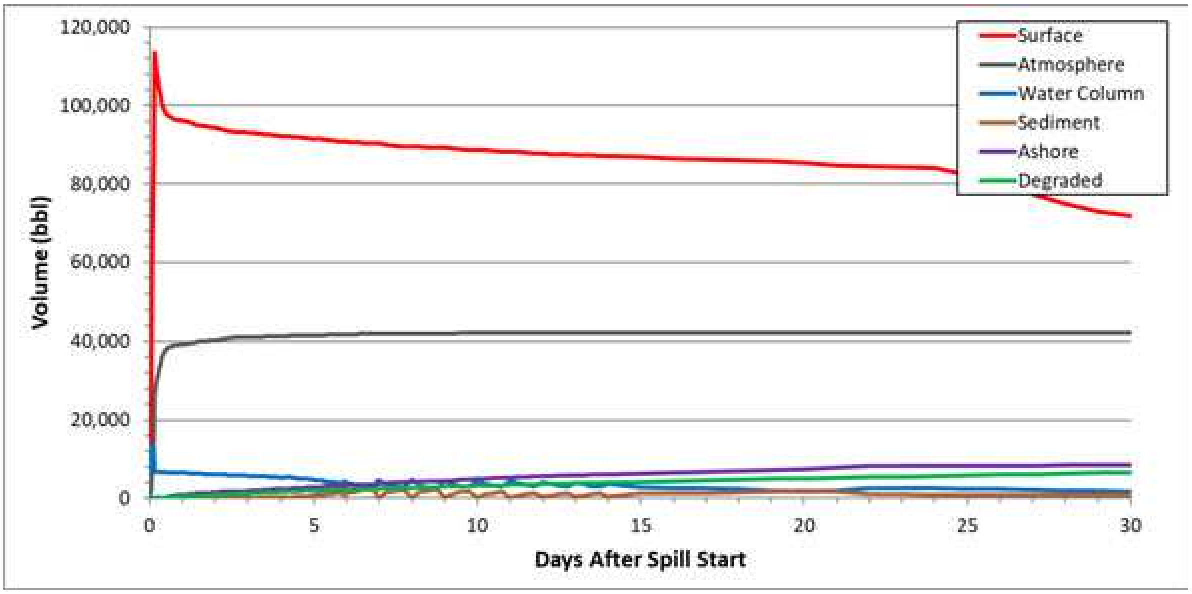

Figure 75: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen–Spring–High Tide

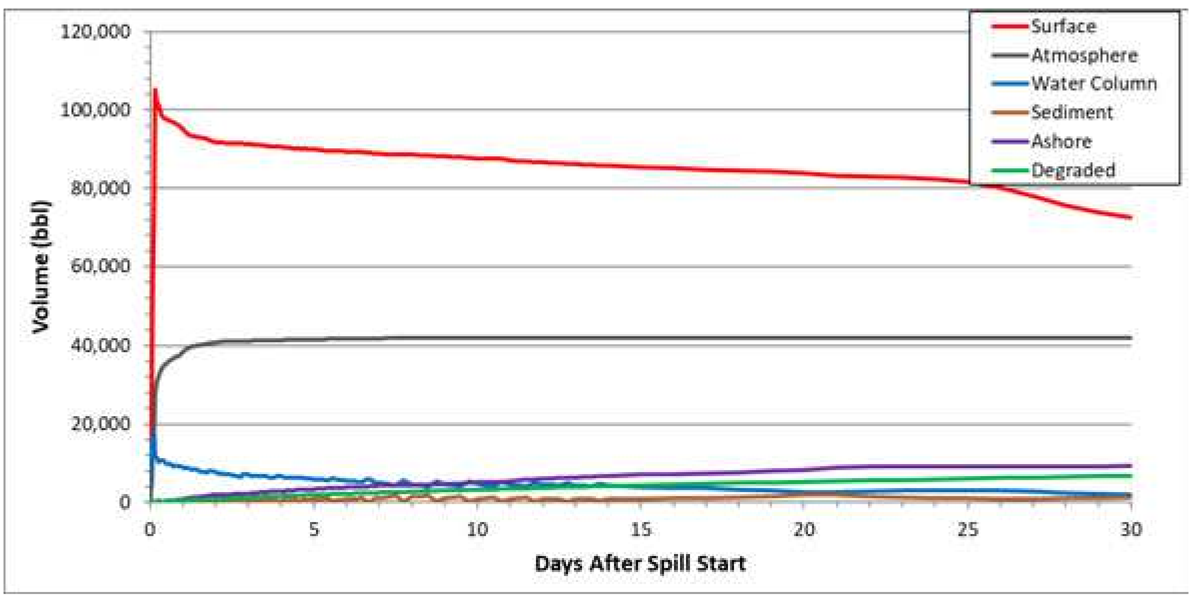

Figure 76: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen–Spring–Low Tide

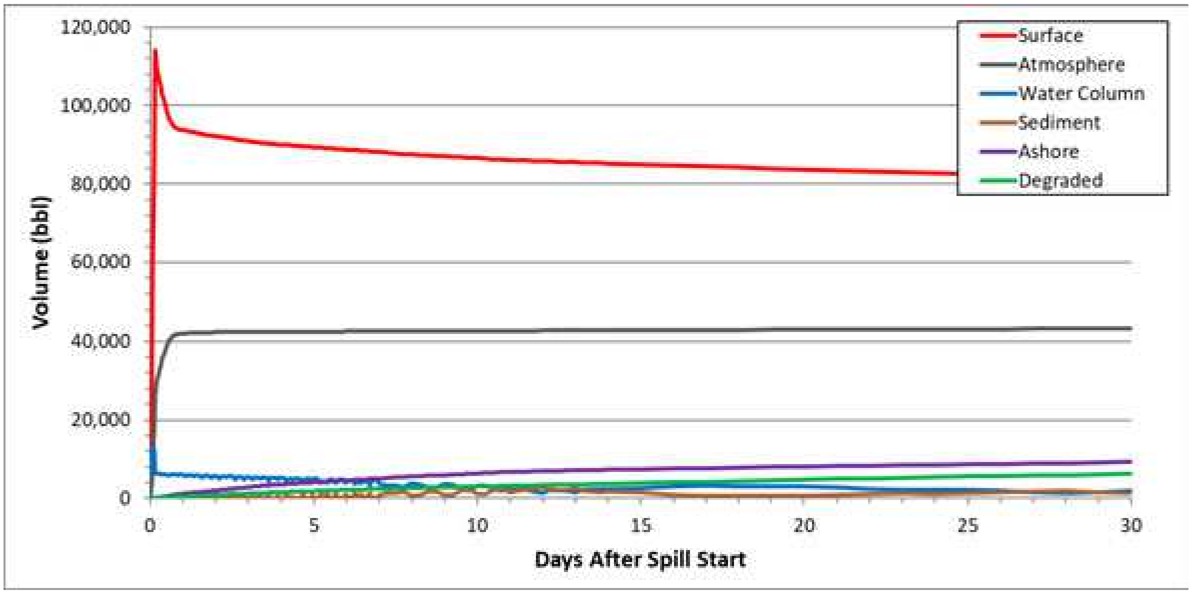

Figure 77: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen–Summer–High Tide

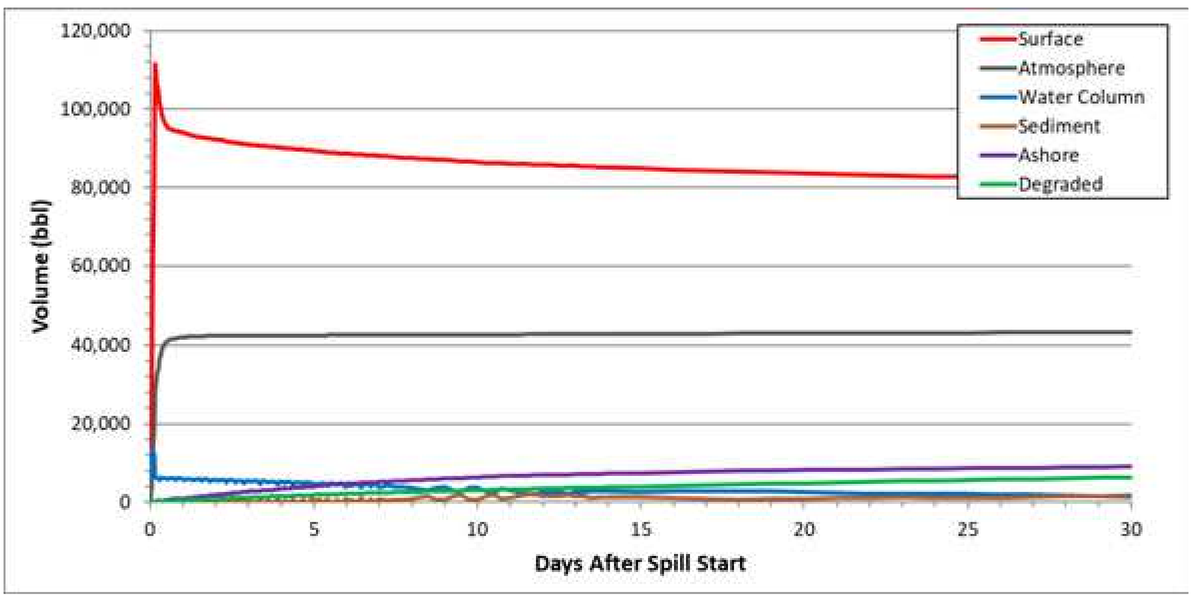

Figure 78: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen–Summer–Low Tide

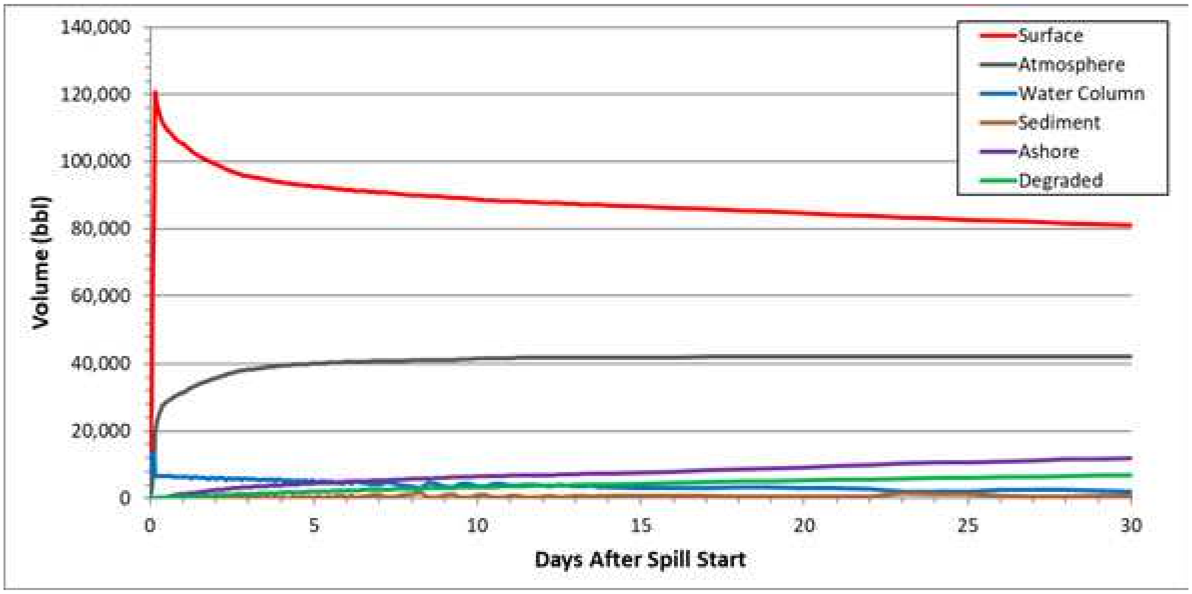

Figure 79: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen–Winter–High Tide

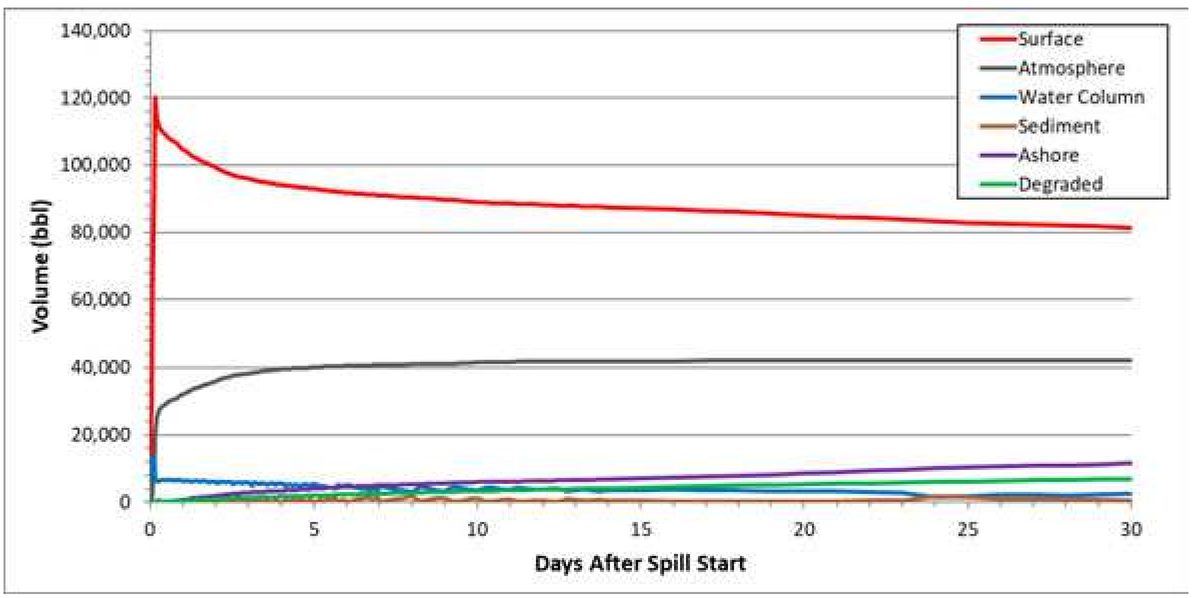

Figure 80: Percent Oil in Different Environmental Compartments over Time: Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen–Winter–Low Tide

Off Rondout Creek–75,421 bbl Bakken Crude

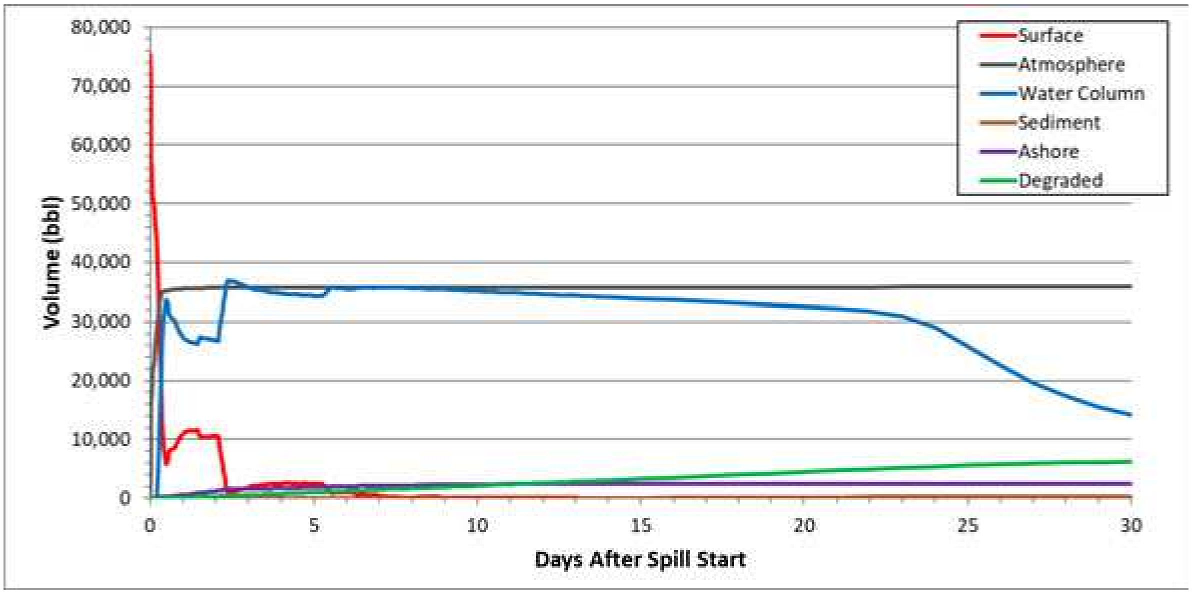

Figure 81: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–75,421 bbl Bakken Crude–Spring–High Tide

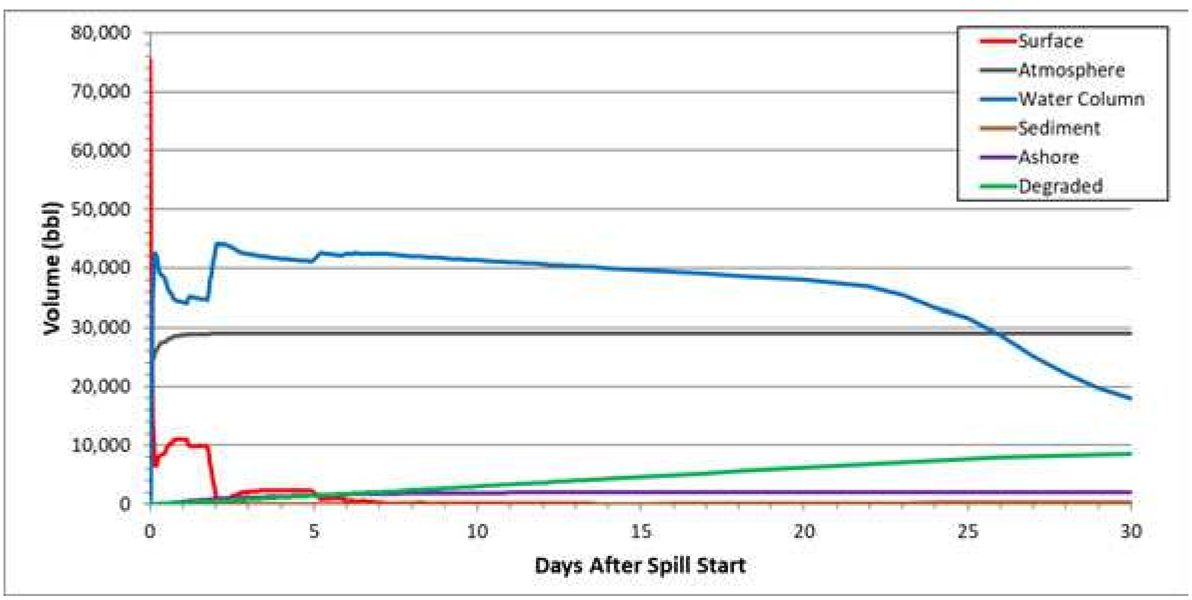

Figure 82: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–75,421 bbl Bakken Crude–Spring–Low Tide

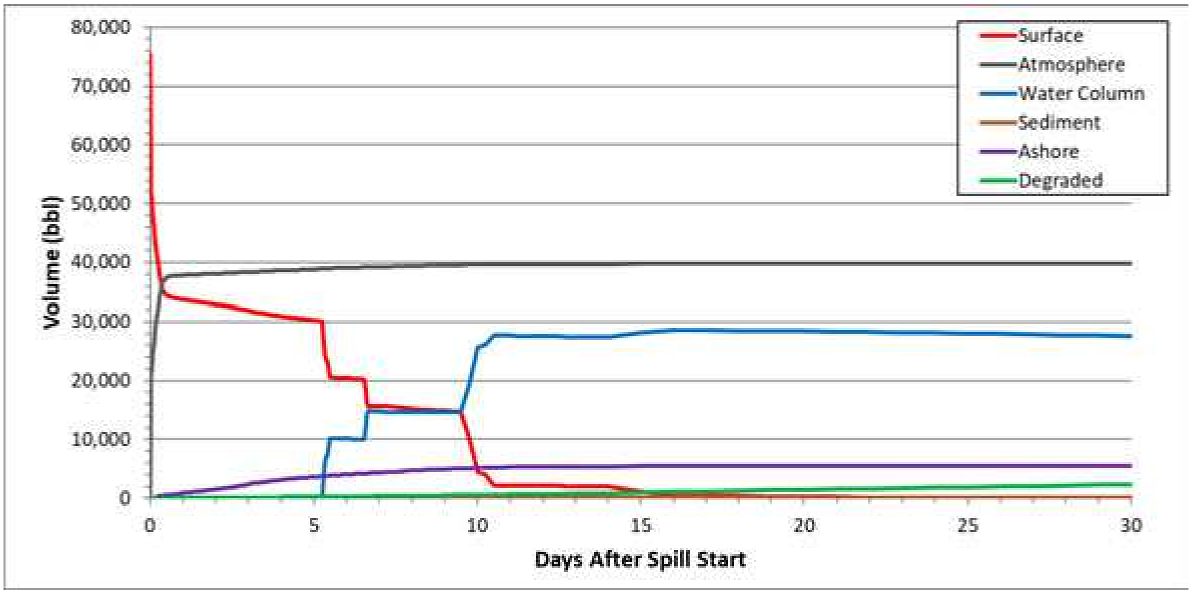

Figure 83: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–75,421 bbl Bakken Crude–Summer–High Tide

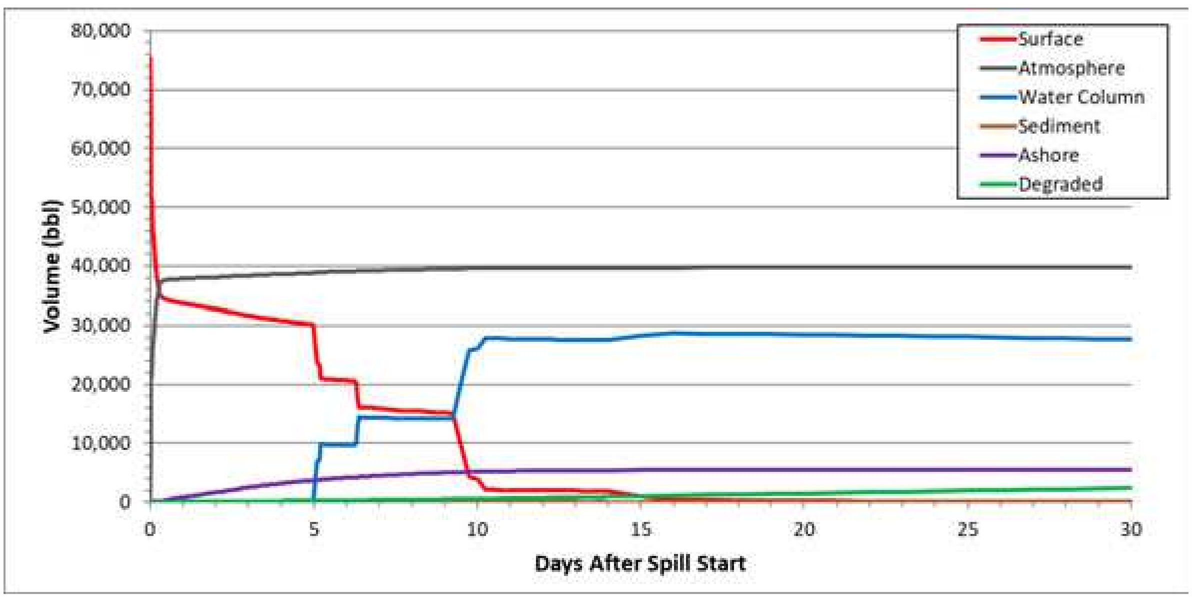

Figure 84: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–75,421 bbl Bakken Crude–Summer–Low Tide

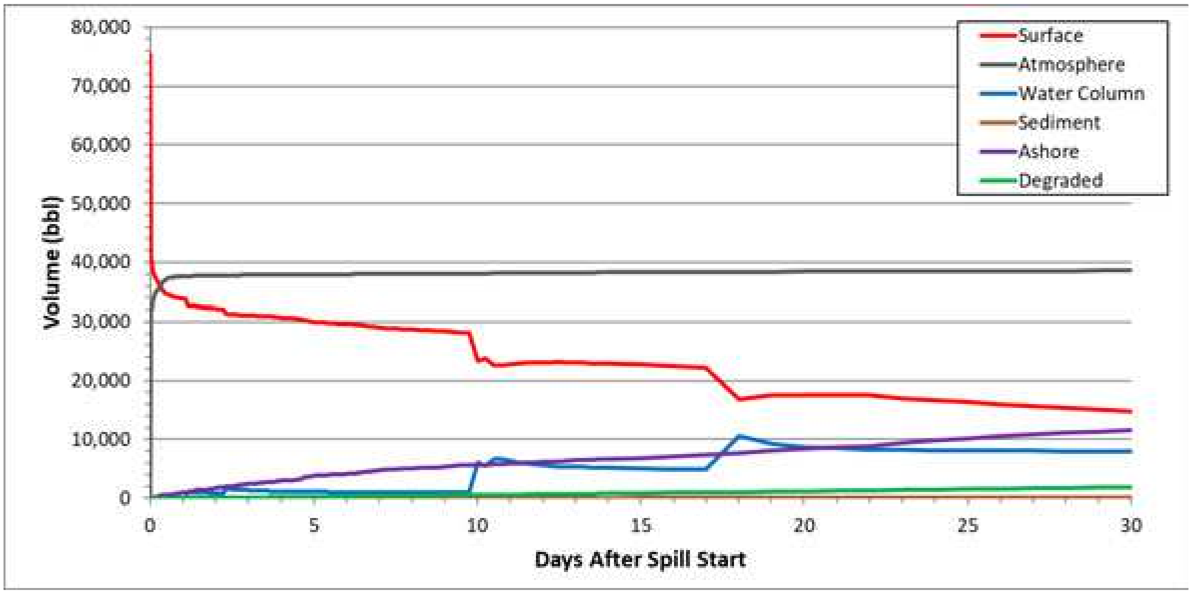

Figure 85: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–75,421 bbl Bakken Crude–Winter–High Tide

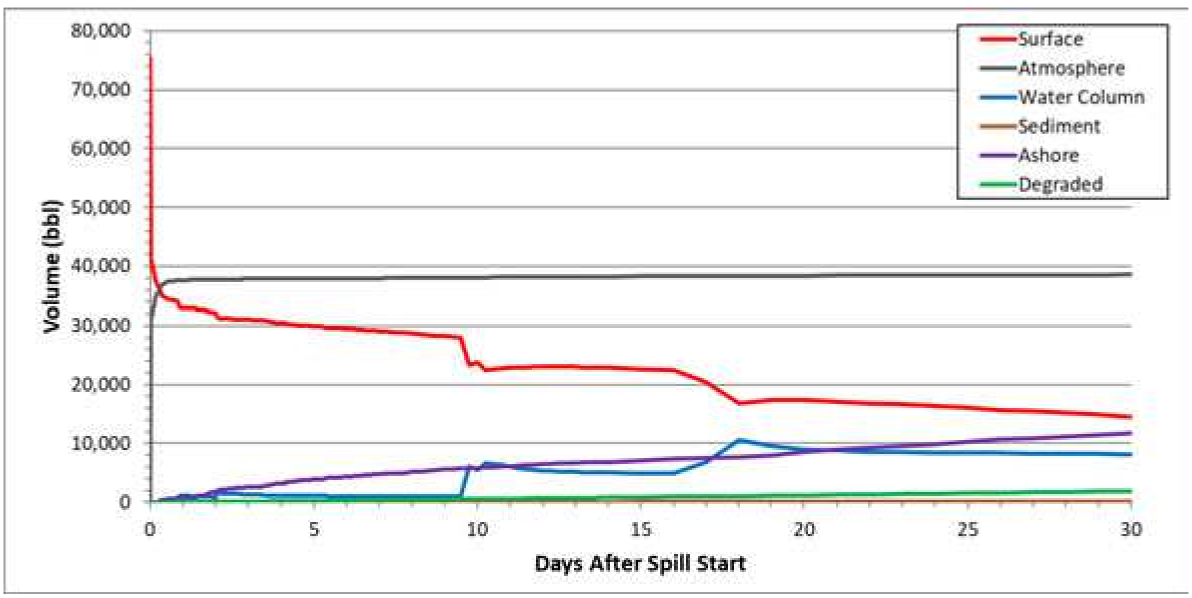

Figure 86: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–75,421 bbl Bakken Crude–Winter–Low Tide

Off Rondout Creek–14,000 bbl Heavy Fuel Oil

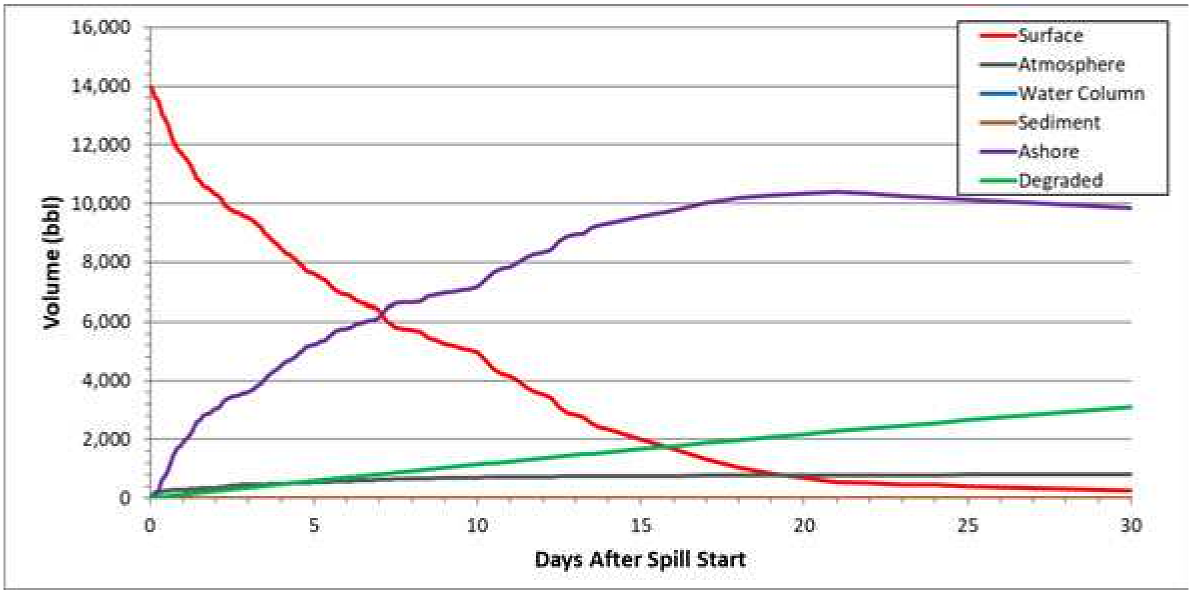

Figure 87: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–14,000 bbl Heavy Fuel Oil–Spring–High Tide

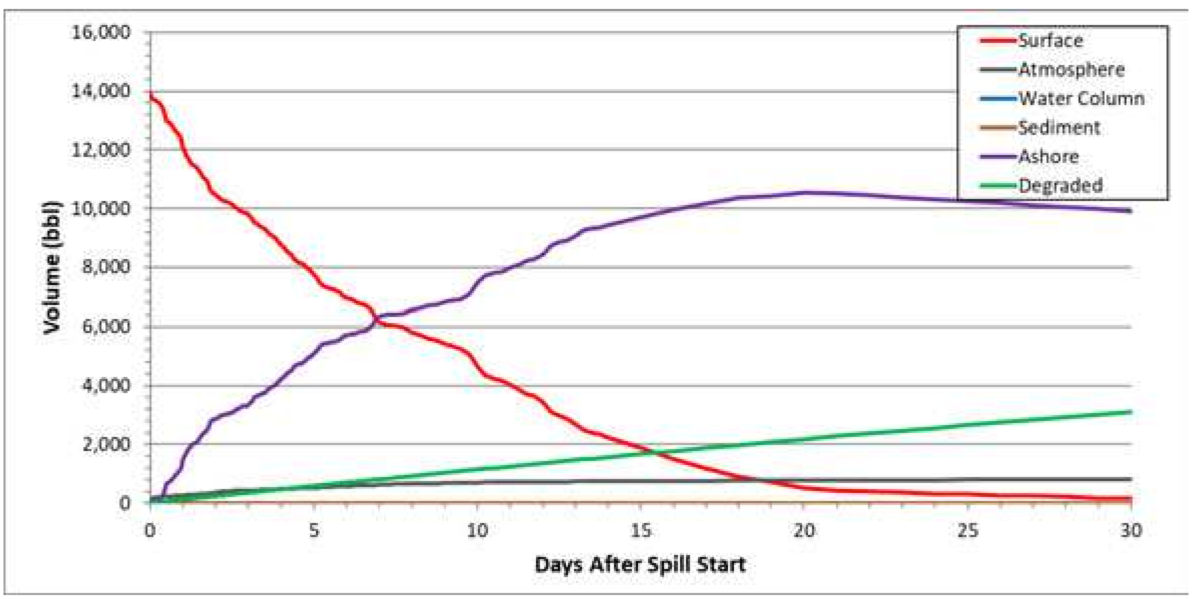

Figure 88: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–14,000 bbl Heavy Fuel Oil–Spring–Low Tide

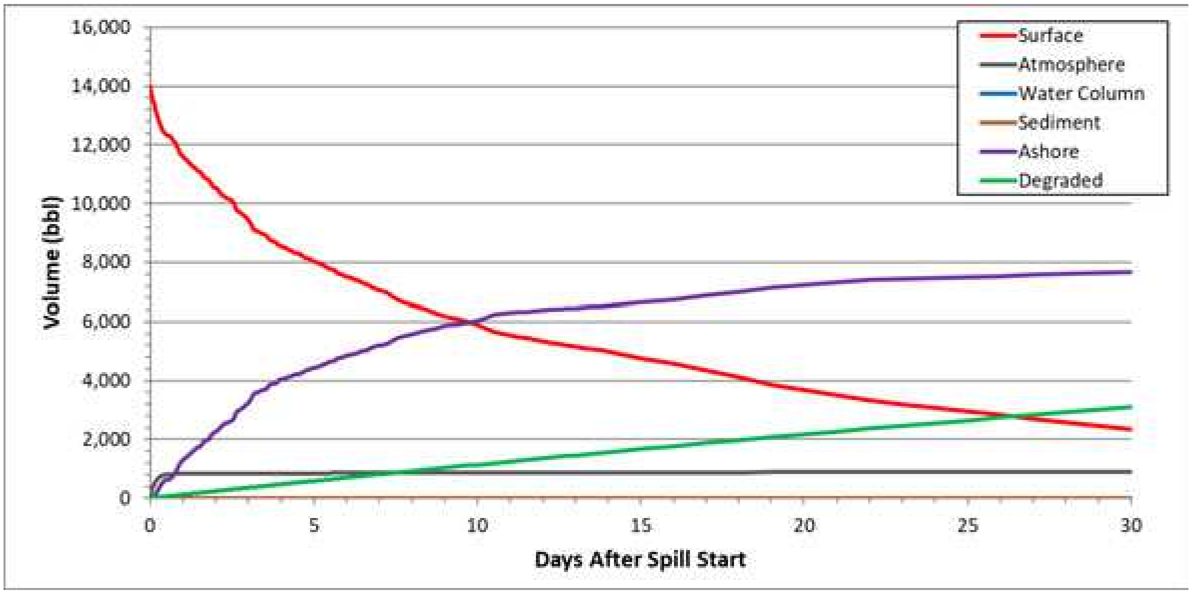

Figure 89: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–14,000 bbl Heavy Fuel Oil–Summer–High Tide

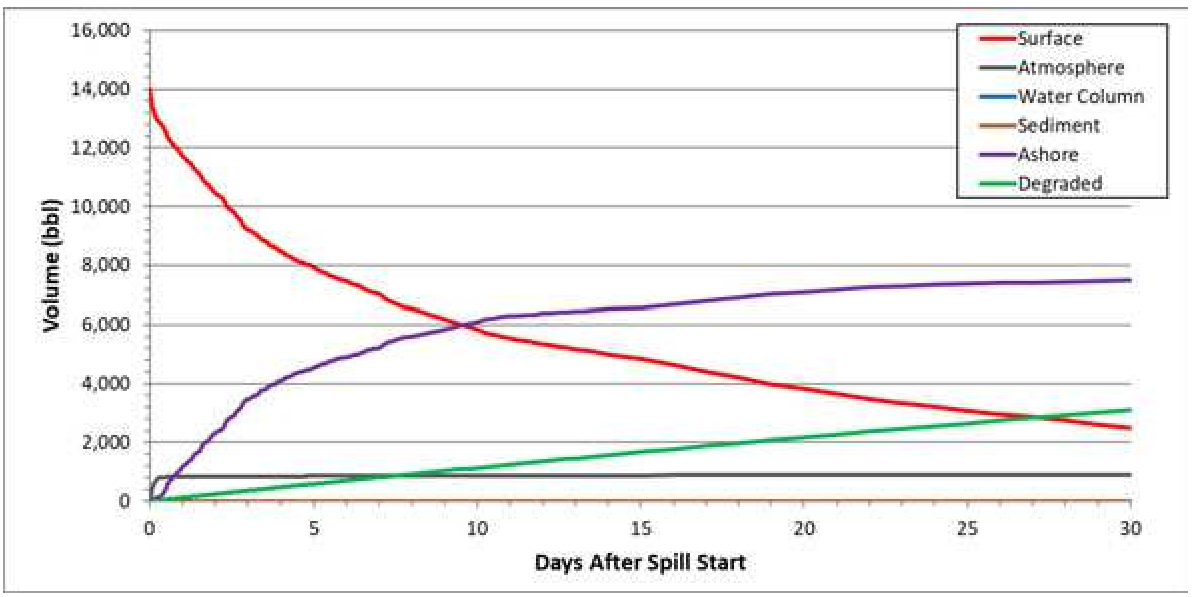

Figure 90: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–14,000 bbl Heavy Fuel Oil–Summer–Low Tide

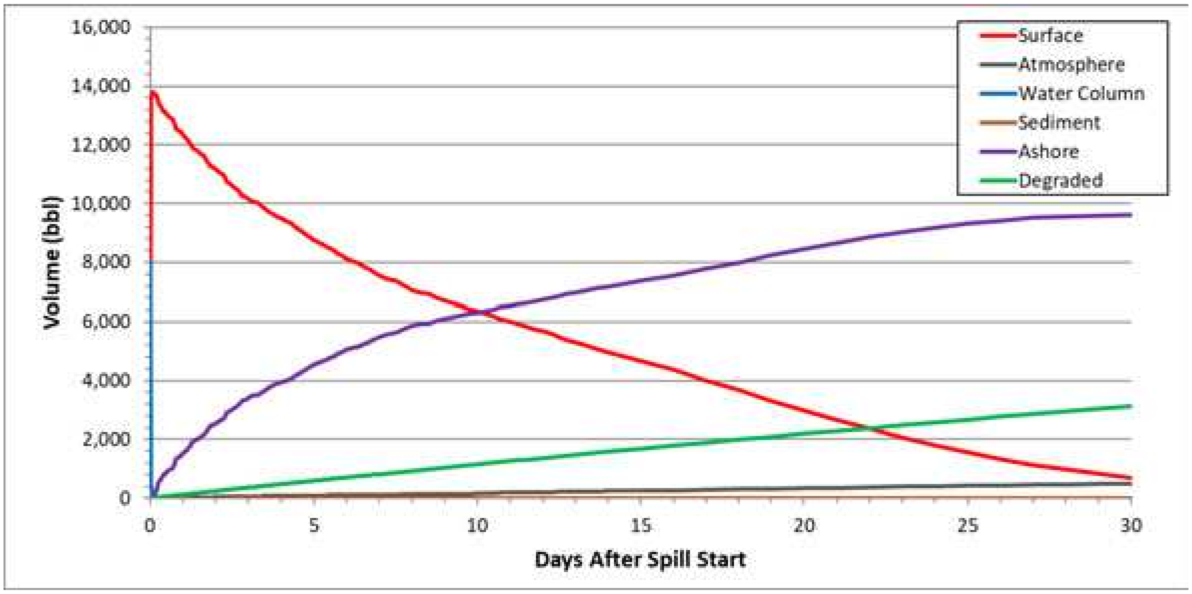

Figure 91: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–14,000 bbl Heavy Fuel Oil–Winter–High Tide

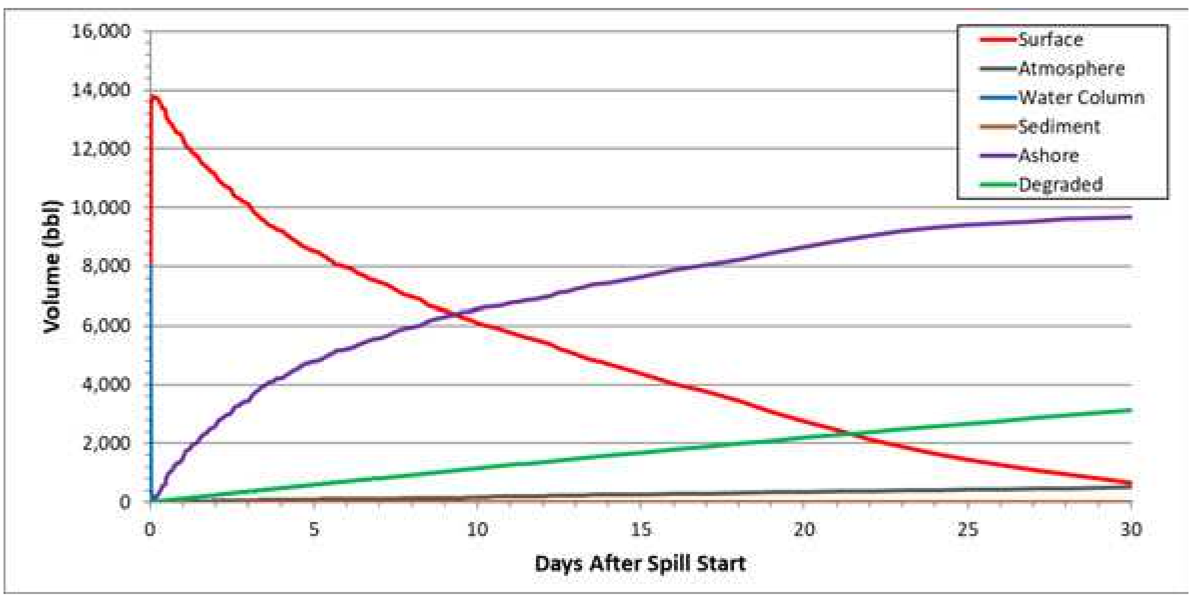

Figure 92: Percent Oil in Different Environmental Compartments over Time: Off Rondout Creek–14,000 bbl Heavy Fuel Oil–Winter–Low Tide

Newburgh Waterfront–11,000 bbl Bakken Crude

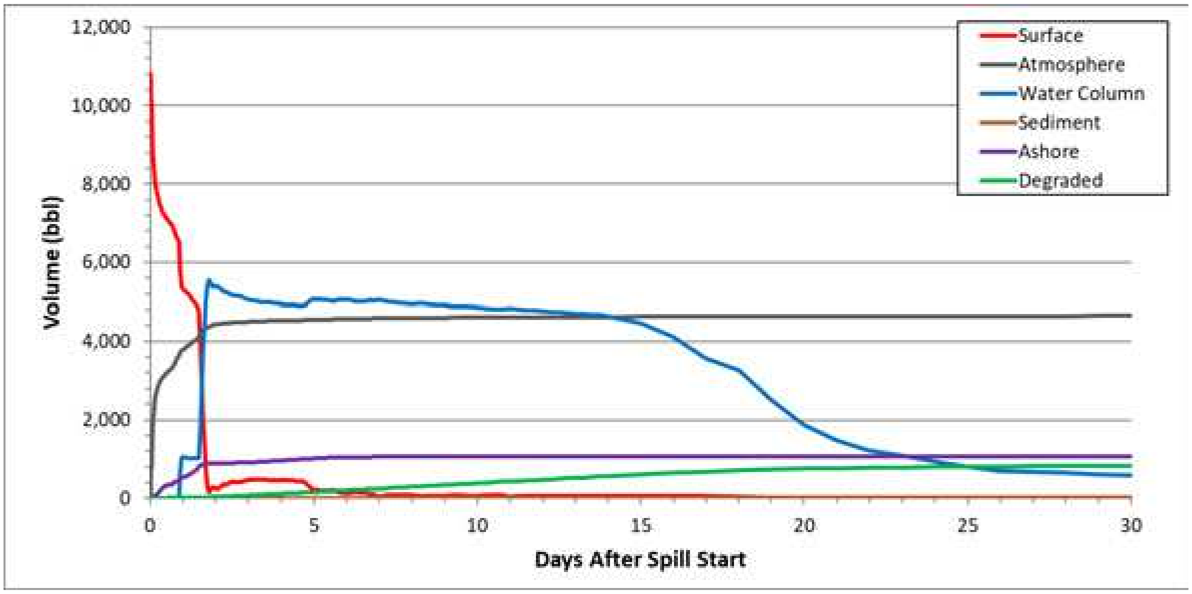

Figure 93: Percent Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Spring–High Tide

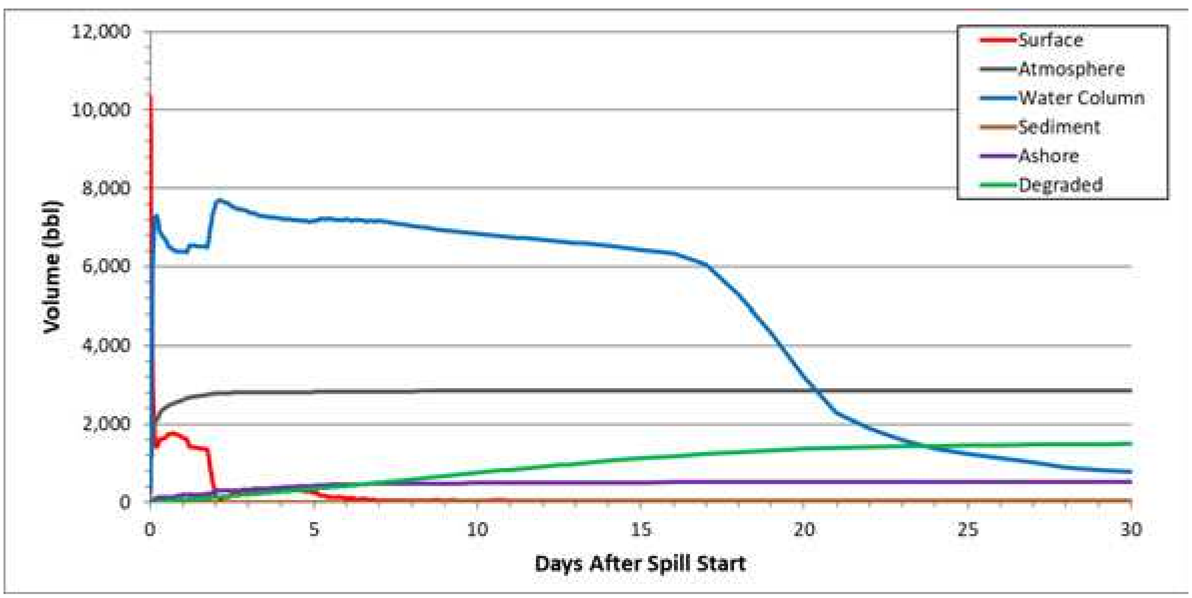

Figure 94: Percent Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Spring–Low Tide

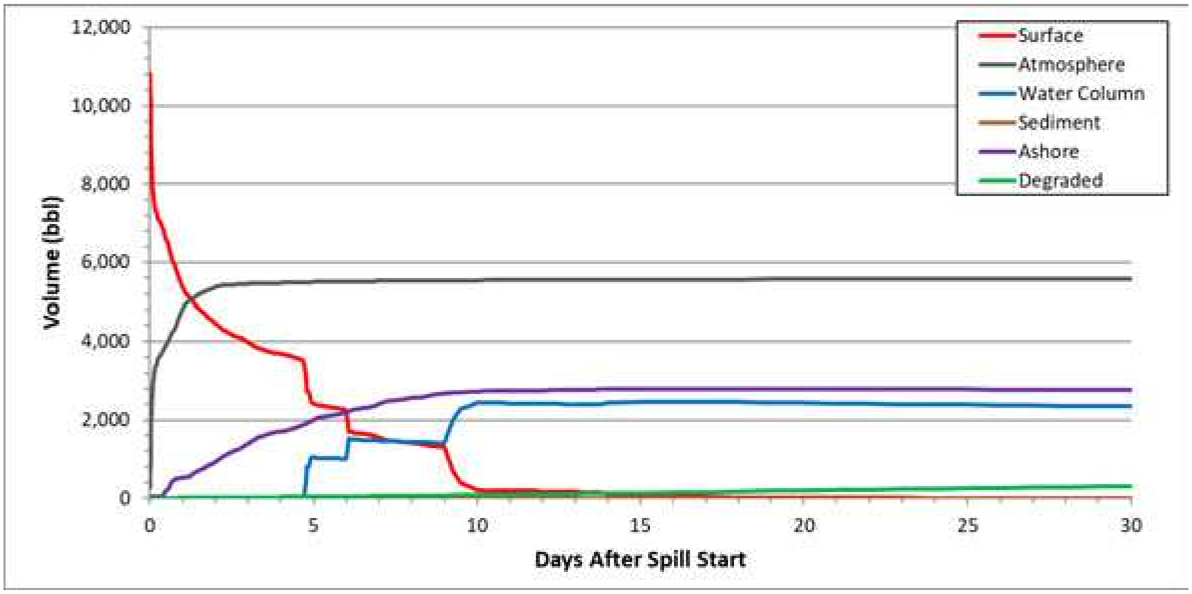

Figure 95: Percent Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Summer–High Tide

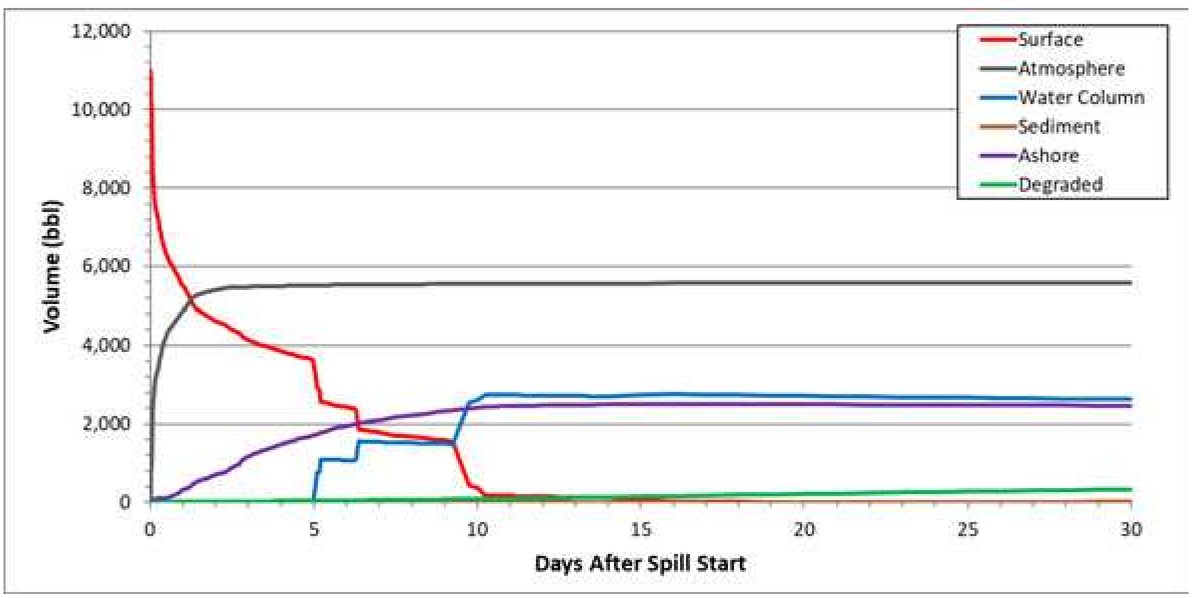

Figure 96: Percent Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Summer–Low Tide

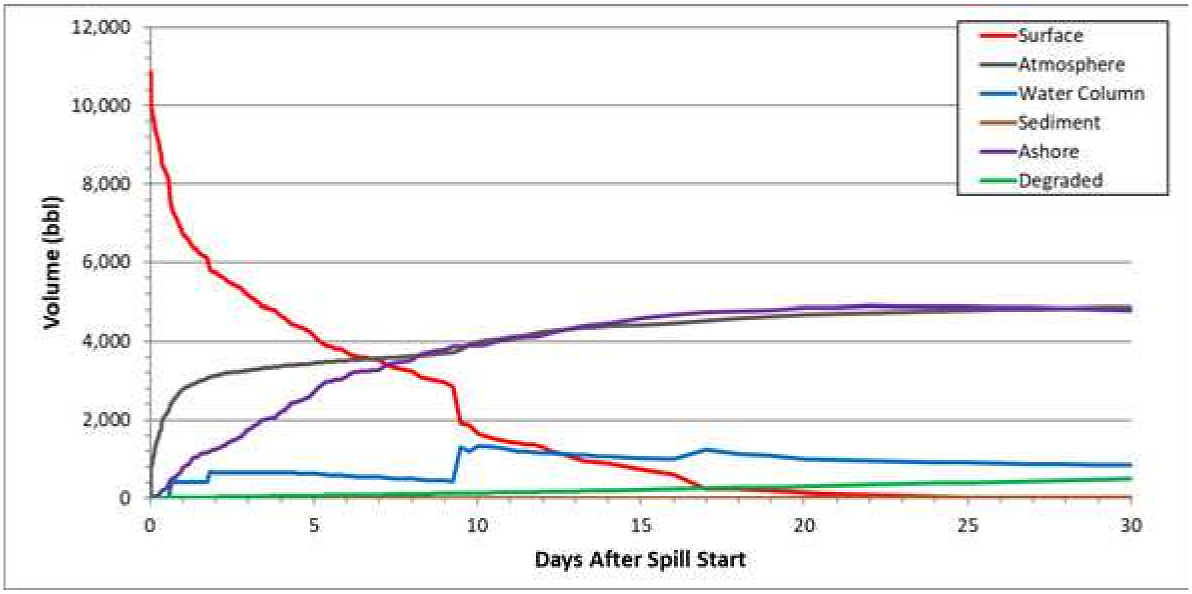

Figure 97: Percent Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Winter–High Tide

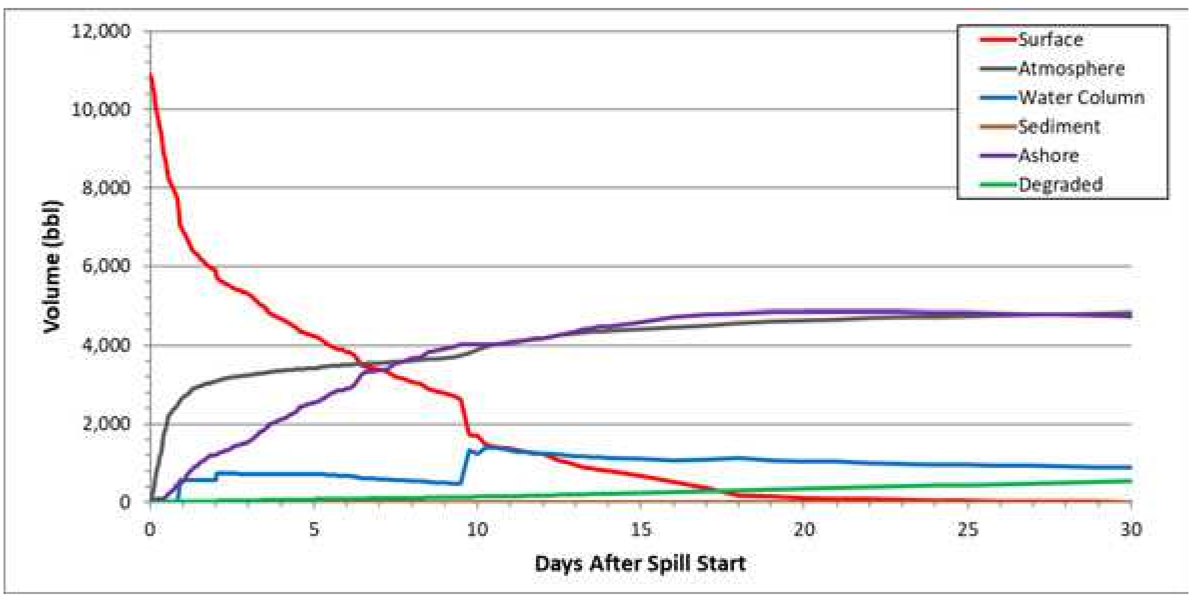

Figure 98: Percent Oil in Different Environmental Compartments over Time: Newburgh Waterfront–11,000 bbl Bakken Crude–Winter–Low Tide

Bear Mountain Bridge–2,500 bbl Home Heating Oil

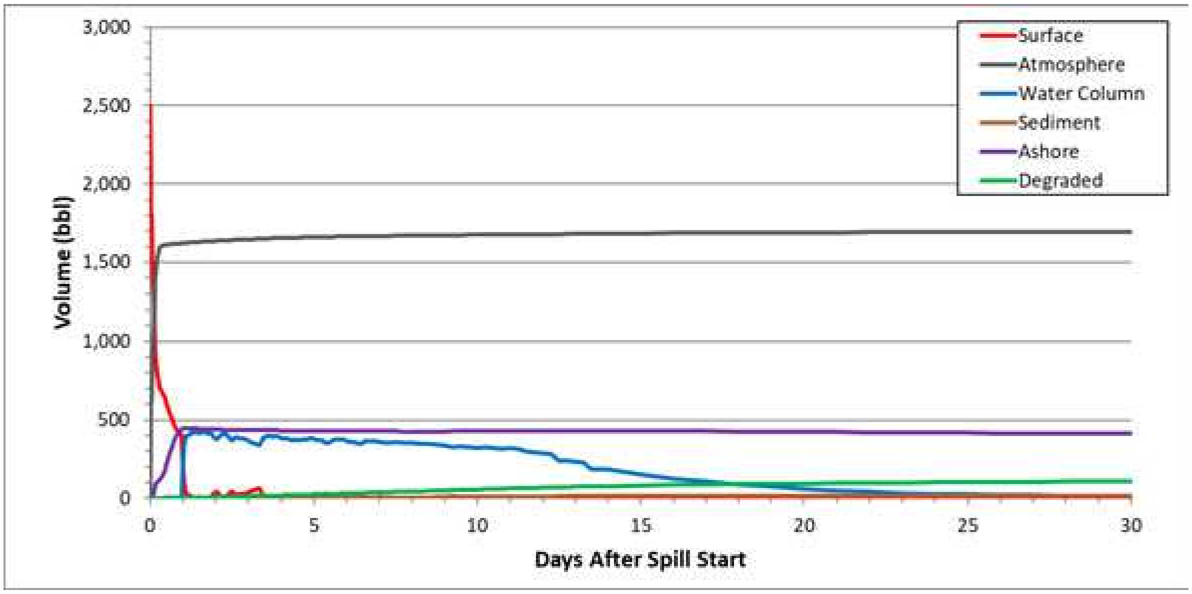

Figure 99: Percent Oil in Different Environmental Compartments over Time: Bear Mountain Bridge–2,500 bbl Home Heating Oil–Spring–High Tide

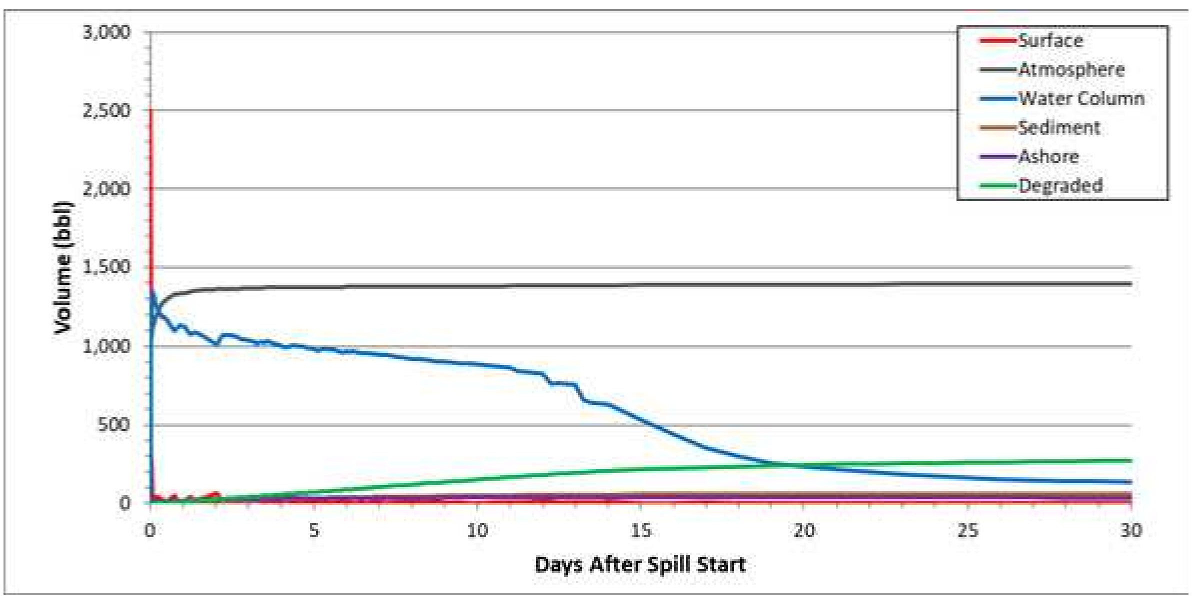

Figure 100: Percent Oil in Different Environmental Compartments over Time: Bear Mountain Bridge–2,500 bbl Home Heating Oil–Spring–Low Tide

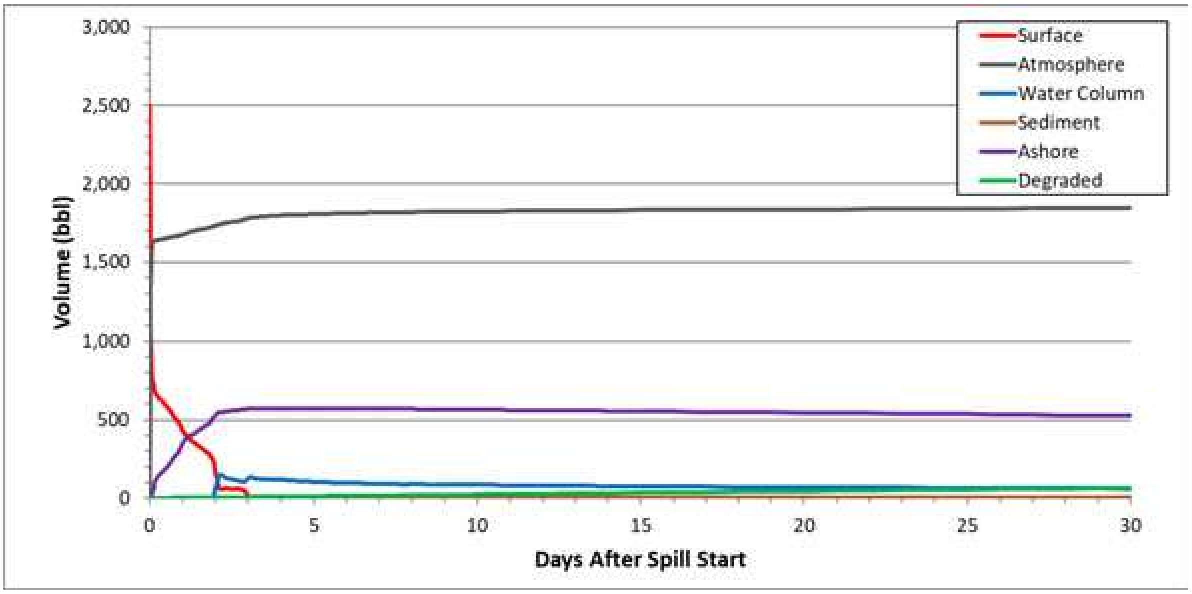

Figure 101: Percent Oil in Different Environmental Compartments over Time: Bear Mountain Bridge–2,500 bbl Home Heating Oil–Summer–High Tide

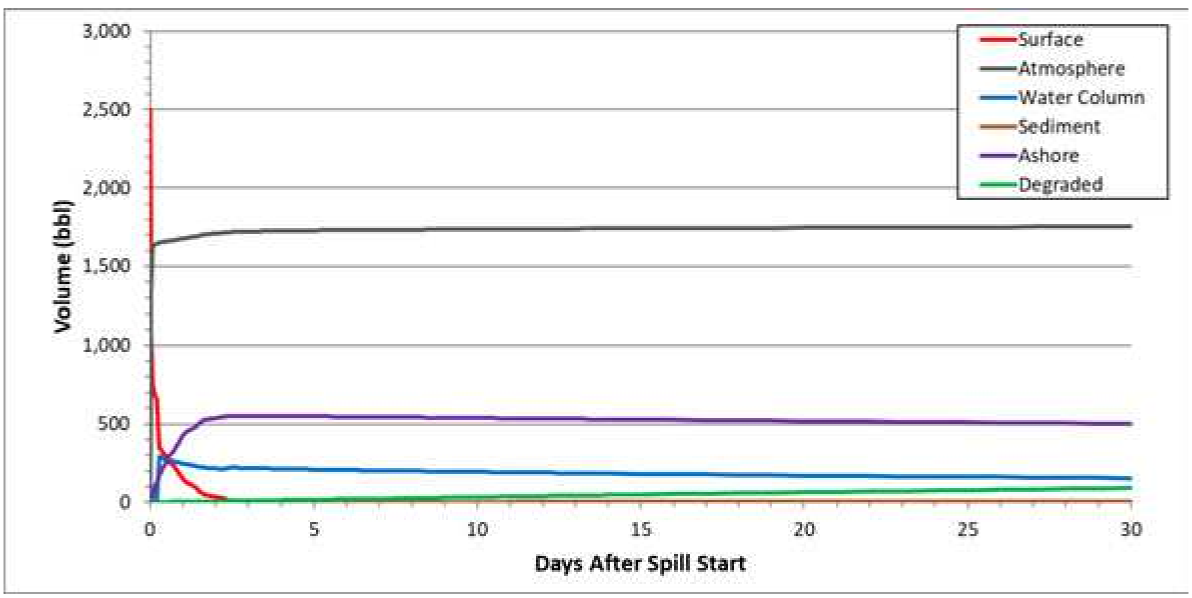

Figure 102: Percent Oil in Different Environmental Compartments over Time: Bear Mountain Bridge–2,500 bbl Home Heating Oil–Summer–Low Tide

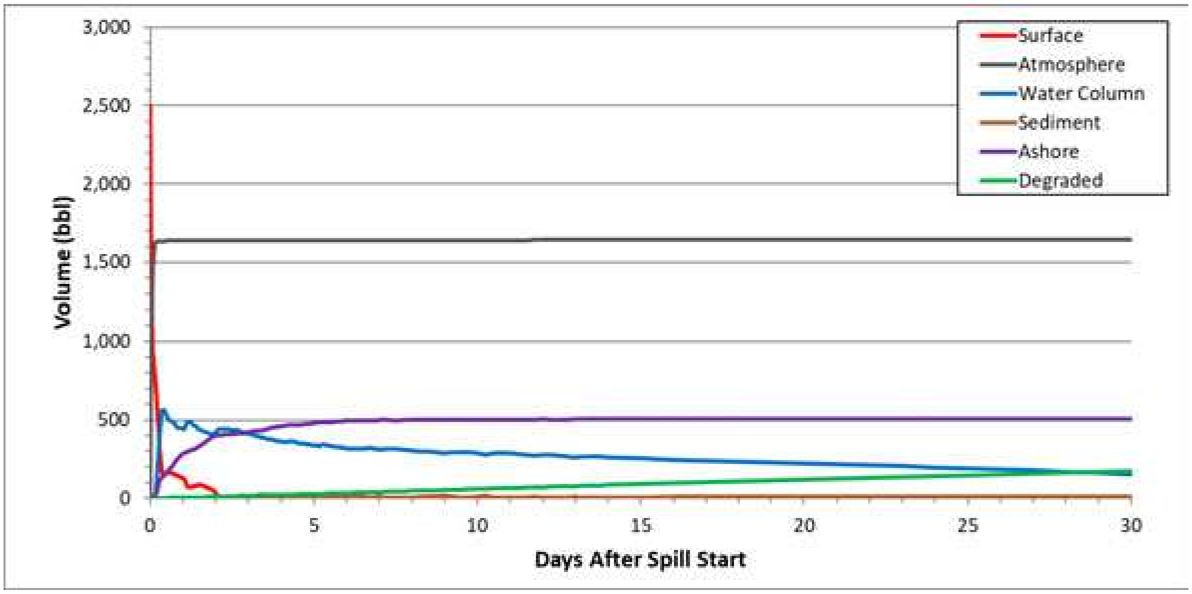

Figure 103: Percent Oil in Different Environmental Compartments over Time: Bear Mountain Bridge–2,500 bbl Home Heating Oil–Winter–High Tide

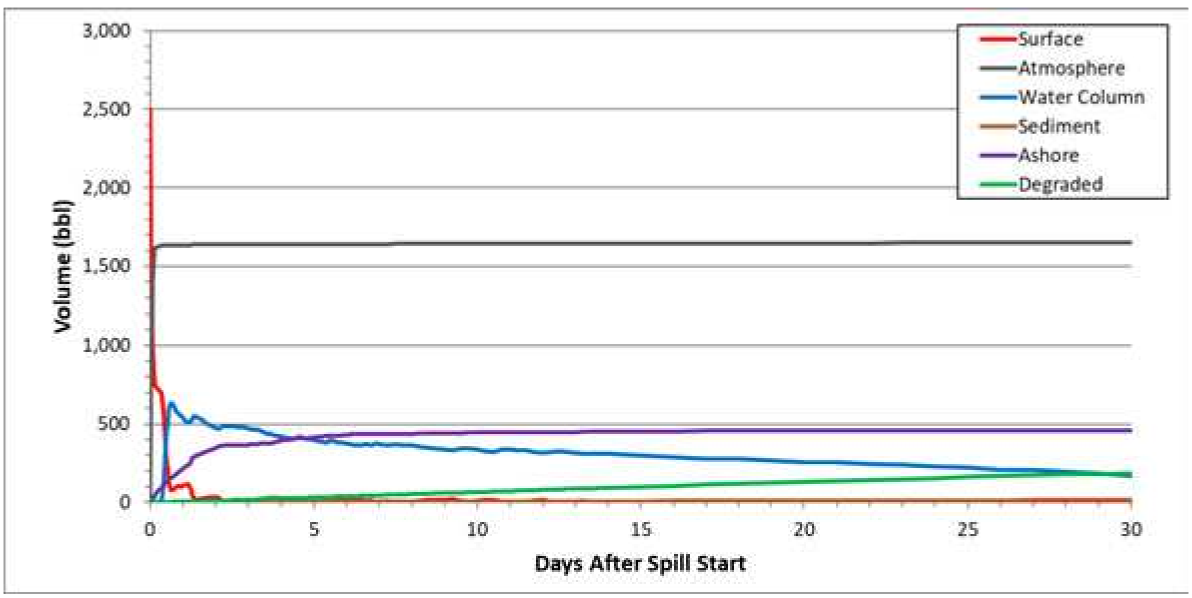

Figure 104: Percent Oil in Different Environmental Compartments over Time: Bear Mountain Bridge–2,500 bbl Home Heating Oil–Winter–Low Tide

Iona Island–11,000 bbl Bakken Crude

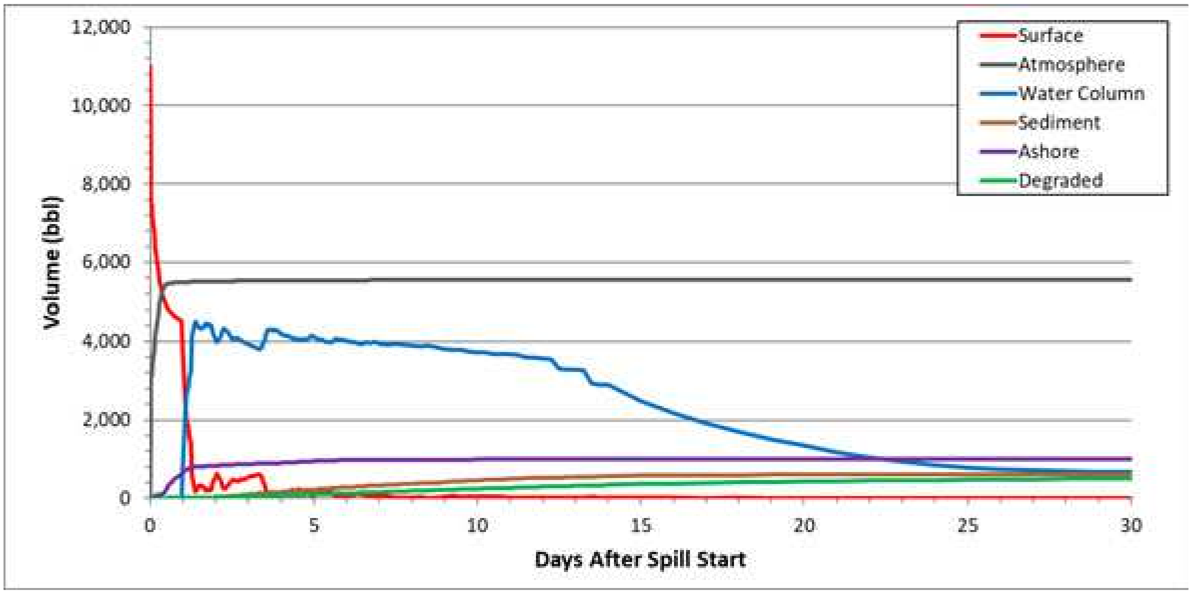

Figure 105: Percent Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Spring–High Tide

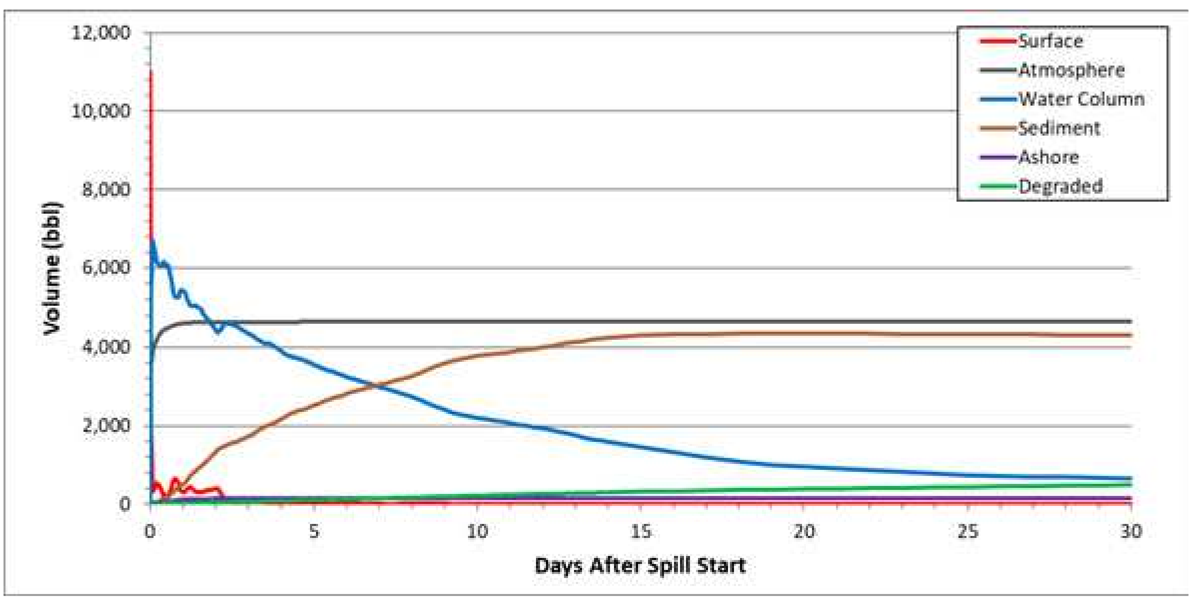

Figure 106: Percent Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Spring–Low Tide

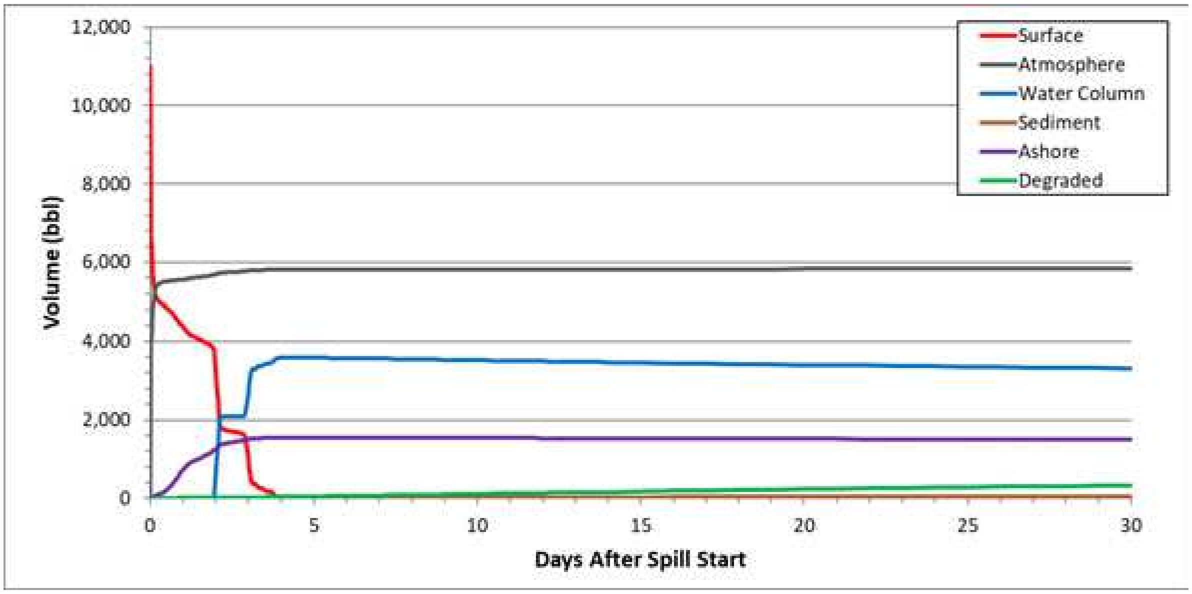

Figure 107: Percent Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Summer–High Tide

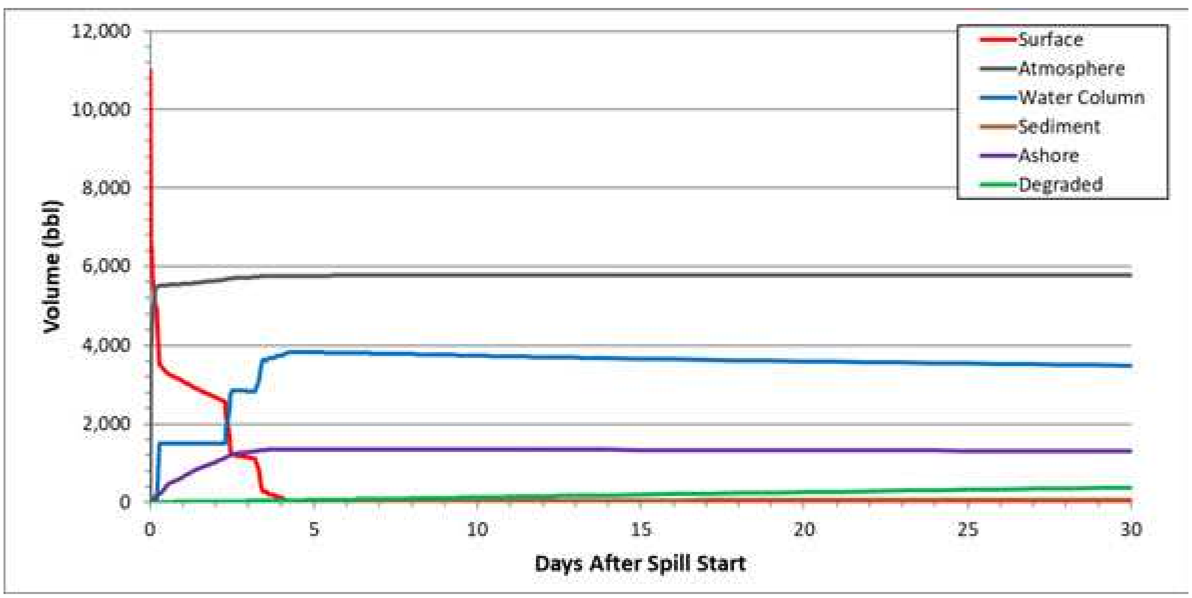

Figure 108: Percent Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Summer–Low Tide

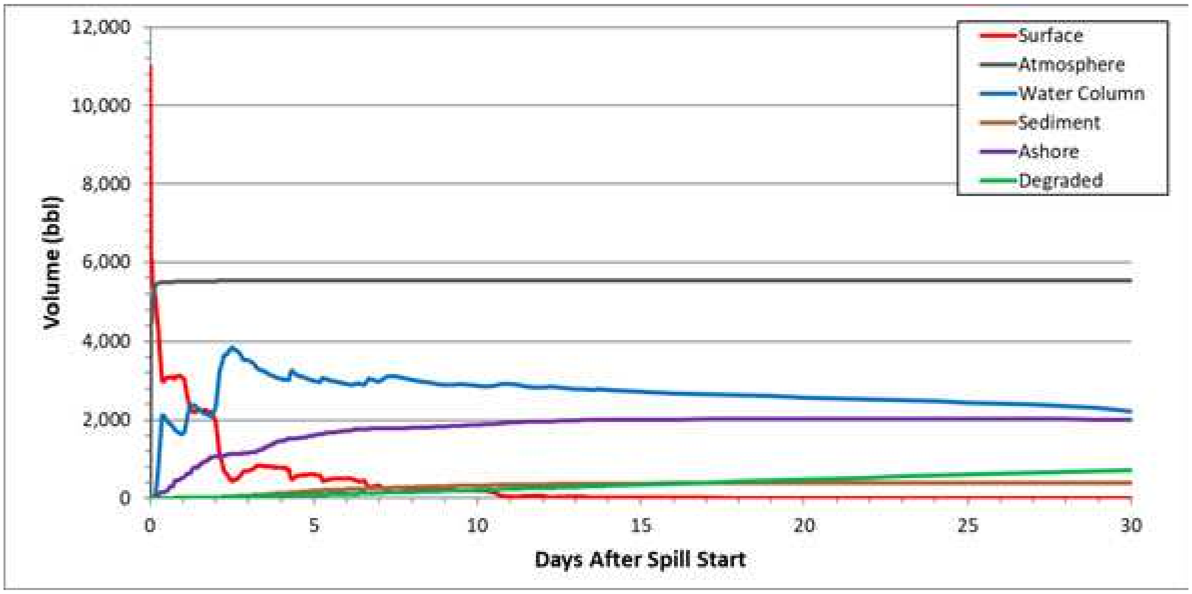

Figure 109: Percent Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Winter–High Tide

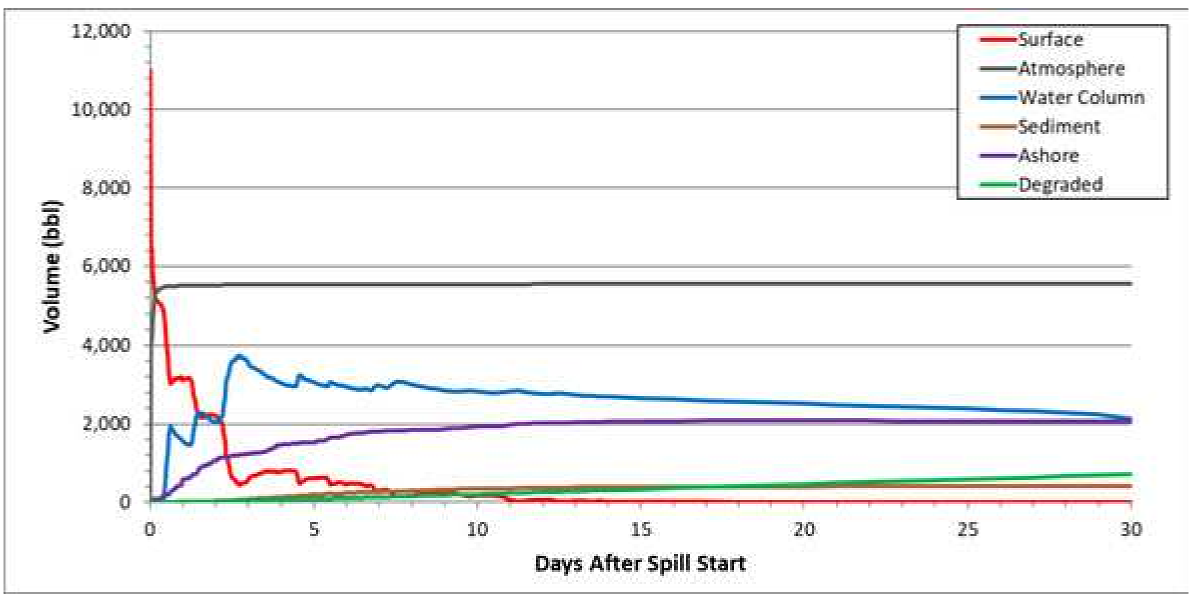

Figure 110: Percent Oil in Different Environmental Compartments over Time: Iona Island–11,000 bbl Bakken Crude–Winter–Low Tide

Tappan Zee–2,500 bbl Home Heating Oil

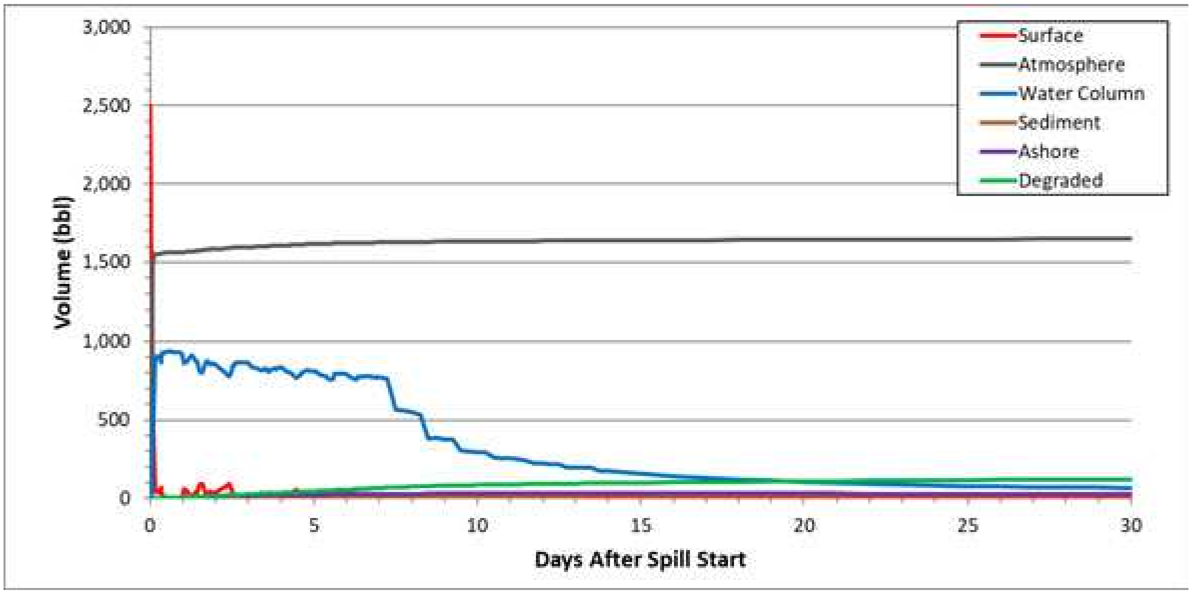

Figure 111: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Spring–High Tide

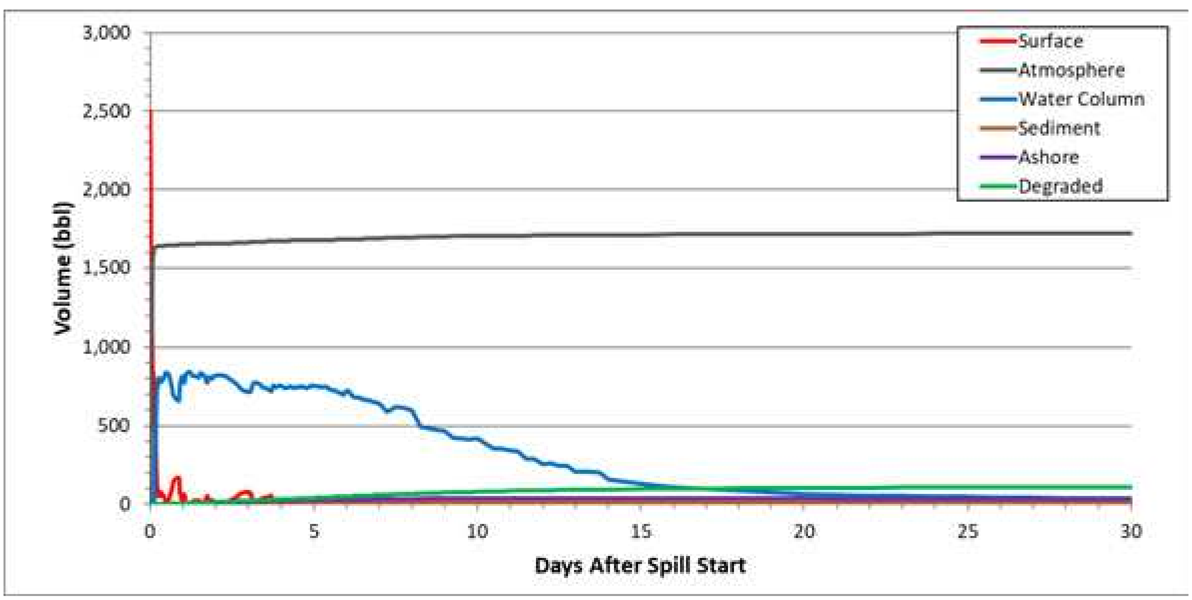

Figure 112: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Spring–Low Tide

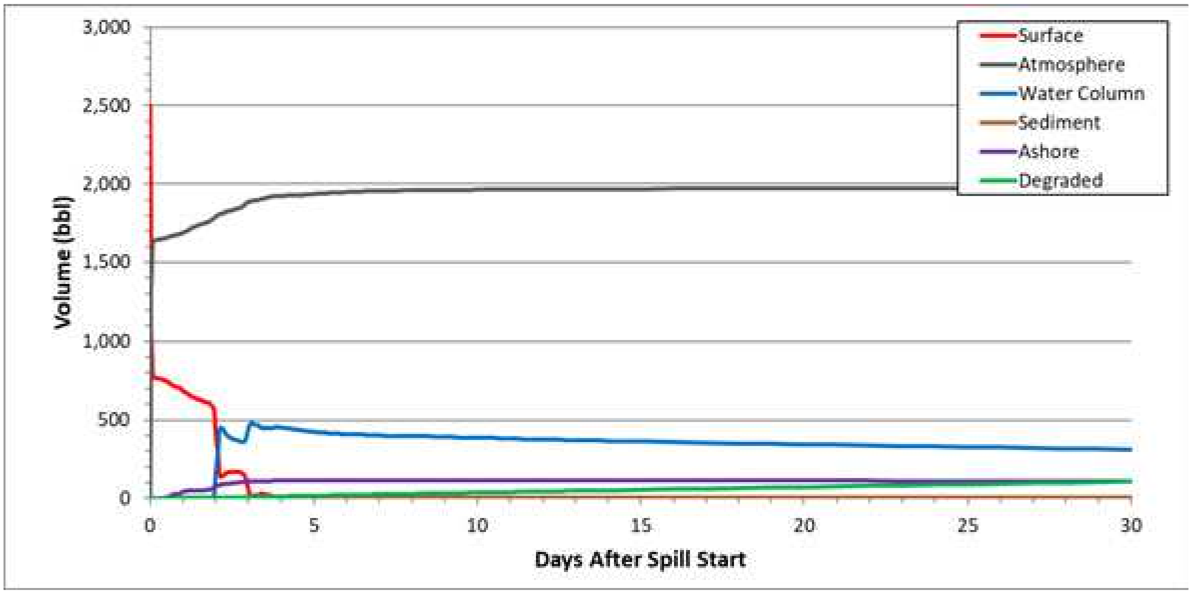

Figure 113: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Summer–High Tide

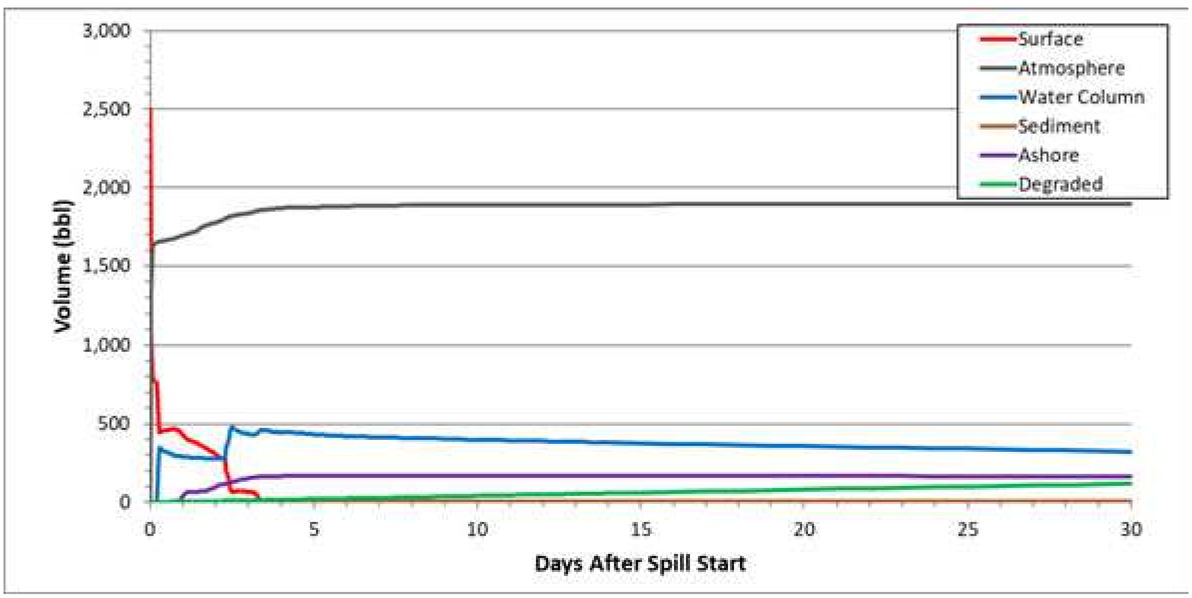

Figure 114: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Summer–Low Tide

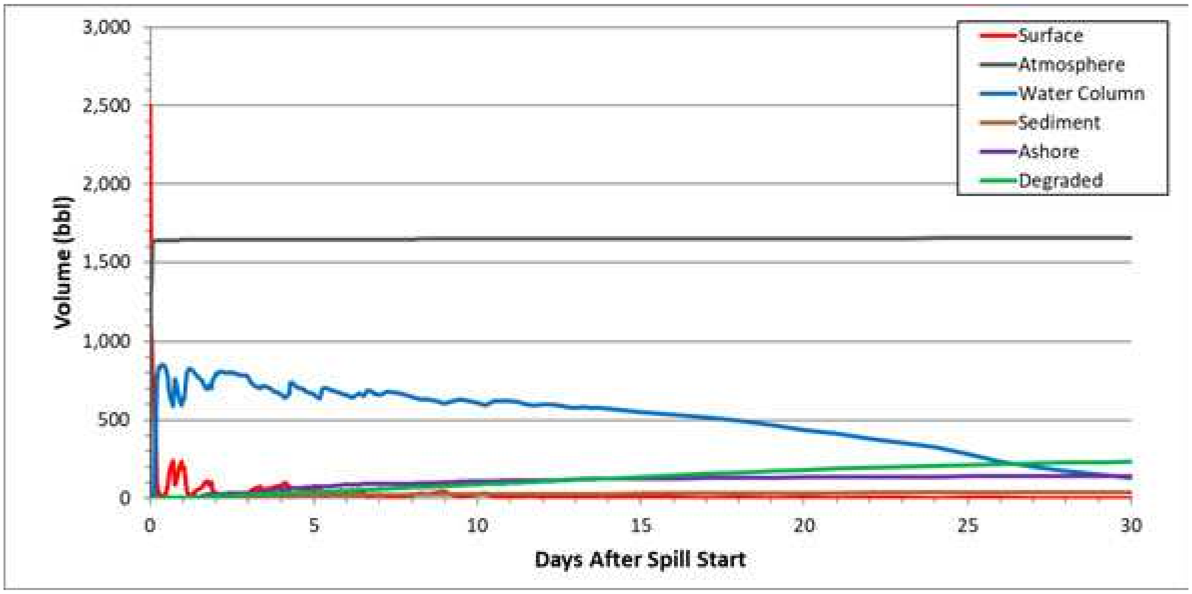

Figure 115: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Winter–High Tide

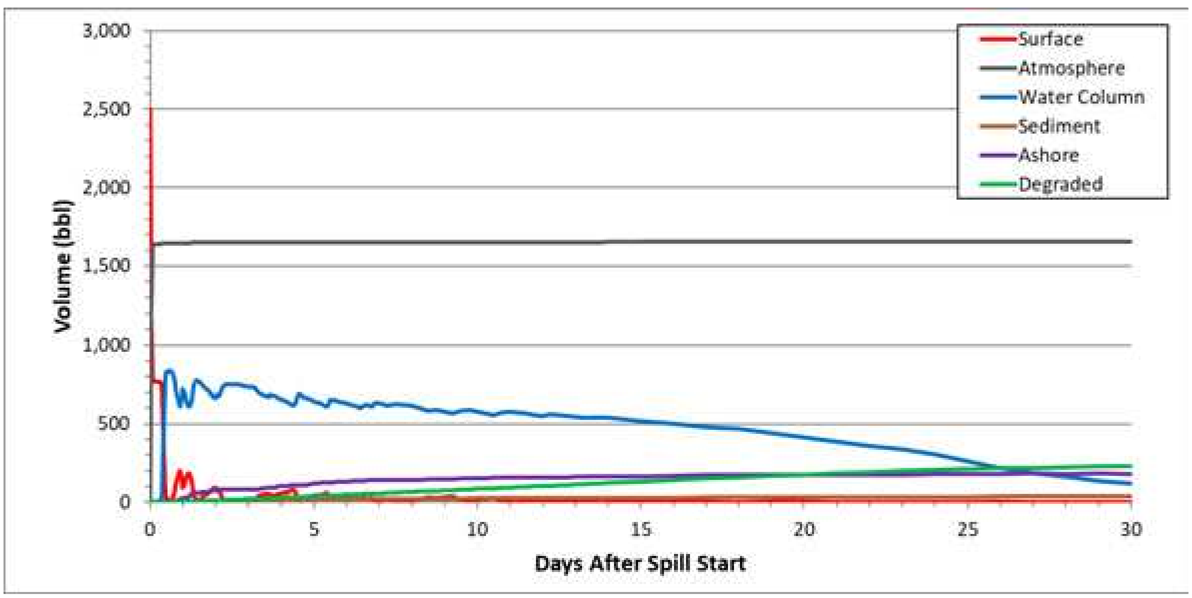

Figure 116: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–2,500 bbl Home Heating Oil–Winter–Low Tide

Tappan Zee–50 bbl Heavy Fuel Oil

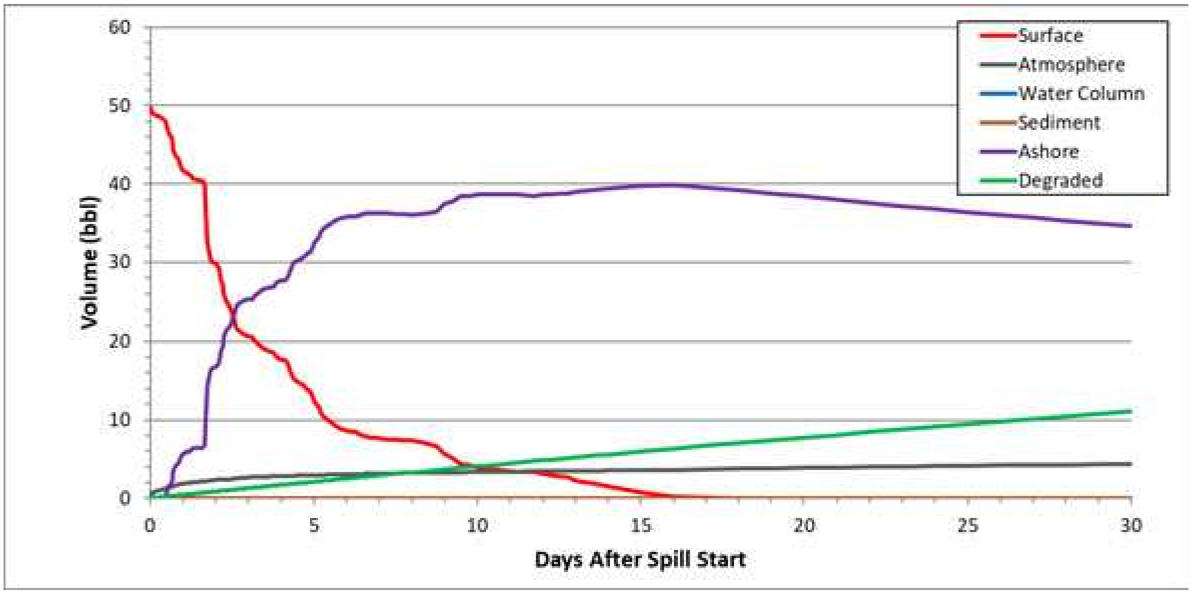

Figure 117: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Spring–High Tide

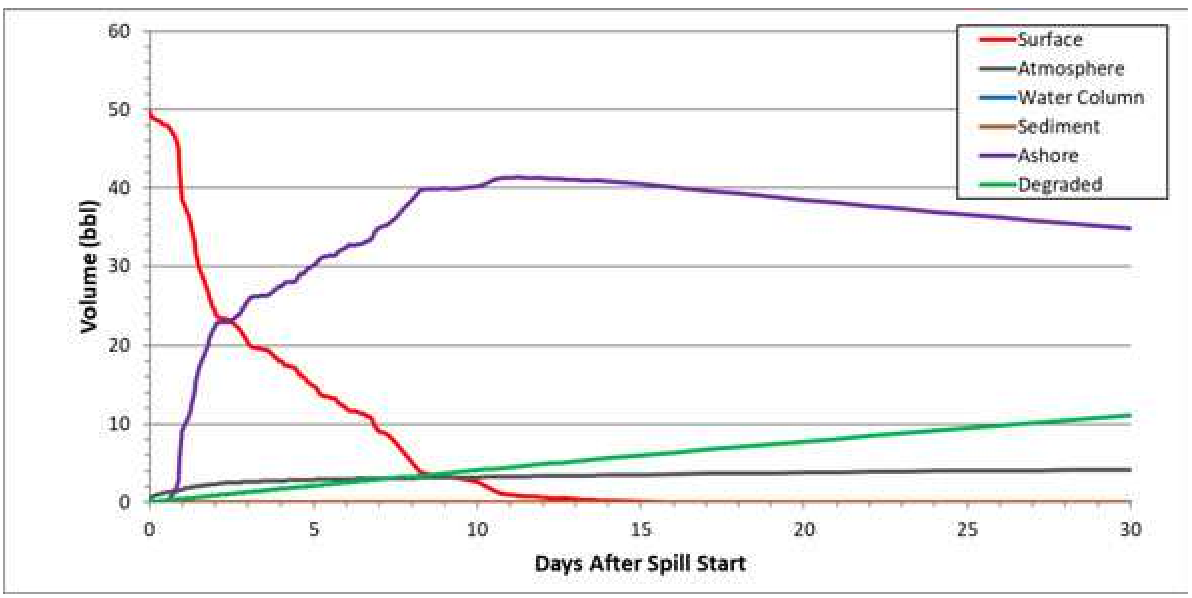

Figure 118: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Spring–Low Tide

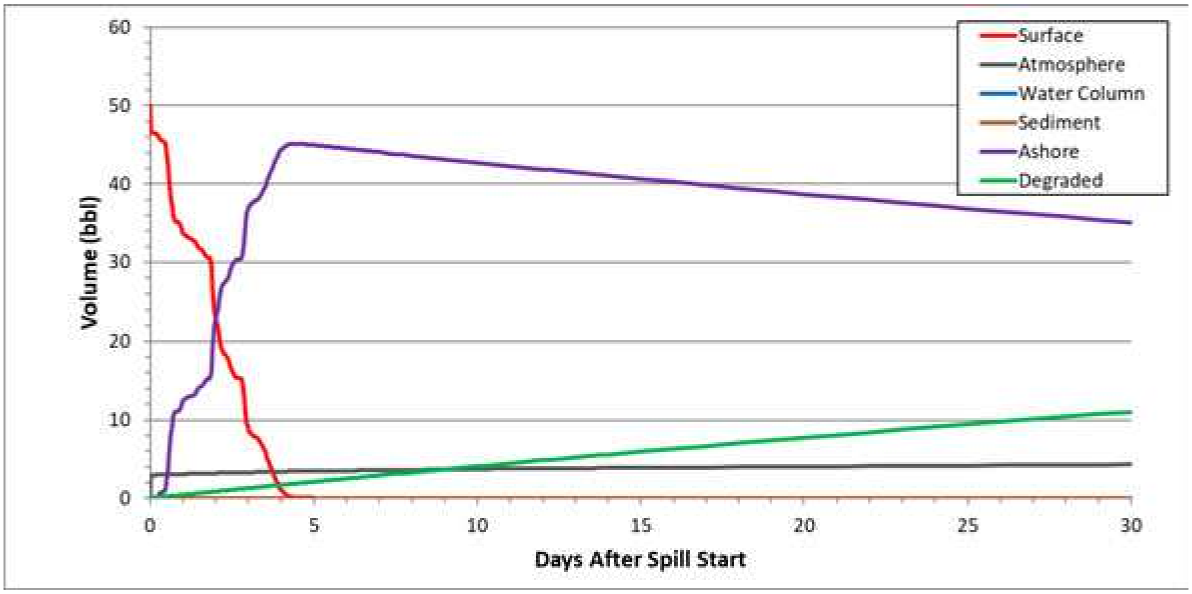

Figure 119: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Summer–High Tide

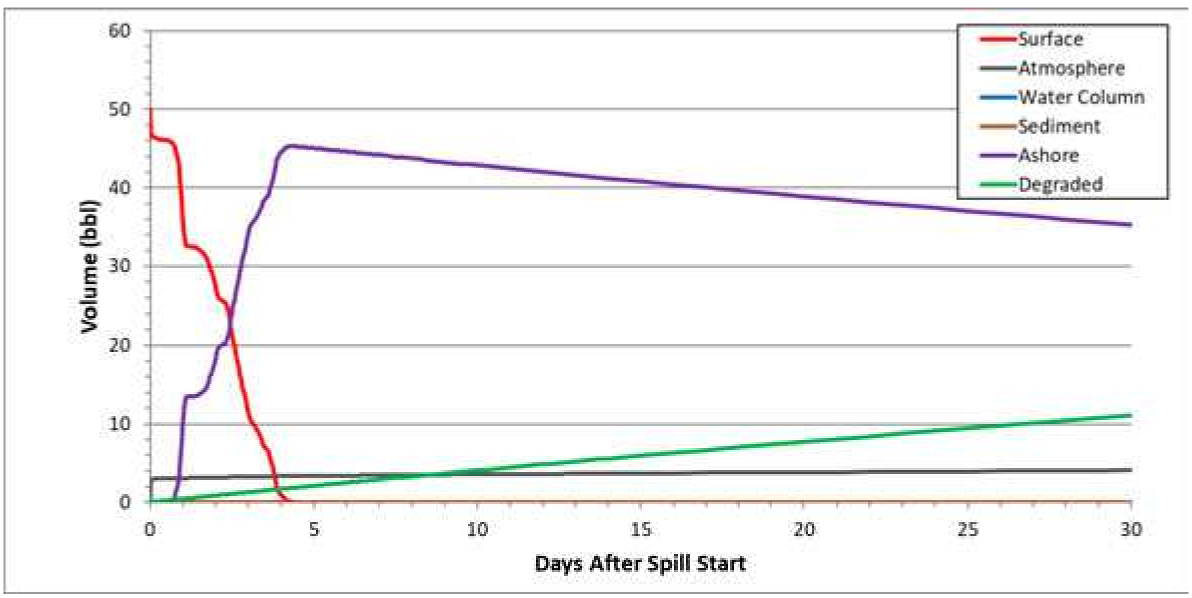

Figure 120: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Summer–Low Tide

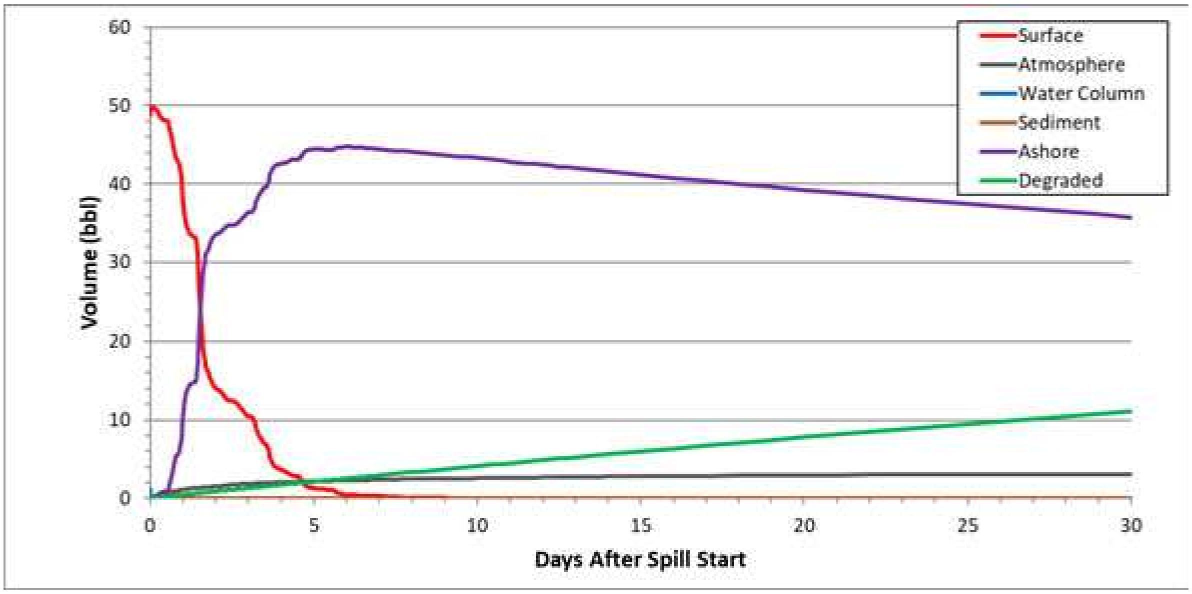

Figure 121: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Winter–High Tide

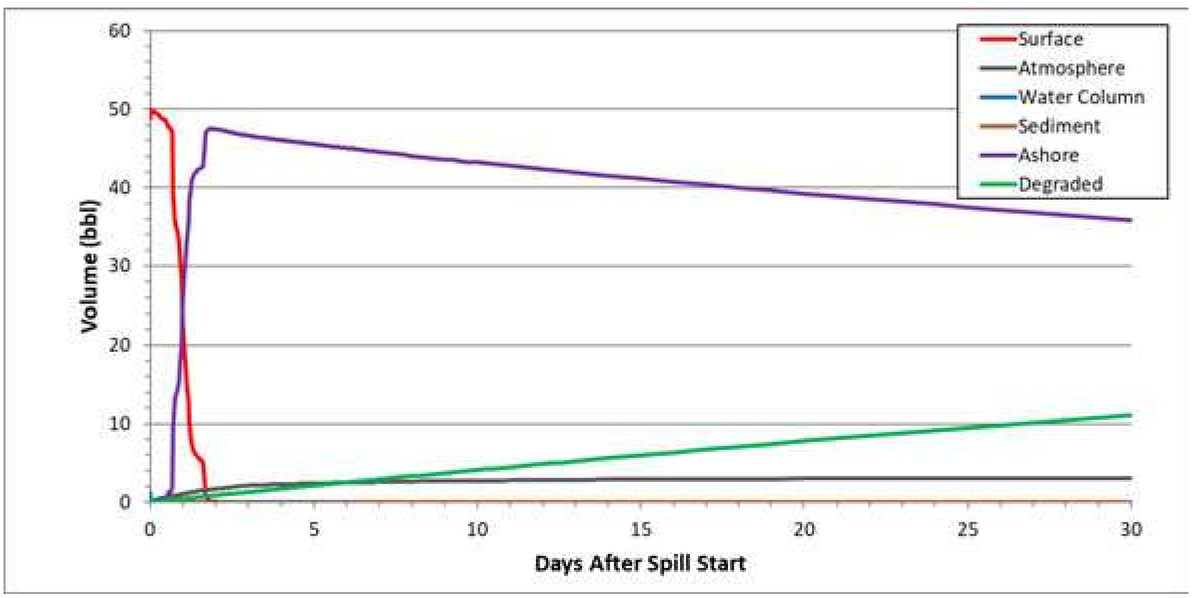

Figure 122: Percent Oil in Different Environmental Compartments over Time: Tappan Zee–50 bbl Heavy Fuel Oil–Winter–Low Tide

Yonkers Anchorage–155,000 bbl Gasoline

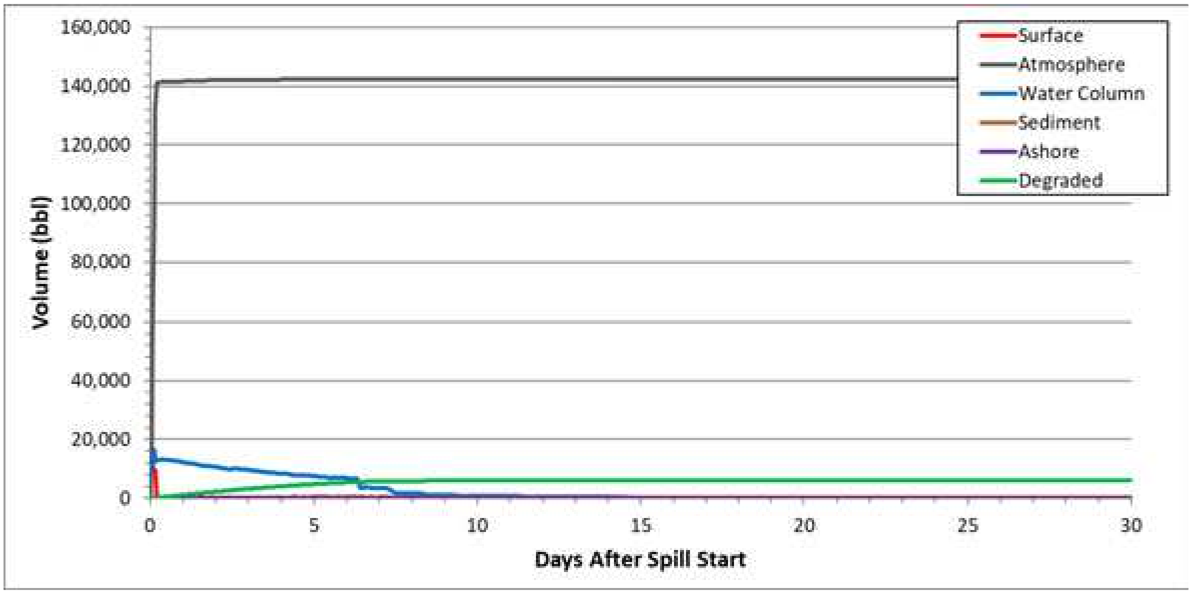

Figure 123: Percent Oil in Different Environmental Compartments over Time: Yonkers Anchorage–155,000 bbl Gasoline–Spring–High Tide

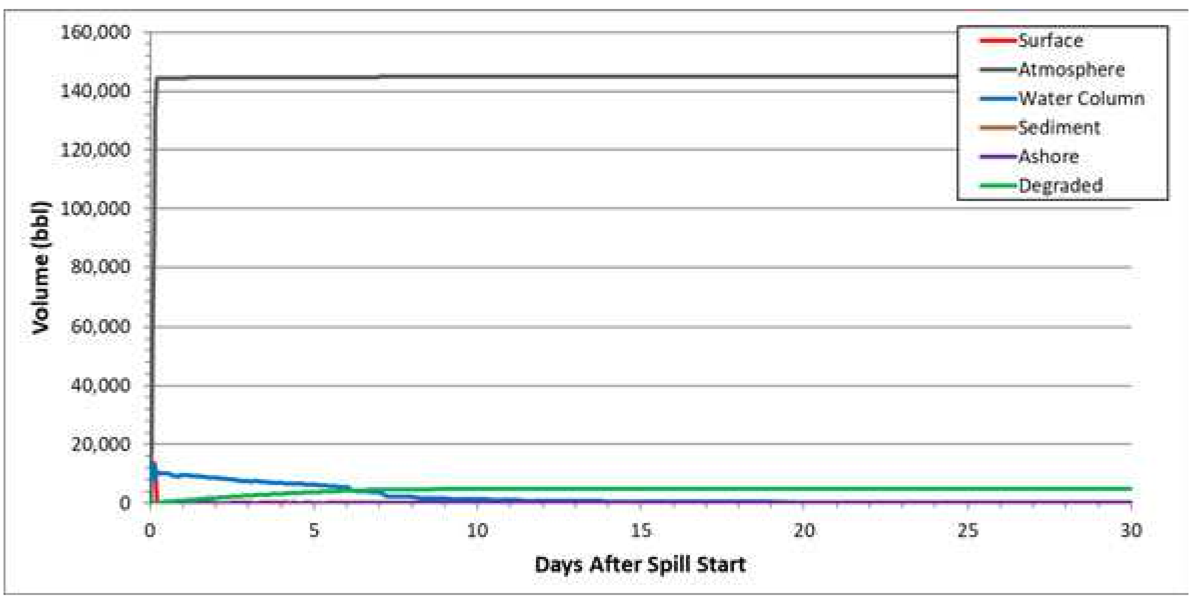

Figure 124: Percent Oil in Different Environmental Compartments over Time: Yonkers Anchorage–155,000 bbl Gasoline–Spring–Low Tide

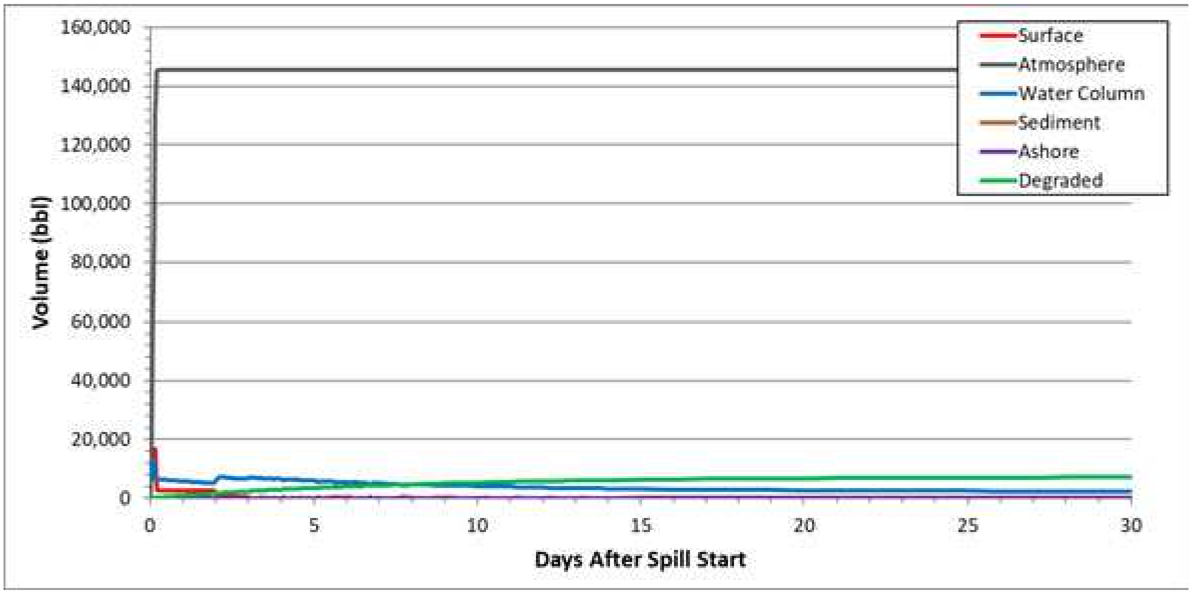

Figure 125: Percent Oil in Different Environmental Compartments over Time: Yonkers Anchorage–155,000 bbl Gasoline–Summer–High Tide

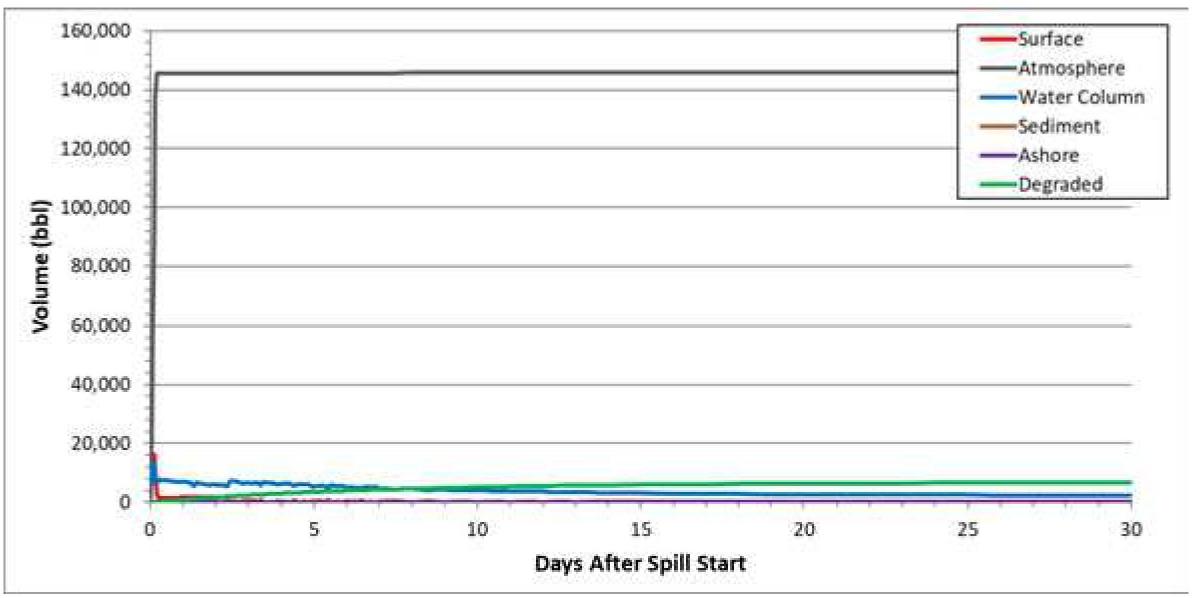

Figure 126: Percent Oil in Different Environmental Compartments over Time: Yonkers Anchorage–155,000 bbl Gasoline–Summer–Low Tide

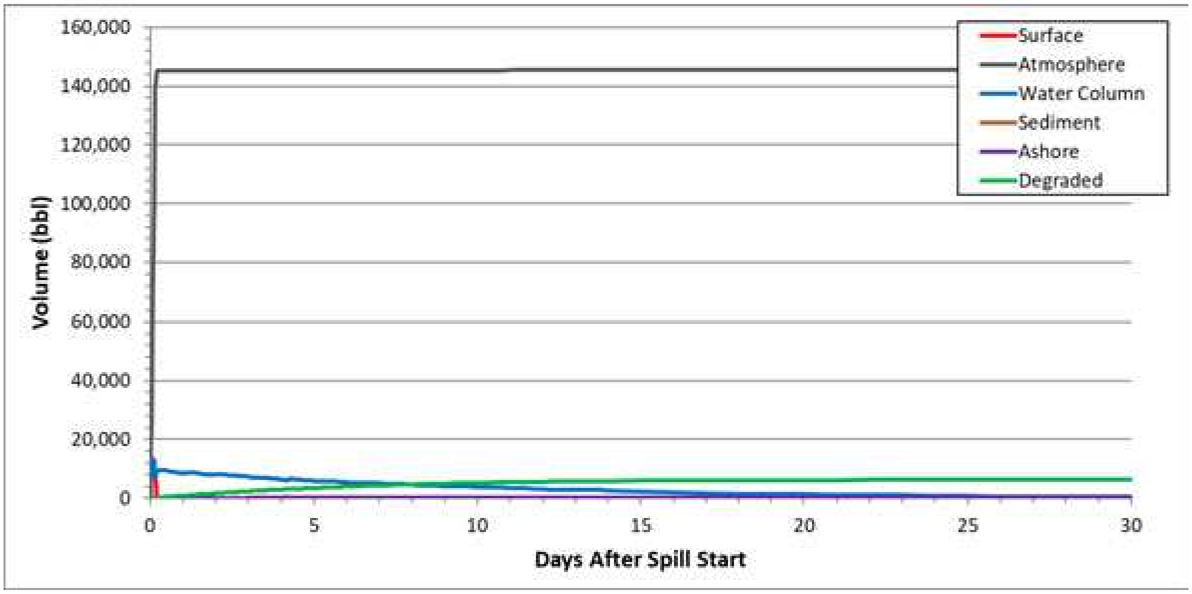

Figure 127: Percent Oil in Different Environmental Compartments over Time: Yonkers Anchorage–155,000 bbl Gasoline–Winter–High Tide

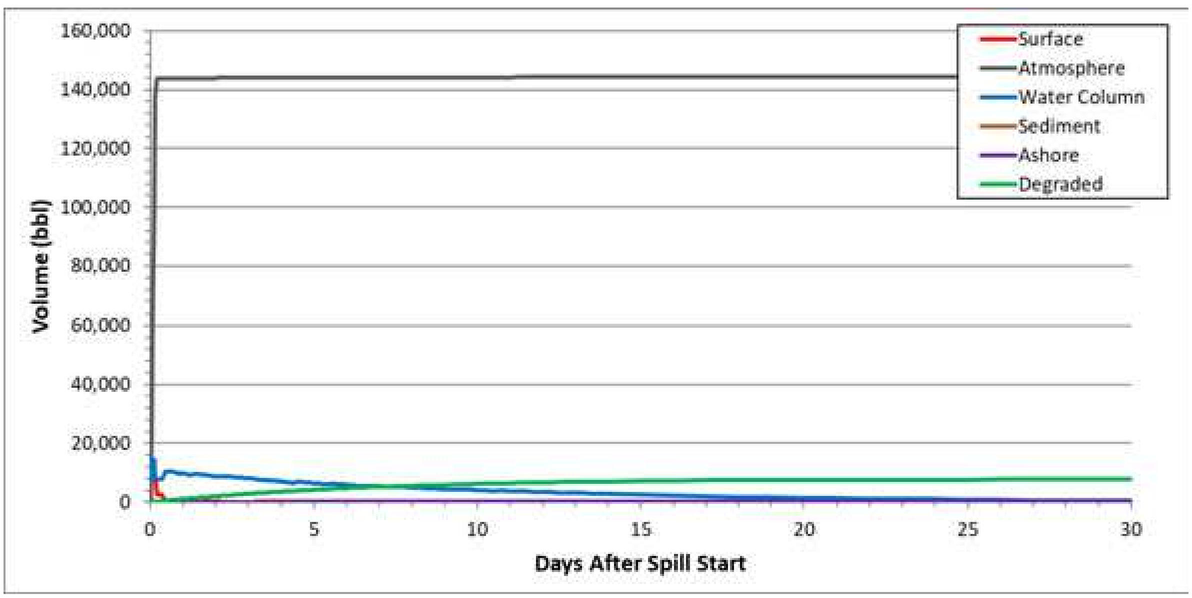

Figure 128: Percent Oil in Different Environmental Compartments over Time: Yonkers Anchorage–155,000 bbl Gasoline–Winter–Low Tide

Appendix C: Oil Trajectory and Exposure Maps

Maps showing the oil spill trajectories and distribution of floating oil, entrained oil droplets, dissolved hydrocarbons, oil on sediments, and ashore are in individual (PDF) files, as listed below. The map files are organized in subfolders named as per the spill location and oil volume and type.

Each scenario has a set of six maps that show:

- Cumulative trajectory – locations where any amount of floating oil passed;
- Floating oil concentration (per unit area) over time;
- Oil concentration (droplets) in the water, as maximum at any depth, over time;
- Dissolved hydrocarbon concentration in the water, as maximum at any depth, over time;
- Cumulative amount of oil settled onto the sediment (by 30 days post-spill); and
- Cumulative amount of oil on the shoreline (by 30 days post-spill).

The files are organized by scenario into 12 separate folders each of which has six PDF files with the maps described above:

- Appendix C1- Port of Albany–155,000 bbl Bakken Crude
- Appendix C2- Coxsackie–25,000 bbl Home Heating Oil
- Appendix C3- Proposed Kingston Anchorage–150,000 bbl Home Heating Oil
- Appendix C4- Proposed Kingston Anchorage–150,000 bbl Diluted Bitumen
- Appendix C5- Off Rondout Creek–75,421 bbl Bakken Crude
- Appendix C6- Off Rondout Creek–14,000 bbl Heavy Fuel Oil
- Appendix C7- Newburgh Waterfront–11,000 bbl Bakken Crude
- Appendix C8- Bear Mountain Bridge–2,500 bbl Home Heating Oil
- Appendix C9- Iona Island–11,000 bbl Bakken Crude
- Appendix C10- Tappan Zee–2,500 bbl Home Heating Oil
- Appendix C11- Tappan Zee–50 bbl Heavy Fuel Oil
- Appendix C12- Yonkers Anchorage–155,000 bbl Gasoline