ENVIRONMENTAL
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Hudson River Oil Spill Risk Assessment

Volume 2:
Hudson River & Study Overview

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Acknowledgments

This project was commissioned by Scenic Hudson, Inc., of Poughkeepsie, New York, under a Professional Services Contract with Environmental Research Consulting (ERC). RPS ASA, SEAConsult LLC, and Risknology, Inc., were all subcontractors to ERC under separate contracts.

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 Jenna Ducharme, Matt Frediani, Deborah Crowley, 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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Acronyms and Abbreviations

ACP: Area Contingency Plan

AMPD: average most-probable discharge

ATB: articulated tank barge

bbl: barrels of oil (equivalent of 42 gallons)

CBR: crude-by-rail

CFR: *Code of Federal Register*

DPS: Distinct Population Segments

EIS: Environmental Impact Statement

EPA: Environmental Protection Agency

EPF: Environmental Protection Fund

ERC: Environmental Research Consulting

ESA: Endangered Species Act

ESI: Environmental Sensitivity Index

FOSC: Federal On-Scene Coordinator

FW: feet water

GIS: Geographic Information System

HROSRA: Hudson River Oil Spill Risk Assessment

kts: knots

LWRP: Local Waterfront Revitalization Program

MHW: mean high water

MLW: mean low water

MMPD: maximum most-probable discharge

NEPA: National Environmental Policy Act

NMFS: National Marine Fisheries Service

NOAA: National Oceanic and Atmospheric Administration

NYSDEC: New York State Department of Environmental Conservation

NYSDOS: New York State Department of State

PHMSA: Pipeline and Hazardous Material Safety Administration

USCG: US Coast Guard

WCD: worst-case discharge

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.

Jill Rowe (RPS Ocean Science)

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.

Hudson River Oil Spill Risk Assessment Overview

The Hudson River Oil Spill Risk Assessment (HROSRA) is a comprehensive study of the risks of oil spills[1] in (or 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 river-crossings (for the proposed Pilgrim Pipeline). Inland pipelines and sections of rail lines that do not intersect with the river will not be evaluated in this study.

Scope of HROSRA

As a risk assessment, the HROSRA addresses both the probability of spills and the consequences or impacts of spills that could occur. Each factor can be analyzed independently, but the determination of "risk" includes both (Figure 1).

$$Risk_{spill} = Probability_{spill} \cdot Consequences_{spill}$$

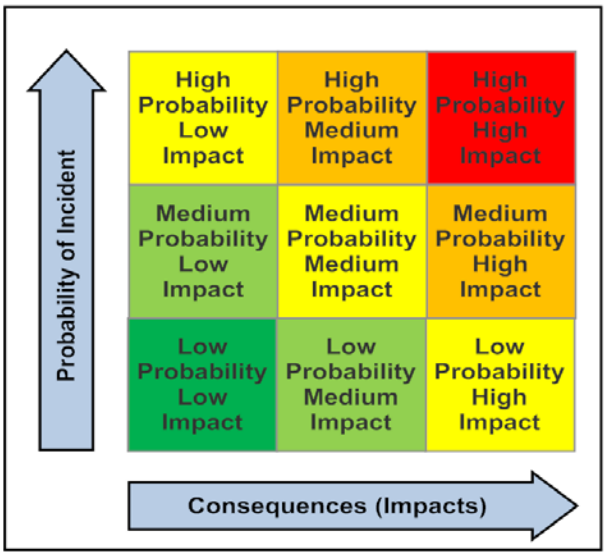

Figure 1: Basis Risk Matrix

The HROSRA is intended to provide both *quantitative* and *qualitative* information on oil spill risk that can be used for a variety of purposes, including, but not limited to:

- Assessing the efficacy of existing spill prevention measures;
- Developing or evaluating the potential for new spill prevention measures;
- Assessing the current state of spill response preparedness;
- Developing or evaluating the potential for new spill response preparedness measures;
- Assessing current spill contingency planning; and
- Developing new spill contingency planning measures.

[1] The general principles of spill risk analysis are outlined in Etkin et al. 2011, and Etkin 2015.

The study is also intended to provide a measure of the degree to which the ecological and socioeconomic resources of the Hudson River might be affected by oil spills and the likelihood of that occurring. That supports the need to consider the mitigation of spills through prevention, preparedness, and response.

Technical Approach to Spill Probability Analysis

The analysis to determine the probability of spill incidents involved technical approaches used in a number of recent studies conducted by the team and others to determine the relative frequencies of incidents of different types. The analyses included both estimating the probability of spill incidents and the distribution of potential spill volumes in the event of a spill. The probabilities were calculated on the basis of frequency per year and based on circumstances that could lead to spillage, including the transport of oil by rail, vessel, or pipeline, and the presence of oil storage facilities. For example, the results are provided as the number of spills per year per vessel transport. This allows for projections of future spill rates based on changes in vessel traffic.

The analysis of the probability of spills, and potential volumes of spillage, from rails were based on a crude-by-rail risk model (CBR-SpillRISK) developed by ERC for several environmental impact statements (EISs) for rail terminals in Washington State.[2] The model incorporates the probability of a rail accident, the probability that a rail accident will result in derailment and/or damage of tank cars, and the numbers of cars (and thus spill volume) involved. CBR-SpillRISK takes into account changes in rail operations that may decrease or increase the likelihood of CBR spills.

For vessel spills (tankers, tank barges, ATBs), the probability and volumes of spillage were be based on a number of studies conducted on other waterways (e.g., the Puget Sound, Columbia River, Vancouver, BC, Cook Inlet, Alaska). The analysis includes:

- Evaluating the likelihood of accidents (groundings, collisions, allisions) based on vessel traffic (vessel numbers and types), and navigational hazards and conditions (based on reviews of previous accidents in the Hudson River and analogous waterways);
- Calculating the potential outflow based on vessel type and size; and
- Determining the worst-case discharge based on vessel types and size.

The analyses of pipeline spill probabilities and volumes (at river crossings) were based on previously-applied methodologies in studies conducted by ERC, including environmental impact statements.[3] Again, the analyses involved examining both the probability of occurrence and the spill volume involved.

Technical Approach to Spill Modeling

Worst-case discharge volumes, as well as some smaller volumes, were used in the modeling of the trajectory (path), fate (behavior and distribution in the environment), and exposure above thresholds for potential environmental and socioeconomic effects of spills of five types of oils:

- Bakken crude oil;
- Diluted bitumen (tar sands oil);

[2] Etkin 2016a, 2016b, 2017a, 2017b.
[3] Etkin 2014; Etkin et al. 2017; Etkin 2017b.

- Home heating oil (similar to diesel fuel);
- Heavy fuel oil; and
- Gasoline.

A number of locations were selected for the modeling of hypothetical worst-case scenarios under different conditions. In each case, the environmental conditions (currents, winds, etc.) that result in the worst potential outcome, with respect to the spread of the water and shoreline exposure were identified. The potential exposure of shoreline and river habitats and organisms to oil of the five very different oil types were evaluated.

RPS's oil spill modeling system, SIMAP[4] was used to determine transport and weathering of oil released in the project region of interest. SIMAP uses site specific wind, ice, and current data, and state-of-the-art three-dimensional transport and oil weathering algorithms in its physical fates model (Figure 2) to quantify areas swept by floating surface oil of varying thicknesses, fates and concentrations of subsurface oil components (dissolved and particulate), areas of shoreline exposed to varying degrees, and areas/volumes where biological effects might occur for habitats and wildlife.

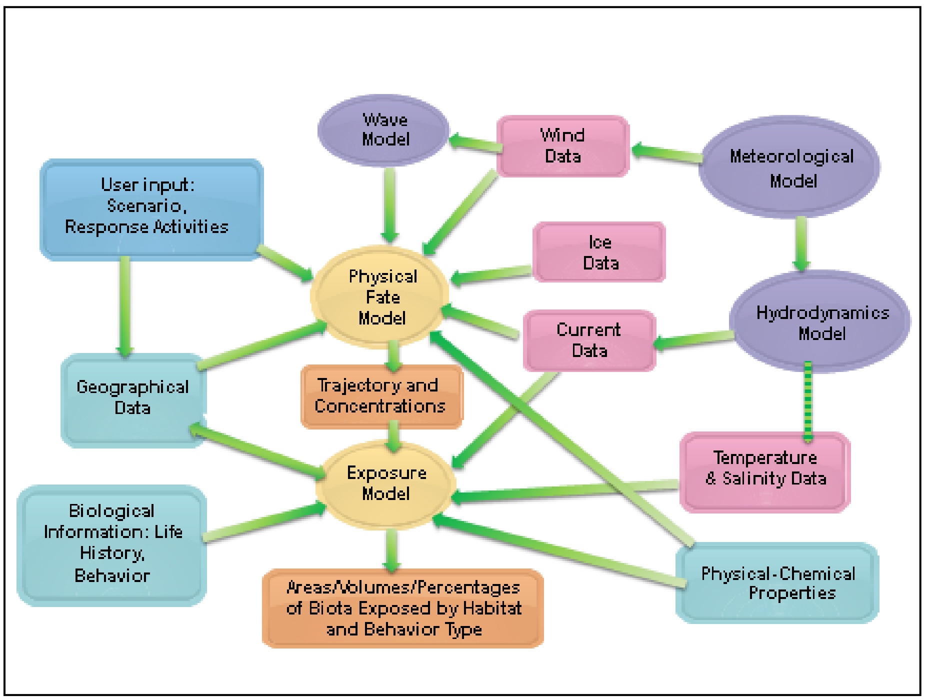

Figure 2: Flow Diagram of SIMAP 3-D oil Fate and Exposure Model Components/Inputs.

SIMAP is a three-dimensional Lagrangian model and each component of the spilled oil is represented by an ensemble of independent mathematical (Lagrangian) Elements or "spillets." Each spillet is a sub-set of the total mass spilled and is transported by both currents and surface wind drift. Various response actions can be modeled including mechanical removal activities.

[4] French McCay 2009.

Processes simulated in the SIMAP physical fates model include oil spreading (gravitational and by shearing), evaporation, transport, vertical and horizontal dispersion, emulsification, entrainment (natural and facilitated by dispersant), dissolution, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and sparingly-soluble hydrocarbons to suspended sediments, sedimentation, and degradation (Figure 3). SIMAP is unique in that it not only models particulate oil concentrations at the surface and in the water column, but it also accounts for the dissolved components of oil. SIMAP calculates the particulate and dissolved in-water concentrations and tracks the subsurface contamination over time.

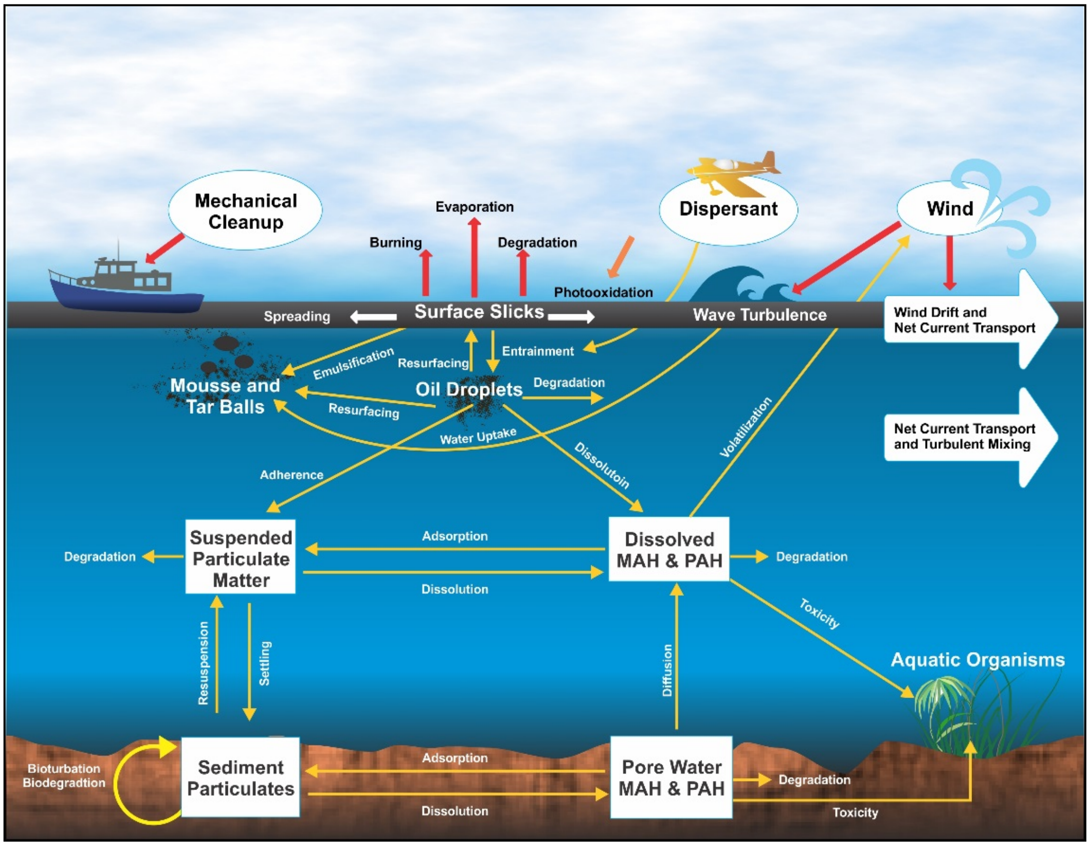

Figure 3: Open Water Oil Fate and Behavior Processes Simulated in SIMAP

Selected Hypothetical Oil Spill Scenarios for HROSRA

There were a total of 12 hypothetical oil spill scenarios–with each scenario being a location-oil type combination. Note that several scenarios are based on worst-case discharges, which are highly unlikely for a variety of reasons. (For example, a soft grounding would be unlikely to cause the release of a large amount of oil.) Probabilities of these incidents were analyzed, as presented in HROSRA Volume 2.

Each scenario of a specific volume of a specific type of oil at a specific location was modeled in six different ways–with releases timed at both high and low tide[5] in three seasons:

- Spring (high flow);

[5] Tide at the specific spill location.

- Summer (low flow); and
- Winter (medium flow with ice).

Three of the spring scenarios were specifically modeled assuming a storm. In addition for five of the scenarios, a fire/explosion scenario was modeled. For those scenarios, the spills were modeled without ignition and with ignition. The scenarios are summarized in Table 1 (presented from north to south). The scenarios are described in greater detail thereafter.

Note that all of these scenarios are *hypothetical*, i.e., they have not actually occurred. There is no expectation that these spills are even likely to occur, though it is possible that they might occur at some point in the future. It is important to keep in mind that these hypothetical scenarios were selected to illustrate the trajectory, fate, and effects of representative spills, several of which are worst-case discharge events that are highly unlikely to occur. If a spill were to occur, the specific circumstances of the scenario–location, timing, and environmental conditions would all affect the outcome. In addition, there would be response measures implemented that would mitigate the effects to varying degrees.

Table 1: HROSRA Hypothetical Spill Scenarios

Location	Latitude Longitude	Spill Source	Volume[6]	Oil Type	Season	Fire/ Explosion
Port of Albany	42.61673 -73.76020	Tanker loading accident at dock	155,000 bbl (WCD)	Bakken Crude	Spring: high flow	Yes
					Summer: low flow	
					Winter: medium flow/ice	
Coxsackie	42.35119 -73.78982	Tanker collision/allision accident	25,000 bbl	Home Heating Oil	Spring: high flow	No
					Summer: low flow	
					Winter: medium flow/ice	
Proposed Kingston Anchorage	41.93017 -73.95700	Articulated tank barge (ATB) in collision/allision with another vessel at the anchorage	150,000 bbl (WCD)	Home Heating Oil	Spring: high flow	No
					Summer: low flow	
					Winter: medium flow/ice	
				Diluted Bitumen	Spring: high flow	No
					Summer: low flow	
					Winter: medium flow/ice	
Off Rondout Creek (Based on ACP Scenario)	41.91833 -73.96333	Tank barge collision	75,421 bbl	Bakken Crude	Spring: high flow	Yes
					Summer: low flow	
					Winter: medium flow/ice	
		Cargo vessel collision	14,000 bbl	Heavy Fuel Oil	Spring: high flow	No
					Summer: low flow	
					Winter: medium flow/ice	
Newburgh Waterfront	41.51523 -74.00694 41.50517 -74.00572	CBR train accident	11,000 bbl (WCD)	Bakken Crude	Spring: high flow	Yes
					Summer: low flow	
					Winter: medium flow/ice	

[6] Note that worst-case discharge (WCD) volumes for tank barges and tankers are based on oil outflow modeling with double-hulled tank vessels, as described in HROSRA Volume 2. AMPD = average most probable discharge; MMPD = maximum most probable discharge based on US Coast Guard classifications (See HROSRA Volume 2).

Table 1: HROSRA Hypothetical Spill Scenarios						
Location	**Latitude Longitude**	**Spill Source**	**Volume[6]**	**Oil Type**	**Season**	**Fire/ Explosion**
Bear Mountain Bridge	41.32198 -73.98311	Tanker collision with vessel near bridge	2,500 bbl (MMPD)	Home Heating Oil	Spring: high flow	No
					Summer: low flow	
					Winter: medium flow/ice	
Iona Island	41.31363 -73.98598 41.30628 -73.98100	CBR train accident	11,000 bbl (WCD)	Bakken Crude	Spring: high flow	Yes
					Summer: low flow	
					Winter: medium flow/ice	
Tappan Zee	41.07195 -73.88333	Tanker allision with bridge abutment	2,500 bbl (MMPD)	Home Heating Oil	Spring: high flow/storm	No
					Summer: low flow	
					Winter: medium flow/ice	
Tappan Zee	41.07195 -73.88333	Tanker allision with bridge abutment	50 bbl (AMPD)	Heavy Fuel Oil	Spring: high flow/storm	No
					Summer: low flow	
					Winter: medium flow/ice	
Yonkers Anchorage	40.97341 -73.90003	Collision/allision with tanker at anchorage	155,000 bbl (WCD)	Gasoline	Spring: high flow/storm	Yes
					Summer: low flow	
					Winter: medium flow/ice	

Port of Albany Scenario

The scenario at the Port of Albany would involve a fully-loaded tanker accidentally pulling away from the dock during transfer operations and spilling 155,000 bbl of Bakken crude. The scenario was evaluated *with and without a fire/explosion*. The fire/explosion scenario would be similar to the one that occurred with the Tanker Jupiter in Bay City, Michigan in 1990 (Figure 4). The location is: 42.616732, -73.760203 (Figure 4).

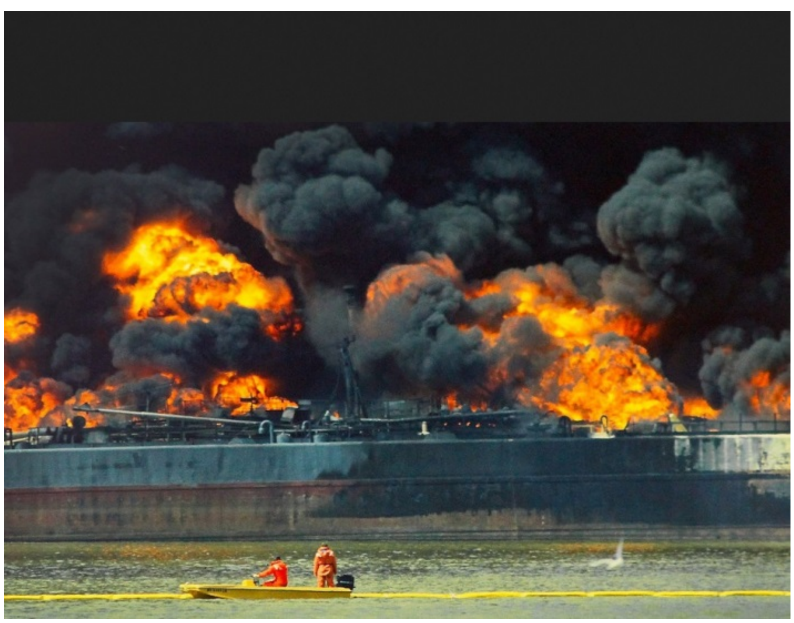

Figure 4: Tanker Jupiter Incident (1990)

Figure 5: Port of Albany Spill Scenario Location

Coxsackie Scenario

A spill from a grounding or collision of a tanker or tank barge off Coxsackie would potentially expose Vosburgh Swamp Wildlife Management Area and other wetlands to oil. This scenario might result in the worst-case consequences with respect to environmental impacts. The scenario would involve spillage of 25,000 bbl of home heating oil. The location is: 42.351193, -73.789820 (Figure 6).

Figure 6: Coxsackie Spill Scenarios Location

Proposed Kingston Anchorage Scenarios

The first set of two scenarios includes the release of two types of oil (home heating oil or diluted bitumen) from the largest tank barge that might hypothetically be anchored at the proposed Kingston Flats South Anchorage[7] due to a collision or allision accident causing the release of the entire load of cargo–estimated to be 150,000 barrels (bbl) or 6.3 million gallons. This is based on the capacity of RTC 150. The specific location is: 41.93107, -73.95700 (Figure 7). This is the southwest corner of the proposed anchorage at Kingston Flats South. In the hypothetical scenario a vessel collides with an anchored tank barge.

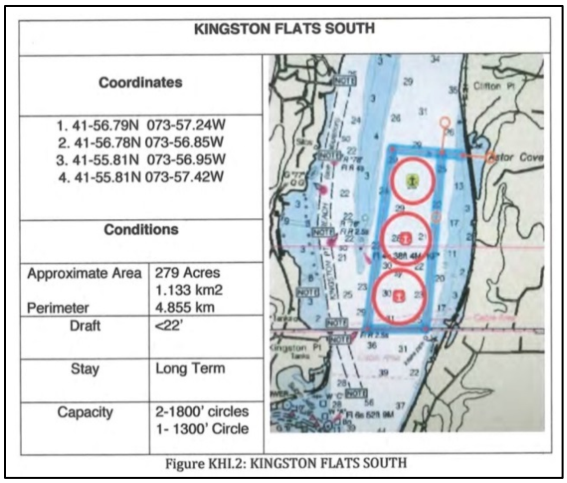

Figure 7: Kingston Flats South

Rondout Two-Vessel Accident Scenarios (ACP Scenario)[8]

This scenario is based on the worst-case-discharge scenario described in the 2016 New York-New Jersey Area Contingency Plan (ACP). It involves the collision of a tank barge loaded with Bakken crude and a cargo vessel resulting in the spillage of 75,421 bbl of Bakken crude and 14,000 bbl of heavy fuel oil near Rondout Creek (41.91833, -73.96333) (Figure 8).

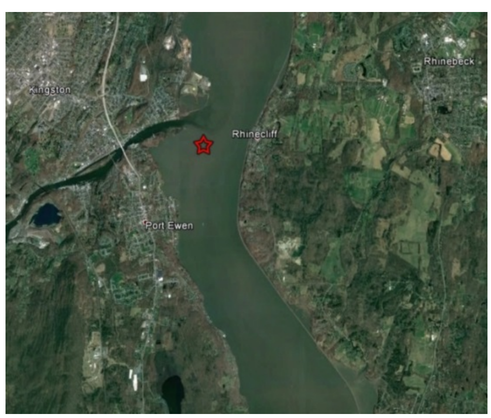

Figure 8: Rondout Two-Vessel Accident (ACP Scenario) Location

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[7] Note: The location of this hypothetical spill scenario was based on the proposed location for an anchorage near Kingston. This anchorage has not been approved or officially implemented.
[8] USCG 2016.

The scenario in the ACP is described as occurring during a winter storm. In the HROSRA, this scenario was modeled as under winter conditions, spring conditions, and summer conditions. In addition, the Bakken crude release was also modeled as a fire/explosion scenario.

Newburgh Waterfront CBR Train Accident Scenarios

A hypothetical scenario of a train accident in Newburgh would provide the opportunity to simulate not only the impact of oil into the Hudson, but also the effect of a potential fire/explosion situation in a populated area.[9] The likely worst-case discharge volume would be 11,000 bbl of Bakken crude (based on current proposed definitions from PHMSA). The scenario would include a fire and/or explosion. (The spill would be modeled without the fire/explosion). The effects of a potential fire/explosion would be evaluated separately. The location is from: 41.515230, -74.006936 to 41.505170, -74.005719. This is about a 0.7-mile length of track (Figure 9).

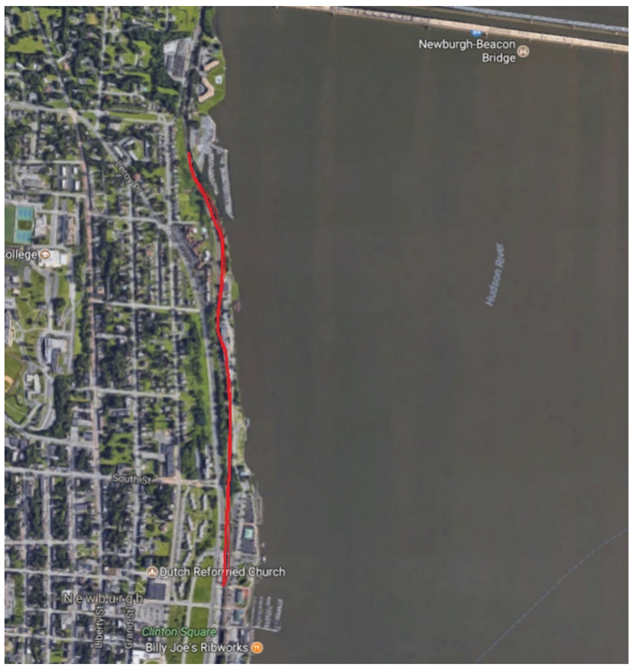

Figure 9: Newburgh Train Accident Scenario Location

Bear Mountain Bridge Tanker Collision Scenarios

This scenario would involve a hypothetical collision between two vessels just above the Bear Mountain Bridge, which is a difficult area to navigate especially if there is limited visibility with fog. This scenario would involve a fully-loaded tanker (the largest of which holds 310,000 bbl) releasing 155,000 bbl (which would be the largest outflow likely with a double hull) of home heating oil. The specific location is: 41.321980, -73.983113 (Figure 10).

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[9] Since the stated purpose of the HROSRA is to determine risk of spills to the river and not necessarily the risk to communities from crude-by-rail (CBR) transport, two CBR scenarios (Newburgh and Iona Island) were selected based on the likelihood of oil spillage into the river. To address additional concerns about effects on communities through which CBR traffic would go, the Newburgh scenario was included. A more comprehensive study of CBR accidents is required to determine the risk of CBR overall.

Figure 10: Bear Mountain Bridge Scenario Location

Iona Island CBR Train Accident Scenarios

This scenario involves a derailment of a fully-loaded unit train at Iona Island, just south of the Bear Mountain Bridge at the over-water trestle crossing of the rails. The likely worst-case discharge volume here would be 11,000 bbl (based on the current proposed definitions from PHMSA) of Bakken crude. The scenario would also include a fire and/or explosion. The specific location is: 41.313627, -73.985983 to 41.306284, -73.981000. This stretch comprises about a half mile of track (Figure 11).

Figure 11: Iona Island Spill Scenario Location

Tappan Zee Allision Scenarios

In this hypothetical scenario, an allision of a tanker or tank barge at one of the bridge structures at Tappan Zee[10] would cause a release of 2,500 bbl of home heating oil. The location is: 41.071948, -73.883325 (Figure 12). A second scenario at this location would involve the release of 50 bbl of heavy fuel oil (the fuel on a tanker or cargo vessel).

Figure 12: Tappan Zee Allision Spill Scenario Location

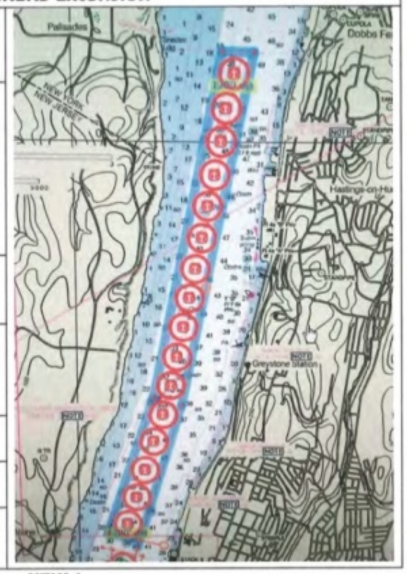
Extended Yonkers Anchorage Scenarios

A collision or allision of a tanker at the proposed Yonkers Anchorage Extension could cause a WCD release of 155,000 bbl of gasoline. The location is: 40.973411, -73.900028 (Figure 13). A fire/explosion for the scenario will also be modeled for this location.

[10] "Tappan Zee" includes the existing Tappan Zee Bridge and the new Mario Cuomo Bridge under construction.

YONKERS Extension

1. 41-00.60N	073-53.61W
2. 41-00.60N	073-53.31W
3. 40-58.05N	073-53.96W
4. 40-56.96N	073-54.39W
5. 40-57.02N	073-54.71W
6. 40-58.11N	073-54.25W
Conditions	
Approximate Area Perimeter	715.24 Acres 2.89 km2 14.58 km
Draft	<35 North
Stay	Long term
Capacity	16-1200' Circles



YEHI.1

Figure 13: Yonkers Anchorage Spill Scenario Location

Technical Approach to Fire and Explosion Analysis

For selected spill scenarios (Table 1), fire and explosion potential was also analyzed:

- Newburgh Waterfront CBR accident (Bakken crude);
- Port of Albany tanker accident at dock (Bakken crude);
- Iona Island CBR accident (Bakken crude);
- Rondout Creek (ACP Scenario) tank barge accident (Bakken crude); and
- Yonkers Anchorage tanker accident (gasoline).

The fire/explosion scenarios were modeled under the seasonal conditions that would cause the greatest impact. For these scenarios, it was assumed that most, if not all, of the spilled oil would be consumed in the fire and/or explosions. The fate of oil not burned was not separately analyzed. A particular spill in which there was an ignition would also have some impacts from any non-consumed oil as well, though the volume that would affect the water surface, water column, and shoreline would be significantly reduced. Each of the scenarios also was modeled assuming no ignition. The impacts of the non-consumed oil (outside of the effects of burning) would be a lesser version of these non-ignition scenarios.

A liquid hydrocarbon spill leads to the pooling and flow of liquid onto a land or water surface. Flammable gas mixtures vaporize from the surface of the pool governed by numerous physical processes as shown in Figure 14. The vapor cloud formed above the liquid could ignite immediately or drift and disperse downwind and ignite at a distant location. If ignition occurs early, the vapors at the pool surface burn. The radiant heat from this type of fire can be felt far from the fire itself, and the fire will burn until all the fuel is consumed, or fire response extinguishes the fire. The effects of a fire can be injuries and fatalities of people, as well as property damage.

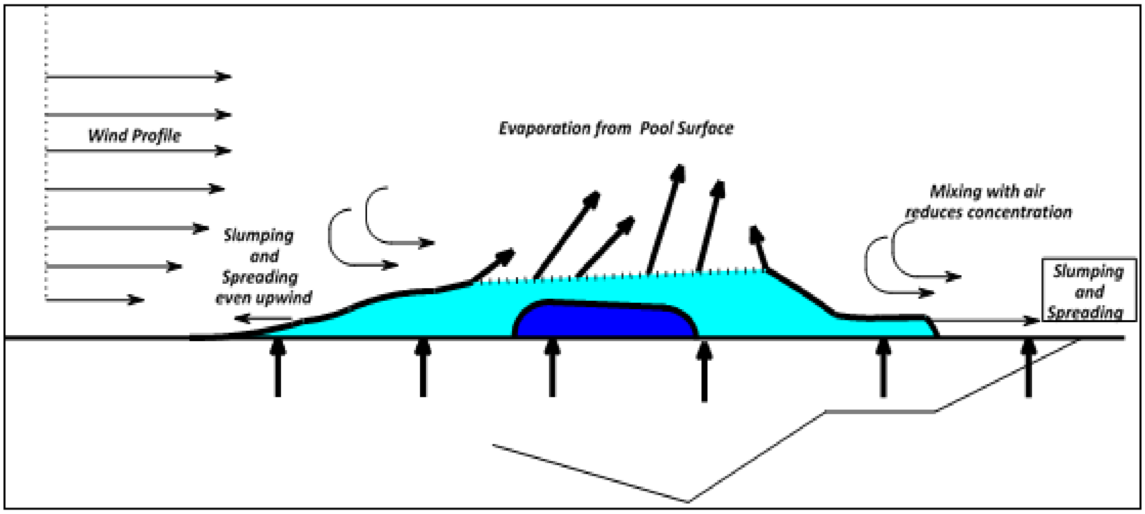


Figure 14: Hydrocarbon Evaporation Processes

If the vapors do not ignite immediately, the vapor cloud will drift and disperse downwind decreasing in concentration as the vapors mix with air. When the vapor to oxygen ratio decreases from its initial rich concentration to within the flammability range, it can ignite. Ignition of a flammable vapor cloud in an open space leads to a flash fire, with impacts to people and structures inside and slightly beyond its volume. However, if the flammable vapor cloud ignites within an area that is both confined (walls, floor, ceilings, decks) and congested (objects densely occupying volume; such as cars, trees, industrial equipment) then a vapor cloud explosion can occur. Depending on the combination of fuel, confinement and congestion, the combustion could either be subsonic, (deflagration) or supersonic (detonation). A vapor cloud explosion, like a fire, can lead to effects on people and property. If the explosion occurs proximate to additional stored flammable materials, this can lead to escalation, the situation wherein additional fuel is additive to the initial release inventory.

The timing and location of the ignition determines the physical effect resulting from the hydrocarbon vapors, and includes these types of hazards:

- **Pool Fire:** a fire that burns from a pool of vaporizing fuel. The primary concern associated with pool fires is hazards associated with increased temperatures from thermal radiation (heat).
- **Vapor Cloud Fire (Flash Fire): a** rapidly moving flame front characterized by combustion. Flash fires occur in an environment where fuel and air become mixed in adequate concentrations to combust.
- **Vapor Cloud Explosion: a** vapor cloud explosion is the result of a flammable material that is released into the atmosphere, at which point the resulting vapor cloud is ignited. The primary concern from a vapor cloud explosion is overpressure (pressure caused by a shockwave).

The probability of these types of events and the potential area that would be affected were analyzed.

Technical Approach to Spill Mitigation Analysis

The patterns of shoreline oiling, and spread and behavior of the oil derived from the SIMAP modeling were evaluated to determine the type of cleanup response operations that would be required. This includes the potential for submerged or sinking oil, as well as the potential for fire and explosion events associated with more volatile petroleum products. The issue of river current velocity and its potential impact on the efficacy of containment booms were evaluated. Challenges of spill response during ice conditions were also evaluated.

In addition, an evaluation of the response preparedness for these worst-case discharge scenarios was evaluated based on current response capabilities. The activation of geographic response strategies (GRSs) for the different scenarios was evaluated.

Recommendations for enhanced response capabilities, as a means of mitigating the risk of spills were evaluated.

Hudson River Overview

In this report, the term "Hudson River" is generally used to denote the 115-nautical mile stretch of the Hudson River north of the confluence of the Spuyten Duyvil/Harlem River Creek, excluding the part of the Hudson River that runs alongside Manhattan Island south through the New York Harbor and out to the New York Bight. The northern extent of this definition is the Troy Lock, excluding the sections of the Hudson River that flow from the river's source at Lake Tear of the Clouds to the Troy Locks (Figure 15).

Figure 15: Hudson River Section for Report

Tidal and Current Conditions

The Hudson River (up to Troy Lock) is actually a tidal estuary. The 2016 *New York and New Jersey Area Contingency Plan* describes the Hudson River as "a unique estuary in that geologically, it is technically a fjord." [Throughout this report, the term "Hudson River" is used to denote the Hudson River Estuary.] It has a full tidal cycle through much of its course. The tidal channel of the Hudson River extends from New York City 155 miles north to Albany, then on to Troy, New York. Above Albany, water movement is controlled by the Federal locks at Troy. The overall mean tidal range is about 3.84 feet. Tidal terminology is explained in Figure 16 and Figure 17. Tidal information for the Hudson River is shown in Table 2.

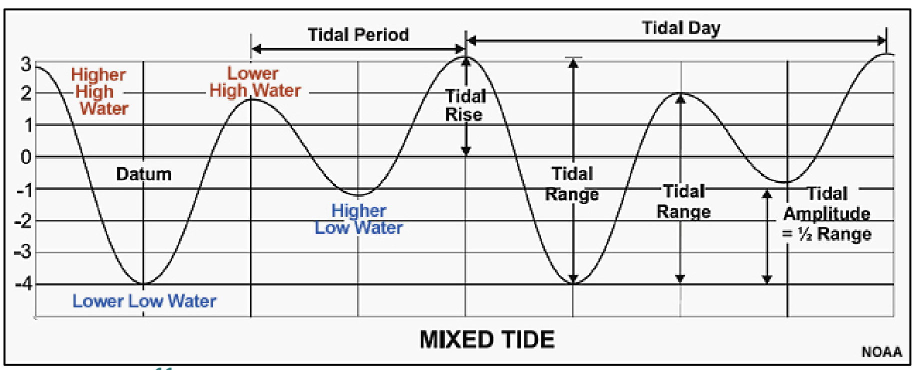


Figure 16: Tidal Cycles[11]

[11] https://noaanhc.wordpress.com/2016/01/29/the-alphabet-soup-of-vertical-datums-why-mhhw-is-mmm-mmm-good/

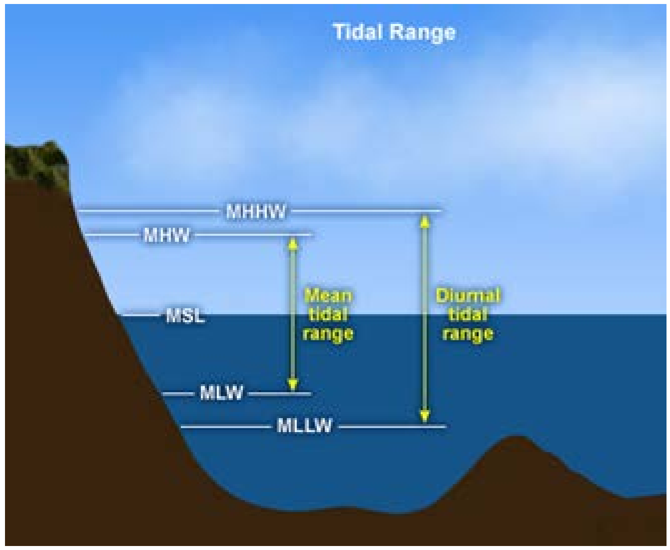


Figure 17: Tidal Range Definitions[12]

Table 2: Tidal Information for Hudson River

Tidal Station		Mean Water Level (ft)[13]			
		Higher High	High	Low	Range
South of HROSRA Study Area[14]	East 27th St., Bellevue Hospital	4.7	4.4	0.2	4.2
	Governors Island, New York Harbor	4.9	4.6	0.2	4.4
	Wallabout Bay, Brooklyn Navy Yard	4.8	4.5	0.2	4.3
	East 41st Street Pier, East River	4.9	4.5	0.2	4.3
	New York (The Battery)	5.1	4.7	0.2	4.5
	Weehawken, Union City	4.9	4.6	0.2	4.4
Within HROSRA Study Area[15]	Spuyten Duyvil Creek Entrance, Harlem River	4.3	4.0	0.2	3.8
	Haverstraw, Hudson River	3.7	3.4	0.2	3.2
	Peekskill, Hudson River	3.5	3.3	0.4	2.9
	Newburgh, Hudson River	3.1	2.9	0.1	2.8
	New Hamburg, Hudson River	3.3	3.0	0.1	2.9
	Poughkeepsie, Hudson River	3.5	3.3	0.2	3.1
	Kingston, Hudson River	4.2	3.9	0.2	3.7
	Tivoli, Hudson River	4.2	3.9	0.2	3.7
	Castleton, Hudson River	--	4.4	0.1	4.3
	Albany, Hudson River	5.5	5.1	0.2	4.9

[12] https://noaanhc.wordpress.com/2016/01/29/the-alphabet-soup-of-vertical-datums-why-mhhw-is-mmm-mmm-good/
[13] See Figure 16 and Figure 17
[14] Figure 18
[15] Figure 19

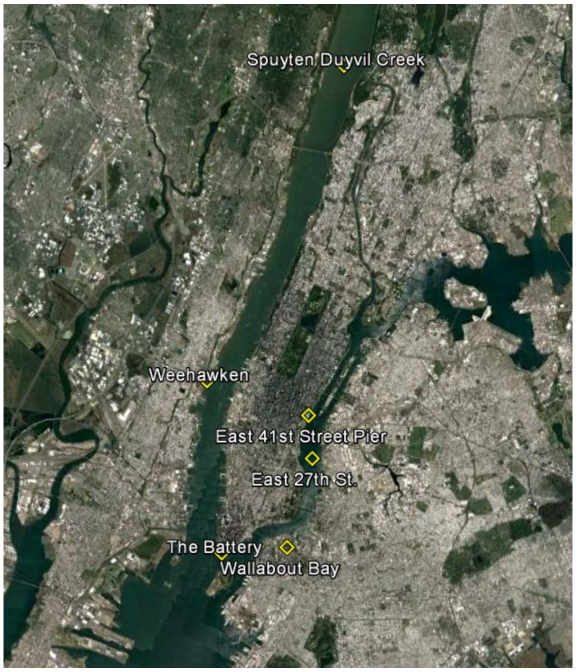


Figure 18: Tidal Stations South of HROSRA Study Area

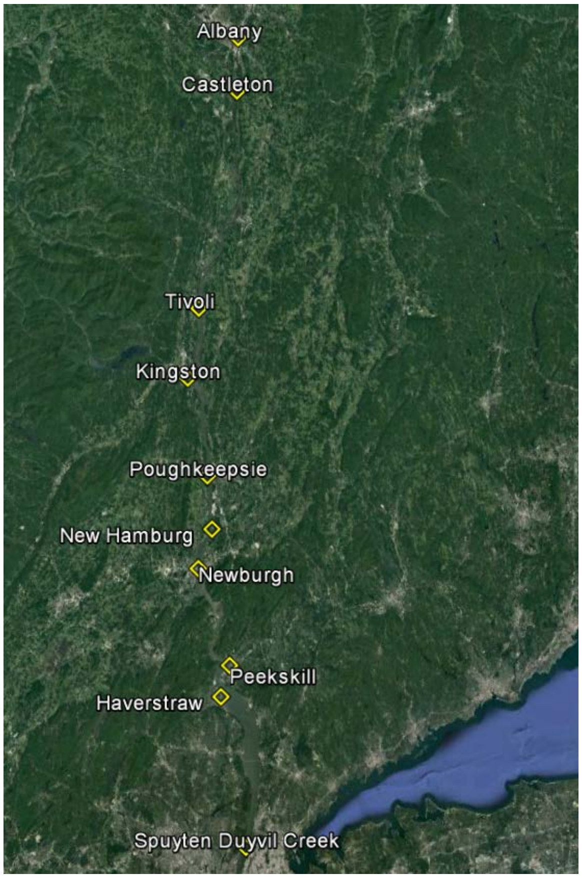


Figure 19: Tidal Stations within HROSRA Study Area

Tides affect river ship traffic with respect to bridge air clearance. The bridge height at mean high water (MHW) is 134 feet. At normal water levels, 132 feet of air draft gives the minimum vertical clearance of 2 feet at any stage of tide, which is required to pass under all bridges on the Hudson River.[16]

In the Upper Hudson, the maximum draft is 30 feet of water (FW). Vessels transiting the Upper Hudson with drafts of 27 to 30 feet must be set up for the correct stage of the rising tide. Only daylight transits are allowed north of Kingston. In the Lower Hudson (south of Kingston), the maximum draft is 33 feet (FW). Vessels transiting the Lower Hudson with drafts of 31 to 33 feet must be set up for the correct stage of the rising tide. Vessels with a draft of 31 feet or less may transit the Lower River at any time.

The speed of the currents and direction is germane to this study is that affect the way in which oil moves on the water surface (and beneath the water surface) in the event of a spill.[17] Current speed in the Hudson River varies throughout the day and between days, by location, by tide, and water depth (generally decreasing with depth at the same location) (Table 3 and Figure 20). Average current speed in the Hudson River[18] varies from about 0.4 kts to as much as nearly 3.0 kts.[19] Current speed also affects the efficacy of protection and containment booming operations. Booms rapidly begin to lose their effectiveness at 0.7 kts. Oil begins to entrain (go under) booms regardless of skirt depth at higher current speeds.

Table 3: Current Velocity Measurements on Hudson River[20]

Location	Latitude	Longitude	Current Velocity (kts)[21]		
			Average	% > 0.7 kts	Maximum
George Washington Bridge	40.848550	-73.950317	1.1	59.5%	2.97
Tappan Zee	41.067433	-73.881533	0.7	45.0%	2.15
Haverstraw	41.209167	-73.951333	0.7	47.4%	1.87
Stony Point	41.241583	-73.966683	0.8	56.3%	1.78
Bear Mountain Bridge	41.315917	-73.983850	0.7	40.2%	1.59
Beacon-Newburgh Bridge	41.516583	-73.991683	0.7	52.8%	1.33
Roseton	41.562467	-73.970533	0.8	61.9%	1.56
Mid-Hudson Suspension Bridge	41.701667	-73.945850	1.0	70.0%	1.84
Kingston Point	41.918267	-73.959500	1.0	74.4%	1.58
Kingston-Rhinecliff Bridge	41.977383	-73.952267	0.7	52.6%	1.27
Silver Point	41.138183	-73.908517	0.9	67.8%	1.49
Hudson	42.247883	-73.818600	1.0	76.0%	1.58
Coxsackie	42.351267	-73.789883	1.1	75.1%	1.61
Houghtaling Island	42.422417	-73.780067	0.8	64.9%	1.32
Castleton-on-Hudson Bridge	42.504433	-73.777383	0.7	41.8%	1.14
Port of Albany	42.623100	-73.755600	0.5	5.2%	0.74
Troy (Below Locks)	42.734050	-73.690783	0.9	78.2%	1.15

[16] http://www.hudsonriverpilots.com/ship-transit-information.html
[17] River hydrodynamics are incorporated into SIMAP modeling, as discussed in greater detail later in this report.
[18] https://tidesandcurrents.noaa.gov/currents12/tab2ac4.html
[19] 2.81 mph or 1.255 m/s
[20] https://tidesandcurrents.noaa.gov/cdata/StationList?type=Current+Data&filter=historic&pid=15
[21] Near surface or as close to surface as uppermost measurements taken in each location.

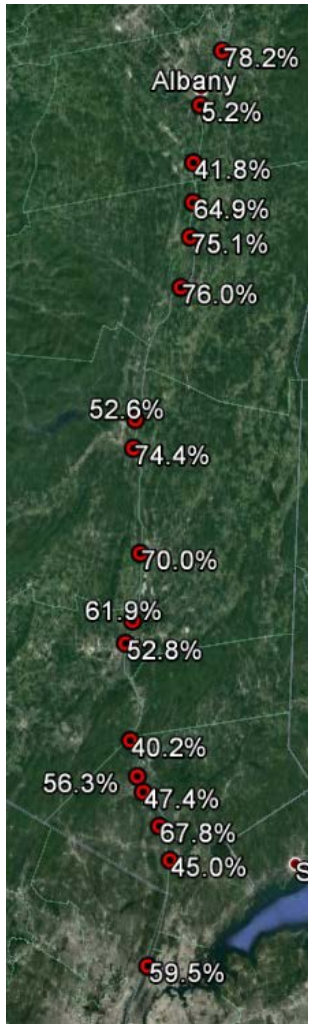


Figure 20: Percent Time Surface Currents Exceed Boom Capacity

Troy Federal Lock and Dam

The Hudson River is tidal as far north as the Troy Federal Lock and Dam. In addition to controlling water flow and marking the end of the tidal reach in the river, the Troy Federal Lock and Dam (Figure 21) also has significance with respect to jurisdiction in the event of an oil or hazardous material spill. In the event of a spill, the Environmental Protection Agency (EPA) is the pre-designated Federal On-Scene Coordinator (FOSC) above the Troy Lock (although the US Coast Guard recognizes a spill in the upper Hudson or Mohawk River could float downstream to or over the locks). South of the Troy Lock, the US Coast Guard is the pre-designated FOSC.

The Troy Lock also restricts the bulk movement of oil to small barges north of the lock. Tankships and tank barges travel as far north as Albany, bulk and breakbulk freight ships, which can carry substantial amounts of bunker oil in bottom tanks, also call on the port regularly. Two Albany oil terminals, Global and Buckeye, are the origin points for Bakken Crude shipments southward down the river.

Figure 21: Troy Federal Lock and Dam[22]

Bathymetry and River Bottom Morphology

The bathymetry[23] and morphology of the Hudson River bottom is complex and varies from one part of the river to another. In 1998, the New York State Department of Environmental Conservation began an extensive project to map the submerged lands of the estuary.[24] Some examples of the types of bottom substrates and sediment classifications are shown in Figure 22 through Figure 23.[25]

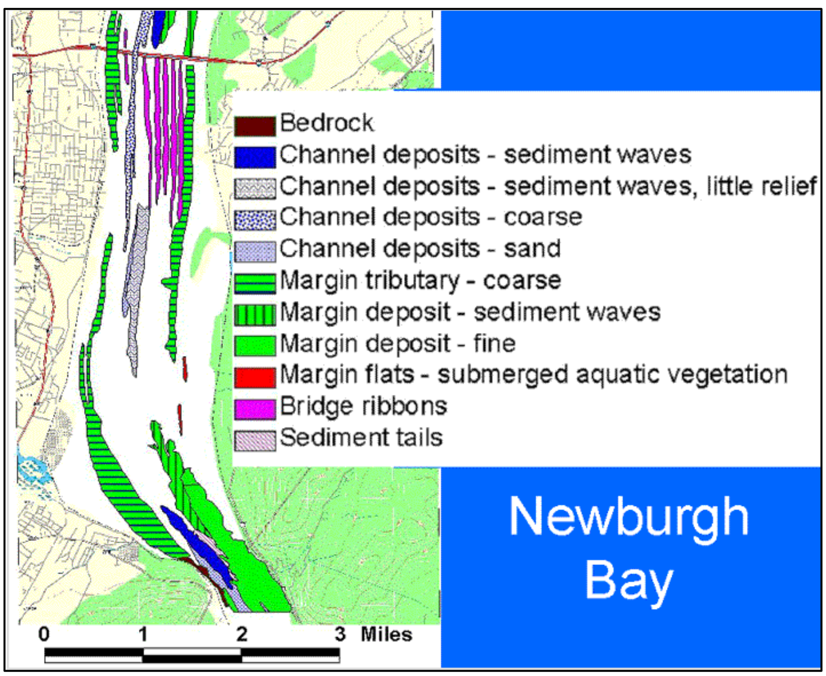


Figure 22: Submerged Lands of Newburgh Bay

[22] Photo: US Army Corps of Engineers
[23] Water depth from the surface to the bottom.
[24] Ladd et al. 2002. (See also: http://www.dec.ny.gov/imsmaps/benthic/viewer.htm)
[25] All figures from Ladd et al. 2002.

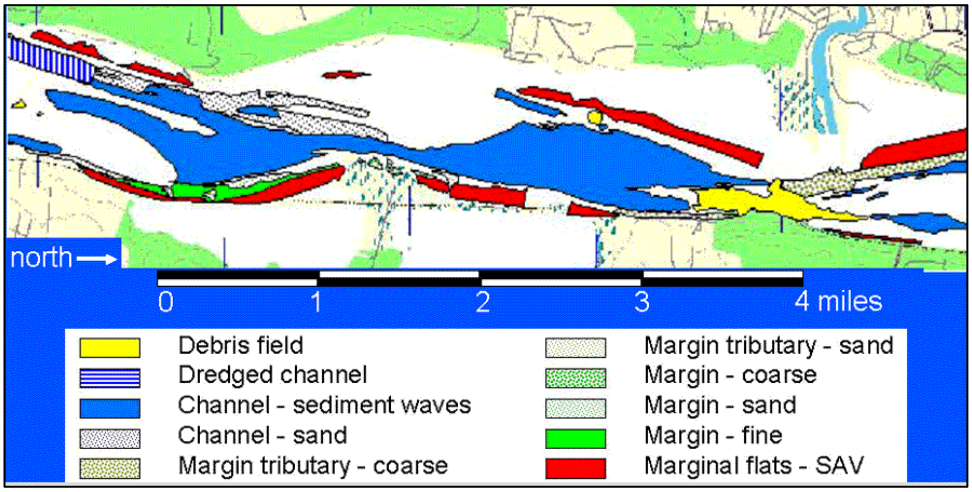


Figure 23: Submerged Lands South from Saugerties

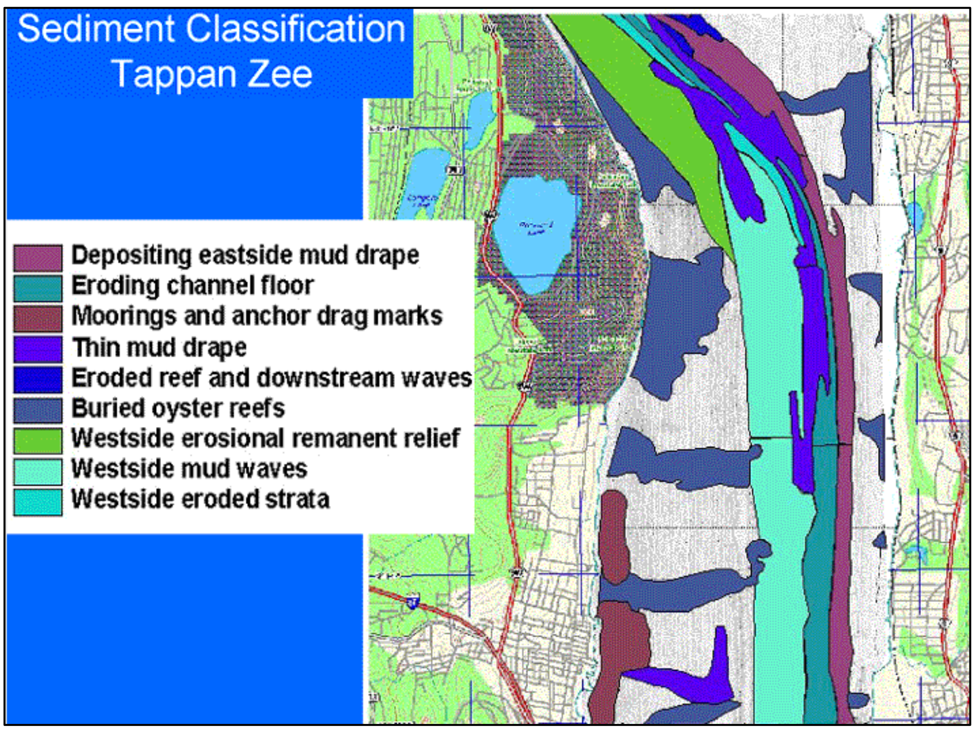


Figure 24: Submerged Lands of Tappan Zee

Water depth is also of concern for shipping. The shipping channel in the Hudson River is generally deep and the bottom is soft. The shipping channel is generally maintained to a minimum depth of 9 to 11 meters (29.5 to 36 feet), though there are many deeper parts of the river. The deeper parts of the river are generally about 50 meters (164 feet) deep. At World's End in the Hudson Highlands near Garrison on the eastern shore and West Point on the western shore, the depth reaches 66 meters (216 feet) (Figure 26).

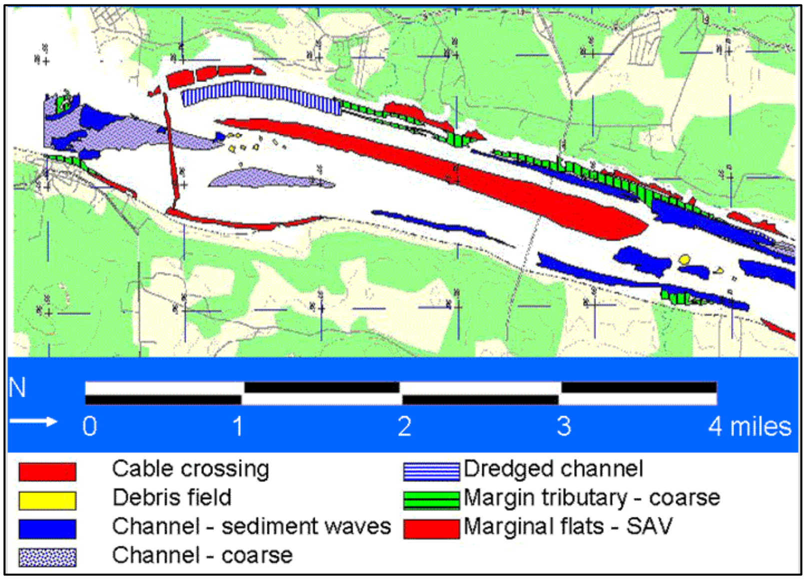


Figure 25: Submerged Lands North from Kington

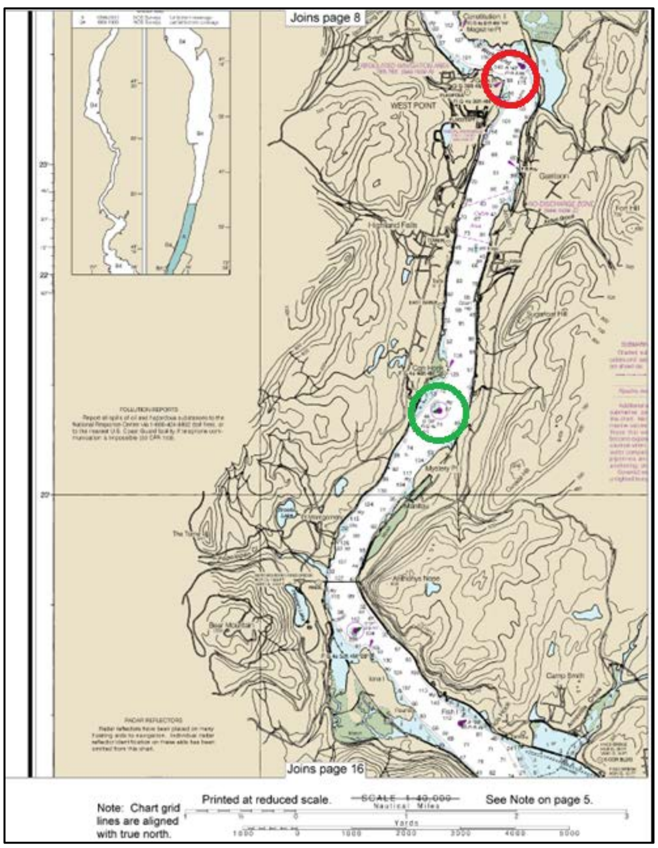


Figure 26: Hudson River Nautical Chart with World's End and Con Hook Rock[26]

[26] From NOAA Booklet Chart Hudson River–New York to Wappinger Creek (NOAA Chart 12343). World's End (greatest depth on Hudson River) shown in red circle and Con Hook Rock shown in green circle.

There are, however, several areas of rock bottom which can pose a hazard to shipping. One historical grounding location Con Hook Rock, which is south of West Point (Figure 26), where the tank barge Ethel H. (II) spilled 10,000 bbl of No. 6 fuel oil. Another location is Diamond Reef (Figure 27) which has a history of groundings. For example, in January 1983, the tank barge McAllister 80 grounded on Diamond Reef causing a minor spill, and in October 1990 tank barge Hygrade 42 grounded on Diamond Reef and spilled 3,900 bbl of kerosene.

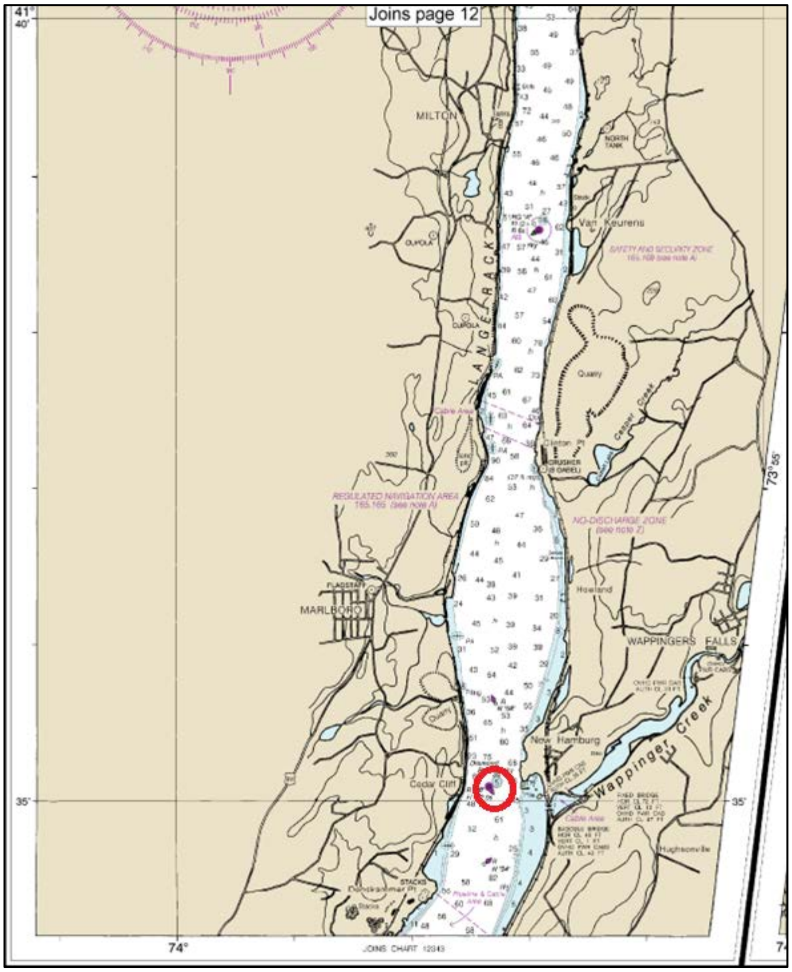


Figure 27: Hudson River Nautical Chart with Diamond Reef[27]

Salinity

The Hudson River is a partially mixed estuary, which means that a distinct mixing occurs between the ocean and freshwater, leading to a layer structure. Higher salinity water is overlain by lower salinity water over a broad stretch of mixing between the river and the ocean.

There are four salinity zones: polyhaline (18.5– 30 g/kg or ppt[28]), mesohaline (5–18 g/kg or ppt), oligohaline (0.3–5 g/kg or ppt),[29] and limnetic (<0.3 g/kg or ppt). The location of these zones varies

[27] From NOAA Booklet Chart Hudson River –Wappinger Creek to Hudson (NOAA Chart 12347). Diamond Reef is shown in red circle.

[28] Parts per thousand.

seasonally as well as daily depending on tidal and freshwater inputs and weather. There is also variation in salinity at different water depths and locations even at the same river mile, as water circulation can affect the distribution of salt in the water.

The leading edge of seawater, or the "salt front,"[30] also varies over the seasons (Figure 28). In the late 1990s, the salt front generally varied from Hastings-on-Hudson (River Mile 21.5) to New Hamburg (River Mile 67.7).[31] Currently, the maximum salt front is approximately at Poughkeepsie (River Mile 73) (Figure 29).

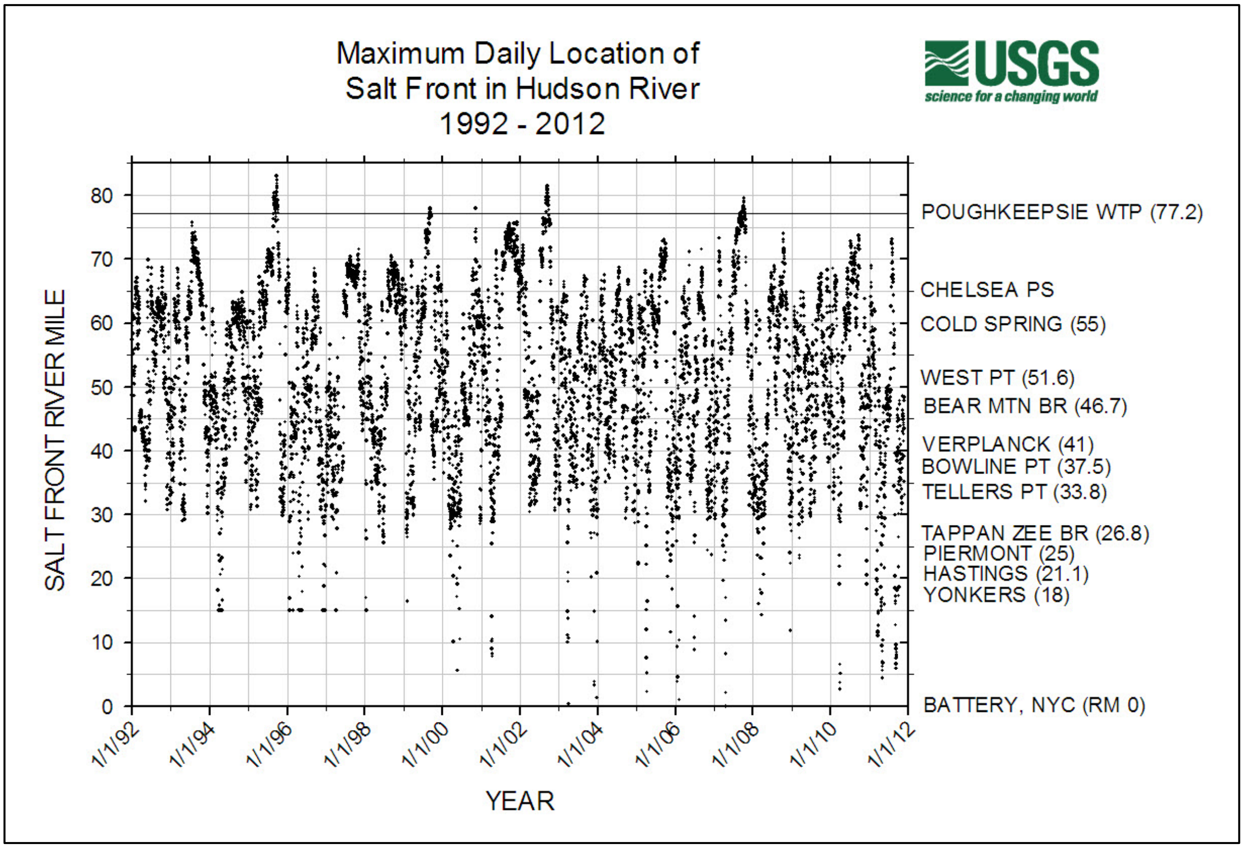


Figure 28: Maximum Daily Location of Salt Front in Hudson River (1992-2012)[32]

The salt front and salinity levels are important in that they affect the distributions of species of fish and other organisms at different times of the year. Salinity also affects the way in which oil behaves after a spill. Oil generally floats because it is lighter than water. Saltwater is more dense than fresh water. While very light oils will float on both seawater and freshwater (and estuarine water with intermediate salinity), heavier oils are somewhat more likely to become submerged in freshwater or less saline water in estuaries.

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[29] Roughly, Stony Point to Poughkeepsie.
[30] Salt front is defined as 250 mg/liter of chloride (or 0.25 g/kg).
[31] de Vries and Weiss. 2001.
[32] Source: US Geological Survey (https://ny.water.usgs.gov/projects/dialer_plots/saltfront.html)

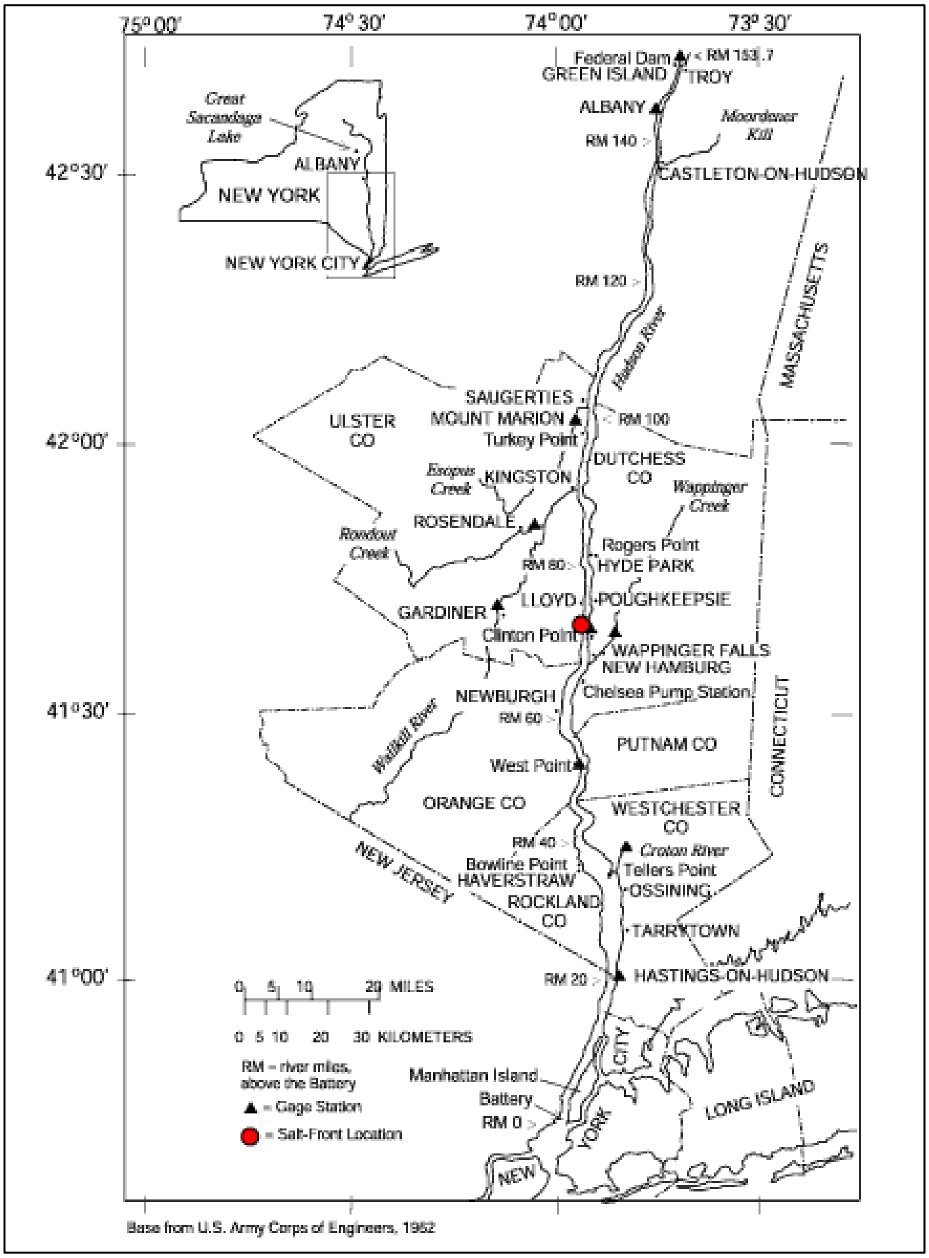

Figure 29: Hudson River Salt Front at High-Slack Tide[33]

Hudson River Watershed

The Hudson River watershed covers 13,400 square miles (Figure 30). There are more than 65 tributaries bringing freshwater into the Hudson, the largest of which is the Mohawk River, which enters the Hudson less than a third of a mile north of the Troy Lock.

[33] Source: US Geological Survey (https://ny.water.usgs.gov/projects/dialer_plots/saltfront.html)

Figure 30: Hudson River Watershed[34]

Water Temperature

The water temperature in the Hudson River varies throughout the year, varying from about 32°F in January to a high of 78°F in August at Albany (Figure 31). Temperatures further south on the river would tend to be somewhat higher.

The temperatures in the Hudson River appear to be rising due to climate change, as evidenced by an analysis conducted on water temperatures taken at the Poughkeepsie Water Treatment Facility during the years 1945 and 2015.[35] According to the researchers, many of the warmest years in the record occurred in the last 16 years. A seasonal analysis of trends indicated significant warming for the months of April through August. They concluded that the warming of the Hudson is primarily related to increasing air temperature, and that increasing freshwater discharge into the estuary has not mitigated the warming trend (Figure 32).

[34] Source: NY DEC 2015.
[35] Seekell and Pace 2011.

Figure 31: Water Temperature in Hudson River at Albany[36]

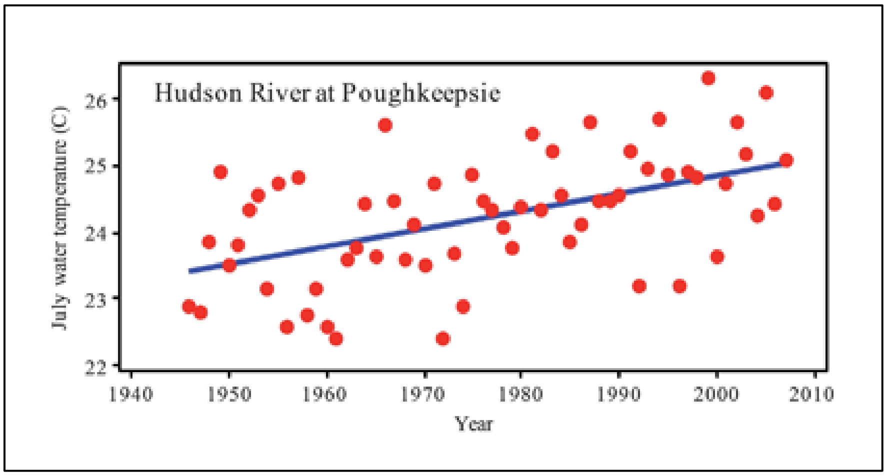

Figure 32: Hudson River Annual Mean Summer Temperatures (Poughkeepsie)[37]

Fog

Fog is a common occurrence in the Hudson River Valley particularly within a few hours prior to sunrise. Generally, the fog clears up within a few hours after sunrise.[38] The Hudson River Valley has specific conditions that promote the formation of widespread "radiation fog." This type of fog forms overnight as the air near the ground cools. When the cooling causes the air to reach saturation, fog will form. Radiation fog is particularly difficult to predict.[39]

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[36] Source: US Geological Survey (https://nwis.waterdata.usgs.gov/)
[37] Seekel and Pace 2011.
[38] Cushing 2016.
[39] Fitzjarrald and Lala 1989.

Fog events occur most frequently during the warm season months (May through October) and are tied to radiational cooling effects of moisture-laden air over the water to below the dew point.[40] Fog events may also occur in the later fall and winter, when they may last all day. These persistent fog events tend to be thicker–up to as much as 150 feet. Patchy fogs occur when the thickness is less than 60 feet.

Fog poses a navigational hazard due to limited or significantly reduced visibility. There may be errors in navigation leading to groundings and collisions. During periods of fog-related visibility issues, vessels must proceed at a reduced rate of speed and sound appropriate signals–bells and gongs, if anchored, and fog horns if underway.

In the 2015 Hudson River US Coast Guard Waterways Analysis and Management System (WAMS),[41] it was noted that, "Waterway users almost unanimously agreed that the fog, ice, and snow continue to complicate navigation in the winter months."

Ice Conditions

Ice season on the Hudson River generally runs from about 12 December through 31 March, but varies somewhat each year. The USCG reported it to be "over" as of 10 March 2017 during the last winter. Ice is of concern because it hinders vessel transits. In addition, aids to navigation may be covered and/or unreliable in areas impacted by ice. An example of a vessel stuck in ice in the Hudson River is shown in Figure 33.

Figure 33: Tug Brooklyn Stuck in Ice at Saugerties, NY, on 2 January 2018[42]

Areas of the Hudson River north of Spuyten Duyvil that are considered to be "problem areas" with respect to ice are identified as:[43]

[40] Lee 2015.
[41] USCG performs a WAMS for the Hudson River every five years, and whenever they establish a federal anchorage.
[42] Photo by USCG Petty Officer 3rd Class Steven Strohmaier (USCG District 1 PADET New York) (https://www.dvidshub.net/image/4061713/coast-guard-responds-vessels-beset-ice-hudson-river#)

- Port of Albany to Troy Locks (Albany, NY, to Troy, NY)
- World's End (Hudson Highlands near West Point, NY)
- Crum Elbow (near Hyde Park, NY)
- Silver Point (near Alsen, NY)
- Middle Ground Flats (near Hudson, NY)

Ice conditions vary annually, but, as an example, the conditions on 15 February 2017 were as shown in Table 4 and Table 5. For definitions of ice types, see Appendix B.

Table 4: Ice Conditions by Section on Hudson River on 15 February 2017

Location	Ice Type	Form	Thickness	Coverage[44]
George Washington Bridge[45]	None	-	-	-
Tappan Zee to West Point	None	-	-	-
West Point to Newburgh	Drift	Brash	2–6 inches	40%
Newburgh to Poughkeepsie	Drift	Brash	2–6 inches	75%
Poughkeepsie to Kingston	Drift	Brash	2–6 inches	75%
Kingston to Catskill	Fast	Brash	6–8 inches	90%
Catskill to Albany[46]	Fast	Brash	6–8 inches	40%

Table 5: Ice Conditions at Choke Points on Hudson River on 15 February 2017

Location	Ice Type	Form	Thickness	Coverage
West Point	Drift	Brash	2–5 inches	50%
Crum Elbow	Drift	Brash	10–12 inches	90%
Hyde Park Anchorage	Drift	Brash	6–8 inches	90%
Esopus Meadows	Drift	Brash	2–5 inches	40%
Silver Point	Drift	Brash	2–5 inches	40%
Hudson Anchorage	Drift	Brash	2–5 inches	40%
Stuyvesant Anchorage	Drift	Brash	2–5 inches	30%

Shoreline Types in Hudson River

Different shoreline types are affected in different ways in the event of an oil spill. To assist in risk assessments and planning for spills, a common scale has been developed by NOAA. The vulnerability or sensitivity of different shoreline types with respect to oiling has been classified by Environmental Sensitivity Index (ESI) classifications, as shown in Table 6. The ESI numbers indicate the relative sensitivity of different shoreline types – from the lowest sensitivity (1) to the highest (10).

Shoreline habitats in most parts of the US have been mapped with respect to ESI classifications, including the Hudson River from the tip of Manhattan to Troy. The ESI maps are a compilation of information on

[43] *Sector New York 2016-2017 Ice Breaking Season.*
[44] The percentage of water surface covered by ice to the total surface area at a specific location.
[45] All locations south of the George Washington Bridge were likewise open.
[46] Locations above Albany to Troy were not observed.

three main categories: shoreline habitats, sensitive biological resources, and human-use resources (e.g., water intakes, marinas, beaches). An example of an ESI map for the Hudson River is shown in Figure 34.

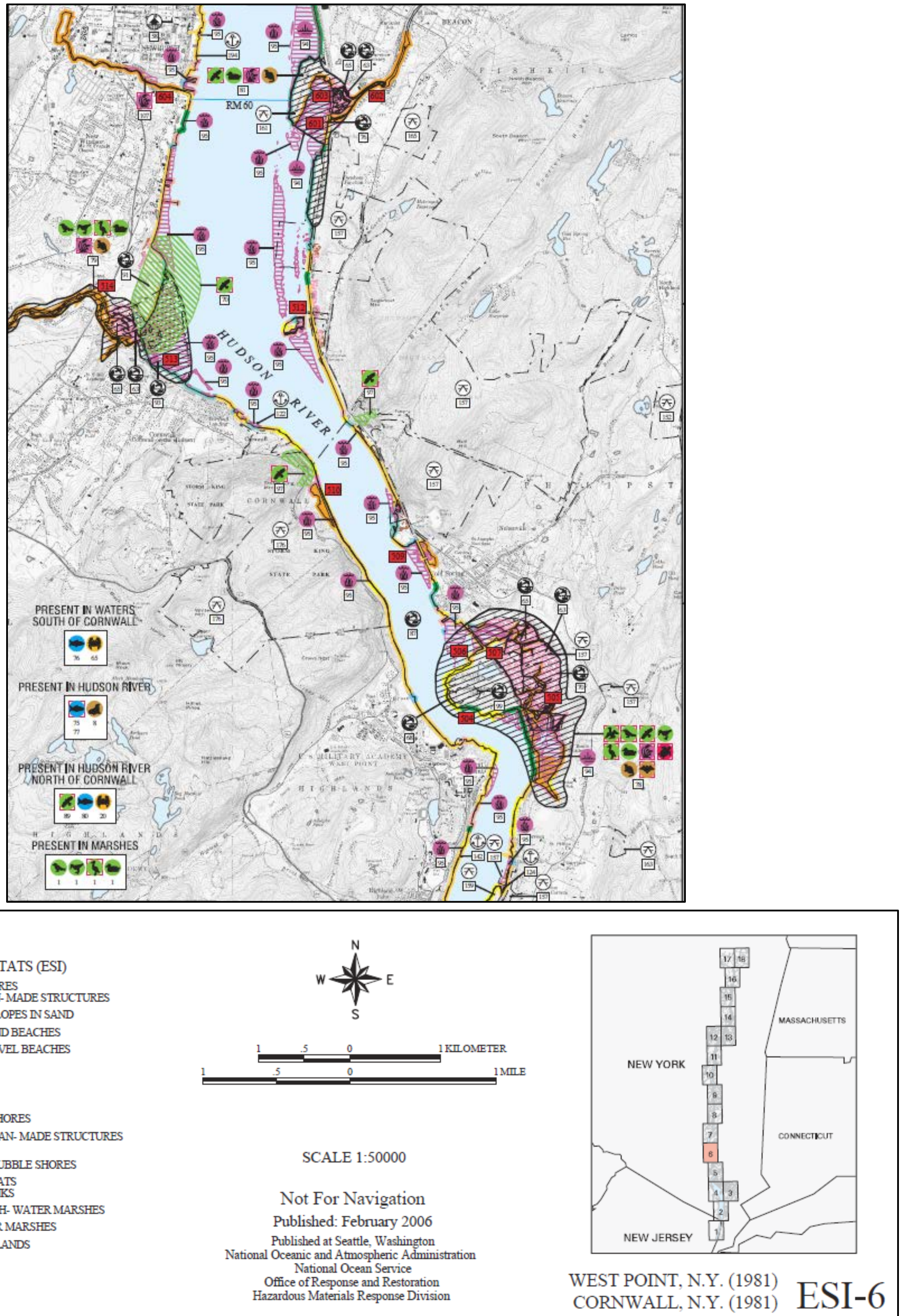

Figure 34: Example of ESI Map for Hudson River

ESI shoreline sensitivity is based on an integration of four main factors:

- Shoreline type (substrate, grain size, tidal elevation, origin);
- Exposure to wave and tidal energy;
- Biological productivity and sensitivity; and
- Ease of cleanup in the event of an oil spill.

Table 6: Environmental Sensitivity Index (ESI) Classifications in the Hudson River[47]

ESI Number/ Classification[48]	Physical Description	Predicted Oil Behavior	Response Considerations
1A **Exposed Rocky** (Figure 35)	• Steep intertidal zone steep (>30° slope), with very little width; solid and composed of bedrock • Sediment accumulations uncommon because waves and currents remove debris slumped from eroding cliffs • Strong vertical zonation of intertidal biological communities in estuarine parts of river • Shoreline regularly exposed to wave action and strong currents • Wave reflection is common phenomenon along outer coast • Species density/diversity vary greatly depending on exposure and salinity, but barnacles, snails, mussels, amphipods, and macroalgae can be abundant • Present in more exposed portions of river south of Peekskill, typically along Palisades	• In lower estuary and outer coast, oil held offshore by waves reflecting off steep, hard surfaces; Any oil deposited rapidly removed from exposed faces • Along river, oil can form band at high water line • Most resistant oil would remain as patchy band at or above high-water line • Impacts to intertidal communities expected to be short-term in duration; exception where heavy concentrations of light refined product comes ashore very quickly	• Cleanup usually not required • Access can be difficult and dangerous
1B **Exposed, Solid Man-Made Structures** (Figure 36)	• Structures are solid, man-made structures such as seawalls, groins, revetments, piers, and port facilities • Many structures are constructed of concrete, wood, or metal • Often no exposed substrate at low tide, but multiple habitats indicated if present	• Oil can be held offshore by waves reflecting off vertical, hard surface in exposed settings • Oil readily adheres to dry, rough surfaces at high-tide line, but does not adhere to wet substrates • Most resistant oil would remain as patchy band at or above high-tide line	• Cleanup usually not required • High-pressure water spraying may be conducted to remove persistent oil in crevices, improve aesthetics, and prevent direct contact with oiled surfaces

[47] Shoreline types not present in the Hudson River were omitted from the table, which affects the numbering (some ESI numbers are not included as these shoreline types are not present in the Hudson.)
[48] Photos corresponding to ESI type are indicated. (Photos from NOAA Environmental Sensitivity Index: Hudson River.)

Table 6: Environmental Sensitivity Index (ESI) Classifications in the Hudson River[47]			
ESI Number/ Classification[48]	**Physical Description**	**Predicted Oil Behavior**	**Response Considerations**
	• Built to protect shore from erosion by waves, boat wakes, and currents, and thus exposed to rapid natural removal processes • Attached animals and plants sparse to moderate • Common along in commercial zones and urbanized areas in open bays south of Peekskill		
3B Scarps and Steep Slopes in Sand (Figure 37**)**	• Scarps composed of relatively soft, unconsolidated sediments • Scarps show evidence of active erosion, and beaches in front of scarps narrow or absent • Present in upper portions of river; often associated with eroding mid-channel islands	• Any stranded oil will form band along high-water line. • Some potential for oil penetration into any sediment accumulations at base of scarp, but active erosion of scarp will also erode oil	• In some cases, cleanup not necessary because of short oil residence time • Need for removal of oiled sediments should be carefully evaluated due to potential for increased erosion • Manual labor and close supervision should be used so that minimal amount of sediment removed during cleanup
4 Coarse-Grained Sand Beach (Figure 38**)**	• Highly variable beachface slopes; sediments soft and permeable with low trafficability • Rate of sediment mobility relatively high, as beachface is reworked by boat wakes • Beach fauna vary in type and density; mobile surface, burrowing, and interstitial forms are typical • Very common along river	• During small spills oil deposited primarily as band along high-water line • Under heavy accumulations oil may spread across entire intertidal zone, though it will be lifted off lower part of beach during rising tides or water levels in river • Penetration up to 10 inches possible • Burial of oiled layers by clean sand can be rapid • Organisms living in beach may be killed by smothering or lethal oil concentrations in interstitial water	• Cleanup more difficult than for finer-grained beaches; equipment tends to grind oil into substrate due to loosely packed and permeable nature of coarser-grained sediments; special care must be exercised while using heavy equipment to prevent mixing oil deeper into beach sediment • Use of heavy equipment for oil/sand removal may also result in export of excessive amounts of sand; where feasible and for smaller amounts of oil, manual cleanup desirable • Vehicular and foot traffic through oiled areas and riparian habitat should be limited to prevent contamination of clean areas and disturbance of riparian vegetation • Removal of sediment should be limited as much as

Table 6: Environmental Sensitivity Index (ESI) Classifications in the Hudson River[47]			
ESI Number/ Classification[48]	**Physical Description**	**Predicted Oil Behavior**	**Response Considerations**
			possible to avoid erosion problems on beach in future; common occurrence of multiple buried oil layers in these types of beaches increases amount of sediment to be handled and disposed of
5 Mixed Sand and Gravel Beach **(**Figure 39**)**	• Moderately sloping beach composed of mixture of sand and gravel (gravel component 20 to 80 % total sediments) • Because of mixed sediment sizes, may be zones of pure sand, pebbles, or cobbles • May be large-scale changes in sediment distribution patterns depending upon season, because of transport of sand fraction offshore during storms • Because of sediment desiccation and mobility on exposed beaches, low densities of attached animals and plants • Very common along river, particularly near gravel or exposed bedrock shores	• During small spills, oil will be deposited along and above high-tide swash • Large spills will spread across entire intertidal area • Oil penetration into beach sediments may be up to 20 inches; however, sand fraction quite mobile, and oil behavior is much like on sand beach if sand fraction exceeds about 40% • Burial of oil may be deep at and above high-tide line, where oil tends to persist, particularly where beaches only intermittently exposed to reworking by waves • In sheltered pockets on beach, pavements of asphalted sediments can form if no removal of heavy oil accumulations • Once formed, asphalt pavements can persist for many years	• Heavy accumulations of pooled oil should be removed quickly from upper beachface • All oiled debris should be removed • Sediment removal should be limited as much as possible • Low-pressure flushing may be used to float oil away from sediments for recovery by skimmers or sorbents. High pressure spraying should be avoided due to potential for transporting contaminated finer sediments (sand) to lower intertidal or subtidal zones • Mechanical reworking of oiled sediments from high-tide zone to upper intertidal zone may be effective in areas regularly exposed to wave activity (as evidenced by storm berms). However, oiled sediments should not be relocated below mid-tide zone • In-place tilling may be used to reach deeply buried oil layers in middle zone on exposed beaches
6A Gravel Beach **(**Figure 40**)**	• Gravel beaches can be steep, with multiple wave-built berms forming upper beach; gravel beaches have lowest trafficability of all beach types and may contain shell and woody debris • Because of high mobility of sediments on exposed gravel beaches, low densities of	• Deep penetration of stranded oil likely on gravel beaches because of high permeability • Long-term persistence controlled by depth of routine reworking by waves and boat wakes • Along sheltered portions of shorelines, chronic sheening and formation of asphalt	• Heavy accumulations of pooled oil should be removed quickly from upper beachface • All oiled debris should be removed • Sediment removal should be limited as much as possible • Low-pressure flushing can

Table 6: Environmental Sensitivity Index (ESI) Classifications in the Hudson River[47]

ESI Number/ Classification[48]	Physical Description	Predicted Oil Behavior	Response Considerations
	animals and plants • Very common along river, particularly near exposed bedrock shores	pavements likely where accumulations are heavy	be used to float oil away from sediments for recovery by skimmers or sorbents • Mechanical reworking of oiled sediments from high-tide zone to upper intertidal zone may be effective in areas regularly exposed to wave activity (as evidenced by storm berms). However, oiled sediments should not be relocated below mid-tide zone • In-place tilling may be used to reach deeply buried oil layers in middle zone on exposed beaches
6B **Riprap** **(**Figure 41**)**	• Riprap structures composed of cobble- to boulder-sized blocks of rock • Riprap structures used for shoreline protection and as jetties in harbors • Attached biota sparse on exposed riprap • Common in more exposed portions of river south of Peekskill, often associated with railroads and boat ramps	• Deep penetration of oil between blocks likely • Oil adheres readily to rough surfaces of blocks • Uncleaned oil can cause chronic leaching until oil hardens	• When oil is fresh and liquid, high pressure spraying and/or water flooding may be effective, making sure to recover all liberated oil • Heavy and weathered oils more difficult to remove, requiring scraping and/or hot-water spraying
7 **Exposed Tidal Flat** **(**Figure 42**)**	• Exposed tidal flats are broad, flat intertidal areas composed primarily of sand and minor amounts of gravel • Presence of sand and gravel indicates tidal currents and waves strong enough to mobilize sediments • Biological utilization very high, with large numbers of infauna, heavy use by birds for roosting and foraging, and use by foraging fish • Common along river; often associated with mid-channel islands	• Oil does not usually adhere to surface of exposed tidal flats, but moves across the flat and accumulates at high-tide line • Deposition of oil on flat may occur on falling tide if concentrations heavy • Oil does not penetrate water-saturated sediments • Biological damage may be severe, primarily to infauna, reducing food sources for birds and other predators	• Currents and waves very effective in natural removal of oil • Cleanup very difficult (possible only during low tides) • Use of heavy machinery should be restricted to prevent mixing of oil into sediments

Table 6: Environmental Sensitivity Index (ESI) Classifications in the Hudson River[47]			
ESI Number/ Classification[48]	**Physical Description**	**Predicted Oil Behavior**	**Response Considerations**
8A Sheltered Rocky Shore (Figure 43)	• Substrate solid, composed of bedrock • Sheltered from large waves and strong currents • Sediments may accumulate at base • Slope of intertidal zone is generally moderate to steep (>15°) with little width • Present in central portion of river in Highlands and Ridge and Valley regions.	• Heavy oils tend to coat dry, irregular surface • Stranded oil will persist due to low energy setting	• Low-pressure flushing at ambient temperatures most effective when oil fresh and still liquid • Care must be taken during flushing operations to prevent oily effluents from affecting biologically rich, lower intertidal levels • Where high-tide area accessible, may be feasible to remove heavy oil accumulations and oiled debris
8B Sheltered, Solid Man-Made Structures (Figure 44)	• Solid man-made structures, such as seawalls, groins, revetments, piers, and port facilities • Structures constructed of concrete, wood, or metal • Often no exposed beach at low water, but multiple habitats indicated if present • Attached animal and plant life highly variable • Present along developed commercial waterfront areas in Newburgh, Poughkeepsie, Albany, and Troy	• Oil will adhere readily to rough surfaces, particularly along high-tide line, forming distinct oil band • Lower intertidal zone usually stays wet (particularly if algae covered), preventing oil from adhering to surface	• Cleanup of seawalls usually conducted for aesthetic reasons or to prevent leaching of oil • Low- to high-pressure spraying at ambient water temperatures most effective when oil is fresh
8C Sheltered Riprap (Figure 45)	• Riprap structures composed of cobble- to boulder-sized blocks of rock • Structures found inside harbors and bays in highly developed areas, sheltered from direct exposure to waves • Attached animal and plant life can be present • Very common in northern and central portions of river, often associated with railroads and boat ramps	• Deep penetration of oil between boulders likely • Oil adheres readily to rough surfaces • If oil left uncleaned, may cause chronic leaching until oil hardens	• High-pressure spraying may be required to remove oil for aesthetic reasons and to prevent leaching of oil from structure • Cleanup crews should make sure to recover all released oil
8D Sheltered Rocky Shore (Figure 46)	• Relatively steep and narrow rocky shore covered by veneer of angular rubble with no evidence of reworking by waves or sediment transport • Surface rubble highly variable in size and packing, but always some permeability	• Oil tends to adhere to upper intertidal zone where rock surface dries out during low tide, and algal cover sparse • On solid bedrock surfaces, oil will occur as surface coating • Oil will pool and penetrate crevices surface rubble	• Thick accumulations of pooled oil high priority for removal, to prevent re-mobilization and/or penetration • Manual removal of heavy oil likely to leave significant residues, but may be useful for oil in crevices or

Table 6: Environmental Sensitivity Index (ESI) Classifications in the Hudson River[47]			
ESI Number/ Classification[48]	**Physical Description**	**Predicted Oil Behavior**	**Response Considerations**
	in surface materials • Can co-occur with gravel beaches; gravel beach can be either at upper or lower half of intertidal zone, depending on nature of rock outcrop • Sheltered from significant wave activity and strong currents • Present along river, particularly as intertidal talus fields near exposed bedrock shores	• Where rubble loosely packed, oil can penetrate deeply, causing long-term contamination of subsurface	sediment pockets • Flushing techniques most effective when oil still fresh and liquid; restrict operations to tidal levels to prevent oily effluents from impacting lower tidal elevations with rich intertidal communities • Increase temperature and pressure over time as oil weathers; evaluate trade-offs between oil removal and pressure/temperature impacts on intertidal communities • Consider potential impacts to rich rocky shore biological communities in conducting cleanup of associated gravel beaches
9A Sheltered Tidal Flat (Figure 47)	• Composed primarily of mud with minor amounts of sand and shell • Present in calm-water habitats, sheltered from major wave activity, and frequently backed by marshes • Sediments very soft; cannot support even light foot traffic in many areas • May have heavy wrack deposits along upper fringe • Large concentrations of shellfish, worms, and snails can be found on and in sediments • Heavily utilized by birds for feeding • Common along river, generally associated with emergent marshes and tributaries	• Oil does not usually adhere to surface of sheltered tidal flats, but rather moves across flat and accumulates at high-tide line • Oil deposition on flat may occur on falling tide if concentrations heavy • Oil will not penetrate water-saturated sediments, but could penetrate burrows and desiccation cracks or other crevices in muddy sediments • In areas of high suspended sediments, sorption of oil can result in deposition of contaminated sediments on flats • Biological damage may be severe	• High-priority areas necessitating use of spill protection devices to limit oil-spill impact; deflection or sorbent booms and open water skimmers should be used • Cleanup of flat surface very difficult because of soft substrate; many methods may be restricted • Low-pressure flushing and deployment of sorbents from shallow-draft boats may be helpful
9B Sheltered, Vegetated Low Banks (Figure 48)	• Composed of low banks with grasses or shrubs along smaller tributaries • Can be flooded occasionally by high water • Important habitat for fish, shellfish, birds, and terrestrial mammals	• During low water, unlikely that oil in main river would affect these areas; however, during high river levels, oil could flow into them • Oil will coat any vegetation at water line • Oil can contaminate and	• Low-pressure flushing may be effective in small waterbodies, to flush oil trapped along banks and in debris to collection sites • Care to prevent mixing of oil into sediments during response activities

Table 6: Environmental Sensitivity Index (ESI) Classifications in the Hudson River[47]			
ESI Number/ Classification[48]	**Physical Description**	**Predicted Oil Behavior**	**Response Considerations**
	• Present in sheltered areas and along smaller tributaries	become trapped in debris	• Deployment of sorbents may be necessary to recover sheens after gross oil removal
10A Salt- and Brackish-Water Marsh (Figure 49)	• Intertidal wetlands containing emergent, herbaceous vegetation • Width of marsh varies widely, from narrow fringe to extensive areas • Marsh soils range from sand to high-organic peats • Exposed areas located along bays with wide fetches and along heavily trafficked waterways • Sheltered areas not exposed to significant wave or boat wake activity • Resident flora and fauna abundant with numerous species with high utilization by birds, fish, and shellfish • Present in lower portion of river, typically south of Poughkeepsie	• Oil adheres readily to intertidal vegetation • Band of coating varies widely, depending upon water level at time oil slicks in vegetation. May be multiple bands • Large slicks persist through multiple tidal cycles and coat entire stem from high-tide line to base • If vegetation thick, heavy oil coating restricted to outer fringe, although lighter oils can penetrate deeper, to limit of tidal influence • Medium to heavy oils do not readily adhere to or penetrate fine sediments, but can pool on surface or in burrows • Light oils can penetrate top few centimeters of sediment and deeply into burrows and cracks (up to three feet)	• Under light oiling, best practice is natural recovery; natural removal processes and rates should be evaluated prior to conducting cleanup • Heavy accumulations of pooled oil can be removed by vacuum, sorbents, or low-pressure flushing • Cleanup activities should be carefully supervised to avoid vegetation damage • Cleanup activity must not mix oil deeper into sediments. Trampling of roots must be minimized • Cutting of oiled vegetation should only be considered when other resources present at great risk from leaving oiled vegetation in place
10B Freshwater Marsh (Figure 50)	• Grassy wetlands composed of emergent herbaceous vegetation in tidal freshwater settings • Marsh soils vary widely from sand and gravel to peat • Resident flora and fauna abundant • Common along river north of Poughkeepsie, both as larger marsh complexes and narrow fringing marsh	• Oil adheres readily to vegetation • Band of coating varies widely, depending upon water level changes at time oil slicks in vegetation. May be multiple bands • If vegetation thick, heavy oil coating will be restricted to outer fringe, although lighter oils can penetrate deeper	• Under light oiling, best practice is natural recovery; natural removal processes and rates should be evaluated prior to conducting cleanup • Heavy accumulations of pooled oil can be removed by vacuum, sorbents, or low-pressure flushing • Cleanup activities should be carefully supervised to avoid vegetation damage • Any cleanup activity must not mix oil deeper into sediments. Trampling of roots must be minimized • Cutting of oiled vegetation only considered when other resources present are at great risk from leaving oiled vegetation in place
10D Scrub-Shrub	• Consist of woody vegetation less than 20 ft tall including	• Generally not risk of oiling from marine spills because of	• Under light oiling, best practice is natural recovery

Table 6: Environmental Sensitivity Index (ESI) Classifications in the Hudson River[47]

ESI Number/ Classification[48]	Physical Description	Predicted Oil Behavior	Response Considerations
Wetlands (Figure 51)	true shrubs, small trees, and trees and shrubs stunted due to environmental conditions •Sediments silty clay mixed with organic debris • Grow above normal spring high tides, thus seldom inundated by salt water • Resident flora and fauna abundant • Usually found in association with artificial ponds created by railroad tracks	position above normal high tides • Could become oiled during very high water levels, from land-based spills, or during cleanup of adjacent areas • Woody vegetation less sensitive than grasses to oil	• Heavy accumulations of pooled oil can be removed by vacuum, sorbents, or low-pressure flushing • Oily debris can be removed where access • Any cleanup activity must not mix oil deeper into sediments. Trampling of roots must be minimized • Woody vegetation should not be cut

Figure 35: ESI 1A Exposed Rocky Shore on Hudson River

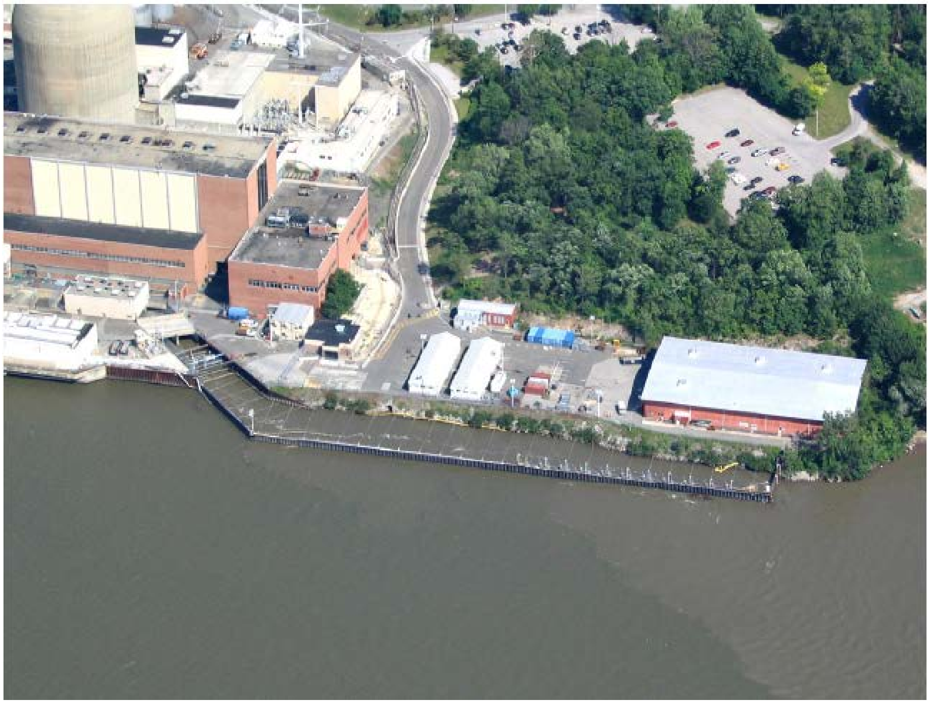

Figure 36: ESI 1B Exposed/Solid Man-Made Structures on Hudson River

Figure 37: ESI 3B Scarps and Steep Slopes on Hudson River

Figure 38: ESI 4 Coarse-Grained Sand Beach on Hudson River

Figure 39: ESI 5 Mixed Sand and Gravel Beach on Hudson River

Figure 40: ESI 6A Gravel Beach on Hudson River

Figure 41: ESI 6B Riprap Shore on Hudson River

Figure 42: ESI 7 Exposed Tidal Flats on Hudson River

Figure 43: ESI 8A Sheltered Rocky Shore on Hudson River

Figure 44: ESI 8B S Sheltered Man-Made Structures on Hudson River

Figure 45: ESI 8C Sheltered Riprap on Hudson River

Figure 46: ESI 8D Sheltered Rock Shore on Hudson River

Figure 47: ESI 9A Sheltered Tidal Flats on Hudson River

Figure 48: ESI 9B Vegetated Low Banks on Hudson River

Figure 49: ESI 10A Salt- and Brackish-Water Marsh on Hudson River

Figure 50: ESI 10B Freshwater Marsh on Hudson River

Figure 51: ESI 10D Scrub-Shrub Wetland on Hudson River

Overview of Natural Habitats of Hudson River

The Hudson River and its shorelines include a complex mix of various kinds of habitats, including both seaward (brackish water) and landward (freshwater) types (Table 7).

Table 7: Shoreline Habitats in Hudson River Study Area

Habitat Type		Area (Acres)[49]	Shore Length (Miles)
Water Type	**Habitat Name**		
Seaward Brackish Water South of Bear Mountain Bridge	**Solid Bedrock Shoreline**	2.3	5.88
	Unconsolidated Rock Shoreline	18.9	47.41
	Sand or Sand with Brick Shoreline	0.2	0.42
	Mud, Mixed Mud-Sand, Timber Edge	6.1	15.46
	Saltmarsh (*Spartina* spp.)	33.6	1.72
	Upper Intertidal Mix	1.8	4.63
	Lower Intertidal Mix	0.2	0.52
	***Phragmites australis* (Common Reed)**	459.6	4.68
	Estuarine Silt-Mud	54,595.8	0.00
	Estuarine Submerged Aquatic Vegetation	268.7	0.00
	Sheet Pile or Concrete or Other	72.5	182.22
	Estuarine Unvegetated Flats	143.9	0.00
Landward Freshwater Wetlands North of Bear Mountain Bridge	**Solid Bedrock Shoreline**	9.8	24.67
	Unconsolidated Rock Shoreline	55.2	138.91
	Sand or Sand with Brick Shoreline	0.9	2.24
	Mud, Mixed Mud-Sand, Timber Edge	39.3	98.84
	***Typha* spp. (cattail)**	5.2	13.12
	Upper Intertidal Mix	16.0	40.28
	Lower Intertidal Mix	3.2	8.17
	Phragmites australis	33.8	2.24
	Freshwater Gravel Bottom Submerged Land	79.8	0.00
	Freshwater Sand Bottom Submerged Land	12,936.8	0.00
	Freshwater Silt-Mud Submerged Land	19,322.0	0.00
	Freshwater Scrub/Shrub Wetland Edge	788.8	0.00
	Solid Bedrock Shoreline	2,175.8	0.00
	Freshwater Lower Intertidal Mix	246.2	0.00
	Freshwater Submerged Aquatic Vegetation	404.0	0.00
	Sheet Pile or Concrete or Other Shoreline	8.5	21.50
	Scrub/Shrub or Forested Wetland Edge	0.8	2.08
	Freshwater Unvegetated Flats	83.2	0.00

The vast majority of the river shore areas are composed of silt-mud areas, followed by sand bottom. There are about 200 tidal freshwater wetlands fringing the Hudson River from the Tappan Zee up to Troy.[50]

[49] For shorelines, areas are based on assumed width of oiling in SIMAP modeling of one meter (3.28 ft. or 1.09 yd.)
[50] Findlay et al. 2002.

Tidal wetland and submerged aquatic vegetation maps are available from NYSDEC[51]. The following is a summary of the types of habitats found in the Hudson River.[52]

Submerged aquatic vegetation (SAV) communities are exclusively found in lower intertidal and shallow water habitats, primarily in the fresh water, northern portion of the estuary to the slightly brackish portions further south in Haverstraw Bay. Hudson River SAV beds are dominated by water celery (*Vallisneria Americana*), a rooted, freshwater native plant.

In the 1940s, the Hudson River was invaded by water chestnut (*Trapa natans*), a prolific non-native plant species that quickly overtook shallows in protected or semi-protected areas. Water chestnut is a rooted annual with long stems to support rosettes of leaves and flowers that float on the water surface and shade plants below. Water chestnut replaced native plants such as water celery in protected shallows and today occupies almost 2,000 acres of Hudson River shallows, from Hastings to Troy (river miles 33 to 152). Restoration projects are underway to control this plant's growth and spread.

The Hudson River estuary's more than 6,000 acres of intertidal wetlands (Tappan Zee Bridge to Troy) occur between low and high tide and are regularly flooded and drained twice a day by rising and falling tides. Intertidal wetlands are found in the main stem of the Hudson as well as in tidal mouths of tributaries. They include: brackish marshes (e.g., Iona Island, Constitution and Manitou marshes) and freshwater tidal marshes (e.g., Tivoli Bays, Ramshorn, Hudson South Bay and Mill Creek mashes). Mud and sand flats, broad-leaf emergent and graminoid-dominated marshes, and tidal shrub and tree swamps can all be found in Hudson River tidal wetlands. Hudson River intertidal habitats also include extensive areas of non-vegetated mud and sand flats regularly inundated by water.

Brackish marshes, vegetated by non-woody plants that are salt tolerant, exist in the lower estuary but are uncommon. The invasive common reed, *Phragmites australis*, has taken over many areas that might otherwise be brackish marshes. Freshwater tidal marshes are common from the Bear Mountain Bridge north. They contain richly diverse wetland plant communities dominated by non-woody plants, often cattail (*Typha angustifolia*) and spatterdock (*Nuphar advena*), with many other plant species present. Freshwater tidal swamps are highly diverse communities dominated by shrubs and/or trees, with diverse understories that can tolerate regular flooding.

Shorelines along the Hudson River estuary are diverse. About half of the shorelines from Troy to the Tappan Zee Bridge are "natural," ranging from steep rock to shallow slopes. Some are unvegetated, while others support a mix of woody or grassy communities on mud, sand, cobbles or bedrock. The other half of the shoreline has been engineered with a variety of structures designed to protect property or support transportation, recreation or industrial activities. Common engineered shorelines include revetment (sloping structures that armor the shore), bulkhead (vertical structures made of steel, concrete or wood), cribbing (interlocking logs filled with broken rock) and riprap (typically sloping rock walls).

The bottom morphology is important in determining the type of aquatic organisms and benthic habitats that exist in the river. For example, ideal spawning grounds for the Atlantic sturgeon include stones and

[51] https://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1210; https://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1350

[52] http://www.dec.ny.gov/docs/remediation_hudson_pdf/hrhrp.pdf

vegetation to which their scattered eggs can adhere. The Hudson River is an ecologically heterogeneous environment with a diverse array of habitats.[53] Table 8 gives a summary of the habitat types of the river. Two-thirds of the river had a depth of more than 9.8 feet (3 meters). The deepwater tidal river zones occur below depths that can support plant growth (about two meters or 6 feet). These zones generally have swift currents and rocky bottoms. The shallow zones have a variety of vegetation.[54]

Table 8: Habitat Types of the Hudson River Estuary–Troy Dam to the Battery

Habitat Type	Habitat Subtype	% Total
Shallows	Tidal wetlands	9%
	Submerged attached vegetation	6%
	Floating vegetation	2%
	Non-vegetated bare bottom	17%
	Total shallows	**34%**
Deep-Water Bottom > 3 meter (9.8 ft) depth		**66%**

Threatened Sturgeon

One of the unique features of the Hudson River is the presence of threatened sturgeon species. The Hudson River is a critical habitat for Atlantic Sturgeon according to the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS).

Atlantic sturgeon that are spawned in US rivers, or are captive progeny of Atlantic sturgeon that were spawned in US rivers, are listed under the Endangered Species Act (ESA) as five Distinct Population Segments (DPSs). As of 6 February 2012, the New York Bight DPS of the Atlantic Sturgeon, which includes the Hudson River, was listed as endangered. The Greater Atlantic Region of NMFS has jurisdiction for implementing the ESA with respect to the New York Bight DPS. This represents the largest population of Atlantic Sturgeon in the US.[55] The final rule designates critical habitat that includes the Hudson River from river mile 0 to the Troy Dam and includes all of the potential anchorage areas. The critical habitat designation is for habitats that support successful Atlantic sturgeon reproduction and recruitment.

The critical habitat includes approximately 547 km (340 miles) of aquatic habitat within the Connecticut, Housatonic, Hudson, and Delaware Rivers of the New York Bight DPS. This includes the entire Hudson River from the New York Harbor up to Troy.

NOAA National Marine Fisheries[56] determined that the New York Bight distinct population segment of Atlantic sturgeon is endangered because it is currently in danger of extinction throughout its range due to:

- Precipitous declines in population sizes and the protracted period in which sturgeon populations have been depressed;
- Limited amount of current spawning; and
- Impacts and threats that have and will continue to prevent population recovery.

[53] Levinton and Waldman 2006.
[54] https://nctc.fws.gov/pubs5/web_link/text/mhr_form.htm
[55] Dunton et al. 2016.
[56] http://www.nmfs.noaa.gov/pr/pdfs/species/atlanticsturgeon_nybright_dps.pdf

Population numbers of Atlantic sturgeon in the New York Bight distinct population segment are extremely low compared to historical levels and have remained so for the past 100 years. For example, prior to 1890, there were an estimated 6,000-6,800 females contributed to the Hudson River spawning stock each year during the late 1800s. Currently, the existing spawning population in the Hudson River is estimated to have 870 adults spawning each year (600 males; 270 females). The spawning population of this distinct population segment is thought to be one to two orders of magnitude below historical levels (Figure 52).

In addition to having fewer fish spawning, some spawning populations have been completely eliminated. There are known to be spawning populations exist in two rivers (the Hudson and Delaware Rivers) within the distinct population segment. The elimination of at least two historic spawning populations is believed to have occurred.

Threats to already depressed populations of Atlantic sturgeon can occur from habitat degradation, vessel strikes, and accidental capture and potential injury and mortality in fisheries. These threats are working in combination to put the distinct population segment in danger of extinction.

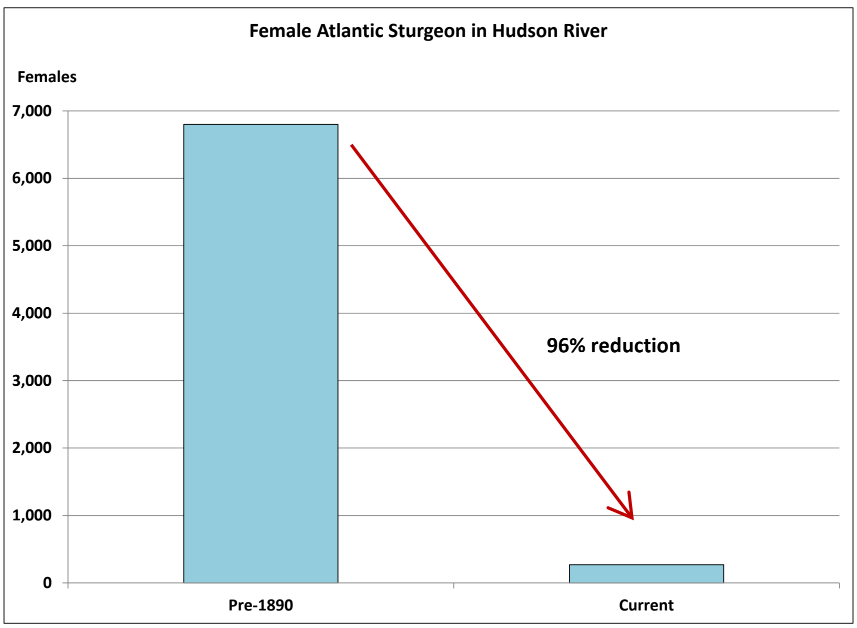

Figure 52: Female Sturgeon Individuals in Hudson River

In addition to the Atlantic sturgeon, there are also known to be shortnose sturgeon (*Acipenser brevirostrum*) populations in the Hudson River that are of concern with respect to effects of potential spills and overall vessel activity in the Hudson River. According to the New York Department of Environmental Conservation: [57]

> The shortnose sturgeon's life history is complex. Much of its spawning behavior and early life stages are still not fully understood. The shortnose sturgeon is anadromous, migrating from salt water to spawn in freshwater. In the Hudson River, it spawns from April-May. Adult sturgeon

[57] http://www.dec.ny.gov/animals/26012.html

migrate upriver from their mid-Hudson overwintering areas to freshwater spawning sites north of Coxsackie.

Unlike most fish species, spawning is not a yearly event for most shortnose sturgeon. Males spawn every other year and females every third year. Females lay between 40,000-200,000 eggs which hatch in approximately 13 days. Newly-hatched fry are poor swimmers and drift with the currents along the bottom. As they grow and mature, the fish move downriver into the most brackish parts of the lower Hudson. Shortnose sturgeon are long-lived. The oldest known female reached 67 years of age and the oldest known male was 32.

Bottom feeders, shortnose sturgeon eat a variety of organisms. Using their barbels to locate food and their extendable mouths to then vacuum it up, they eat sludge worms, aquatic insect larvae, plants, snails, shrimp, and crayfish.

Officially listed by the National Marine Fisheries Service as endangered, the shortnose sturgeon is fully protected by the Endangered Species Act of 1973. It is unlawful to kill or possess this fish. This action, combined with ongoing water quality and habitat protection efforts, offer a bright future for New York's shortnose sturgeon populations. No additional management actions are considered necessary at this time.

Overview of River Communities, Commerce, and Cultural Resources

The Hudson River Valley is rich with natural and cultural resources that are treasured by the over one million residents of the riverside communities as well as tourists from all over the nation and world. Tourism in the Hudson River Valley generates about $4.8 billion annually and employs 82,455 people in riverside communities.[58] The river itself acts as the center of cultural and recreational activities and many historic sites.

At the same time, the river acts as an important shipping route for a large variety of commodities. The Hudson River has served as a “corridor of commerce” for as long as humans have lived along its banks. According to the Hudson River Institute:

> Archaeological evidence tells the story of Native American communities' use of the Hudson as a means to travel for hunting and trade. When the Europeans came to its shores they used it as a pathway deeper into Northern New York. As such, the length of the Hudson led the Dutch settlers to found their two largest cities at opposite ends of its depths; Albany where it is joined by the Mohawk River and the future New York City where its waters pour out into the Atlantic.
>
> With the growth and prosperity of New York City, trade along the Hudson increased. With the opening of the Erie Canal in 1825, the Hudson became a major link in trade from the East Coast to the rapidly opening West. In addition to transportation, the river and its shores were also treated as industrial resources. Business such as ice harvesting, brick making, and stone quarrying took place on the river itself, and the products were then shipped in season on the same. Iron manufacturing, ship building and whaling, and brewing dominated the 1800s. The following

[58] Hudson River Estuary Program 2018.

century saw an increase in high tech industry settling into the Hudson Valley led by IBM and DuPont.

Yet despite the growth of industry along the Hudson, agriculture has remained a key piece of the regional economy. Its shores and weather create a perfect growing environment for grapes that have led to award winning wineries; apple orchards and dairies flourished as well. Historically, as well as more recently due to "niche" gourmet farming, these enterprises have benefited by their proximity to New York City.[59]

The Hudson River study area includes a large number of communities in two states, New York and New Jersey, along both the western and eastern banks of the river. There are over one million residents living in towns along the river. A summary of the characteristics and vulnerable shoreline features of these Hudson River communities is shown in Table 9.[60]

[59] http://www.hudsonrivervalley.org/themes/commerce.html
[60] Detailed information about the river communities can be found in Appendix B.

Table 9: Summary of Riverfront and River Vicinity Features of Hudson River Towns and Communities[61]

River Bank	Town	Shore Miles	Water Intake	Homes	Restaurant/ Hotel	Industry	Oil Terminal	Rail Station	Rail Tracks	Historic Site	Park	Marina	Natural Area	Agriculture	Bathing Beach
West	**Englewood Cliffs, NJ**	2.9									●	●			
West	**Alpine, NJ**	6.5								●	●	●			
East	**Riverdale, NY**	2.6						●	●		●	●			
East	**Yonkers, NY**	4.3	●	●	●	●●		●	●		●	●			
East	**Hastings-on-Hudson, NY**	2.1		●	●			●	●		●	●			
East	**Dobbs Ferry, NY**	1.3		●	●			●	●		●				
East	**Irvington, NY**[62]	1.8		●	●			●	●		●●				
East	**Tarrytown, NY**	2.6	●	●	●			●	●	●●		●●			
East	**Sleepy Hollow, NY**[63]	2.5		●				●	●	●●	●	●			●
East	**Scarborough, NY**[64]	1.2	●	●				●	●						
East	**Ossining, NY**	2.8		●	●			●	●		●	●●			●
East	**Cortlandt, NY**[65]	15.1	●	●		●●		●	●	●		●			●
East	**Peekskill, NY**	1.5		●	●	●		●	●		●	●			
East	**Philipstown, NY**[66]	13.1	●	●	●			●	●	●	●	●	●●●		
East	**Beacon, NY**	4.2	●	●				●	●	●	●●	●	●●		
East	**Fishkill, NY**	1.6		●					●						
East	**Wappinger, NY**[67]	5.3	●	●					●			●●			

[61] The number of dots (from one to three) indicates the relative number of features in each town. If blank, there are no such features in that town along the river.
[62] Includes: Ardsley-on-Hudson
[63] Hudson River adjacent part of Town of Mt Pleasant.
[64] Riverfront part of Briarcliff Manor.
[65] Includes: Croton-on-Hudson, Crugers, Verplanck, Buchanan, Montrose, and Cortlandt Manor.
[66] Includes: Garrison and Cold Spring
[67] Includes: Chelsea.

Table 9: Summary of Riverfront and River Vicinity Features of Hudson River Towns and Communities[61]

River Bank	Town	Shore Miles	Water Intake	Homes	Restaurant/ Hotel	Industry	Oil Terminal	Rail Station	Rail Tracks	Historic Site	Park	Marina	Natural Area	Agriculture	Bathing Beach
East	**Poughkeepsie, NY**	9.8	●	●	●			●	●	●	●●	●●●	●		
East	**Hyde Park, NY**[68]	8.8	●	●				●	●	●●	●●	●			
East	**Rhinebeck, NY**[69]	8.9	●	●				●	●	●					
East	**Red Hook, NY**	7.3		●	●				●	●			●●●		
East	**Clermont, NY**	1.9							●		●		●		
East	**Germantown, NY**	3.9		●					●		●			●	
East	**Livingston, NY**[70]	1.6		●					●				●	●	
East	**Hudson, NY**	6.9		●				●	●	●●	●		●●		
East	**Stockport, NY**	3.9							●					●	
East	**Stuyvesant, NY**	9.2							●			●	●	●	
East	**Schodack, NY**[71]	8.3	●	●					●		●	●	●	●	
East	**Rensselaer, NY**	4.6	●	●		●●	●●●	●	●			●●		●	
West	**Orangetown, NY**[72]	12.6		●	●						●●	●●●	●●		
West	**Haverstraw, NY**	2.9		●	●				●		●●	●			
West	**Stony Point, NY**[73]	7.4		●			●		●	●	●●	●●	●●		
West	**Highlands, NY**[74]	11.8		●	●				●	●	●	●			
West	**Cornwall, NY**	4.4		●					●		●	●			

[68] Includes: Staatsburg
[69] Includes: Rhinecliff
[70] Includes: Linlithgo.
[71] Includes: Castleton-on-Hudson
[72] Includes: Piermont and Grand View-on-Hudson, Nyack, and South Nyack.
[73] Including: Tomkins Cove.
[74] Includes: West Point, Highland Falls, and part of Bear Mountain State Park

Table 9: Summary of Riverfront and River Vicinity Features of Hudson River Towns and Communities[61]															
River Bank	**Town**	**Shore Miles**	**Water Intake**	**Homes**	**Restaurant/ Hotel**	**Industry**	**Oil Terminal**	**Rail Station**	**Rail Tracks**	**Historic Site**	**Park**	**Marina**	**Natural Area**	**Agriculture**	**Bathing Beach**
West	**New Windsor, NY**	2.5		●			●●		●				●		
West	**Newburgh, NY**	2.3		●	●				●		●	●●			
West	**Balmville, NY**	0.9		●					●						
West	**Marlboro, NY**	8.3	●						●			●			
West	**Milton, NY**	1.9	●	●	●				●					●	
West	**Lloyd, NY[75]**	6.9		●					●	●	●	●			
West	**Esopus, NY[76]**	10.2	●	●●								●	●●	●●	●
West	**Kingston, NY**	3.3		●	●		●			●	●●	●●●			●
West	**Ulster, NY[77]**	4.7		●							●●	●			●
West	**Saugerties, NY[78]**	8.1		●	●					●	●●	●●	●	●	●
West	**Catskill, NY[79]**	10.4	●	●	●	●	●				●	●●		●	
West	**Athens, NY**	7.3	●	●	●	●	●				●	●●		●●	
West	**Coxsackie, NY**	6.7	●	●	●							●	●●●	●	
West	**New Baltimore, NY**	5.2		●	●						●	●	●●	●	
West	**Coeymans, NY[80]**	3.4		●	●	●●●						●●			
West	**Bethlehem, NY[81]**	7.8	●	●		●●●	●●				●			●	
West	**Albany, NY**	4.9	●		●	●●●	●●●			●		●●			

[75] Includes: Highland
[76] Includes: West Park and Port Ewen.
[77] Includes: East Kingston and Ulster Landing.
[78] Includes: Glasco and Malden-on-Hudson.
[79] Includes: Hamburg.
[80] Includes: Ravena
[81] Includes: Glenmont

Water Intakes

The Hudson River serves as a source of water for industrial and commercial facilities, recreational facilities (e.g. pools, golf courses), agricultural lands, and for drinking water, as summarized in Table 10.

Table 10: Water Intakes in Hudson River Study Area

Facility	Town	Public	Agriculture	Industrial	Recreation
Domino Sugar Refinery	Yonkers			●	
Montefiore Hospital	Tarrytown			●	
Tallman Mountain State Park	Orangetown				●
Sleepy Hollow Country Club	Briarcliff				●
Rockland Lake Golf Course	Orangetown				●
Tilcon Stone Quarry	Haverstraw			●	
Haverstraw Power Plant	Haverstraw			●	
Indian Point Energy Center	Cortlandt			●	
Camp Smith Military	Cortlandt			●	
Charles Point Resource Recovery	Peekskill			●	
Town of Fort Montgomery	Fort Montgomery	●			
Town of Cold Spring	Philipstown	●			
Town of Beacon	Beacon	●			
Southern Dutchess Country Club	Beacon				●
Danskammer Power	Newburgh			●	
Roseton Power	Newburgh			●	
Town of Chelsea	Wappinger	●			
VA Hudson Valley Castle Point	Wappinger	●			
Marlboro Quarry	Marlboro			●	
Agricultural Area	Milton		●		
IBM	Poughkeepsie			●	
Dutchess Golf Club	Poughkeepsie				●
Marist College	Poughkeepsie	●			
Town of Highland	Highland	●			
Town of Hyde Park	Hyde Park	●			
Town of Rhinebeck	Rhinebeck	●			
Town of Port Ewen/Rondout	Esopus	●			
Town of Catskill	Catskill	●			
Town of Ulster	Ulster	●			
Town of Athens	Athens	●			
Town of Coxsackie	Coxsackie	●			
Town of Castleton-on-Hudson	Schodack	●			
Epcor Utilities	Schodack			●	
PSEG Power New York	Bethlehem			●	
Pfizer/AMRI	Rensselaer			●	
City of Albany	Albany	●			

Table 10: Water Intakes in Hudson River Study Area					
Facility	**Town**	**Public**	**Agriculture**	**Industrial**	**Recreation**
Agricultural Area	**Menands**		●		
Office of General Services (OGS)	**Albany**				●
Town of Watervliet	**Watervliet**	●			
Town of Green Island	**Green Island**	●			
Town of Troy	**Troy**	●			

PCB Contaminant Issue

While PCB contamination is not within the scope of the HROSRA study, it is important to take note of this baseline condition for the Hudson River with respect to the overall environmental health of the river. There are also implications for spill response related to PCB contamination that need to be considered.[82]

In the late 1940s through 1977, the General Electric Corporation (GE) discharged millions of pounds of polychlorinated biphenyls (PCBs) into the Hudson River from two electric capacitor manufacturing plants at Fort Edward and Hudson Falls, New York. These facilities are about 40 and 45 miles north of the Troy Federal Lock and Dam, respectively (Figure 53).

Figure 53: Site of General Electric Capacitor Plants

[82] This issue is discussed in HROSRA Volume 6.

The US EPA recommended that 2.65 million cubic yards of contaminated sediments containing PCBs be dredged from the Upper Hudson River.[83] In 2009, the EPA ordered Phase 1 dredging for the areas shown in Figure 54 through Figure 56. This removed 283,000 cubic yards of PCB-contaminated sediment along a six-mile stretch. Phase 2 dredging during 2011 through 2015, removing 2.75 million cubic yards of contaminated sediment from selected areas above the Troy Federal Lock and Dam.

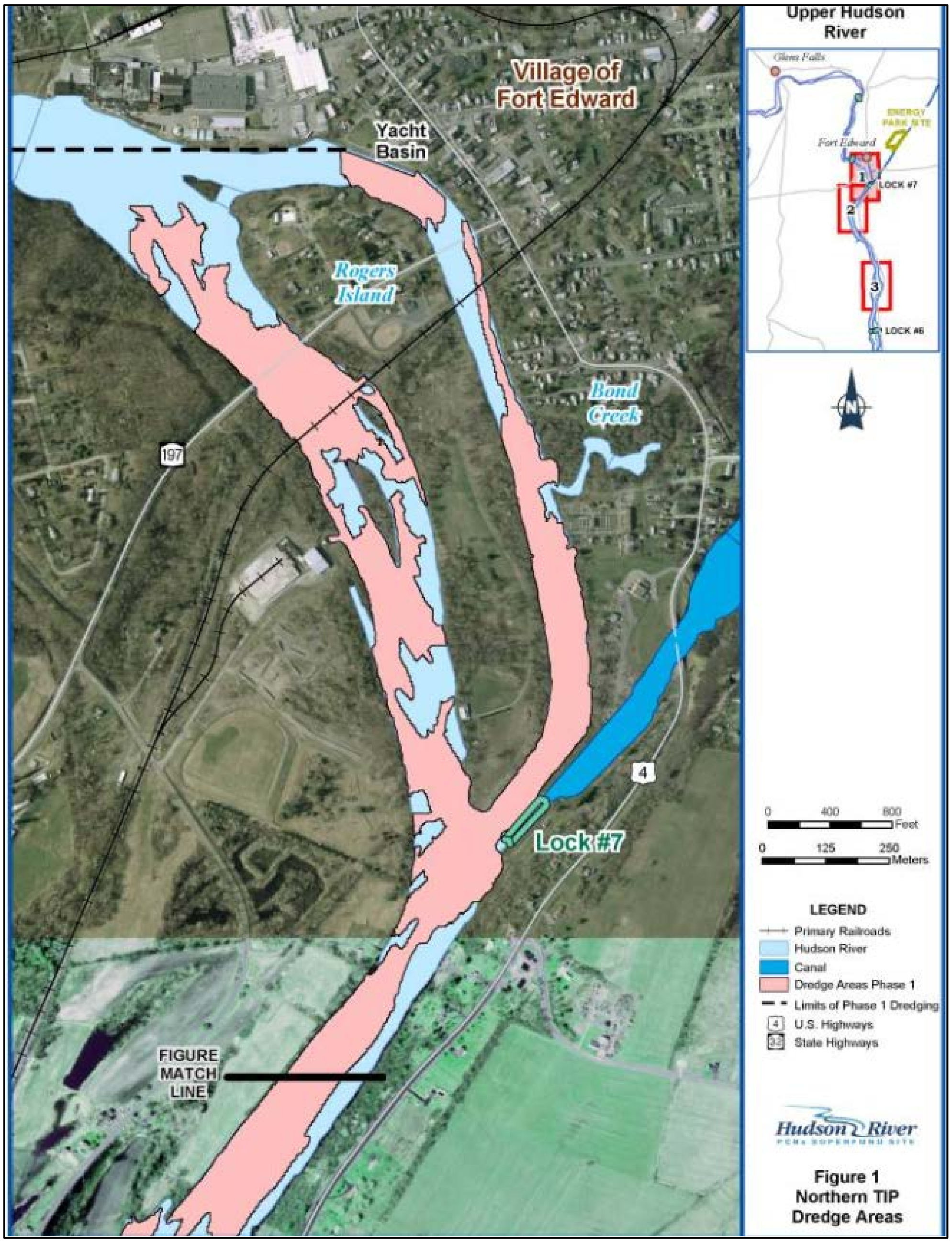

Figure 54: Phase 1 PCB Northern Dredging Areas (Thompson Island Pool-North)[84]

[83] US EPA 2000a.

[84] https://www3.epa.gov/hudson/pdf/factsheet2005.pdf

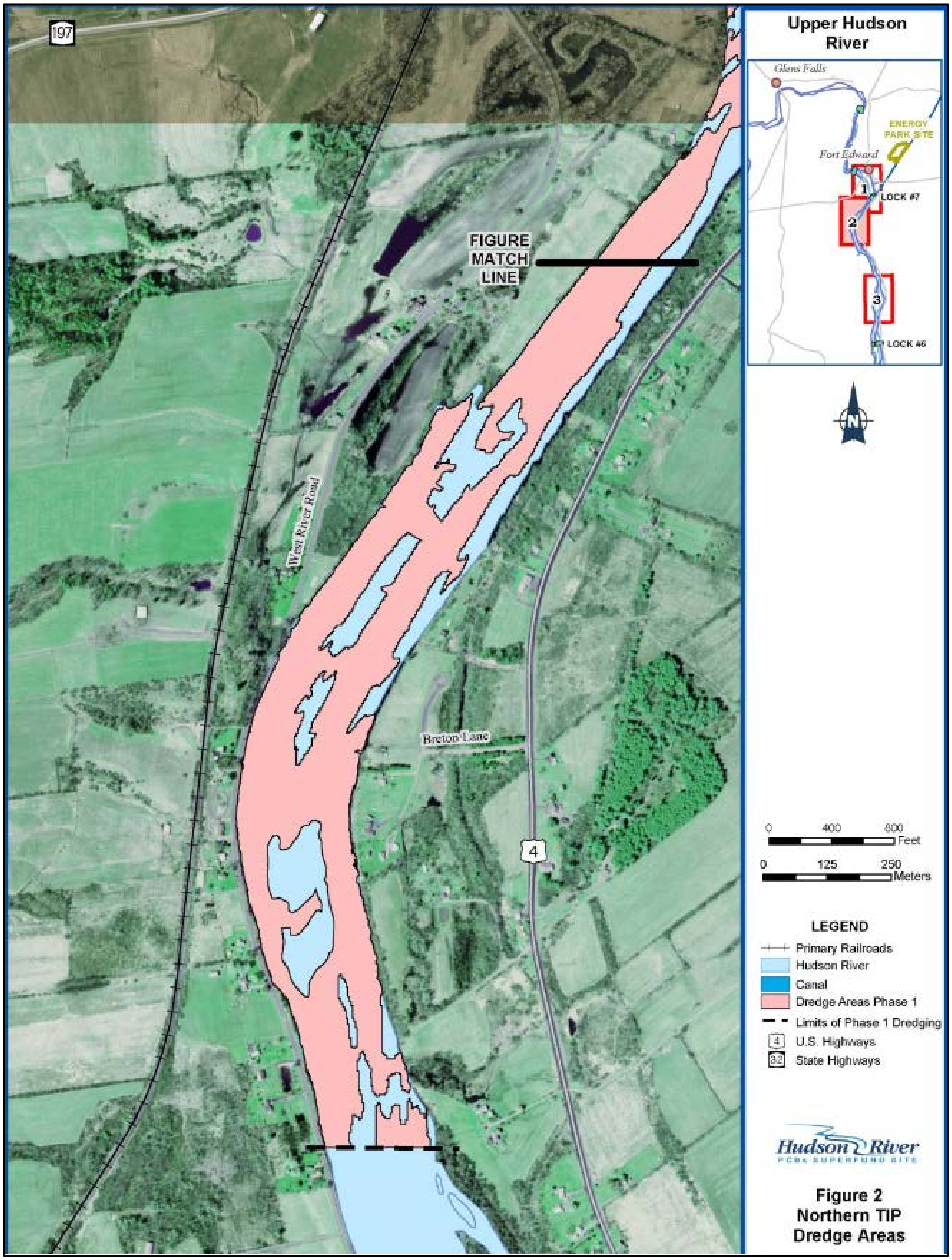

Figure 55: Phase 1 PCB Northern Dredging Areas (Thompson Island Pool-South)[85]

[85] https://www3.epa.gov/hudson/pdf/factsheet2005.pdf

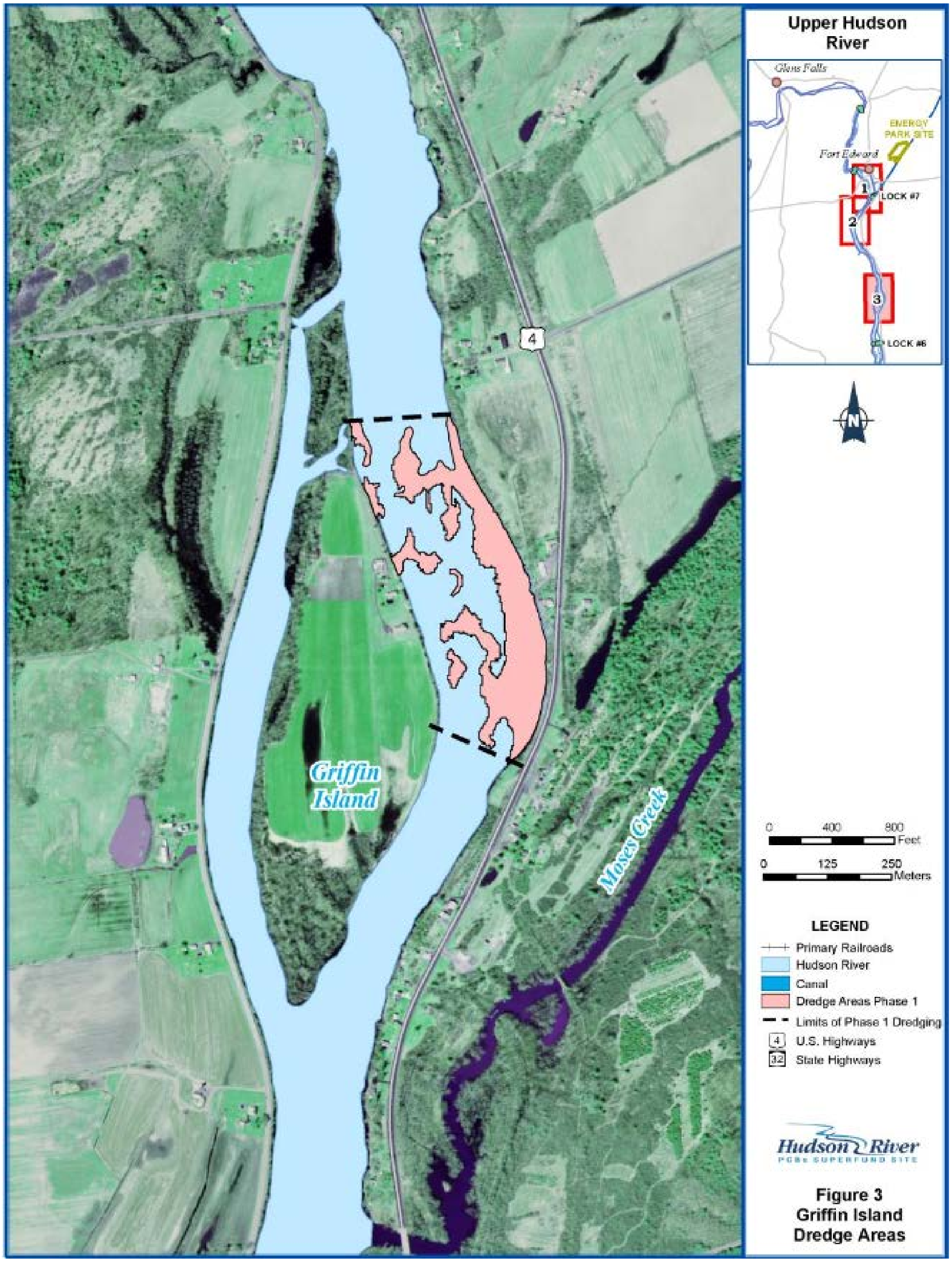

Figure 56: Phase 1 PCB Dredging Areas (Griffin Island)[86]

[86] https://www3.epa.gov/hudson/pdf/factsheet2005.pdf

Prior to the dredging operations, the levels of PCBs in fish in the Upper Hudson River far exceed those believed to impact health of people who consume fish based on risk-based levels established by credible toxicological methods. In addition, the concentrations of PCBs in fish and wildlife exceed levels believed to cause harm (Table 11 and Table 12).[87]

Table 11: PCB Levels in Upper Hudson River Fish Compared to Other Coastal Waters[88]

Location		Mean PCB Concentration (ppm) (Pre-Dredging)
Hudson River[89]	**Thompson Island Pool**	7–29
	Stillwater Reach	1.6–41
	Waterford Reach	3–19
	Below Troy Federal Dam	1.1–11
Great Lakes[90]		0.4–1.9
Delaware Bay[91]		0.4–0.7
Chesapeake Bay[92]		0.05–1.0

Table 12: Great Lakes Protocol Risk-Based PCB Advisory[93]

PCB Concentration in Edible Fish Tissue	Advisory
Less than 0.05 ppm	Unlimited consumption, no advisory
0.06–0.2 ppm	Restrict intake to one fish serving per week
0.21–1.0 ppm	Restrict intake to one fish serving per month
1.1–1.9 ppm	Restrict intake to one fish serving every two months
Greater than 2.0 ppm	Do not eat

The NYSDEC also rejected the findings of the EPA that the PCB cleanup had been satisfactory. NYSDEC's research and analysis indicate that there are still unacceptable levels of PCBs in river sediments and fish tissue.[94] In addition to PCB contamination, NYSDEC also concluded that a substantial number of Hudson River walleye, a popular gamefish, contained mercury concentrations that exceed the NY Department of Health's guidance values. Walleye also have a "do not eat" advisory due to high PCB concentrations.

Other Contaminants in Lower Hudson River Sediments

Industrial activity along the Lower Hudson River has resulted in the deposition of other contaminants in the sediment of the river as well, including: metals, organochlorine pesticides, petroleum compounds (PAHs), and chlorinated organics.[95]

The metal contaminants commonly found in the Hudson River notably include:

87 Baker et al. 2006.
88 Based on: Baker et al. 2006.
89 US EPA 2000b.
90 http://www.epa.gov/grtlakes/glindicators/fish/topfish/topfishb.html
91 Ashley et al. 2003.
92 Liebert et al. 2001.
93 Great Lakes Sport Fish Advisory Task Force 1993.
94 Hudson River Estuary Program 2018.
95 Holochuck 2005.

- Copper: In addition to its use in plumbing, electrical wiring, and circuit board manufacturing, copper is also used in anti-fouling marine paints and applied to the hulls of marine vessels.
- Cadmium: Cadmium is used in metal plating and coating for machinery, including transportation equipment, as well as in batteries and paint pigments.
- Lead: Lead was commonly used in pipes until banned in 1998. It was also used as a gasoline additive and in automotive and marine batteries as an electrode.
- Mercury: Mercury is released in the combustion of fossil fuels (especially coal) and garbage.

The organochlorine pesticide dichlorodiphenyltrichloroethane (DDT) as used extensively until banned in 1973. Its breakdown products – dichlorodiphenyldichloroethylene (DDE) and 1,1dichloro-2,2-bis(p-chlorophenyl) ethane (DDD) – are found in soil and sediment in the Hudson River.

Concentrations of contaminants found in sediment in the Hudson River are shown in Table 13. Concentrations of DDT in sediment are shown in Table 14. As with PCBs, the presence of these contaminants is relevant with respect to the baseline conditions of the river, as well as potentially for spill response operations that require dredging or substrate removal.

Table 13: Sample Ambient Contaminant Levels along Locations in Lower Hudson Valley[96]

Location	Maximum Concentrations[97] (in ppm – except for PCBs in ppb)[98]									
	Copper	Cadmium	Lead	Mercury	PCBs	Benzo(a) anthracene	Anthracene	Chrysene	PAHs	Benzene
Nyack Marina (Mile 28)	87.5	2.8	96	0.51	12	-	-	-	-	-
Shattemuc YC (Mile 32)	7.8	1.0	6.9	nd <0.04	43	-	-	-	-	-
Cortlandt YC (Mile 40)	15.6	0.4	2.48	0.52	-	-	0.39	-	1.67	-
Cornwall YC (Mile 57)	89.5	0.011	0.11	0.005	-	-	0.39	-	1.67	-
Chelsea Pump Sta. (Mile 65)	21.7	1.2	16.4	0.071	-	-	-	-	-	-
Hyde Park Marina (Mile 78)	86	0.4	0.78	nd <0.04	-	-	-	-	-	-
Norrie Point Marina (Mile 78)	86	0.4	0.78	nd <0.04	-	0.017	-	-	-	-
Anchorage Marina (Mile 91)	6.2	0.62	2.5	nd <0.004	-	-	-	-	-	-
Athens Ferry Slip (Mile 118)	120	2.52	212	1.74	1.25	2	-	2.39	-	2
Ravena-Coeymans YC (Mile 133)	46.8	1.11	45.6	-	4.96	-	-	-	-	-
National Gypsum (Mile 143)	46.8	1.11	45.6	nd (<0.25)	-	-	-	-	-	-

96 Holochuck 2005.
97 Different sampling programs have yielded differing results; Maximum values are presented (Holochuck 2005).
98 nd = not detected.

Table 14: DDT, DDE, DDD, and Dioxin Levels in Hudson River Sediment[99]				
Location	**Concentrations**			**Year**
	DDT, DDE, DDD[100] (ppm)	**Dioxins,[101] Furans**		
		ppm	**Total Dioxin/Furan TEQs[102]**	
River Mile 152.7 (Port of Albany)		nd (0.99)	9	1996
River Mile 120.2 (Athens)	0.004	-	-	1998
River Mile 88.6 (Esopus)	0.003	nd (0.23)	4.8	1998
River Mile 1.7 (New York Harbor)	0.020	9.54	33	1998

Recreational and Commercial Fishing

The Hudson River estuary's range of habitats and salinities supports a wide vary of fishes. The 2017 Great Hudson River Fish Count netted 1,325 samples of 48 species of fish, which gives a general sense of the distribution of species.[103] Species specifically found in the HROSRA study area are in Table 15.

Table 15: Great Hudson River Fish Count (August 2017)													
Fish	**Number of Specimens by Hudson River Mile**												
	18	**25**	**28**	**35**	**55**	**59**	**61**	**76**	**84**	**92**	**123**	**133**	**Total**
American Eel	0	0	1	6	0	0	0	0	0	0	0	0	**7**
Alewife	0	0	0	0	7	9	0	0	0	0	0	0	**16**
Blueback Herring	0	0	0	29	16	7	0	0	0	0	0	0	**52**
Herring Species	0	0	0	16	0	0	0	0	0	20	20	31	**87**
Golden Shiner	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Spotfin Shiner	0	0	0	0	0	0	0	0	0	0	5	0	**5**
Spottail Shiner	0	0	0	0	45	6	1	0	0	10	23	10	**95**
Brown Bullhead	0	0	0	11	0	0	0	0	0	0	0	0	**11**
Oyster Toadfish	0	2	0	0	0	0	0	0	0	0	0	0	**2**
Banded Killifish	0	0	2	5	0	0	0	0	0	0	0	2	**9**
Mummichog	0	3	0	0	0	0	0	0	0	0	0	0	**3**
Atlantic Silverside	0	16	2	9	0	0	0	0	0	0	0	0	**27**
Northern Pipefish	0	0	8	1	0	0	0	0	0	0	0	0	**9**
White Perch	1	14	13	50	10	12	0	10	0	2	3	5	**120**
Striped Bass	4	47	5	335	8	6	6	29	0	15	10	0	**465**
Redbreast Sunfish	0	0	0	1	0	0	0	0	5	0	0	0	**6**
Pumpkinseed	0	0	0	0	0	0	0	1	0	0	0	3	**4**

99 Holochuck 2005.
100 Dichlorodiphenyltrichloroethane (DDT); dichlorodiphenyldichloroethylene (DDE); 1,1dichloro-2,2-bis(p-chlorophenyl) ethane (DDD).
101 Polychlorinated dibenzo dioxins (PCDSs); polychlorinated bibenzo furans (PCDFs).
102 Toxic equivalency values. (TEQ is calculated by multiplying the actual grams weight of each dioxin and dioxin-like compound by its corresponding toxic equivalency factor, TEF (e.g., 10 grams X 0.1 TEF = 1 gram TEQ) and then summing the results. The number that results from this calculation is referred to as grams TEQ. 30g of compound C, with a TEF of 0.2.)
103 http://www.dec.ny.gov/docs/remediation_hudson_pdf/hrepfc17rev.pdf

Fish	Number of Specimens by Hudson River Mile												
	18	25	28	35	55	59	61	76	84	92	123	133	Total
Bluegill	0	0	0	0	0	1	0	0	0	0	0	0	**1**
Sunfish Species	0	0	0	8	0	0	0	0	0	0	0	0	**8**
Smallmouth Bass	0	0	0	0	0	0	0	0	3	0	0	0	**3**
Largemouth Bass	0	0	1	1	0	0	0	0	0	0	0	0	**2**
Tessellated Darter	0	0	0	0	0	0	0	1	0	0	0	4	**5**
Bluefish	0	11	0	12	0	0	0	0	0	0	0	0	**23**
Hogchoker	0	0	0	0	0	0	0	0	0	1	0	0	**1**
Total	**5**	**93**	**32**	**484**	**86**	**41**	**7**	**41**	**8**	**48**	**61**	**56**	**962**

Table 15: Great Hudson River Fish Count (August 2017)

The Hudson has had a rich history of commercial fishing in the past, particularly of sturgeon, shad, and striped bass.[104] However, the PCB contamination, in addition to over-fishing and other problems have effectively closed those fisheries. There are still recreational, and subsistence fishing activities in the Hudson River, but there are health issues associated with the consumption of fish caught in the river. Current regulations for the tidal Hudson River are shown in Table 16. In addition to finfish, there is also fishing for blue crabs. For blue crabs, there is a daily limit of 50 crabs per person.

Table 16: Fishing Regulations for Tidal Hudson River

Species	Location	Open Season	Minimum Length	Daily Limit
American Eel	Hudson River from NYC Battery to Troy Dam; all tributaries upstream to first barrier impassable by fish	All year	Eels (9-14 inches) for bait only; no processing for food	25
Black Bass (Largemouth and Smallmouth)[105]	Hudson River from Troy Dam downstream and all tributaries to first barrier impassable by fish	3rd Saturday June–30 November	15 inches minimum	5
Striped Bass	Hudson River and tributaries north of George Washington Bridge	1 April–30 November	One fish 18–28 inches total or one fish >40 inches	1
American Shad	Fishing for or possessing American Shad is prohibited in the Hudson River			
Hickory Shad	Hudson River and tributaries north of Tappan Zee	1 August–30 November	Any size	5
Anadromous River Herring[106]	Hudson River Waterford Lock south to George Washington Bridge	15 March–15 June	Any size	10/angler; 50/boat[107]

Despite concerns about PCB, mercury, and other contamination, there is still a significant amount of subsistence fishing in the Hudson River. In a survey conducted by Scenic Hudson and the Sierra Club,[108] 32% of anglers were found to consume fish in exceedance of the amounts and portion size recommended in New York State Department of Health Guidelines (Table 17). The 2016 survey found that Latino

[104] http://www.dec.ny.gov/lands/74069.html [These are just the fish that were caught and released, not the total number of fish in the river, which would be a much higher number.]
[105] It is illegal to fish (including catch & release) for largemouth bass and smallmouth bass during closed season.
[106] Includes: alewife and blueback herring; only angling or personal nets allowed.
[107] Whichever is lower.
[108] Garcia and Stone 2016.

anglers reported the highest rate of fish consumption (64%), followed by African-Americans (41%) (Figure 57). The socioeconomic groups most affected were those with an annual income between $25,000 and $50,000.

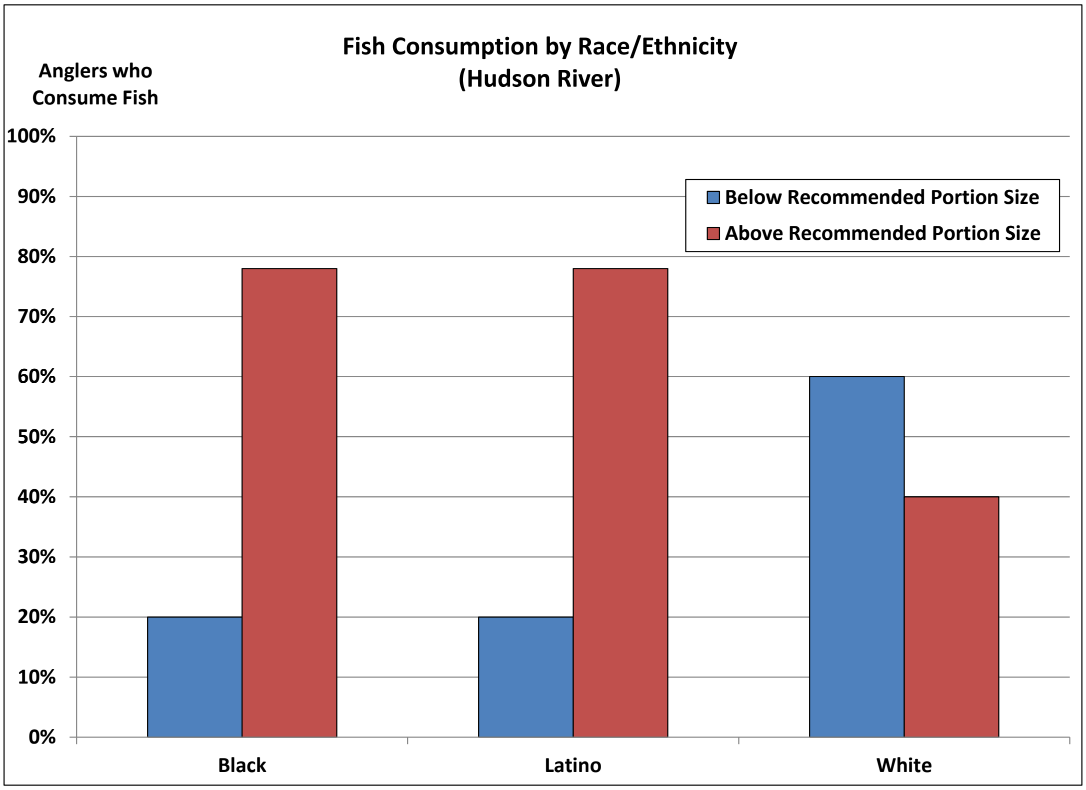

Figure 57: Hudson River Fish Consumption by Race/Ethnicity[109]

Table 17: Hudson River Fish Consumption Advice			
River Section	**Type of Fish**	**NYS Department of Health Advice**	
		Men >15 Women > 50	**Women <50 Children <15**
***Upper Hudson* South Glens Falls to Troy Dam**	Any type	Do not eat	Do not eat
***Mid-Hudson* Troy Dam to Catskill**	Alewife, blueback herring, rock bass, yellow perch	Up to 1 meal/month	Do not eat
	All other fish (including striped bass, walleye)	Do not eat	Do not eat
***Lower Hudson* Catskill to NYC Battery**	Walleye, white catfish, channel catfish, American eel, gizzard shad	Do not eat	Do not eat
	Striped bass, smallmouth bass, largemouth bass, bluefish, brown bullhead, white perch, carp, rainbow smelt, goldfish, Atlantic needlefish	Up to 1 meal/month	Do not eat
	Blue crab (without tomalley)	Up to 6 crabs/week	Do not eat
	All other species	Up to 4 meals/month	Do not eat

[109] Based on: Garcia and Stone 2016.

Subsistence fishers, especially those from economically-disadvantaged populations[110] would be at particular risk in the aftermath of an oil spill on the Hudson River. There would clearly be additional advisories issued by state and federal authorities, but given that even with the existing advisories on limiting or prohibiting the consumption of fish from the Hudson River, there may still be consumption of affected fish nevertheless. However, fish that are oil-tainted generally have a characteristic odor that is clearly recognizable at concentrations far lower than those that would have health effects.[111]

Recreational Boating

The high value on boating for recreational purposes on the Hudson River is evident by the large number of marinas and boat and yacht clubs along the river. There is at least on recreational boating-related facility in each of at least 36 communities (Table 9). There are a large number of regattas and other events that take place in addition to informal boating activities.

Table 18: 2016 Vessel Registrations by County and Length[112]

County	Total	Vessel Class					
		Uncoded	Class A <16 ft	Class 1 16-25 ft	Class 2 26-30 ft	Class 3 40-64 ft	Class 4 ≥ 65 ft
Albany	**8,879**	23	3,457	4,776	574	35	14
Bronx	**2,292**	5	856	936	434	44	17
Columbia	**2,780**	3	1,169	1,486	107	15	0
Dutchess	**6,260**	10	2,807	2,864	541	34	4
Greene	**2,260**	5	868	1,199	176	8	4
Orange	**8,133**	22	3,927	3,603	524	46	11
Putnam	**2,904**	7	1,122	1,529	224	20	2
Rensselaer	**5,709**	3	2,447	2,953	282	23	1
Rockland	**3,904**	10	1,882	1,384	556	55	17
Ulster	**5,103**	7	2,243	2,411	407	32	3
Westchester	**11,060**	16	3,525	4,964	2,153	350	52
Total	**59,284**	**111**	**24,303**	**28,105**	**5,978**	**662**	**125**

According to the New York State Office of Parks, Recreation, and Historic Preservation (ORPHP), the vessel registrations of the counties along the Hudson River are as shown in Table 18. Note that not all of the boats would necessarily be exclusively used in the Hudson River. There are lakes and other waterways in some of the counties that might also be locations for recreational boating.[113] Oil spills would affect boating by preventing or limiting the use of the river during spill response operations. Boats and marina structures could also be oiled.

[110] See Table 18 through Table 20 in Appendix B.
[111] Yender at al. 2002; Reilly et al. 2001; Yender 2003.
[112] NYS ORPHP 2017.
[113] For example, Westchester County has shorelines along the Long Island Sound in addition to the Hudson River.

In addition to boating, there are at least 81 locations within the study are from which kayaks, canoes, and other personal paddle craft are regularly launched on the Hudson River Greenway Trail,[114] which is a National Water Trail.[115] [See Appendix C.]

Swimming Beaches in Hudson River

Swimming occurs in the Hudson River at a number of private beaches and public parks with beaches at least seven locations (Table 9). There are also several river swimming events, most notably the annual 8-Bridges Hudson River Swim each June.[116] The swimmers (and accompanying kayakers and other boats) begin the swim at the Rip Van Winkle Bridge in Catskill, New York, and continue to the Verrazano Narrows Bridge in the New York Harbor. An oil spill and the response operations associated with a spill would clearly have an impact of these activities and potentially present health risks to swimmers.

Waterfront Redevelopment, Preservation, and Recreational Facilities

There has been significant effort in the last 25 years to redevelop the Hudson River waterfront after about 150 years of industrial use towards more usage for residential, recreational, and land preservation purposes. This includes a significant effort by Hudson River Valley Greenway,[117] Historic River Towns of Westchester,[118] Scenic Hudson, and others.

A prime example is the Hudson River Trail or Westchester RiverWalk that spans 51.5 miles of Westchester County shoreline through 14 municipalities (Figure 58).

Scenic Hudson has been instrumental in developing, creating, and enhancing public parks, preserves, and historic sites throughout the Hudson River Valley including those shown in Table 19. Many of these parks and facilities are enjoyed not only by residents but also by tourists that come north from New York City and other areas in the region.

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[114] The Hudson River Greenway Trail extends 265 miles from northern Saratoga County in the Adirondack Park and northern Washington County at the head of Lake Champlain, to Battery Park in Manhattan.

[115] http://hudsonrivergreenwaywatertrail.org/

[116] http://www.8bridges.org/

[117] The Hudson River Valley Greenway is an innovative state agency created to facilitate the development of a voluntary regional strategy for preserving scenic, natural, historic, cultural and recreational resources while encouraging compatible economic development and maintaining the tradition of home rule for land use decision making (http://www.hudsongreenway.ny.gov).

[118] Westchester County Department of Planning 1998.

Figure 58: Westchester RiverWalk Map[119]

119 https://planning.westchestergov.com/images/stories/RiverWalk/riverwalkmap11x17.pdf

Table 19: Scenic Hudson Parks along the Hudson River

Park	Location (County)	Available Park Activities						
		Hiking Walking	Bicycling	Winter Sports	Wildlife Viewing	Fishing	Boating	Picnics
Bob Shepard Highland Landing	Highland Ulster	•				•	•	•
Black Creek Preserve	Esopus Ulster	•		•	•	•		
Clausland Mountain Park	Orangeburg Rockland	•		•	•			
Draytown Grant Park	Rhinebeck Dutchess	•		•	•			•
Emeline Park	Haverstraw Rockland	•				•	•	•
Esopus Meadows Preserve	Esopus Ulster	•		•	•	•	•	•
Esplanade Park	Yonkers Westchester	•						•
Estie & Hellie Stowell Trailhead	Cornwall Orange	•			•			•
Falling Waters Preserve	Galsco Ulster	•		•	•	•		
Fishkill Ridge	Beacon Dutchess	•	•	•	•			
Foundry Dock Park	Cold Spring Putnam	•			•		•	•
Four-Mile Point Preserve	Coxsackie Greene	•		•	•	•	•	
Franny Reese State Park	Highland Ulster	•	•	•	•			•
Habirshaw Park	Yonkers Westchester	•			•	•		
Harrier Hill Park	Stockport Columbia	•		•	•			•
High Banks Preserve	Ulster Park Ulster	•	•	•	•			•
Hudson Highlands Gateway Park	Cortlandt Westchester	•		•	•	•		•
Hudson Highlands Nature Museum	Cornwall Orange	•		•	•			•
Hyde Park Trail River Overlook	Hyde Park Dutchess	•		•	•			
Illinois Mountain	Lloyd Ulster	•	•	•	•			•
Kathryn W. Davis RiverWalk Center	Sleepy Hollow Westchester	•	•		•	•		
Lighthouse Park	Esopus Ulster	•			•	•	•	•
Madam Brett Park	Beacon Dutchess	•		•	•	•		
Manitou Point Preserve	Garrison Putnam	•			•			•

Table 19: Scenic Hudson Parks along the Hudson River								
Park	**Location (County)**	**Available Park Activities**						
		Hiking Walking	**Bicycling**	**Winter Sports**	**Wildlife Viewing**	**Fishing**	**Boating**	**Picnics**
Mount Beacon Park	Beacon Dutchess	•		•	•			
Olana Viewshed	Hudson Columbia	•		•	•			•
Peach Hill Park	Poughkeepsie Columbia	•			•			•
Poet's Walk Park	Red Hook Dutchess	•		•	•			
RamsHorn-Livingston Sanct.	Catskill Greene	•		•	•		•	•
Roosevelt Farm Lane Trail	Hyde Park Dutchess	•	•	•	•			
Scenic Hudson Mine Dock Park	Highlands Orange	•			•	•	•	•
Scenic Hudson Park Irvington	Irvington Westchester	•			•		•	
Scenic Hudson Park Peekskill	Peekskill Westchester	•			•	•	•	•
Scenic Hudson Park Tarrytown	Tarrytown Westchester	•	•			•		•
Scenic Hudson Long Dock Park	Beacon Dutchess	•	•	•		•	•	•
Scenic Hudson Long View Park	New Baltimore Greene	•		•	•			•
Shaupeneak Ridge	Esopus Ulster	•	•	•	•	•	•	•
Sleightsburgh Park	Esopus Ulster	•				•	•	
Walkway Loop Trail	Poughkeepsie Dutchess[120]	•	•					
Walkway Over Hudson	Poughkeepsie Dutchess[121]	•	•					
West Point Foundry Preserve	Cold Spring Putnam	•			•			•
Van der Donck Park Larkin Plaza	Yonkers Westchester	•						•

In addition, waterfront "revitalization" has included redevelopment of a number of previous industrial sites along the Hudson River as residential areas, often with accompanying community services and facilities, and restaurants to attract tourists, including (Figure 59 and Figure 60):

- Sleepy Hollow (General Motors Site Redevelopment – Edge-on-Hudson)
- Yonkers (Alexander Street and Urban Renewal Area)

[120] Trail links Walkway over the Hudson State Historic Park and Mid-Hudson Bridge in Poughkeepsie and Lloyd (Ulster County).
[121] Trail goes across bridge on river between Poughkeepsie (Dutchess County) and Highland (Ulster County).

- Haverstraw (Harbors-at-Haverstraw)
- Newburgh Waterfront
- Kingston Landing
- Ossining (Harbor Square)
- Greystone/Yonkers (River Tides)
- Nyack (TZ Vista)

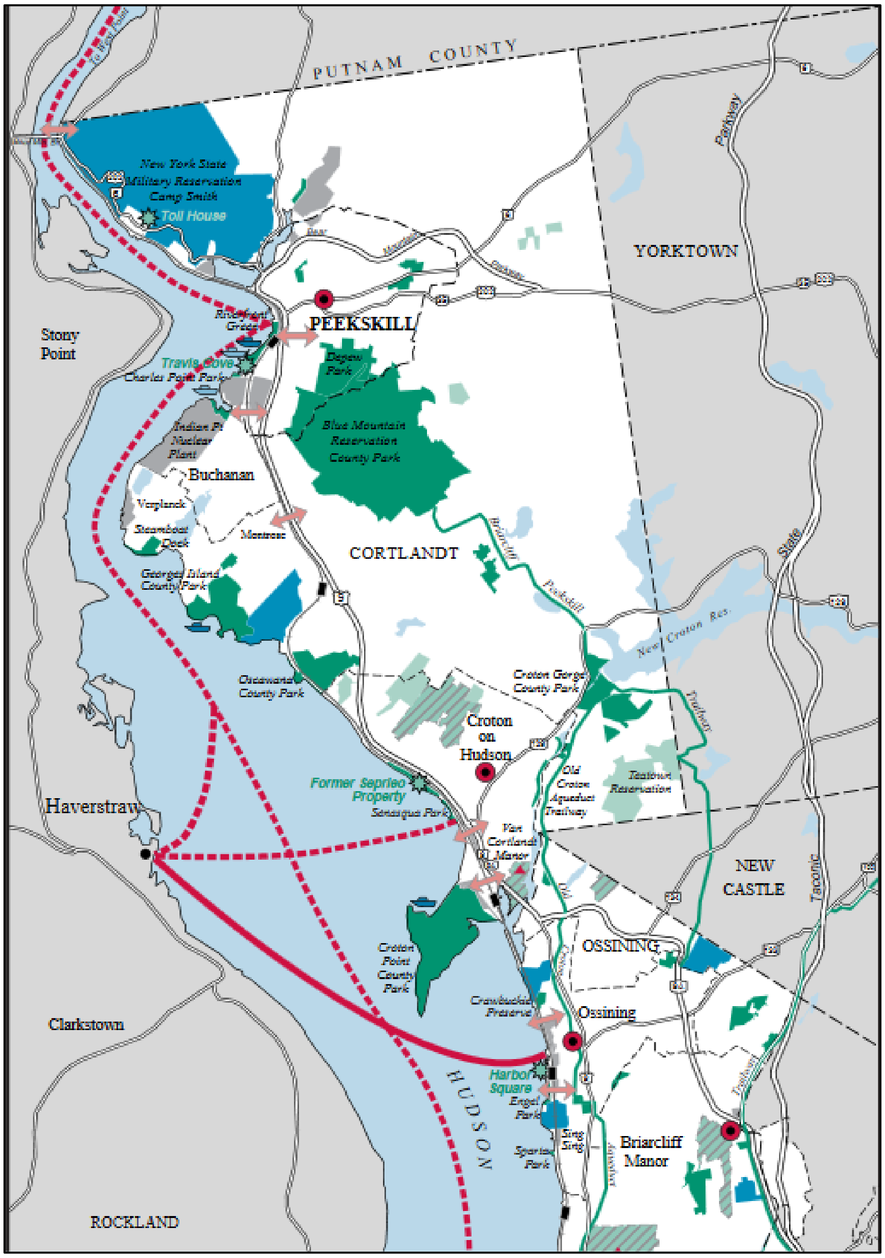

Figure 59: Northern Westchester Waterfront Revitalization Map[122]

[122] Westchester County Department of Planning 1998

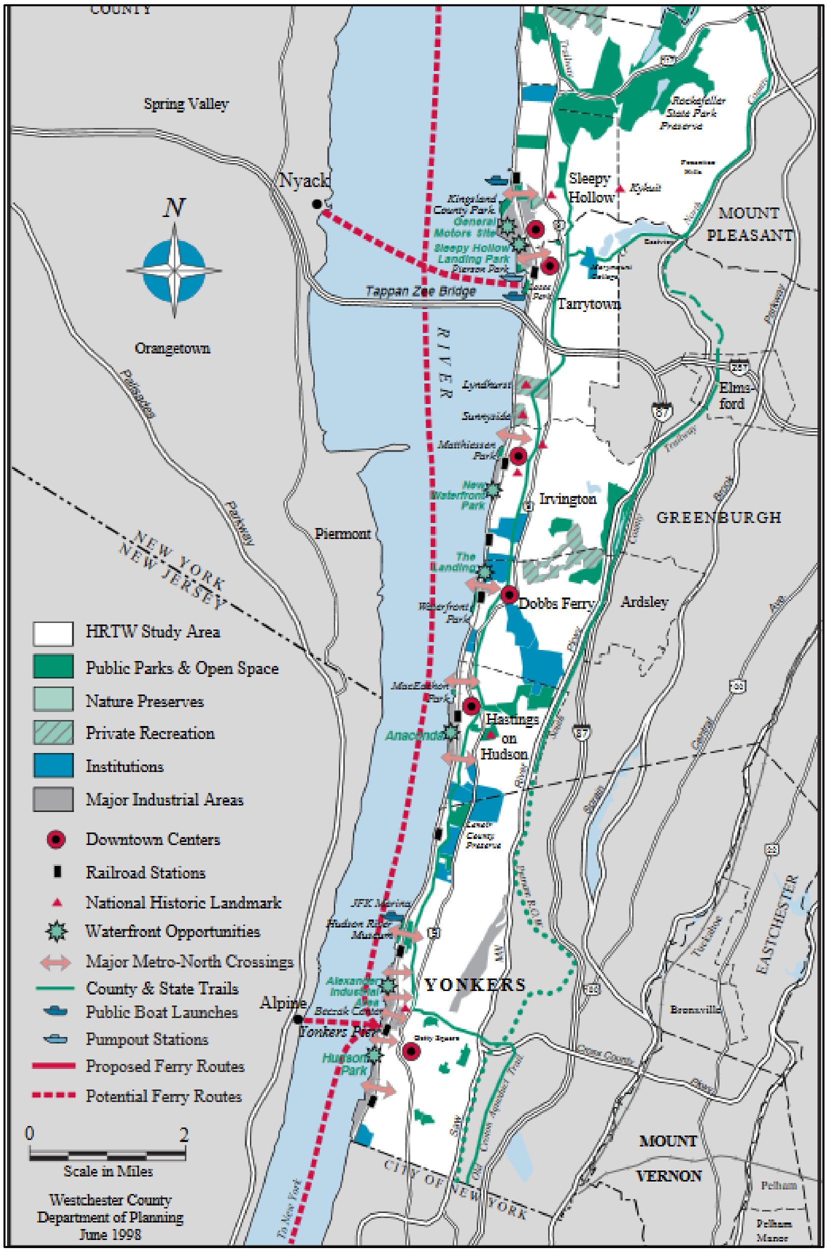

Figure 60: Southern Westchester Waterfront Revitalization Map[123]

Some of this waterfront revitalization and redevelopment has included the cleaning up of previously contaminated industrial sites as part of "brownfields" and other assistance programs in the state. Part of this assistance has come from the New York State Environmental Protection Fund (EPF)[124]. Through the Local Waterfront Revitalization Program (LWRP), the EPF has invested more than $186 million to help more than 330 communities revitalize their waterfronts and downtowns, expand public access, improve natural resources, and boost tourism and recreational opportunities. For waterfront communities across the state, the LWRP—administered by New York's Department of State (NYSDOS)—has become a

[123] Westchester County Department of Planning 1998.
[124] NYSDEC 2013.

reliable, dedicated source of funding for community and waterfront revitalization. Matched by municipal partners, more than $372 million has been invested for community revitalization in the 20 years of the program.

This development has increased the real property value of riverfront areas and reinvented the Hudson River as a place of tourism and commerce rather than an area of industry. A major oil spill could have a significant effect on these newly-developed waterfronts.

Hudson River as a Port[125]

The Hudson River north of New York City up to the Port of Albany (as in the HROSRA study area) acts as an important port area. Vessel traffic on the Hudson River has been transporting an average of nearly 17 million tons of commodities up and down the river for decades (Figure 61). Vessel trips (or transits) up and down the river for the years 1994 through 2015 are shown in Figure 62 for all commodities.

Currently, there are an estimated 16,000 vessel trips up and down the river, 91% of which are shallow-draft vessels (14 feet or less). Vessels on New York waterways transport $264 million of domestic freight daily.[126] A major oil spill and its ensuing response operations could have a significant effect on port activities. During response operations in a port area, it is often necessary for the federal on-scene coordinator (FOSC), often the Captain of the Port (COTP), to block or restrict vessel traffic temporarily to prevent interference with response operations.

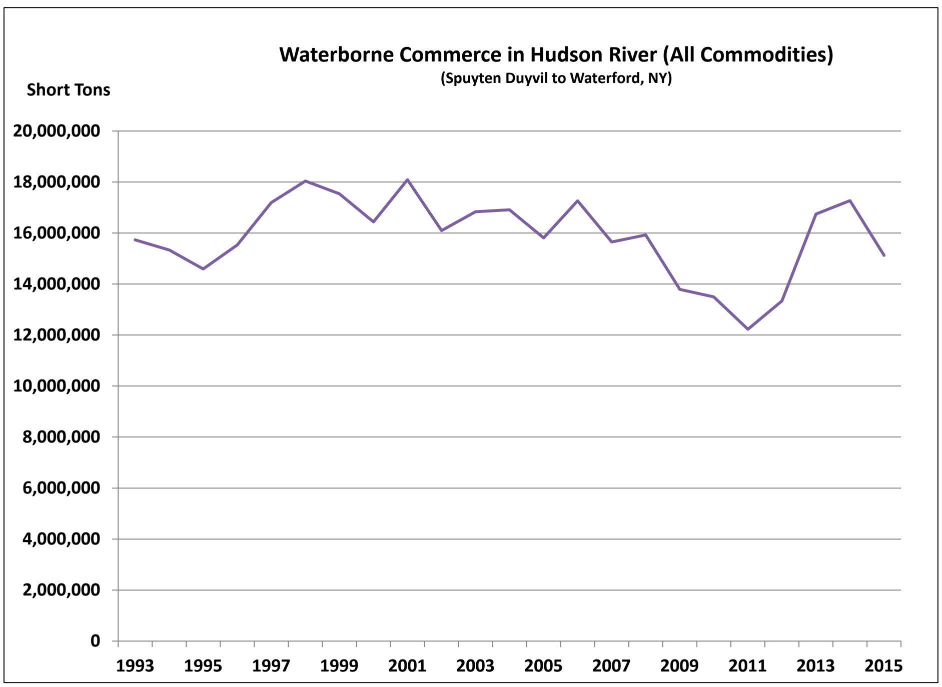

Figure 61: Total Annual Waterborne Commerce on Hudson River

[125] A more comprehensive analysis of Hudson River port activities, including vessel traffic appears in HROSRA Volume 3 as part of the oil spill probability analysis.
[126] Port of Albany 2016.

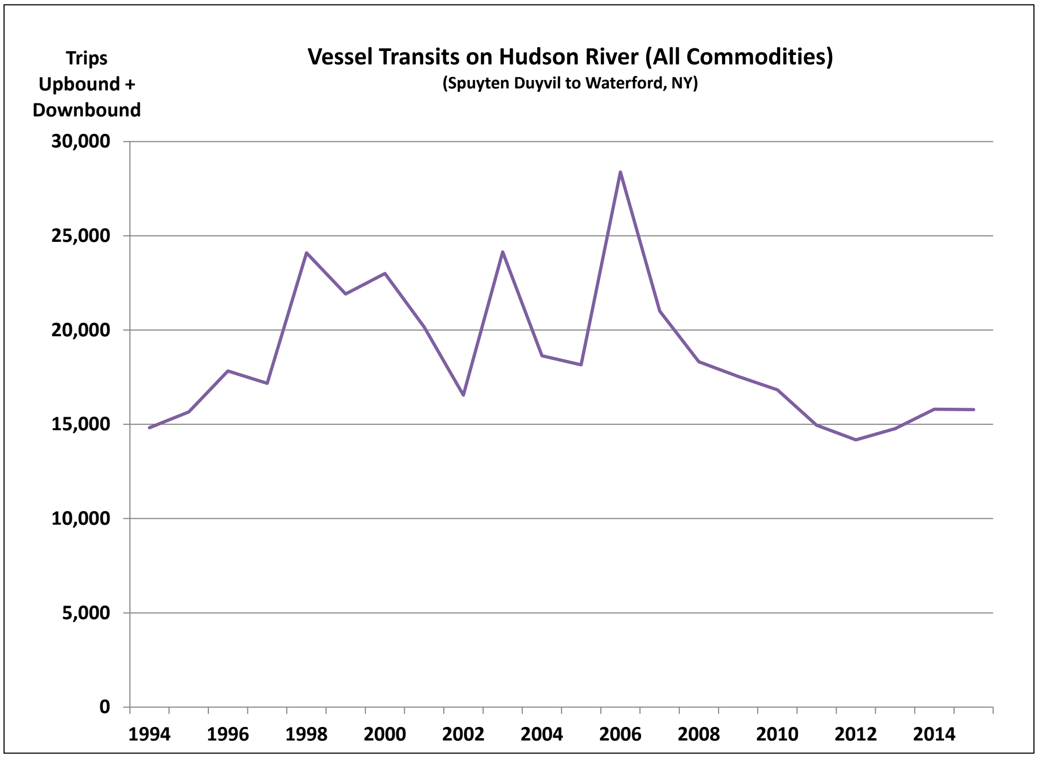

Figure 62: Annual Vessel Transits on Hudson River (All Commodities)

Delaying vessel traffic either north (e.g., at Port of Albany or Port of Coeymans) or south of the spill location (e.g., the New York Harbor or Yonkers Anchorage) would have a rippling effect on port operations up and down the river and beyond. The Hudson River is part of America's Marine Highway System"[127] as "M-87" (Figure 63) is a major connector between the Great Lakes (M-90) and the Atlantic (M-95). In addition, the Port of Albany also connects to three railroads and to truck-shipping systems. Because of the geographic layout of the Hudson River and, in particular, the locations of the northern ports, there are no viable alternative routes for vessel traffic. Temporary use of rail and truck transport may be employed in certain cases.

Delays in port operations could potentially cause economic impacts to industry and could have effects on various levels of the regional economy. For example, these impacts could include the cost of temporarily delaying northbound vessels in or outside of the New York Harbor and south-bound vessels at the Ports of Albany and Coeymans. Daily costs for the operation of deep-draft vessels, of which there are about four per day transiting the Hudson River, range from about $16,000 to $58,000 at sea and $12,000 to $44,000 in port for each vessel, or about $48,000 to $232,000 for each day of the delay for all vessels. For the estimated 40 daily shallow-draft vessels that transit the Hudson River, the costs are approximately $5,000 per day for each vessel, or $200,000 per day of the delay for all the vessels. [128]

A delay of even day or two may also result in effects to towing and tugboat services, passenger ferry transport, marina operations, and marine cargo operations, which may affect industry and commercial

[127] https://www.marad.dot.gov/ships-and-shipping/dot-maritime-administration-americas-marine-highway-program/

[128] Based on: US Army Corps of Engineers 2000a, 2000b.

costs, as well workers in the region. The Port of Albany, for one, brings $2.2 million a day to the state and regional economy and supports nearly 1,400 jobs locally and 4,500 jobs statewide.[129] Commuters who rely on the ferry system to get across the river (e.g., Haverstraw-Ossining) would need to find alternate transportation.

In addition, even temporary delays in the transport of home heating oil and other fuels, as well as other commodities, could conceivably affect local and regional residents and businesses depending on the time of year.

Figure 63: Marine Highway Routes[130]

[129] https://en.wikipedia.org/wiki/Port_of_Albany%E2%80%93Rensselaer#cite_note-Thriving-24

[130] Source: Maritime Administration (MARAD)

Summary

This volume described the risk assessment process and provided an overview of the unique conditions and resources of the Hudson River.

The Hudson River Oil Spill Risk Assessment (HROSRA) provides a comprehensive analysis of the risk of oil spills in the Hudson River study area (between Spuyten Duyvil and the Federal Lock and Dam at Troy). As a risk assessment, the analysis includes a quantification and qualification of the probability or frequency of spills and the potential consequences of spills. The study also includes an assessment of the ways in which spills can be mitigated through prevention (addressing spill probability or frequency) and response (addressing spill consequences or impacts).

A selection of 72 hypothetical oil scenarios was simulated with SIMAP. These scenarios involve varying combinations of 10 locations, five oil types, three seasons, two tidal conditions, and potential ignition to create fire and explosion. Each of the hypothetical spill scenarios in Table 20 was modeled under three seasons (spring with high flow, summer with low flow, and winter with medium flow and ice).

Each of the seasons was also modeled under high- and low-tide conditions at the onset of the spill. Some of the spills were also simulated assuming ignition to cause fire and/or explosions to occur, in addition to modeling of the same scenario without ignition. The potential for environmental and socioeconomic effects from hypothetical spills is discussed.

Table 20: HROSRA Spill Scenario Summary

Location	Spill Source	Volume (bbl)	Oil Type	Additional Fire/Explosion
Proposed Kingston Anchorage	ATB impact accident	150,000	Home heating oil	No
Proposed Kingston Anchorage	ATB impact accident	150,000	Diluted bitumen	No
Newburgh Waterfront	Crude oil train accident	11,000	Bakken crude oil	Yes
Port of Albany	Tanker loading accident	155,000	Bakken crude oil	Yes
Iona Island	Crude oil train accident	11,000	Bakken crude oil	Yes
Rondout Creek	ATB collision	75,421	Bakken crude oil	Yes
Rondout Creek	Cargo vessel collision	14,000	Heavy fuel oil	No
Bear Mountain Bridge	Tanker collision	2,500	Home heating oil	No
Coxsackie	Tanker impact accident	25,000	Home heating oil	No
Tappan Zee	Tanker allision with bridge	2,500	Home heating oil	No
Tappan Zee	Tanker allision with bridge	50	Heavy fuel oil	No
Yonkers Anchorage	Tanker impact accident	155,000	Gasoline	Yes

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Appendix A: Ice Definitions

Ice forms in freshwater at 33°F to 34°F, and in salt water at 29°F. In an estuary like the Hudson River, the formation of ice would tend to occur at some point between these temperatures. [Note that these are water temperatures and not ambient air temperatures, which may be slightly different.]

Ice is classified by formation in the following ways:[131]

> **Brash ice:** Conglomerates of small ice cakes and chunks that has broken off from other ice formations. These conglomerations coalesce and refreeze into irregularly-shaped masses, one to six feet in diameter usually with sharp projections. Brash ice can extend all the way to the bottom of an ice-congested waterway (Figure 64).

Figure 64: Brash Ice

> **Drift ice:** Any unattached ice formation or any areas of ice other than fast ice (Figure 65).

[131] Source: US Coast Guard Homeport New York Sector (http://homeport.uscg.mil/newyork)

Figure 65: Drift Ice

Fast ice: Immobilized ice formations. Ice is so firmly frozen into place along the shore or held by islands that winds and water currents cannot dislodge the formation (Figure 66).

Figure 66: Fast Ice

Floe ice: Detached segments of floating ice sheets (Figure 67). There are four recognized categories of floe measurement:

- Cake floe (0 to 66 feet across)
- Small floe (66 to 328 feet across)
- Medium floe (328 to 1,640 feet across)

- Big floe (1,640 to 6,652 feet across)

Figure 67: Floe Ice

Frazil ice: Fine spicules or ice crystals that float freely and individually in the water (Figure 68).

Figure 68: Frazil Ice

Grease ice: Water surface completely covered with frazil ice but the ice crystals have not yet begun to freeze together. The surface has a greasy, matte appearance and may look like an oil slick.

Figure 69: Grease Ice

Hummocked ice: Pressure-formed piles of ice usually jagged in appearance (Figure 70).

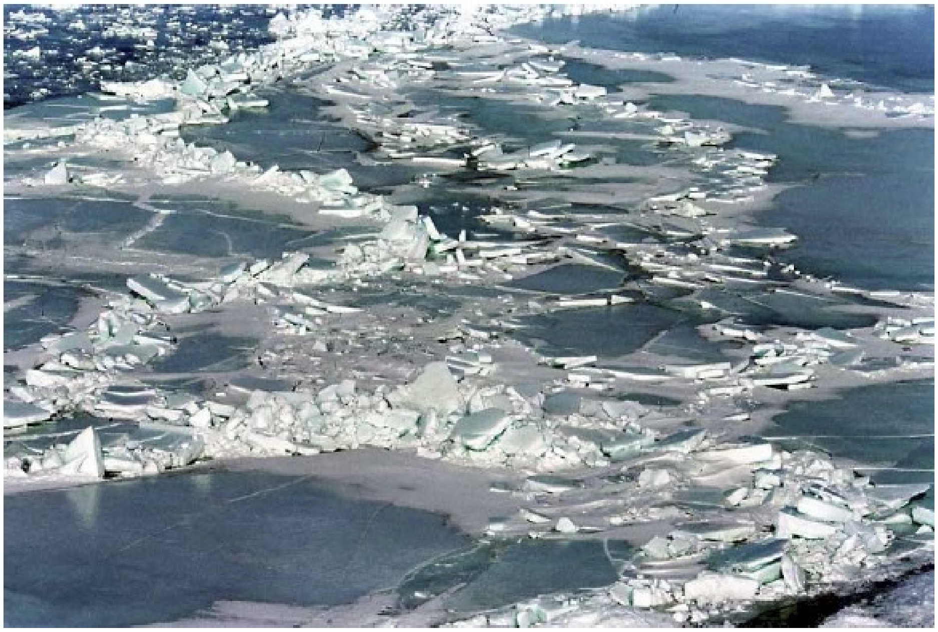

Figure 70: Hummocked Ice

Ice edge: The boundary, at any given time, of the open sea and ice of any kind, whether drifting or fast (Figure 71).

Figure 71: Ice Edge

Plate ice: Flat ice with approximately uniform thickness without ridges or windrows (Figure 72).

Figure 72: Plate Ice

Pancake ice: Predominantly circular pieces of ice. Pieces are one to eight feet across with raised rims resulting from the pieces striking one another (Figure 73)

Figure 73: Pancake Ice

Pressure ridge: A line or wall of broken ice forced upward and downward by pressure. This is usually formed when two floes collide with each other (Figure 74).

Figure 74: Pressure Ridge

Rafted ice: A type of ice formed by one flow overriding another; some parts of the overlap will trap water that may freeze and cement the two floes together, while other parts will trap air and take on a characteristic white appearance (Figure 75).


Figure 75: Rafted Ice

Appendix B: Hudson River Communities Data

The Hudson River study area includes a large number of communities in two states, New York and New Jersey, along both the western and eastern banks of the river as summarized in Table 21 (from south to north) for New Jersey and in Table 22 and Table 23 for New York. One county in New Jersey–Bergen on the western bank–and 11 counties in New York–Bronx, Westchester, Putnam, Dutchess, Columbia, and Rensselaer on the eastern bank, and Rockland, Orange, Ulster, Greene, and Albany counties on the western bank–are included in the study area. Population and population characteristics (income, poverty levels, and race/ethnicity) have been included as a rough measure of the degree to which spill impacts might affect vulnerable populations as a consideration of environmental justice.

Table 21: Hudson River Study Area West Bank Communities in New Jersey[132]

Town/Village (County)	Population (Est. 2016)	Median per Capita Income (% Poverty)[133]	% Non-White Population (% Latino)[134]	Length River Shoreline	River-Based Economic and Cultural Features[135]
Englewood Cliffs (Bergen)	5,406	$53,260 (16.1%)	43.65% (5.98%)	2.9 miles	Palisades Park Englewood Boat Basin
Alpine (Bergen)	1,869	$107,604 (3.4%)	31.86% (4.81%)	6.5 miles	Alpine Picnic Area Alpine Boat Basin Kearney House Historic Site

Table 22: Hudson River Study Area East Bank Communities in New York[136]

Town/Village (County)	Population	Median per Capita Income (% Poverty)	% Non-White Population (% Latino)	Length River Shoreline	River-Based Economic and Cultural Features
Riverdale (Bronx)	47,850	$40,198 (n/a)	21.26% (13.38%)	2.6 miles	Riverdale Park Riverdale Yacht Club Commuter rail station
Yonkers (Westchester)	200,807	$22,793 (15.5%)	44.2% (34.7%)	4.3 miles	Westchester Co. Wastewater Domino Sugar Riverfront restaurants Riverfront homes Yonkers Paddling & Rowing Beczak Environmental Center Commuter/Amtrak rail station
Hastings-on-Hudson (Westchester)	7,969	$48,914 (3.5%)	10.21% (4.5%)	2.1 miles	Tennis Club of Hastings MacEachron Park Riverfront restaurant Tower Ridge Yacht Club Riverfront homes Commuter rail station
Dobbs Ferry (Westchester)	11,093	$35,090 (5.8%)	19.3% (7.0%)	1.3 miles	Riverfront Park Riverfront restaurant Riverfront homes Mercy College

[132] Based on most recent data available in Wikipedia or other sources.
[133] Percent of total population below the poverty threshold.
[134] Based on US Census data. Hispanic/Latino percentage may include "White" race.
[135] Facilities (including recreational) near or directly located on the riverfront and/or take water from the river for operations that might be affected in the event of an oil spill.
[136] Based on most recent data available in Wikipedia or other sources.

Table 22: Hudson River Study Area East Bank Communities in New York[136]					
Town/Village (County)	**Population**	**Median per Capita Income (% Poverty)**	**% Non-White Population (% Latino)**	**Length River Shoreline**	**River-Based Economic and Cultural Features**
					Commuter rail station
Irvington[137] (Westchester)	6,587	$59,116 (3.1%)	11.4% (3.79%)	1.8 miles	Scenic Hudson Park Matthiessen Park Riverfront restaurants Riverfront homes Commuter rail station
Tarrytown (Westchester)	11,532	$39,472 (4.7%)	22.6% (16.17%)	2.6 miles	Lyndhurst Historic Site Sunnyside Historic Site Riverfront homes Riverfront restaurants Washington Irving Boat Club Tarrytown Marina/Boat Club Losee Park Pierson Park Scenic Hudson Riverwalk Commuter rail station
Sleepy Hollow[138] (Westchester)	10,198	$28,325 (7.4%)	38.99% (51.04%)	2.5 miles	Philipsburg Manor Site Kingsland Point Park Philipse Manor Beach Club Philipse Manor Marina Tarrytown Lighthouse John D. McKean Fireboat Commuter rail station Riverfront homes Rockwood Hall State Park
Scarborough[139] (Westchester)	8,032	$76,256 (2.2%)	13.6% (5.3%)	1.2 miles	Riverfront homes Commuter rail station
Ossining (Westchester)	37,674	$34,195 (8.4%)	29.74% (19.93%)	2.8 miles	Sing Sing Correctional Facility Louis Engel Riverfront Park Riverfront homes Riverfront restaurants Ossining Boat Club Shattemuc Yacht Club Westerly Marina Henry Gourdine Park Ossining/Haverstraw Ferry Paradise Heating Oil Crawbuckle Park Dominican Sisters of Hope Commuter rail station

[137] Includes: Ardsley-on-Hudson
[138] Hudson River adjacent part of Town of Mt Pleasant.
[139] Riverfront part of Briarcliff Manor.

Table 22: Hudson River Study Area East Bank Communities in New York[136]					
Town/Village (County)	**Population**	**Median per Capita Income (% Poverty)**	**% Non-White Population (% Latino)**	**Length River Shoreline**	**River-Based Economic and Cultural Features**
Cortlandt[140] (Westchester)	42,821	$33,432 (4.5%)	11.4% (7.19%)	15.1 miles	Van Cortlandt Manor Site Riverfront homes Croton Point Park Half Moon Marina Senasqua Park Croton Landing Park Oscawana Island Park George's Island Park Cortlandt Yacht Club Hudson Valley Marine King Marine Viking Boat Yard Riverfront homes Lafarge Gypsum Indian Point Energy Center Lents Cove Park Annsville Preserve Park Hudson River Expeditions Annsville Creek Paddlesport Camp Smith Military Base Commuter/Amtrak rail stations
Peekskill (Westchester)	24,053	$22,595 (13.7%)	64.2% (21.92%)	1.5 miles	Charles Point Park Charles Point Marina Wheelabrator Waste Energy Peekskill Yacht Club Travis Point Park Riverfront Green Park Trinity Cruises Peekskill Landing Park Riverfront restaurants Franciscan Sisters Home Riverfront homes Commuter rail station
Philipstown[141] (Putnam)	9,662	$37,738 (6.0%)	4.43% (3.79%)	13.1 miles	Manitou Point Preserve Capuchin Monastery Garrison Institute Garrison Landing Park Garrison Marina Garrison Art Center Depot Theatre Constitution Island Historic Constitution Marsh/Audubon West Point Foundry Preserve Dockside Park Riverfront restaurants Riverfront homes Private docks

140 Includes: Croton-on-Hudson, Crugers, Verplanck, Buchanan, Montrose, and Cortlandt Manor.
141 Includes: Garrison and Cold Spring

Table 22: Hudson River Study Area East Bank Communities in New York[136]

Town/Village (County)	Population	Median per Capita Income (% Poverty)	% Non-White Population (% Latino)	Length River Shoreline	River-Based Economic and Cultural Features
					Commuter rail station
Beacon (Dutchess)	14,271	$20,654 (11%)	31.63% (16.90%)	4.2 miles	Breakneck Ridge Trail Bannerman Castle Historic Dennings Point State Park Riverfront homes Dia Beacon Museum Scenic Hudson River Center Long Dock Park Pete & Toshi Seeger Park Beacon /Newburgh Ferry Mount Gulian Historic Site Commuter rail station
Fishkill (Dutchess)	2,116	$26,504 (8.4%)	6.28% (6.05%)	1.6 miles	Riverfront homes
Wappinger[142] (Dutchess)	26,780	$25,817 (4.1%)	13.82% (7.87%)	5.3 miles	Chelsea Yacht Club Chelsea Marina Riverfront homes Commuter rail station
Poughkeepsie[143] (Dutchess)	30,267	$16,759 (22.7%)	47.2% (10.6%)	9.8 miles	Carnwath Farms Historic Site Wheeler Hill Historic District New Hamburg Yacht Club White Hudson River Marina Bottini Fuel Terminal Riverfront homes Bowdoin County Park Tilcon Aggregates Pirate Canoe Club Shadows Marina Riverfront restaurants Kaal Rock Park Waryas Park Walkway Across Hudson Hudson River Rowing Assoc. Marist Boathouse Cornell Boathouse Longview Park Fern Tor Nature Preserve Quiet Cove Riverfront Park Rivers Edge Marina Hyde Park Marina Commuter rail/Amtrak station
Hyde Park[144] (Dutchess)	21,048	$21,260 (5.7%)	8.98% (3.23%)	8.8 miles	Culinary Institute of America Franklin Roosevelt Library Springwood (FDR Historic) Rogers Point Boating Assoc. Riverfront homes

[142] Includes: Chelsea.
[143] Includes: New Hamburg and Wappingers Falls.
[144] Includes: Staatsburg

Table 22: Hudson River Study Area East Bank Communities in New York[136]					
Town/Village (County)	**Population**	**Median per Capita Income (% Poverty)**	**% Non-White Population (% Latino)**	**Length River Shoreline**	**River-Based Economic and Cultural Features**
					Riverfront Park Hyde Park Landing Hotel Vanderbilt Mansion Historic Bolles Island (private) Poughkeepsie Yacht Club Margaret Norrie State Park Mills Norrie Marina Norrie Point Envtl. Center Atlantic Kayak Tours Mills Mansion Historic Site
Rhinebeck[145] **(Dutchess)**	7,548	$26,069 (9.7%)	7.5% (3.94%)	8.9 miles	Linwood Spiritual Center Wyndclyffe Mansion Historic Wilderstein Historic Site Riverfront homes Ferncliff Nursing Home Amtrak station; Water intake
Red Hook[146] **(Dutchess)**	11,181	$20,410 (8.7%)	5.8% (2.65%)	7.3 miles	Red Hook Boat Club Unification Theol. Seminary Montgomery Place Historic Hessel Museum of Art Bard College Tivoli Bays Wildlife Area Riverfront homes Riverfront hotel
Clermont (Columbia)	1,909	$21,566 (9.4%)	3.42% (2.72%)	1.9 miles	Clermont State Park Livingston State Forest
Germantown (Columbia)	1,906	$22,198 (7.9%)	3.07% (1.29%)	3.9 miles	Ernest Lasher Memorial Park Riverfront homes Agricultural land
Livingston[147] **(Columbia)**	3,503	$22,434 (5.9%)	2.86% (1.69%)	1.6 miles	Livingston State Forest Riverfront homes Agricultural land
Hudson (Columbia)	6,404	$22,353	41.0% (8.2%)	6.9 miles	Olana State Historic Site Rogers Island Wildlife Area Harrier Hill Park Hudson Athens Lighthouse Henry Hudson Riverfront Pk Hudson River Public Boat Furgery Fishing Village Site Greenport Conservation Area Riverfront homes Amtrak station
Stockport (Columbia)	2,680	$18,137 (12.5%)	3.51% (1.81%)	3.9 miles	Agricultural land
Stuyvesant (Columbia)	1,921	$21,314 (4.3%)	2.7% (0.69%)	9.2 miles	Stuyvesant Boat Launch Lewis A. Swyer Preserve

[145] Includes: Rhinecliff
[146] Includes: Barrytown, Annandale-on-Hudson, and Tivoli.
[147] Includes: Linlithgo.

Table 22: Hudson River Study Area East Bank Communities in New York[136]

Town/Village (County)	Population	Median per Capita Income (% Poverty)	% Non-White Population (% Latino)	Length River Shoreline	River-Based Economic and Cultural Features
					Riverfront homes Agricultural land
Schodack[148] **(Rensselaer)**	13,151	$24,560 (4.3%)	2.46% (1.49%)	8.3 miles	Schodack Island State Park Castleton Boat Club Papscanee Island Nature Pres. Riverfront homes Agricultural land
Rensselaer (Rensselaer)	9,340	$19,674 (12.8%)	17.89% (4.72%)	4.6 miles	Paulsinello Fuel Terminal Gold Bond Building Products Buckeye Oil Terminal Sprague Oil Terminal Gorman Oil Terminal Getty Petroleum Rensselaer Cogeneration Albany Yacht Club Riverfront Park Agricultural lands Riverside homes Amtrak station

Table 23: Hudson River Study Area West Bank Communities in New York[149]

Town/Village (County)	Population	Median per Capita Income (% Poverty)	% Non-White Population (% Latino)	Length River Shoreline	River-Based Economic and Cultural Features
Orangetown[150] **(Rockland)**	50,234	$33,170 (4.8%)	16.03% (6.02%)	12.6 miles	Piermont Marsh Tallman Mountain State Park Tappan Zee Marina Cornetta's Marina Nyack Marina Nyack Boat Club Hook Mountain Yacht Club North River Shipyard Nyack Beach State Park Hook Mountain State Park Hudson River Greenway Trail Private docks Riverfront homes Riverfront church Riverfront restaurants
Haverstraw (Rockland)	37,414	$22,188 (10.6%)	33.76% (31.73%)	2.9 miles	Haverstraw Beach State Park Ossining/Haverstraw Ferry Emeline Park Bowline Point Park Haverstraw Bay Park Haverstraw Marina

[148] Includes: Castleton-on-Hudson
[149] Based on most recent data available in Wikipedia or other sources.
[150] Includes: Piermont and Grand View-on-Hudson, Nyack, and South Nyack.

Table 23: Hudson River Study Area West Bank Communities in New York[149]

Town/Village (County)	Population	Median per Capita Income (% Poverty)	% Non-White Population (% Latino)	Length River Shoreline	River-Based Economic and Cultural Features
					Riverfront restaurants Riverfront homes
Stony Point[151] **(Rockland)**	15,475	$28,244 (3.7%)	5.67% (6.84%)	7.4 miles	Minisceongo Yacht Club Panco Petroleum Terminal Pennybridge Marine Seaweed Yacht Club Patsy's Bay Marina Stoney Point Bay Marina Stoney Point State Park Stoney Point Lighthouse Bear Mountain State Park Iona Island Nat. Estuarine Res. Riverfront homes
Highlands[152] **(Orange)**	12,138	$17,830 (3.6%)	24.82% (9.71%)	11.8 miles	Bear Mountain State Park Mine Dock Park Riverfront homes West Point Military Academy West Pont History Museum Highland Falls Park/Marina Riverfront hotels
Cornwall (Orange)	12,480	$28,509 (5.0%)	5.32% (5.11%)	4.4 miles	Storm King State Park Cornwall Yacht Club Riverfront homes
New Windsor (Orange)	27,272	$22,806 (1.03%)	15.28% (11.10%)	2.5 miles	Kowawese Unique Area Sloop Hill State Unique Area Plum Point Park Warex Fuel Terminal Diesel Direct Fuel Terminal Riverfront homes
Newburgh (Orange)	28,200	$13,360 (25.8%)	60.6% (47.9%)	2.3 miles	Newburgh Rowing Club Newburgh Waterfront Trail Gulf Harbor Marina Beacon/Newburgh Ferry Front Street Marina Hudson River Adventures River Rose Cruises Unico Park Newburgh Yacht Club Riverfront restaurants Riverfront church Riverfront retail Riverfront homes
Balmville (Orange)	3,339	$30,646 (2.2%)	20.34% (10.03%)	0.9 miles	Riverfront homes
Marlboro (Ulster)	2,339	$20,123 (12.0%)	4.32% (4.96%)	8.3 miles	Marlboro Yacht Club
Milton	1,251	$23,785	6.63%	1.9 miles	Agricultural land

[151] Including: Tomkins Cove.
[152] Includes: West Point, Highland Falls, and part of Bear Mountain State Park

Table 23: Hudson River Study Area West Bank Communities in New York[149]					
Town/Village (County)	**Population**	**Median per Capita Income (% Poverty)**	**% Non-White Population (% Latino)**	**Length River Shoreline**	**River-Based Economic and Cultural Features**
(Ulster)		(5.1%)	(3.76%)		Riverfront hotel Riverfront homes
Lloyd[153] (Ulster)	10,517	$22,229 (7.3%)	9.71% (5.07%)	6.9 miles	Franny Reese State Park Walkway Over Hudson Park Highland Landing Park FDR National Historic View Riverfront homes
Esopus[154] (Ulster)	8,839	$21,174 (n/a)	5.43% (1.91%)	10.2 miles	Vineyard Seminaries/monasteries Black Creek Preserve Esopus Meadows Preserve Esopus Meadows Lighthouse Lighthouse Park High Banks Preserve Port Ewen water intake Hidden Harbor Yacht Club George H. Frior Mem. Beach Sleightsburgh Park Riverfront homes Private docks Riverfront hotel Agricultural land Riverfront school
Kingston (Ulster)	23,210	$18,662 (15.8%)	26.8% (13.4%)	3.3 miles	Hudson R. Maritime Museum Waterfront restaurants Waterfront retail Kingston Point Rotary Park TR Gallo Waterfront Park Rondout Yacht Basin Hideaway Marina 340 Abeel Marina Tivoli Sailing Company Riverfront church Rondout Lighthouse Kingston Point Rail Trail Kingston Point Beach Kingston Point Fuel Terminal
Ulster[155] (Ulster)	12,455	$22,069 (9.0%)	6.56% (2.45%)	4.7 miles	Robert E. Post Memorial Park Charles Rider Park/Boat Ramp Ulster Landing County Park Ulster Landing Beach Riverfront homes
Saugerties[156] (Ulster)	19,097	$17,900 (12.2%)	5.8% (5.0%)	8.1 miles	Falling Waters Preserve Saugerties Lighthouse Saugerties Marina

[153] Includes: Highland
[154] Includes: West Park and Port Ewen.
[155] Includes: East Kingston and Ulster Landing.
[156] Includes: Glasco and Malden-on-Hudson.

Table 23: Hudson River Study Area West Bank Communities in New York[149]

Town/Village (County)	Population	Median per Capita Income (% Poverty)	% Non-White Population (% Latino)	Length River Shoreline	River-Based Economic and Cultural Features
					Ruth Reynolds Glunt Preserve Glasco Mini-Park Saugerties Steamboat Marina Tina Chorvas Waterfront Park US Coast Guard Base Bristol Beach Park/Landing Agricultural land Riverfront convent Riverfront hotels Riverfront homes Private docks
Catskill[157] **(Greene)**	11,365	$18,563 (14.9%)	10.06% (4.03%)	10.4 miles	Lehigh Cement North American Quarry Dutchman's Landing Park Main-Care Energy Terminal Riverfront homes Riverfront restaurants Riverview Marina Catskill Yacht Club Assisted living facility Riverfront church Riverfront homes Seminary Agricultural lands
Athens (Greene)	3,941	$20,910 (8.7%)	4.13% (1.7%)	7.3 miles	Elco Motor Yachts Athens Boat Launch Athens Riverfront Park Peckham Asphalt/Cement Vosburgh's Nurseries Small fuel terminal Riverfront homes Riverfront hotel Riverfront restaurants Agricultural land Private docks/small marinas
Coxsackie (Greene)	8,498	$16,830 (12.9%)	7.76% (11.15%)	6.7 miles	Vosburgh Swamp Wildlife Four Mile Point Reserve Hudson River Islands Coxsackie Boat Launch Coxsackie Yacht Club Detached Forest Preserve Riverfront homes Private docks Agricultural land
New Baltimore (Greene)	3,254	$20,636 (7.2%)	2.6% (1.61%)	5.2 miles	Bronck Island Unique Area Donovan's Shady Harbor Cornell Park Hannacroix Preserve

[157] Includes: Hamburg.

Table 23: Hudson River Study Area West Bank Communities in New York[149]					
Town/Village (County)	**Population**	**Median per Capita Income (% Poverty)**	**% Non-White Population (% Latino)**	**Length River Shoreline**	**River-Based Economic and Cultural Features**
					Riverfront restaurants Riverfront homes Private docks Agricultural land
Coeymans[158] (Albany)	7,374	$21,686 (6.9%)	5.39% (3.24%)	3.4 miles	Coeymans Sewer Plant Riverfront homes Riverfront restaurants Ace Charters Fishing Coeymans Landing Ravena Coeymans Yacht Club Port of Coeymans Lafarge NA
Bethlehem[159] (Albany)	35,324	$31,492 (3.1%)	5.26% (1.74%)	7.8 miles	Henry Hudson Town Park Moh-He-Con-Nuck Preserve North Albany Oil Terminal Citgo Petroleum PSEG Power Plant Scarano Boatbuilding Sims Metal Riverfront homes Agricultural land
Albany (Albany)	98,111	$56,236 (21.7%)	47.7% (9.2%)	4.9 miles	Buckeye Albany Terminal Albany Asphalt & Aggregates Port Welding Services MMC Millwork Westway Terminal Port of Albany Gorman Asphalt Global Oil Terminal Dutch Apple Cruises USS Slater Museum Jennings Landing Riverfront restaurants

158 Includes: Ravena
159 Includes: Glenmont

Appendix C: Hudson River Greenway Trail Maps[160]

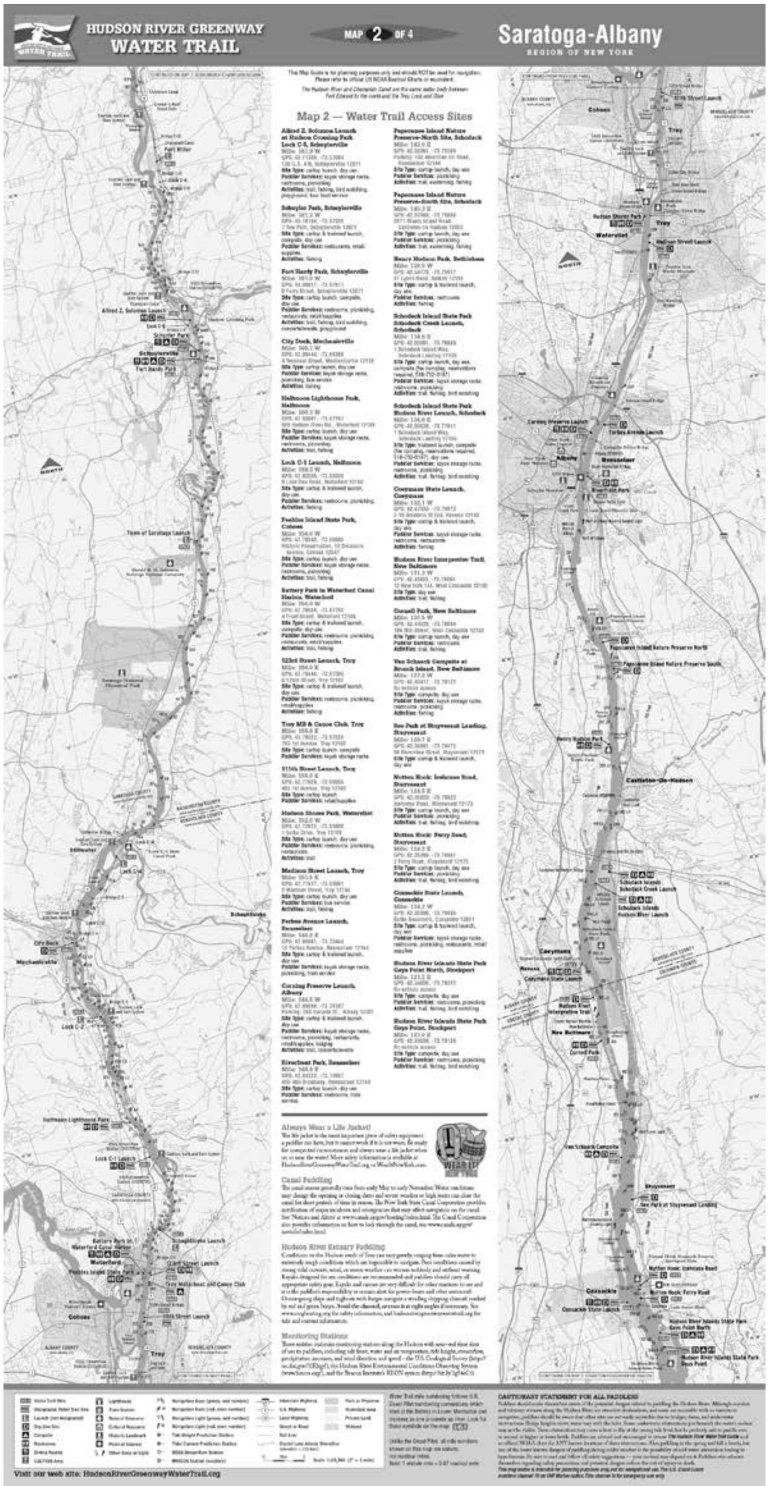

Figure 76: Saratoga-Albany Hudson River Greenway Water Trail Map

[160] High-resolution maps may be viewed by increasing on-screen magnification.

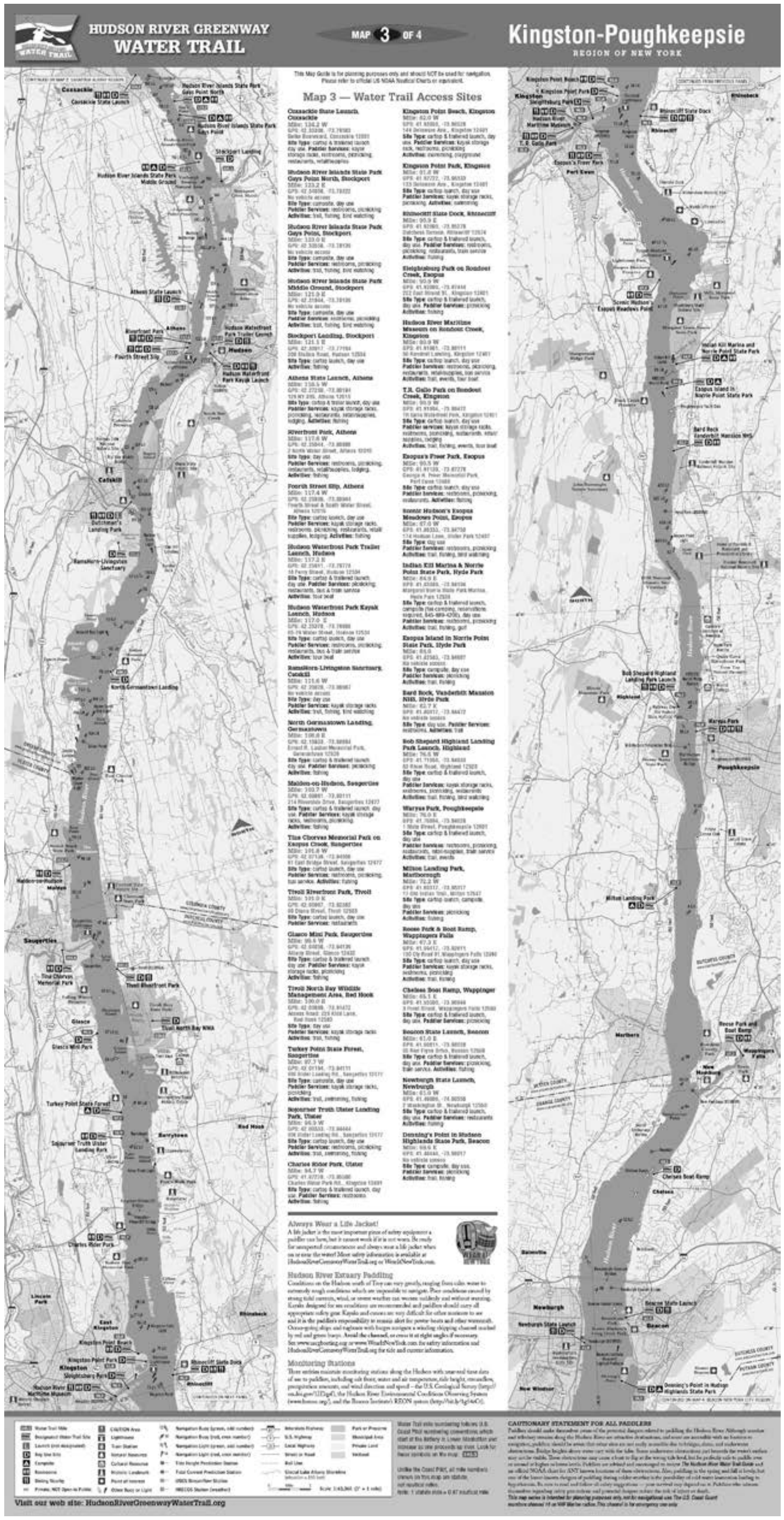

Figure 77: Kingston-Poughkeepsie Hudson River Greenway Water Trail Map

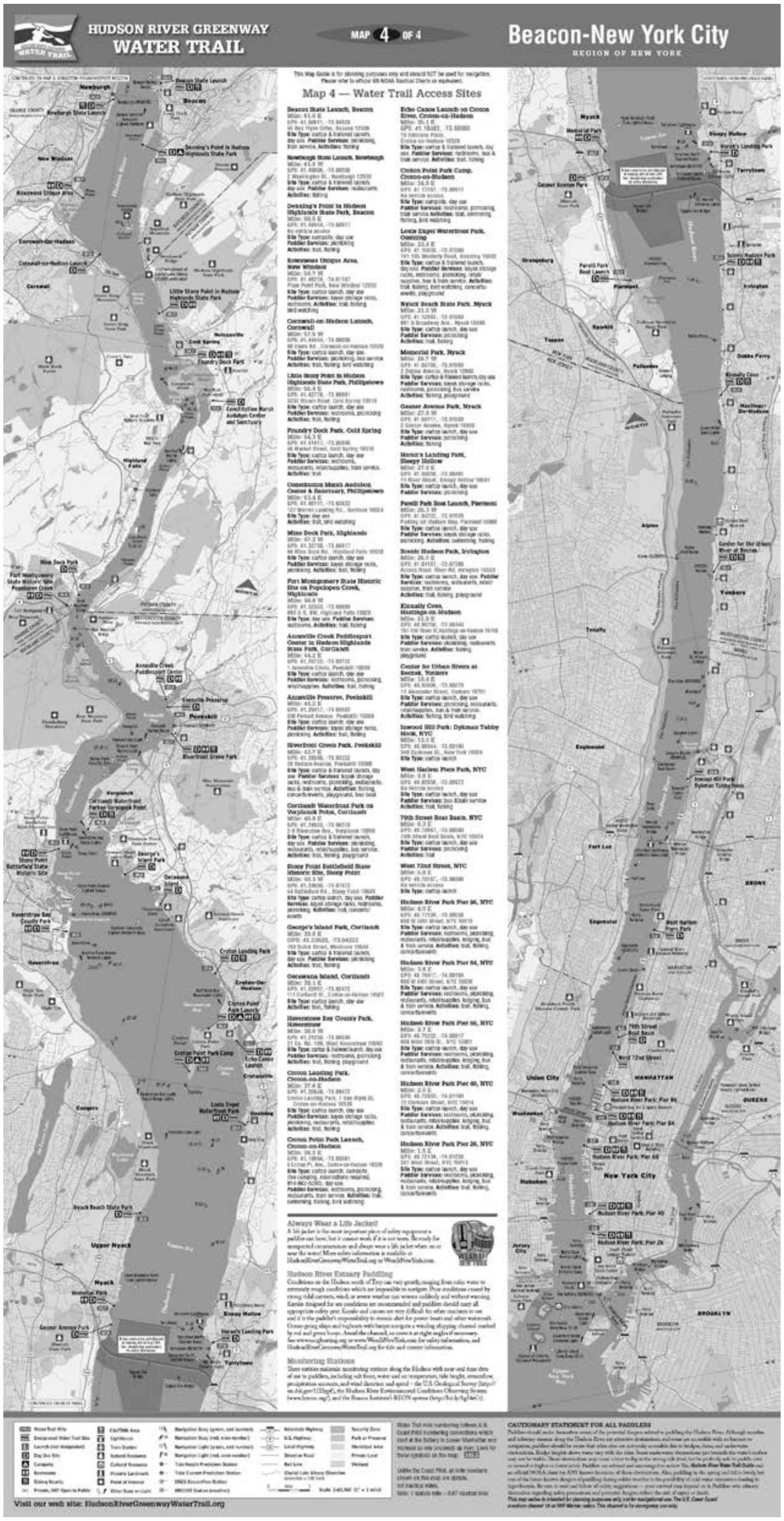

Figure 78: Beacon-New York City Hudson River Greenway Water Trail Map