Hudson River Oil Spill Risk Assessment

Volume 3:
Oil Spill Probability Analysis

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

The diligent efforts of the RPS SIMAP modeling team of 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

AMPD: average most-probable discharge

ANPRM: Advanced Notice of Proposed Rulemaking

ATB: articulated tank barge

AWO: American Waterways Operators

bbl/hr: barrels per hour

bbl: barrels of oil (equivalent of 42 gallons)

BLEVE: boiling liquid expanding vapor explosion

CBR: crude-by-rail

CEMS: Crew Endurance Management System

CFR: *Code of Federal Register*

DAPL: Dakota Access Pipeline

DEIS: Draft Environmental Impact Statement

ECP: electronically-controlled pneumatic [brakes]

EPA: Environmental Protection Agency

ERC: Environmental Research Consulting

FEMA: Federal Emergency Management Agency

FRA: Federal Railroad Administration

gal: gallons

HAZMAT: hazardous material

hr: hours

HROSRA: Hudson River Oil Spill Risk Assessment

ITB: integrated tug barge

kts: knots

mi: miles

mi^2: square miles

mil: million

MMPD: maximum most-probable discharge

MSIB: Marine Safety Information Bulletin

NCP: National Contingency Plan

ND: North Dakota

NEPA: National Environmental Policy Act

NOAA: National Oceanic and Atmospheric Administration

NPDES: National Pollution Discharge Elimination System

NTSB: National Transportation Safety Board

NVIC: Navigational and Vessel Inspection Circular

NYSDEC: New York State Department of Environmental Conservation

ORPHP: Office of Parks, Recreation, and Historic Preservation

p: probability

PADD: Petroleum Administration for Defense Districts

PAWSA: Ports and Waterways Safety Assessment

PHMSA: Pipeline and Hazardous Material Safety Administration

PTC: positive train control

PWCS: Ports, Waterways, and Coastal Security

SAR: Search and Rescue

STCW: International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers

Tbbl/day: thousand barrels per day

TOAR: Towing Officers' Assessment Record

TSS: traffic separation scheme

USCG: US Coast Guard

VHF: very high frequency

VTS: vessel traffic system

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.

Terminology

Risk

The term "risk" is often used as a synonym for "probability." Technically, however, the term means the probability of an event (e.g., a spill) multiplied by the consequences of that event, as follows:

$$risk_{spill} = probability_{spill} \cdot consequences_{spill}$$

Expected Frequency, Probability, and Return Periods

The objective of the analyses in this report is to determine the expected annual frequency or probability that spill events of various sizes might occur. The results are represented in terms of expected *frequencies* and as *return periods*. (The return period is also sometimes called the "recurrence interval.") These terms express the same concepts in different ways. The expected frequency is an estimate of the likelihood or probability that an event (in this case, a spill of a certain volume) will occur in any given year. The inverse of this is the return period.

For example, if there is a 1% chance, or a one in 100 chance, that a large spill event will occur in one year. The "return period" for this event is 100 years. The return period is the inverse of the frequency.

$$Frequency(event) = \frac{number(events)}{year}$$

$$Return = \frac{1}{Frequency(event)} = \frac{years}{event}$$

$$Frequency(event) = \frac{0.01}{year}$$

$$Return(event) = \frac{1}{0.01} = 100$$

The return period (e.g., 100 years) is used in an attempt to simplify the definition of a specific statistically-determined chance of an event occurring in any one year (1%). It does not however mean that it will necessarily take 100 years before this event occurs or that it will only occur once in a 100-year time frame. The return period or recurrence interval can also be viewed as the "odds" or "chances" that an event will occur in any one year.

Because the concept of "return period" can be confusing in that it seems to imply that there should be one event every *x* number of years, it is not used in this report. Instead the annual probability is expressed as 1 in *x* chance, which is often easier to conceptualize. A 100-year event has a 1 in 100 chance each year. In this report, the "annual probability" is shown in addition to the annual frequency.

$$AnnualProbability = \frac{1}{return}$$

Note that if there is an expected frequency of more than one spill a year, the annual probability will appear as a “1 in *x* chance” where *x* is less than one. This means that it is nearly certain to occur each year.

Rounding of Numbers and Significant Digits

Calculated data from modeling and various interim analyses are shown with as many as five digits after the decimal point. This is to allow for greater accuracy in adding and other mathematical processes and to avoid rounding errors that may be confusing to the reader.

In summary tables, however, such as those providing estimates of annual frequencies of specific volumes of spills and return years, the results have been rounded to two or three significant digits, as appropriate, starting with the first non-zero digit. This is a standard methodology applied in many analyses to avoid the implication that one could be so precise in determining the frequency of spill events in the future. For example, if the calculated spill frequency is 0.00128 per year, which would bring a return period of 781.25 years, the spill frequency would be rounded to 0.0013 per year and the return period would be expressed as 780 years. Note that “significant digits” are also called “significant figures.”

Percentiles

The term “percentile” is used throughout this report, generally in reference to spill volumes. Percentile is a statistical measure indicating the value below which a certain percentage of observations fall. For example, the 75th percentile for spill volume is the volume at which 75% of spills are smaller in volume, and only 25% are larger. For the 99th percentile volume only 1% is larger. The 50th percentile is the value for which half are smaller and half are larger. This is the equivalent of the median.

Averages

The term “average” is used in this report to denote the arithmetic mean. The average is derived by adding the group of values and dividing by the number of values included.

Spills versus Chronic Inputs

This study mainly addresses the risk of spills, which are discrete events in which oil is released over a finite period of time. To put the potential inputs of oil from spills into perspective, however, the chronic inputs of oil from non-point sources through runoff, as well as generally legal discharges from the operation of two-stroke engines and vessels are also mentioned. Chronic inputs can be mitigated through prevention, such as better practices, maintenance, or technological advances. These inputs cannot usually be cleaned up through spill response efforts.

Classification of Oil Spill Volumes

According to the National Contingency Plan (NCP)[1] a "major" oil spill is defined as one that involves a spillage of more than 100,000 gallons (2,381 bbl) in coastal (marine) waters, and more than 10,000 gallons (238 bbl) in inland waters. The Hudson River is considered an inland waterway.

Spill volumes for contingency planning purposes are classified as shown in Table 1.

Table 1: AMPD, MMDP, and WCD Planning Volumes

Source Type	Average Most-Probable Discharge (AMPD)	Maximum Most-Probable Discharge (MMPD)	Worst-Case Discharge (WCD)
Facility	Lesser of: 50 bbl *or* 1% of WCD	Lesser of: 1,200 bbl or 10% of WCD	Largest foreseeable discharge in adverse weather conditions.[2]
Vessel	Lesser of: 50 bbl *or* 1% of cargo	2,500 bbl if oil capacity ≥ 25,000 bbl *or* 20% of oil capacity if < 25,000 bbl	Discharge in adverse weather conditions of vessel's entire fuel or cargo oil, whichever is greater.

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[1] 40 CFR§ 300.5

[2] (1) Where applicable, the loss of the entire capacity of all in-line and break out tank(s) needed for the continuous operation of the pipelines used for the purposes of handling or transporting oil, in bulk, to or from a vessel regardless of the presence of secondary containment; plus (2) The discharge from all piping carrying oil between the marine transfer manifold and the non-transportation-related portion of the facility. The discharge from each pipe is calculated as follows: The maximum time to discover the release from the pipe in hours, plus the maximum time to shut down flow from the pipe in hours (based on historic discharge data or the best estimate in the absence of historic discharge data for the facility) multiplied by the maximum flow rate expressed in barrels per hour (based on the maximum relief valve setting or maximum system pressure when relief valves are not provided) plus the total line drainage volume expressed in barrels for the pipe between the marine manifold and the non-transportation-related portion of the facility; and for a mobile facility it means the loss of the entire contents of the container in which the oil is stored or transported.

HROSRA Volume 3 Summary

Volume 3 of the Hudson River Oil Spill Risk Assessment study addresses the *probability* side of the risk equation. [The consequences are addressed in HROSRA Volumes 4, 5, and 7.]

Probability of Oil Spills

The likelihood or probability that a particular type of oil spill might occur is dependent the probabilities of the presence of spill sources, along with the probabilities of accidents (or errors) that could potentially cause spillage, and the probabilities that the accidents (or errors) would cause the release of oil.

$$risk_{spill} = probability_{spill} \cdot consequences_{spill}$$

$$probability_{spill} = probability_{source} \cdot probability_{accident} \cdot probability_{release}$$

In other words, for a spill to occur there needs to be:

- A source that transports or contains oil;
- An accident or error that could potentially result in an oil spill; and
- The actual release of oil.

Each of these probabilities is addressed in succession for each of the types of oil spills that could hypothetically occur in or along the Hudson River study area.

In addition, because the volume of spillage is important for determining impacts (consequences) and response, the probabilities of a spill being of a certain volume also needs to be calculated. In general, most spills are small, but there is a small probability of larger spills.

Oil Spill Types Included

The probability analysis includes potential spillage into the Hudson River from:

- Tank vessels (tankers and tank barges, including articulated tank barges or ATBs) carrying oil or petroleum, which can spill oil cargo and/or bunker fuel;
- Non-tank vessels (all other commercial vessels that carry oil only as fuel or bunkers);
- Recreational vessels;
- Locomotives on passenger and commuter trains;
- Locomotives on freight trains;
- Tank cars and locomotives on crude-by-rail (CBR) trains;
- Facilities that store oil (oil terminals, fuel depots, etc.); and
- Oil pipelines that cross or run near the river.

The analyses of potential spills from these sources are based on the actual current presence of these sources, as well as hypothetical future presence. For example, the analysis includes the proposed Pilgrim Pipeline and hypothetical future transport of crude oil by train, which is not currently in place. In addition, potential changes in future patterns of vessel traffic are incorporated into the vessel spill analysis.

Oil Spill Probability from Tank Vessels and Non-Tank Vessels

The probability of oil spills from tank vessels, including tankers and tank barges (including ATBs), and non-tank vessels involved:

- Analyses of vessel casualties or accidents (i.e., groundings, collisions, allisions, equipment failures, fire, structural failures, and minor incidents) the factors that would affect the rate of casualties by vessel type;
- Analyses of the likelihood of the spillage of oil in the event of a casualty;
- Analyses of the likelihood of a spill during transfer operations (fueling or cargo transfer);
- The potential volume released in the event of a spill;
- Potential changes in vessel casualties and spills with different levels of traffic on the Hudson River.

The expected annual frequencies of oil cargo spills by volume are summarized in Table 2 and of bunker spills in Table 3 based on current vessel traffic. The two types of spills are combined in Figure 1. The majority of spills (86%) are of less than 10 bbl.

Table 2: Annual Frequency of Cargo Spills from Tank Vessels (Current Vessel Traffic)

Spill Volume (bbl)	Annual Spills			Annual Probability		
	Tankers	Tank Barges	Total Tank Vessels	Tankers	Tank Barges	Total Tank Vessels
<1	0.010	0.470	**0.480**	1 in 100	1 in 2	**1 in 2**
1–9	0.005	0.076	**0.081**	1 in 200	1 in 13	**1 in 12**
10–99bbl	0.005	0.088	**0.093**	1 in 200	1 in 11	**1 in 11**
100–999	0.004	0.037	**0.041**	1 in 250	1 in 27	**1 in 24**
1,000–9,999	0.003	0.021	**0.024**	1 in 333	1 in 48	**1 in 42**
10,000– 99,999	0.001	0.011	**0.012**	1 in 1,000	1 in 91	**1 in 83**
100,000+	0.0000015	0.0000000	**0.0000015**	1 in 666,667	0	**1 in 666,667**
Total	**0.029**	**0.703**	**0.732**	**1 in 34.5**	**1 in 1.4**	**1 in 1.4**

Table 3: Annual Frequency of Bunker Spills (Current Vessel Traffic)

Spill Volume (bbl)	Annual Spills	Annual Probability
<1	3.176	1 in 0.31
1–9	0.392	1 in 2.55
10–99bbl	0.172	1 in 5.80
100–999	0.183	1 in 5.48
1,000–9,999	0.118	1 in 8.45
10,000– 99,999	0.031	1 in 32.32
100,000+	0.000	0
Total	**4.073**	**1 in 0.25**

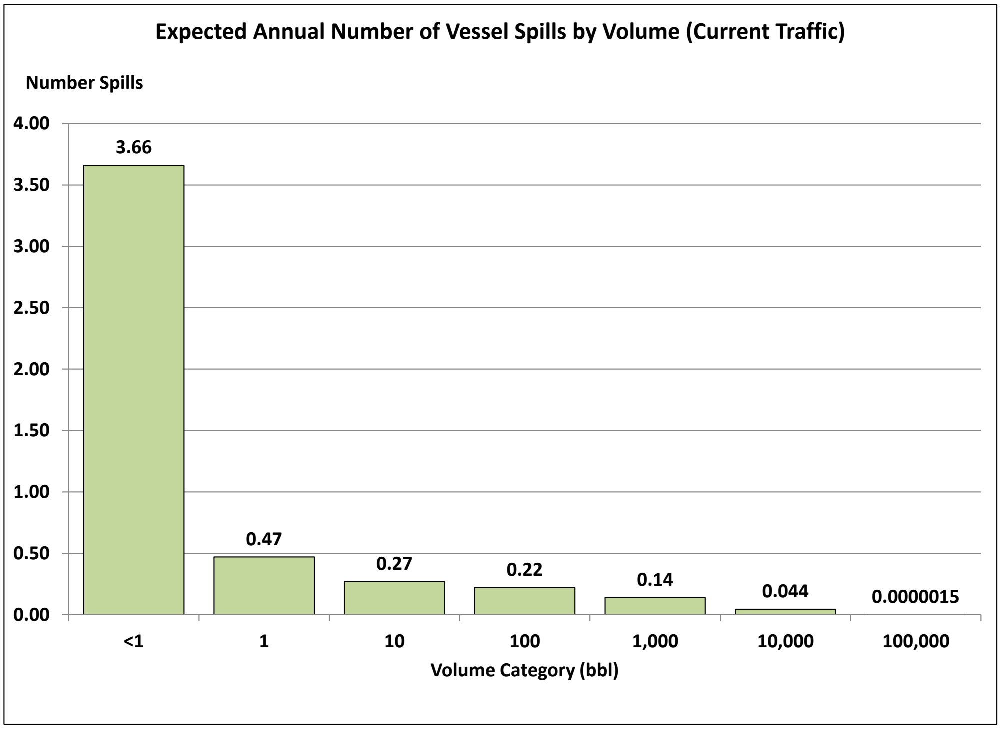

Figure 1: Expected Number of Vessel Spills by Volume (Current Traffic)

Changes in vessel traffic will, of course, affect the potential numbers of spills. In addition, any changes related to spill prevention could also affect the potential numbers of spills. The predicted probabilities of spills of different volumes based on hypothetical future vessel traffic assumptions are shown in Table 4.

Table 4: Predicted Annual Spill Frequencies based on Vessel Traffic Changes

Vessel Traffic Assumption	Estimated Annual Number of Spills by Volume Category (bbl)							
	<1	1	10	100	1,000	10,000	100,000	Total
Current Traffic	3.66	0.47	0.27	0.22	0.14	0.044	0.0000015	**4.81**
50% Overall Decrease	1.83	0.24	0.13	0.11	0.07	0.022	0.0000007	**2.40**
10% Overall Decrease	3.29	0.43	0.24	0.20	0.13	0.039	0.0000013	**4.32**
50% Decrease Tank Vessels	3.16	0.40	0.20	0.19	0.12	0.035	0.0000007	**4.11**
20% Decrease Tank Vessels	3.46	0.44	0.24	0.21	0.13	0.040	0.0000012	**4.53**
10% Decrease Tank Vessels	3.56	0.46	0.25	0.22	0.14	0.042	0.0000013	**4.67**
10% Increase Tank Vessels	3.75	0.49	0.28	0.23	0.15	0.045	0.0000016	**4.94**
20% Increase Tank Vessels	3.85	0.50	0.29	0.24	0.15	0.047	0.0000018	**5.08**
50% Increase Tank Vessels	4.15	0.55	0.33	0.26	0.17	0.053	0.0000022	**5.50**
10% Overall Increase	4.02	0.52	0.29	0.25	0.16	0.048	0.0000016	**5.29**
100% Increase Tank Vessels	4.64	0.62	0.39	0.29	0.19	0.061	0.0000030	**6.19**
20% Overall Increase	4.39	0.57	0.32	0.27	0.17	0.052	0.0000018	**5.77**
200% Increase Tank Vessels	6.62	0.91	0.63	0.44	0.28	0.097	0.0000059	**8.97**
50% Overall Increase	5.49	0.71	0.40	0.34	0.22	0.066	0.0000022	**7.22**
100% Overall Increase	7.27	0.89	0.51	0.42	0.26	0.085	0.0000080	**9.44**

The likelihood of a spill of 100,000 bbl or more is about 1 in 670,000 with current vessel traffic. With increased overall traffic, and, in particular with increases in tank vessels, this probability increases to as much as 1 in 125,000. With decreased traffic, the probability likewise decreases (Table 5). With a 200% increase (i.e., doubling) of the tank vessels on the river, the probability of a 100,000-bbl or larger spill is 1 in 170,000 each year.

Table 5: Expected Frequencies of 100,000-bbl+ Vessel Spills by Traffic Assumption

Traffic	Annual Frequency	Annual Probability
50% Overall Decrease	0.0000007	1 in 1,428,571
50% Decrease TV	0.0000007	1 in 1,428,571
20% Decrease TV	0.0000012	1 in 833,333
10% Overall Decrease	0.0000013	1 in 769,231
10% Decrease TV	0.0000013	1 in 769,231
Current Traffic	**0.0000015**	**1 in 666,667**
10% Increase TV	0.0000016	1 in 625,000
10% Overall Increase	0.0000016	1 in 625,000
20% Increase TV	0.0000018	1 in 555,556
20% Overall Increase	0.0000018	1 in 555,556
50% Increase TV	0.0000022	1 in 454,545
50% Overall Increase	0.0000022	1 in 454,545
100% Increase TV	0.000003	1 in 333,333
200% Increase TV	0.0000059	1 in 169,492
100% Overall Increase	0.0000080	1 in 125,000

The annual probabilities of spills during transfer operations (fueling or cargo transfers to/from vessels at terminals or between vessels) are summarized in Table 5. These spill frequencies can be greatly reduced with stringent transfer regulations.

Table 6: Estimated Annual Transfer Spills in Hudson River

Spill Volume (bbl)	Annual Spill Rate (Annual Probability)					
	Oil Cargo Transfer		Bunkering		Total	
	Annual Spills	Annual Probability	Annual Spills	Annual Probability	Annual Spills	Annual Probability
<1 bbl	0.365	1 in 3	0.514	1 in 2	0.86	1 in 1
1-9 bbl	0.09	1 in 11	0.126	1 in 8	0.216	1 in 5
10-99bbl	0.045	1 in 22	0.063	1 in 16	0.108	1 in 9
100-999 bbl	0.0045	1 in 222	0.0063	1 in 159	0.011	1 in 91
1,000-9,999 bbl	0.00045	1 in 2,222	0.00063	1 in 1,587	0.0011	1 in 909
10,000 bbl +	0.00005	1 in 20,000	0.00007	1 in 14,286	0.00012	1 in 8,333
Total	**0.505**	**1 in 2**	**0.71**	**1 in 1**	**1.19622**	**1 in 1**

Oil Spill Probability from Recreational Vessels

The analysis of spills from recreational vessels involved applying spill rates reported for New York, applied to the estimated population of boats in the Hudson River.

Most recreational vessels have fuel tanks of 0.5 to 3 bbl. The largest yachts can hold as much as 250 bbl. The estimated total annual volume of oil spillage from recreational vessels in the Hudson River is about 20 bbl. With an estimated 16 annual accidents, this comes to about 1.3 bbl per accident. There would be smaller volumes of spillage for smaller vessels, and more for larger ones.

Oil Spill Probability from Railroads

The probability of spills from railroads included:

- Spills from tank cars carrying crude oil in CBR trains;
- Spills from locomotives pulling freight trains, including crude-by-rail (CBR) trains;
- Spills from locomotives pulling/pushing commuter trains; and
- Spills from locomotives pulling long-distance passenger trains (Amtrak).

There currently are no regular CBR trains transiting the Hudson River corridor. If there are no CBR trains there is no probability of spillage from these sources. However, during 2017, there were eight (8) trains that were diverted through the Hudson River rails due to extenuating circumstances with the hurricane damage in Houston. The analyses for potential CBR spills were conducted with various traffic assumptions–ranging from diversion transport (as with the 8 trains in 2017), and occasional and frequent diversion transport (up to 96 trains per year). In addition, two different levels of historical transport (moderate and peak), as well as a hypothetical maximum transport level that would cover the entire capacity of refineries in the Northeast, were analyzed.

The calculated annual frequencies of CBR spills of oil cargo (e.g., Bakken crude) along the Hudson River based on the different traffic scenarios are shown in Table 7. *Note that these are only spills that might potentially affect the Hudson River because of the proximity of the tracks to the river. This is not an estimate of the numbers of spills along the inland lengths of track.*

Table 7: Projected Numbers of CBR Spills along Hudson River

Hypothetical CBR Transport Scenario	Annual CBR Trains	Low Spill Estimate		High Spill Estimate	
		Annual Frequency	Annual Probability	Annual Frequency	Annual Probability
Current (No Diversion Transport)	0	0	n/a	0	n/a
Current (Diversion Transport)	8	0.0000020	1 in 510,000	0.000046	1 in 22,000
Occasional Diversion Transport	32	0.0000078	1 in 128,000	0.00019	1 in 5,400
Frequent Diversion Transport	96	0.000024	1 in 43,000	0.00056	1 in 1,800
Moderate Historical Transport	780	0.00019	1 in 5,200	0.0045	1 in 220
Peak Historical Transport	1,560	0.00038	1 in 2,600	0.0090	1 in 110
Maximum Hypothetical Transport	4,015	0.00098	1 in 1,000	0.023	1 in 43

These are spills of any volume. Low and high estimates of the number of spills by volume are shown in Table 8 and Table 9. They are based on a more optimistic assumption of a high degree of improvement in safety factors that would prevent spills (e.g., safer tank cars and Positive Train Control) for the low estimate and a more pessimistic assumption of minimal safety improvements for the high estimate. With the optimistic/low assumption there is a 1 in 100,000 chance per track mile of a spill (of any volume) based on the peak historical traffic. With the more pessimistic/high estimate, there is a 1 in 4,400 chance of a spill (of any volume) per track mile.

Table 8: Projected Annual Frequency of CBR Spills into Hudson River (Low Estimate)

Spill Volume	Spills/Year (Based on Trains per Year)					
	8 trains Current Diversion	32 trains Occasional Diversion	96 trains Frequent Diversion	780 trains Moderate Historical	1,560 trains Peak Historical	4,015 trains Maximum Hypothetical
<238 bbl	0.000000051	0.0000002	0.00000061	0.0000048	0.0000096	0.000025
2,500 bbl	0.000000046	0.00000018	0.00000055	0.0000044	0.0000087	0.000023
4,000 bbl	0.000000042	0.00000017	0.00000050	0.0000040	0.0000079	0.000021
5,000 bbl	0.000000030	0.00000012	0.00000035	0.0000028	0.0000056	0.000015
8,000 bbl	0.000000027	0.00000011	0.00000033	0.0000026	0.0000051	0.000013
10,000 bbl	0.000000018	0.000000071	0.00000022	0.0000017	0.0000034	0.0000089
15,000 bbl	0.000000014	0.000000054	0.00000017	0.0000013	0.0000026	0.0000068
20,000 bbl	0.0000000051	0.000000020	0.000000061	0.00000048	0.00000096	0.0000025
40,000 bbl	0.00000000051	0.0000000020	0.00000000610	0.000000048	0.000000096	0.00000025
50,000 bbl	0.00000000005	0.00000000020	0.00000000061	0.0000000048	0.0000000096	0.000000025

Table 9: Projected Annual Frequency of CBR Spills into Hudson River (High Estimate)

Spill Volume	Spills/Year (Based on Trains per Year)					
	8 trains Current Diversion	32 trains Occasional Diversion	96 trains Frequent Diversion	780 trains Moderate Historical	1,560 trains Peak Historical	4,015 trains Maximum Hypothetical
<238 bbl	0.000001	0.0000048	0.000014	0.00011	0.00023	0.00058
2,500 bbl	0.00000090	0.0000044	0.000013	0.00010	0.00021	0.00053
4,000 bbl	0.00000083	0.0000040	0.000012	0.000091	0.00019	0.00048
5,000 bbl	0.00000058	0.0000028	0.0000081	0.000064	0.00013	0.00034
8,000 bbl	0.00000054	0.0000026	0.0000075	0.000059	0.00012	0.000311
10,000 bbl	0.00000035	0.0000017	0.0000050	0.000039	0.000082	0.00021
15,000 bbl	0.00000027	0.0000013	0.0000038	0.000030	0.000063	0.00016
20,000 bbl	0.00000010	0.00000048	0.0000014	0.000011	0.000023	0.000058
40,000 bbl	0.000000010	0.000000048	0.00000014	0.0000011	0.0000023	0.0000058
50,000 bbl	0.000000001	0.0000000048	0.000000014	0.00000011	0.00000023	0.00000058

In addition to potential spills of crude oil from loaded CBR trains, there may also be other spills of diesel fuel from locomotives:

- On loaded CBR trains on the western side of the river;

- Empty CBR trains on the western side of the river;
- Other loaded/empty freight trains on either side of the river;
- Long-distance passenger (Amtrak) trains on the eastern side of the river; and
- Commuter trains on the eastern side of the river.

The annual frequency and probability of diesel spills for these different types of trains are summarized in Table 10. With the large number of long-distance passenger and commuter trains, 1 in 3 chance of a diesel locomotive spill along the Hudson River tracks each year. The probabilities of locomotive spills by volume based on current traffic are shown in Table 11.

Table 10: Estimated Annual Frequency of Diesel Locomotive Spills along Hudson River

Train Type	River Side	Annual Spills	Annual Probability	Maximum Spill Volume
Loaded CBR–Current Diversion Transport	West	0.000031	1 in 33,000	525 bbl
Empty CBR–Current Diversion Transport	West	0.000031	1 in 33,000	525 bbl
Loaded CBR–Occasional Diversion Transport	West	0.00012	1 in 8,200	525 bbl
Empty CBR–Occasional Diversion Transport	West	0.00012	1 in 8,200	525 bbl
Loaded CBR–Frequent Diversion Transport	West	0.00037	1 in 2,700	525 bbl
Empty CBR–Frequent Diversion Transport	West	0.00037	1 in 2,700	525 bbl
Loaded CBR–Moderate Historical Transport	West	0.0030	1 in 340	525 bbl
Empty CBR–Moderate Historical Transport	West	0.0030	1 in 340	525 bbl
Loaded CBR–Peak Historical Transport	West	0.0060	1 in 170	525 bbl
Empty CBR–Peak Historical Transport	West	0.0060	1 in 170	525 bbl
Loaded CBR–Maximum Hypothetical Transport	West	0.015	1 in 65	525 bbl
Empty CBR–Maximum Hypothetical Transport	West	0.015	1 in 65	525 bbl
Freight Trains (Mixed Manifest)	West	0.055	1 in 18	525 bbl
Freight Trains (Mixed Manifest)	East	0.023	1 in 43	262 bbl
Amtrak Passenger Trains	East	0.13	1 in 8	124 bbl
Metro-North Commuter Trains	East	0.15	1 in 7	67 bbl
Total (Excluding CBR Trains)	**-**	**0.35**	1 in **3**	**525 bbl**

Table 11: Estimated Annual Hudson River Spills from Diesel Locomotives by Volume

Volume	Annual Spills	Annual Probability
5 bbl	0.078	1 in 13
25 bbl	0.069	1 in 15
40 bbl	0.065	1 in 16
50 bbl	0.043	1 in 23
60 bbl	0.041	1 in 25
70 bbl	0.027	1 in 37
100 bbl	0.020	1 in 49
250 bbl	0.0078	1 in 130
300 bbl or more	0.00078	1 in 1,300
Total	**0.35**	**1 in 3**

Oil Spill Probability from Facilities

The storage of large quantities of oil in tanks at riverside facilities or terminals is another potential source of oil spillage. Spills that occur at facilities will usually be contained with required secondary containment. However, there are circumstances when this containment, which is designed to hold more than the volume of the tanks, may be breached, causing some or all of the spilled oil to enter the river.

There are currently 16 major petroleum storage facilities dotting the Hudson River shorelines storing approximately 144 million gallons (3.5 million barrels, bbl). Individual storage tanks may contain as much as 250,000 to 300,000 bbl of oil. There are 16 facilities that are noted by the US Energy Information Administration as holding *at least* 50,000 bbl.

The projected annual spillage from *existing* facilities is summarized in Table 12.

Table 12: Projected Annual Oil Facility Spills into Hudson River

Spill Volume	Spills/Year	Annual Probability
Any Volume	0.011	1 in 88
≥10 bbl	0.0041	1 in 240
≥238 bbl (Major)	0.00090	1 in 1,100
1–9 bbl	0.0069	1 in 150
10–99 bbl	0.0026	1 in 380
100–999 bbl	0.0012	1 in 830
1,000–9,999 bbl	0.00027	1 in 3,700
10,000–99,999 bbl	0.000028	1 in 36,000
≥100,000 bbl	0.00000080	1 in 1.2 million

Oil Spill Probability from Pipelines

Currently, pipelines are not a very likely source of spillage into the Hudson River study area. There is no crude oil or refined product pipeline crossing the Hudson River study area at this time.

Another factor that could potentially change the nature of crude oil transport in the Northeast and in and along the Hudson River is the construction of the Pilgrim Pipeline. In August 2015, Pilgrim Transportation of New York submitted an application for the construction of two 170-mile parallel interstate pipelines that would run mainly along the New York State Thruway right of way west of the Hudson River. One pipeline would transport crude oil from the Port of Albany south to refineries in Linden, New Jersey, and the second would transport refined petroleum products (gasoline, home heating oil, diesel, and kerosene) north to Albany and points in between. There would be two crossings of the Hudson River at Albany and south of Albany in Glenmont.

The two main pipelines would each be capable of transporting the equivalent of 200,000 bbl of oil per day. This would be the equivalent of two to three CBR trains or one-and-a-half to two tank barges full in each direction. Were the pipeline to be built, and if crude oil transport were still occurring in the Hudson River by tank barge and/or by rail, there may be shifts in the transport patterns, though the degree to which this might occur, if at all, is uncertain.

For the proposed Hudson River Pilgrim Pipeline crossings, there are approximately 0.30 miles of pipeline directly under the river (two crossings covering 0.15 miles each) for each of the crude and refined product lines. In addition, there are approximately 1.8 miles of pipeline on either side of the river that would run within about 1,000 feet of the river. The potential for pipeline spills was calculated as shown in Table 13.

Table 13: Projected Annual Pipeline Spills into Hudson River with Pilgrim Pipeline

Pipeline Volume	Crude Pipeline		Refined Product Pipeline		Total	
	Spills/Year	Annual Probability	Spills/Year	Annual Probability	Spills/Year	Annual Probability
≥10 bbl	0.0023	1 in 440	0.0011	1 in 930	0.0031	1 in 320
≥238 bbl (Major)	0.00060	1 in 1,700	0.00030	1 in 3,300	0.00044	1 in 2,300
<1 bbl	0.0025	1 in 400	0.0012	1 in 840	0.0034	1 in 300
1–9 bbl	0.0025	1 in 400	0.0012	1 in 840	0.0034	1 in 300
10–99 bbl	0.0014	1 in 740	0.00067	1 in 1,500	0.0019	1 in 530
100–999 bbl	0.00074	1 in 1,400	0.00035	1 in 2,800	0.0010	1 in 1,000
1,000–9,999 bbl	0.00019	1 in 5,300	0.000091	1 in 11,000	0.00026	1 in 3,900
≥10,000 bbl	0.000017	1 in 56,000	0.0000081	1 in 120,000	0.000023	1 in 44,000

Other Oil Inputs into the Hudson River

In addition to occasional spills, there are other chronic inputs of oil into the Hudson River, including oil from non-point sources through runoff and dumping of oil. These chronic inputs cannot be effectively removed. The only risk mitigation measures involve the prevention or reduction of these discharges. The estimated annual oil input to the Hudson River from non-point sources and runoff is 60,000 bbl per year.

Another source of chronic oil input is two-stroke engines (personal watercraft and outboard motors), which discharge an estimated 194 bbl into the river each year. Another 1,400 bbl of annual inputs are attributable to operational spillage of lubricating oils from large commercial vessels.

Summary of Oil Spill Probability for Hudson River

The probabilities of oil spills based on *current conditions* are summarized in Table 14 and Figure 2 by volume. The annual probability of a spill of each volume category is shown in Table 15.

Table 14: Annual Frequency of Oil Spills in Hudson River based on Current Conditions

Spill Volume (bbl)	Vessels			Rail		Facilities	Total
	Tank Vessel	Bunkers	Transfers	CBR	Diesel Fuel		
<1	0.48	3.18	0.86	0	0	0	**4.5**
1–9	0.081	0.39	0.22	0	0.078	0.0069	**0.77**
10–99	0.093	0.17	0.108	0	0.25	0.0026	**0.62**
100–999	0.041	0.18	0.011	0.000001	0.029	0.0012	**0.26**
1,000–9,999	0.024	0.12	0.0011	0.0000029	0	0.00027	**0.14**
10,000– 99,999	0.012	0.031	0.00012	0.00000073	0	0.000028	**0.043**
100,000+	0.0000015	0	0	0	0	0.00000080	**0.000002**
Total	**0.73**	**4.1**	**1.2**	**0.0000046**	**0.35**	**0.011**	**6.36**

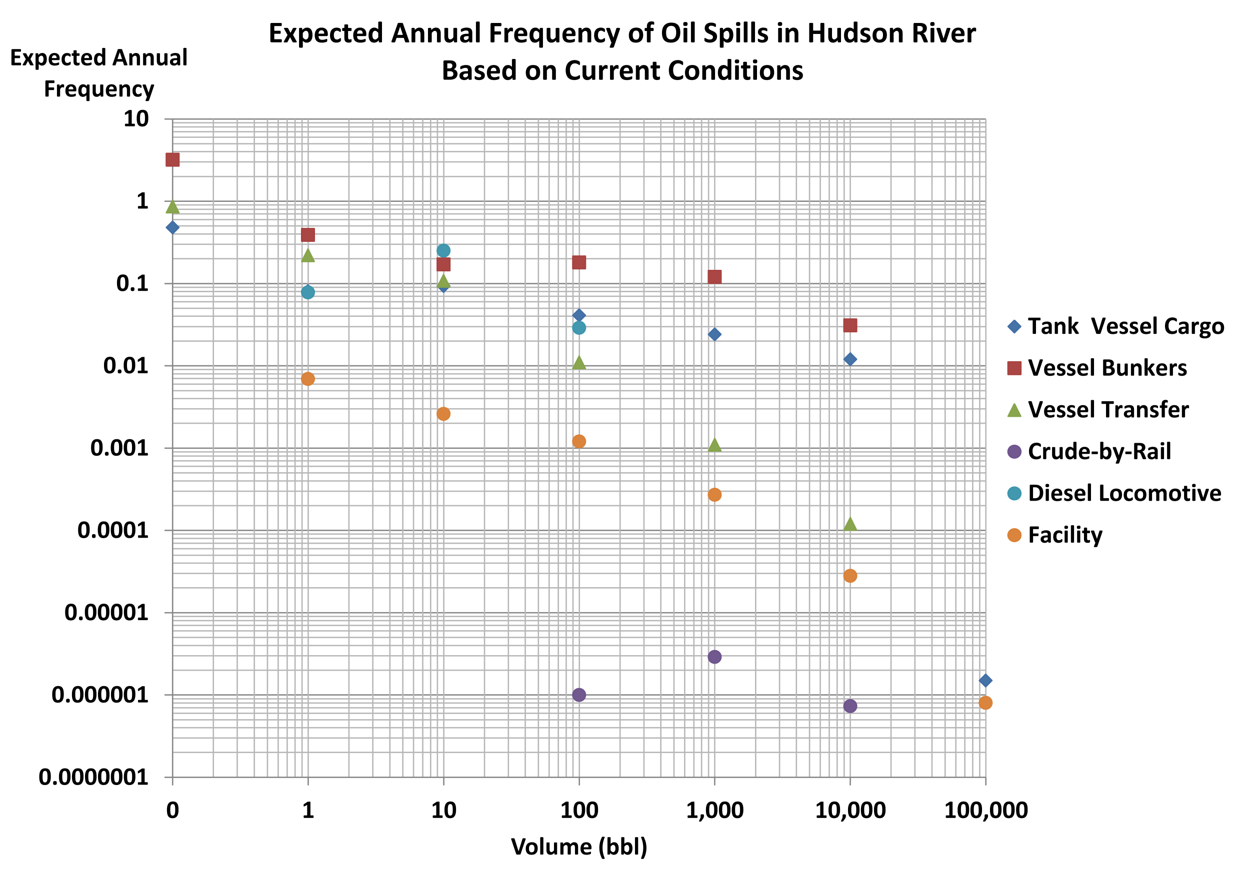

Figure 2: Expected Annual Frequency of Oil Spills in Hudson River (Current Conditions)[3]

Table 15: Annual Probability of Oil Spills in Hudson River based on Current Conditions

Spill Volume (bbl)	Expected Annual Number of Spills	Annual Probability
<1	4.5	4–5 spills per year
1–9	0.77	1 in 1.3
10–99	0.62	1 in 1.6
100–999	0.26	1 in 4
1,000–9,999	0.14	1 in 7
10,000– 99,999	0.043	1 in 23
100,000+	0.000002	1 in 500,000
Total	**6.36**	**6 spills per year**

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[3] Note logarithmic scales.

Potential Oil Spillage in Hudson River: Tank and Non-Tank Vessels

The commercial vessel traffic on the Hudson River is the most likely source of oil spillage on the Hudson River. This includes both tank vessels (those carrying oil as cargo, as well as for fuel) and non-tank vessels (those that carry oil only as bunker fuel).

Hudson River Waterborne Commerce

Vessel traffic data in terms of tonnage transported on the Hudson River over the last 23 years (1993 through 2016)[4] are shown in Figure 3. The overall tonnage transported on the Hudson River has fluctuated over the 23-year time period of 1993 through 2016, averaging about 15.8 million tons per year (Table 16). During this time an average of 54% of the tonnage was petroleum (crude oil and refined petroleum products), and 4.2% of this was crude oil. 2016 shows the decrease in crude oil transport.

During the 2011 through 2015 time period, there was an overall reduction in tonnage by 6% from the previous five-year period. At the same time, there was a reduction in non-petroleum tonnage by 29% to 5.5 million tons per year. There was a large increase in the transport of crude oil from none transported in the previous five years to over three million tons annually in 2011-2015. In previous years (1993-2010), there were only a total of 222,000 tons of crude oil transported (Figure 4). While the proportion of oil (both crude and refined petroleum) as part of the overall commodities transported by vessel on the Hudson River has increased from 52% (averaged over 1993 through 2009) to 62% (averaged over 2010 through 2015), the overall tonnage of commodities decreased after a peak in the late 1990s (Figure 5).

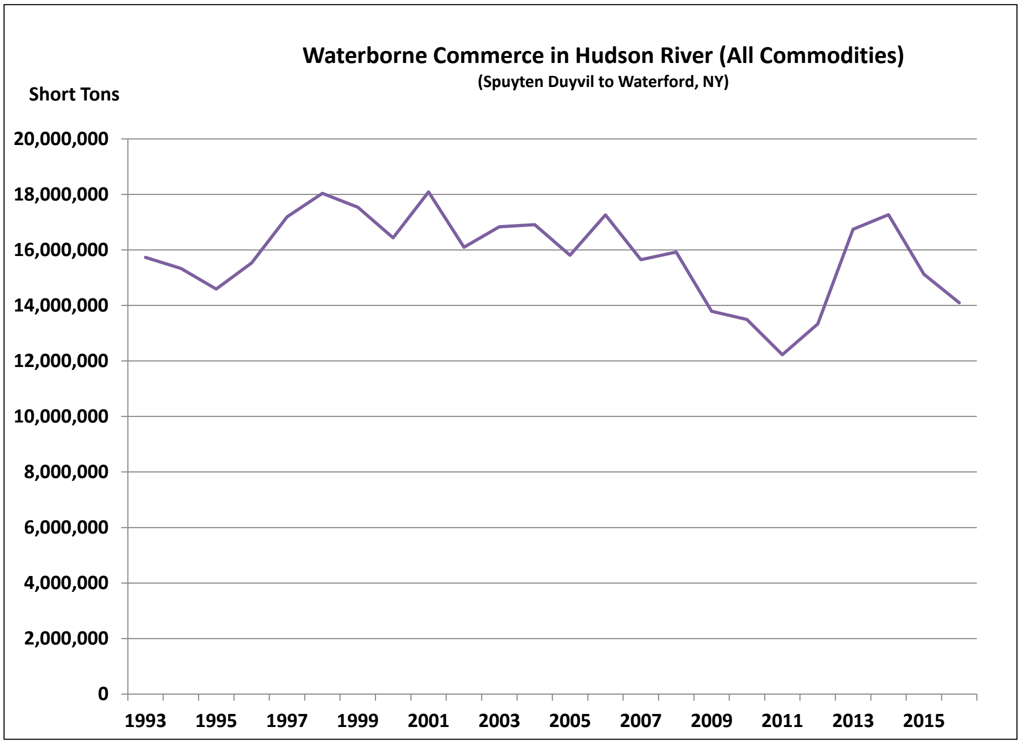

Figure 3: Total Annual Waterborne Commerce on Hudson River (1993-2016)

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[4] http://www.navigationdatacenter.us/index.htm

Table 16: Waterborne Commerce for Hudson River 1993–2016[5]

Year	Annual Tonnage (Short Tons)					% Oil Tonnage[6]
	Non-Petroleum	Crude Oil	Refined Petroleum	Total Petroleum[7]	All Commodities	
1993	7,454,000	132,000	8,144,000	**8,276,000**	**15,730,000**	52.6%
1994	7,654,000	12,000	7,666,000	**7,678,000**	**15,332,000**	50.1%
1995	7,415,000	0	7,174,000	**7,174,000**	**14,589,000**	49.2%
1996	8,009,000	0	7,520,000	**7,520,000**	**15,529,000**	48.4%
1997	8,017,000	62,000	9,110,000	**9,172,000**	**17,189,000**	53.4%
1998	8,324,000	0	9,710,000	**9,710,000**	**18,034,000**	53.8%
1999	8,703,000	0	8,831,000	**8,831,000**	**17,534,000**	50.4%
2000	7,605,000	0	8,828,000	**8,828,000**	**16,433,000**	53.7%
2001	8,764,000	2,000	9,319,000	**9,321,000**	**18,085,000**	51.5%
2002	7,513,000	0	8,583,000	**8,583,000**	**16,096,000**	53.3%
2003	7,477,000	3,000	9,354,000	**9,357,000**	**16,834,000**	55.6%
2004	7,151,000	11,000	9,747,000	**9,758,000**	**16,909,000**	57.7%
2005	6,463,000	0	9,342,000	**9,342,000**	**15,805,000**	59.1%
2006	8,572,000	0	8,691,000	**8,691,000**	**17,263,000**	50.3%
2007	8,047,000	0	7,597,000	**7,597,000**	**15,644,000**	48.6%
2008	8,870,000	0	7,055,000	**7,055,000**	**15,925,000**	44.3%
2009	6,303,000	0	7,485,000	**7,485,000**	**13,788,000**	54.3%
2010	6,959,000	0	6,537,000	**6,537,000**	**13,496,000**	48.4%
2011	6,423,000	36,000	5,767,000	**5,803,000**	**12,226,000**	47.5%
2012	5,648,000	1,790,000	5,894,000	**7,684,000**	**13,332,000**	57.6%
2013	4,902,000	5,526,000	6,315,000	**11,841,000**	**16,743,000**	70.7%
2014	5,881,000	4,536,000	6,848,000	**11,384,000**	**17,265,000**	65.9%
2015	4,545,000	3,178,000	7,400,000	**10,578,000**	**15,123,000**	69.9%
2016	6,793,000	721,000	6,585,000	**7,306,000**	**14,099,000**	51.8%
Total 1993-2016	**173,492,000**	**15,288,000**	**182,917,000**	**198,205,000**	**364,904,000**	**54.3%**
Grand Average	**7,228,833**	**667,042**	**7,895,917**	**8,562,958**	**15,791,792**	**54.2%**
Avg 1993-1995	**7,507,667**	**48,000**	**7,661,333**	**7,709,333**	**15,217,000**	**50.6%**
Avg 1996-2000	**8,131,600**	**12,400**	**8,799,800**	**8,812,200**	**16,943,800**	**51.9%**
Avg 2001-2005	**7,473,600**	**3,200**	**9,269,000**	**9,272,200**	**16,745,800**	**55.4%**
Avg 2006-2010	**7,750,200**	**0**	**7,473,000**	**7,473,000**	**15,223,200**	**49.2%**
Avg 2011-2015	**5,479,800**	**3,013,200**	**6,444,800**	**9,458,000**	**14,937,800**	**62.3%**

At the same time in 2011-2015, there was a decrease in the transport of refined petroleum products on the Hudson River from an average of 7.5 million tons per year to an average of 6.4 million tons. For the years

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[5] Army Corps of Engineers data for Hudson River between Spuyten Duyvil (Harlem River) and Waterford, NY.

[6] Percent of the total tonnage comprised of petroleum (crude plus refined petroleum).

[7] Excludes petroleum coke and liquefied hydrocarbons, which are excluded for this study is that these substances are not included in the definitions of persistent and non-persistent oil as in 33 CFR 155.1020. These commodities are included in the total commodities.

2013 through 2015, the total amount of petroleum transported increased abruptly by 38%. Of the petroleum transported, the percentage of crude oil was 47% in 2013 but then dropped to 30% by 2015, and to less than 10% by 2016. During these years, total tonnage of commodities transported had increased by 19% from the previous five-year period, but was roughly equivalent to the average tonnage transported during the early 2000s. The reduction during 2009–2012 may be attributable to the overall economic conditions at the time.

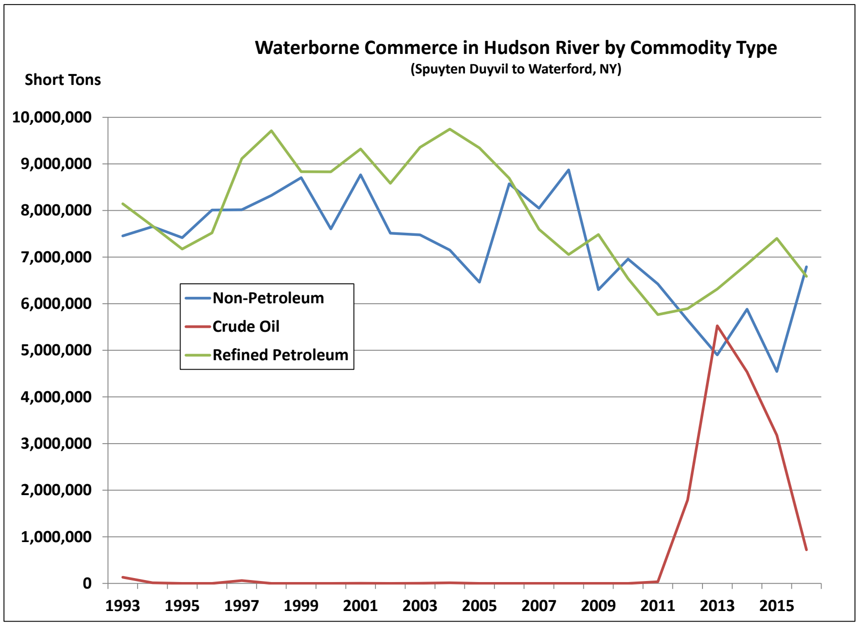

Figure 4: Annual Waterborne Commerce on Hudson River by Commodity Type

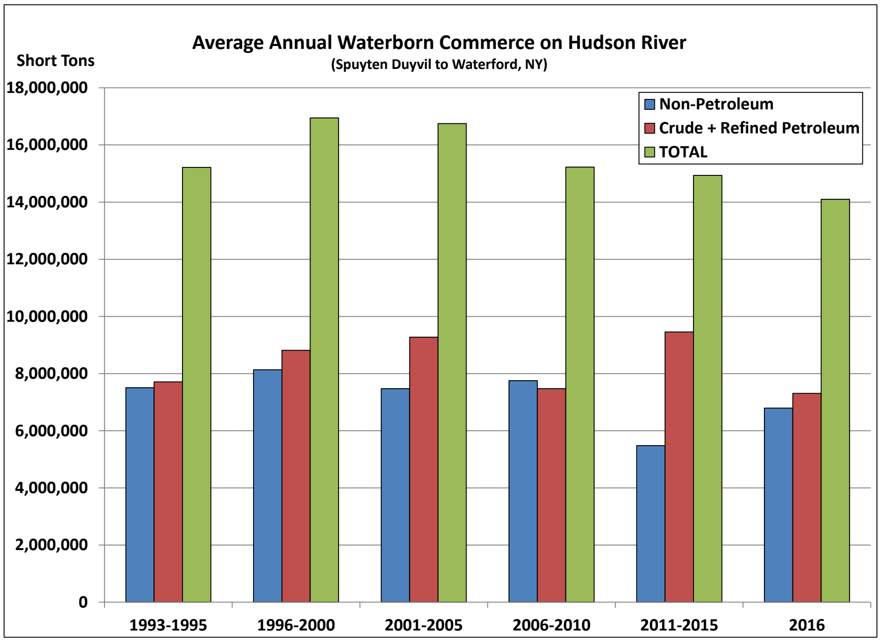

Figure 5: Average Annual Waterborne Commerce on Hudson River by Commodity Type

Vessel Trip Transit Analysis

Vessel trips (or transits) up and down the river for the years 1994 through 2016[8] are shown in Figure 6 for all commodities and Figure 7 by commodity type. Overall, the trips that involved oil-carrying tank vessels averaged 12.6%. In the years 2013 through 2016, the percentage averaged 15.7%.

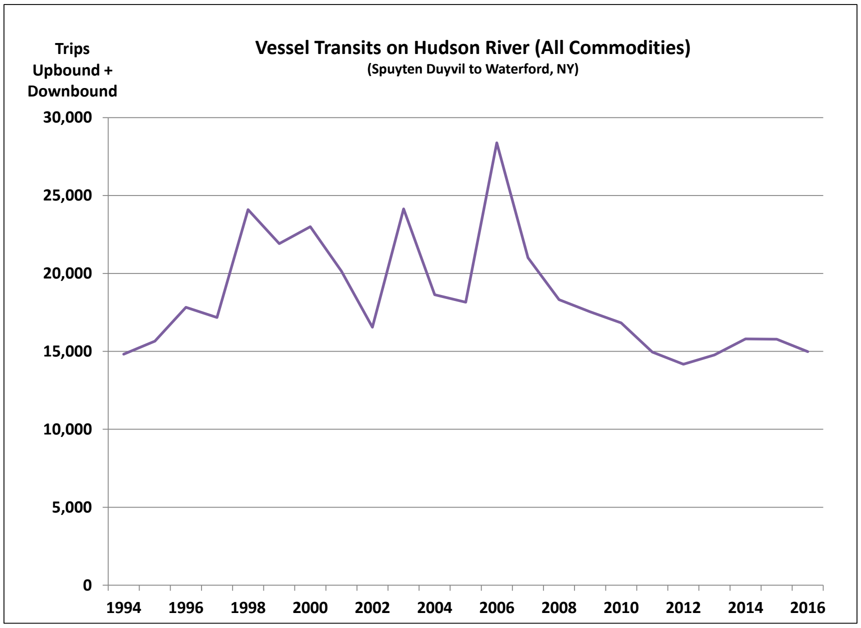

Figure 6: Annual Vessel Transits on Hudson River (All Commodities)

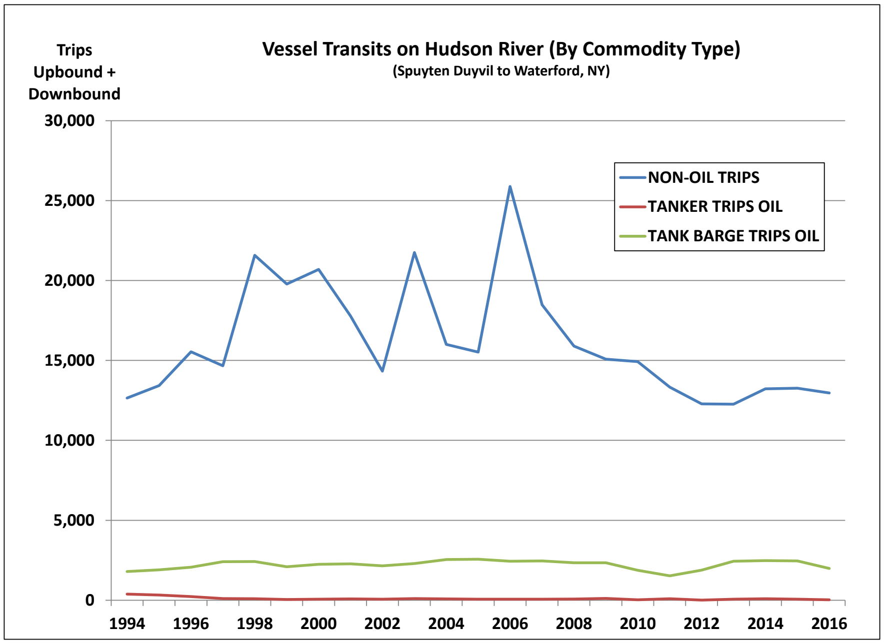

Figure 7: Annual Vessel Transits on Hudson River by Commodity (1994-2015)

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[8] Data for 1993 were not available.

It is important to bear in mind that the tank vessels are only filled with oil on *half* of their trips. Loaded trips by tanker and tank barge are shown in Figure 8. Tanker trips have decreased since a high in 1994 to 1995. Tank barge trips have increased again in the last few years after a significant drop in 2010 to 2012. In the mid-1990s, 10% to 17% of the tank vessel trips involved tankers. By 1997, this had shifted to an average of 3% tankers with 97% of the trips involved tank barges, generally in the form of articulated tank barges (ATBs) or individual pulled tank barges. Annual vessel trip data are shown in Table 17.

Table 17: Vessel Trips on Hudson River Spuyten Duyvil (Harlem River) to Waterford, NY

Year	**Transits (Upbound & Downbound)**				**Loaded Oil Tank Vessel Transits**		
	Non-Oil	**Oil Tanker**	**Oil Tank Barge**	**Total**	**Tanker**	**Tank Barge**	**Total**
1994	12,643	380	1,799	**14,822**	190	900	**1,090**
1995	13,426	327	1,902	**15,655**	164	951	**1,115**
1996	15,539	228	2,062	**17,829**	114	1,031	**1,145**
1997	14,663	103	2,409	**17,175**	52	1,205	**1,256**
1998	21,578	91	2,426	**24,095**	46	1,213	**1,259**
1999	19,780	43	2,090	**21,913**	22	1,045	**1,067**
2000	20,690	62	2,244	**22,996**	31	1,122	**1,153**
2001	17,783	88	2,279	**20,150**	44	1,140	**1,184**
2002	14,330	63	2,154	**16,547**	32	1,077	**1,109**
2003	21,746	108	2,292	**24,146**	54	1,146	**1,200**
2004	16,001	83	2,551	**18,635**	42	1,276	**1,317**
2005	15,523	68	2,566	**18,157**	34	1,283	**1,317**
2006	25,881	64	2,438	**28,383**	32	1,219	**1,251**
2007	18,483	63	2,461	**21,007**	32	1,231	**1,262**
2008	15,893	79	2,346	**18,318**	40	1,173	**1,213**
2009	15,078	116	2,349	**17,543**	58	1,175	**1,233**
2010	14,922	31	1,872	**16,825**	16	936	**952**
2011	13,334	91	1,527	**14,952**	46	764	**809**
2012	12,281	13	1,883	**14,177**	7	942	**948**
2013	12,262	63	2,445	**14,770**	32	1,223	**1,254**
2014	13,225	95	2,479	**15,799**	48	1,240	**1,287**
2015	13,261	64	2,460	**15,785**	32	1,230	**1,262**
2016	12,961	27	1,993	**14,981**	14	997	**1,010**
Total 1994-2016	**371,283**	**2,350**	**51,027**	**424,660**	**1,175**	**25,514**	**26,689**
Grand Average	**18,463**	**102**	**2,219**	**18,463**	**51**	**1,109**	**1,160**
Avg 1994-1995	**13,035**	**354**	**1,851**	**15,239**	**177**	**926**	**1,103**
Avg 1996-2000	**18,450**	**105**	**2,246**	**20,802**	**53**	**1,123**	**1,176**
Avg 2001-2005	**17,077**	**82**	**2,368**	**19,527**	**41**	**1,184**	**1,225**
Avg 2006-2010	**18,051**	**71**	**2,293**	**20,415**	**36**	**1,147**	**1,182**
Avg 2011-2015	**12,873**	**65**	**2,159**	**15,097**	**33**	**1,080**	**1,112**
Avg 2013-2016	**12,927**	**62**	**2,461**	**15,334**	**31**	**1,172**	**1,203**

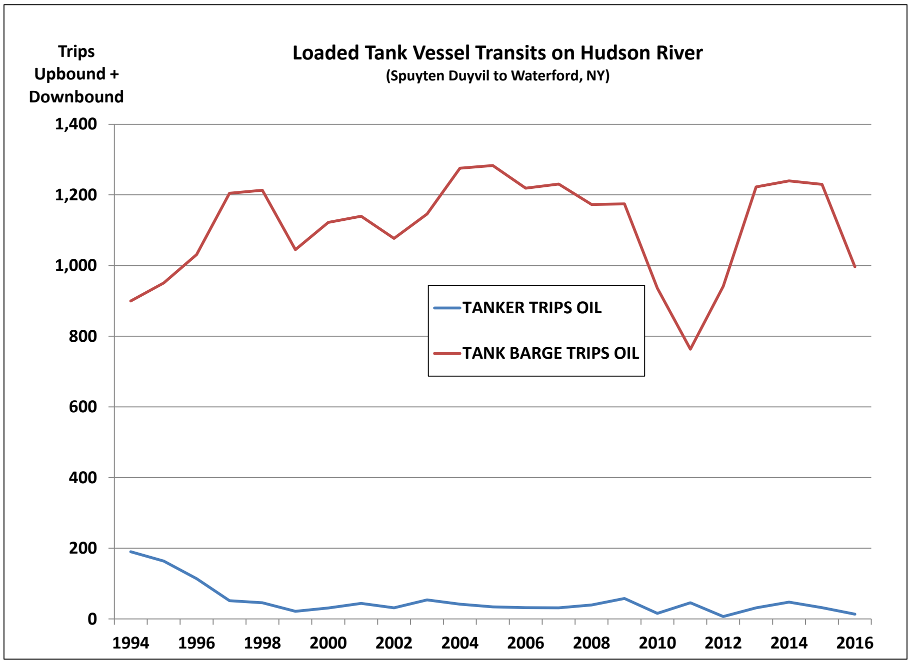

Figure 8: Annual Loaded Tank Vessel Transits on Hudson River (1994-2016)

The total number of loaded oil trips averaged 1,161 per year, or about three per day. (Note that there were seasonal variations in this.) The number of trips has fluctuated around the mean to a high of 1,262 and a low of 809. The number in 2015 is the same as in 2007 (Figure 9).

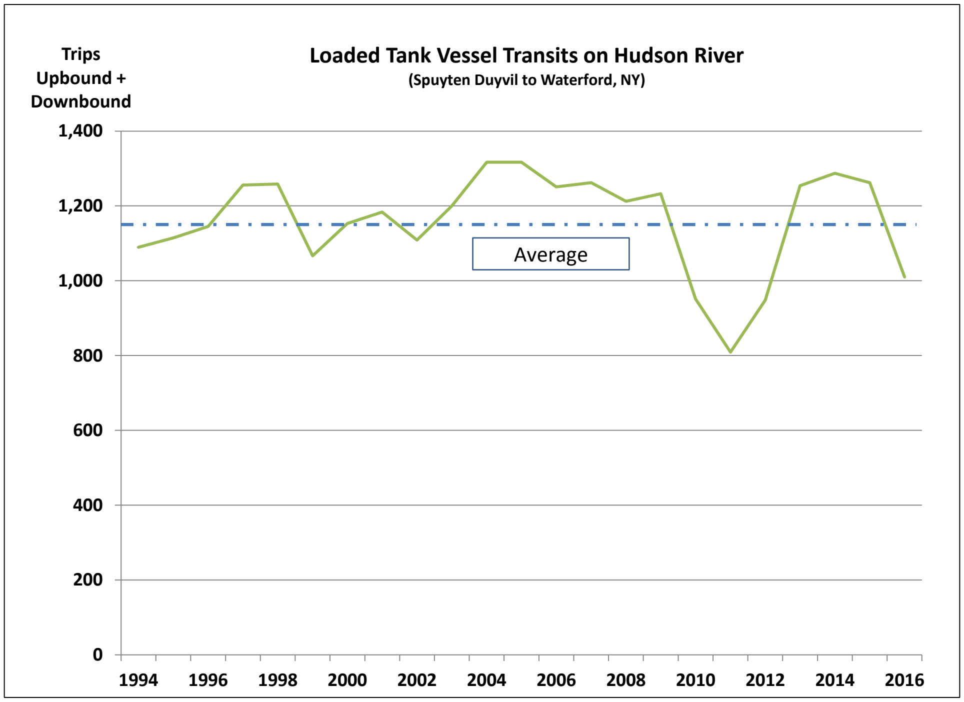

Figure 9: Loaded Oil Tank Vessel Transits on Hudson River (1994-2016)

A comparison between the annual number of loaded tank vessels carrying oil on the Hudson River and the average number of tank vessels (1994-2016) is shown in Table 18.

Table 18: Comparison between Annual and Average Tank Vessel Transits

Year	Tanker		Tank Barge		Total Tank Vessel	
	Transits	Transits/Average	Transits	Transits/Average	Transits	Transits/Average
1994	190	268.6%	900	-19.4%	**1,090**	**-6.6%**
1995	164	217.6%	951	-14.8%	**1,115**	**-4.5%**
1996	114	119.6%	1,031	-7.6%	**1,145**	**-1.9%**
1997	52	-2.0%	1,205	8.1%	**1,256**	**7.7%**
1998	46	-13.7%	1,213	8.8%	**1,259**	**7.9%**
1999	22	-60.8%	1,045	-6.3%	**1,067**	**-8.6%**
2000	31	-43.1%	1,122	0.6%	**1,153**	**-1.2%**
2001	44	-17.6%	1,140	2.3%	**1,184**	**1.5%**
2002	32	-41.2%	1,077	-3.4%	**1,109**	**-5.0%**
2003	54	2.0%	1,146	2.8%	**1,200**	**2.8%**
2004	42	-21.6%	1,276	14.5%	**1,317**	**12.9%**
2005	34	-37.3%	1,283	15.1%	**1,317**	**12.9%**
2006	32	-41.2%	1,219	9.4%	**1,251**	**7.2%**
2007	32	-41.2%	1,231	10.5%	**1,262**	**8.2%**
2008	40	-25.5%	1,173	5.2%	**1,213**	**4.0%**
2009	58	9.8%	1,175	5.4%	**1,233**	**5.7%**
2010	16	-72.5%	936	-16.1%	**952**	**-18.5%**
2011	46	-13.7%	764	-31.6%	**809**	**-30.8%**
2012	7	-90.2%	942	-15.6%	**948**	**-18.9%**
2013	32	-41.2%	1,223	9.7%	**1,254**	**7.5%**
2014	48	-9.8%	1,240	11.3%	**1,287**	**10.3%**
2015	32	-41.2%	1,230	10.4%	**1,262**	**8.2%**
2016	14	-76.5%	997	-10.6%	**1,011**	**-13.4%**

Types of Vessels in Hudson River

The US Army Corps of Engineers Waterborne Commerce vessel trip data for the year 2015 for the Hudson River (north of Spuyten Duyvil) were analyzed to determine the numbers of vessels by type and draft category, as summarized in Table 19. *(Note that tank barges, such as those that carry oil, are considered "non-self-propelled tankers.")* Deep-draft vessel numbers are shaded in red, shallow-draft vessels are in green. This year was selected for the data as it represents the vessel traffic that was typical of the years 2013-2015, before there was a 20% reduction in oil tank vessel traffic, as these were the data to be used for determining vessel casualty rates.

The most common type of vessel is a shallow dry cargo ship. Sixteen percent of the trips involve tank vessels. The percentages of the various types of vessels are shown in Table 20. The summary of vessel types by draft and type is shown in Table 21. Less than 2% of the vessels that transit this part of the river are foreign-flagged. About 91% of the transits are of shallow-draft vessels (14 feet or less).

Table 19: 2015 Vessel Traffic by Type/Draft for Hudson River (Spuyten Duyvil to Waterford)

Draft (ft)	Upbound Trips						Downbound Trips					
	Total Up	Self-Propelled			Non-Propelled		Total Down	Self-Propelled			Non-Propelled	
		Dry Cargo	Tanker	Tow Tug	Dry Cargo	Tanker		Dry Cargo	Tanker	Tow Tug	Dry Cargo	Tanker
Grand Total	**7,892**	**3,987**	**32**	**1,201**	**1,442**	**1,230**	**7,893**	**3,988**	**32**	**1,200**	**1,443**	**1,230**
FOREIGN												
Total	**136**	**104**	**32**	**0**	**0**	**0**	**143**	**111**	**32**	**0**	**0**	**0**
37	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
36	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**
33	**2**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
31	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
30	**25**	**22**	**3**	**0**	**0**	**0**	**7**	**7**	**0**	**0**	**0**	**0**
29	**6**	**3**	**3**	**0**	**0**	**0**	**15**	**2**	**13**	**0**	**0**	**0**
28	**6**	**4**	**2**	**0**	**0**	**0**	**5**	**3**	**2**	**0**	**0**	**0**
27	**2**	**2**	**0**	**0**	**0**	**0**	**6**	**5**	**1**	**0**	**0**	**0**
26	**7**	**7**	**0**	**0**	**0**	**0**	**14**	**14**	**0**	**0**	**0**	**0**
25	**23**	**7**	**16**	**0**	**0**	**0**	**13**	**8**	**5**	**0**	**0**	**0**
24	**12**	**11**	**1**	**0**	**0**	**0**	**14**	**12**	**2**	**0**	**0**	**0**
23	**11**	**9**	**2**	**0**	**0**	**0**	**14**	**12**	**2**	**0**	**0**	**0**
22	**19**	**19**	**0**	**0**	**0**	**0**	**15**	**11**	**4**	**0**	**0**	**0**
21	**9**	**7**	**2**	**0**	**0**	**0**	**9**	**8**	**1**	**0**	**0**	**0**
20	**4**	**4**	**0**	**0**	**0**	**0**	**6**	**6**	**0**	**0**	**0**	**0**
19	**3**	**3**	**0**	**0**	**0**	**0**	**6**	**6**	**0**	**0**	**0**	**0**
18	**3**	**3**	**0**	**0**	**0**	**0**	**6**	**5**	**1**	**0**	**0**	**0**
16	**1**	**1**	**0**	**0**	**0**	**0**	**3**	**3**	**0**	**0**	**0**	**0**
15	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**5**	**0**	**0**	**0**	**0**
14	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**4**	**0**	**0**	**0**	**0**
DOMESTIC (US-FLAGGED)												
Total	**7,756**	**3,883**	**0**	**1,201**	**1,442**	**1,230**	**7,750**	**3,877**	**0**	**1,200**	**1,443**	**1,230**
30	**8**	**0**	**0**	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**0**	**0**
29	**0**	**0**	**0**	**0**	**0**	**0**	**21**	**0**	**0**	**0**	**0**	**21**
28	**4**	**0**	**0**	**0**	**0**	**4**	**10**	**0**	**0**	**0**	**0**	**10**
27	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**
26	**0**	**0**	**0**	**0**	**0**	**0**	**30**	**0**	**0**	**0**	**15**	**15**
25	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**	**0**
24	**14**	**0**	**0**	**0**	**0**	**14**	**42**	**0**	**0**	**0**	**2**	**40**
23	**48**	**0**	**0**	**0**	**0**	**48**	**18**	**0**	**0**	**0**	**2**	**16**
22	**109**	**0**	**0**	**0**	**0**	**92**	**105**	**0**	**0**	**0**	**4**	**101**
32	**53**	**0**	**0**	**0**	**0**	**53**	**18**	**0**	**0**	**0**	**3**	**15**
20	**117**	**0**	**0**	**0**	**17**	**100**	**41**	**0**	**0**	**0**	**17**	**24**

Table 19: 2015 Vessel Traffic by Type/Draft for Hudson River (Spuyten Duyvil to Waterford)

Draft (ft)	Upbound Trips						Downbound Trips					
	Total Up	Self-Propelled			Non-Propelled		Total Down	Self-Propelled			Non-Propelled	
		Dry Cargo	Tanker	Tow Tug	Dry Cargo	Tanker		Dry Cargo	Tanker	Tow Tug	Dry Cargo	Tanker
19	50	0	0	18	27	5	26	0	0	16	2	8
18	72	0	0	2	7	63	17	0	0	3	4	10
17	63	0	0	16	2	45	32	0	0	23	2	7
16	93	0	0	75	3	15	100	0	0	75	21	4
15	40	0	0	17	0	23	29	0	0	18	2	9
14	49	0	0	4	0	45	12	0	0	5	3	4
13	92	0	0	83	3	6	33	0	0	31	2	0
≤12	6,944	3,883	0	986	1,366	709	7,210	3,877	0	1,029	1,358	946

Table 20: 2015 Percentages of Vessels by Draft and Type

Vessel Type	Number	Percent Total
Dry Cargo Ship (Shallow)	7,764	49.2%
Dry Cargo Barge (Shallow)	2,732	17.3%
Tow/Tug (Shallow)	2,138	13.5%
Tank Barge (Shallow)	1,710	10.8%
Tank Barge (Deep)	750	4.8%
Tow/Tug (Deep)	263	1.7%
Dry Cargo Ship (Deep)	211	1.3%
Dry Cargo Barge (Deep)	153	1.0%
Tanker (Deep)	64	0.4%

Table 21: 2015 Deep/Shallow Draft Trips in Hudson River (Spuyten Duyvil to Waterford)

Vessel Type	Deep-Draft (>14 ft) Upbound + Downbound Trips			Shallow-Draft (≤14 ft) Upbound + Downbound Trips			Grand Total
	Foreign	Domestic	Total	Foreign	Domestic	Total	
Dry Cargo Ship	211	0	**211**	4	7,760	**7,764**	**7,975**
Tanker	64	0	**64**	0	0	**0**	**64**
Tow/Tug	0	263	**263**	0	2,138	**2,138**	**2,401**
Dry Cargo Barge	0	153	**153**	0	2,732	**2,732**	**2,885**
Tank Barge	0	750	**750**	0	1,710	**1,710**	**2,460**
Total	**275**	**1,166**	**1,441**	**4**	**14,340**	**14,344**	**15,785**

Types of Oil Spills from Vessels

There are several types of vessel-related oil spills that could conceivably occur, including ones caused by:

- Impact accidents (groundings, collisions, and allisions[9]);
- Operational errors during transit;
- Equipment malfunctions;
- Structural failures (e.g., crack in hull);
- Operational errors during fuel or cargo transfers; and
- Intentional dumping.

Each type of incident has a different probability of occurrence and a different probability distribution of potential spill volumes.

Relationship between Vessel Casualties and Spills

Vessel accidents or casualties present the potential for the loss of human life, human injury, environmental damage, and socioeconomic damage. It is important to remember that in order for a significant spill to occur, a number of sequential events need to occur (Figure 10).

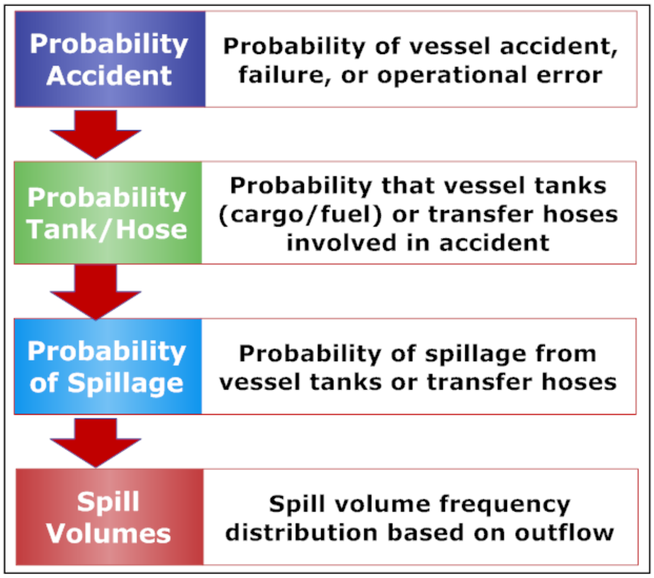

Figure 10: General Approach to Calculating Probabilities of Vessel Spills

Each of these events has a probability and the probability of the final event–a worst-case discharge (or large spill) with significant impacts–is the product of all of those probabilities. (The probabilities are multiplied together.) The sequence of events, each with different probabilities, is:

1. A situation that could cause an accident occurs (e.g., two vessels encounter each other in poor visibility; a vessel operator makes an error in judgment; or a mechanical malfunction occurs in a vital vessel system, such as steering).

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[9] The difference between an allision and a collision is that for an allision to occur one of the two objects needs to be stationary, and in a collision, both objects are moving. Two vessels in motion may collide with each other. A vessel in motion may allide with a pier or another vessel that is stationary.

2. The vessel operator(s) fail to make a corrective maneuver or otherwise correct the situation to avoid a failure, so that the accident occurs.
3. The accident has to be of sufficient magnitude to cause damage to the vessel(s).
4. The vessel has to be sufficiently damaged to cause a breach in the cargo and/or fuel/bunker tanks (through double hulls);
5. The vessel (if a tanker) has to be in a loaded state rather than in ballast;
6. The damage to the tank(s) need to be great enough to cause large quantities (or all) of the fuel and/or oil cargo to escape into the water;
7. The wind, weather, and current conditions have to be such that the spilled oil is transported to environmental/natural and/or socioeconomic resources that are the most vulnerable; and
8. The timing of the incident needs to such that these resources at their highest vulnerability (e.g., during bird nesting season, sturgeon spawning, or tourism season).

The probabilities of each of these events will largely be based on the particular circumstances of each spill scenario. The overall approach to calculating the probability of a spill and the volume of that spill is summarized in Figure 11.

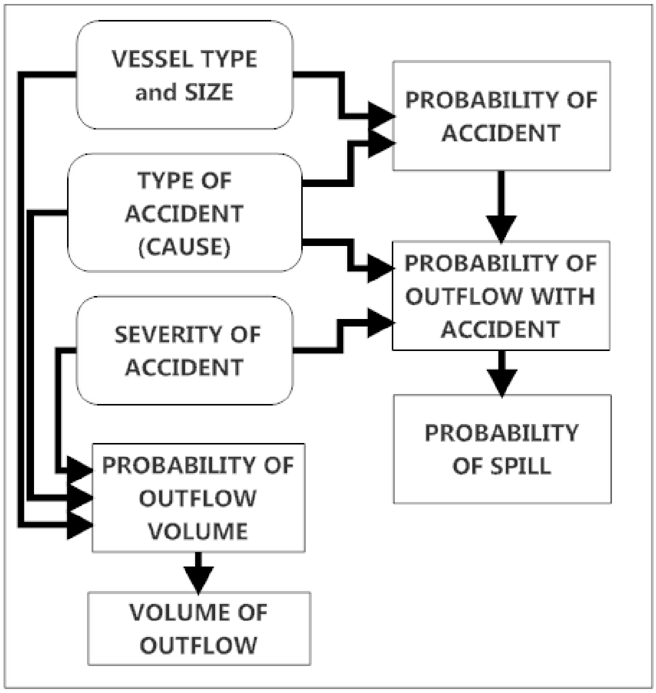

Figure 11: General Approach to Vessel Spill Analysis

Vessel Casualty Rates for Hudson River

Available historical data for vessel casualties in the Hudson River study area for the years 2002 through 2015 indicate that there were 162 vessel casualties involving commercial vessels, 16 of which resulted in spillage. There were also 21 spill incidents that were not attributed to a reportable casualty (accident or vessel failure). These were assumed to be minor spills. The locations of the incidents are shown in Figure

12. A more breakdown of the incidents is shown in Table 22.[10] The same data were used to calculate spillage rates (spills/incident) (Table 23). On average, only 6.4% of vessel casualties result in oil spillage.

Figure 12: Locations of Vessel Casualties/Groundings in the Hudson River (2002-2015)[11]

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[10] Data on recreational vessel incidents were not included; there is a separate analysis of recreational vessel spillage.

[11] USCG Marine Information for Safety and Law Enforcement (MISLE) data (for late 2001 through mid-2015). All reported casualties on left; groundings only on right.

Table 22: Commercial Vessel Casualties in Hudson River Study Area (2002-2015)

Casualty Type	Incident Number by Vessel Type						
	Tank Barge	Tanker	Cargo Ship	Freight Barge	Industrial Vessel	Towing Vessel	Passenger Ship
Allisions	**5**	**1**	**1**	**7**	**1**	**7**	**15**
With Spill	0	0	0	0	0	0	1
No Spill	5	1	1	7	1	7	14
Collisions	**0**	**0**	**0**	**2**	**0**	**0**	**0**
With Spill	0	0	0	0	0	0	0
No Spill	0	0	0	2	0	0	0
Grounding	**10**	**2**	**4**	**2**	**7**	**2**	**5**
With Spill	2	1	1	0	0	0	0
No Spill	8	1	3	2	7	2	5
Equipment Failure	**0**	**0**	**1**	**0**	**0**	**2**	**5**
With Spill	0	0	0	0	0	0	0
No Spill	0	0	1	0	0	2	5
Fire	**0**	**0**	**0**	**0**	**0**	**3**	**1**
With Spill	0	0	0	0	0	0	0
No Spill	0	0	0	0	0	3	1
Structural Failure	**8**	**0**	**7**	**7**	**3**	**34**	**13**
With Spill	2	0	1	0	0	1	0
No Spill	6	0	6	7	3	33	13
All Casualties	**23**	**3**	**13**	**18**	**11**	**48**	**40**
With Spill	4	1	2	0	0	1	2
No Spill	19	2	11	18	11	47	38
Spills–No Casualty[12]	**3**	**1**	**1**	**5**	**0**	**6**	**5**

Table 23: Commercial Vessel Spills per Casualty in Hudson River Study Area (2002-2015)

Casualty Type	Spill Rate (Spills/Incident) by Vessel Type							
	Tank Barge	Tanker	Cargo Ship	Freight Barge	Indust. Vessel	Towing Vessel	Pass. Ship	Total
Allisions	0.000	0.000	0.000	0.000	0.000	0.000	0.067	**0.027**
Collisions	-	-	-	0.000	-	-	-	**0.000**
Grounding	0.200	0.500	0.250	0.000	0.000	0.000	0.000	**0.125**
Equip Failure	-	-	0.000	-	-	0.000	0.000	**0.000**
Fire	-	-	-	-	-	0.000	0.000	**0.000**
Struct Failure	0.250	-	0.143	0.000	0.000	0.029	0.000	**0.056**
All Casualties	**0.174**	**0.333**	**0.154**	**0.000**	**0.000**	**0.021**	**0.050**	**0.064**

Based solely on these data for the Hudson River study area, paired with corresponding vessel transits (as in Table 19 through Table 21), the per-transit casualty data was calculated as shown in Table 24. Freight

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[12] Spills reported with no precipitating cause related to a casualty (accident or failure).

barges were combined with industrial vessels. Passenger ships were not included as there were no reliable data on passenger ship transits. The annual casualty rates are shown in Table 25.

Table 24: Per-Transit Casualty Rates for Hudson River Study Area (2002-2015)

Vessel Type	Per-Transit Casualty Rate							
	Allision	Collision	Grounding	Equip Failure	Fire	Structural Failure	Any Casualty[13]	Minor Spill
Tank Barge	0.00015	0.00	0.00030	0.00	0.00	0.00024	**0.00069**	0.000090
Tanker	0.0012	0.00	0.0023	0.00	0.00	0.00	**0.0035**	0.0012
Cargo Ship	0.0000093	0.00	0.000037	0.0000093	0.00	0.000065	**0.00012**	0.0000093
Freight Barge	0.00021	0.000051	0.00023	0.00	0.00	0.00026	**0.00075**	0.00013
Towing Vessel	0.00022	0.00	0.000062	0.000062	0.000093	0.0010	**0.0015**	0.00019
Average	**0.00036**	**0.000010**	**0.00059**	**0.000014**	**0.000019**	**0.00031**	**0.0013**	**0.00032**

Table 25: Annual Casualty Rates for Hudson River Study Area (2002-2015)

Vessel Type	Annual Casualty Rate (Annual Probability)[14]							
	Allision	Collision	Grounding	Equip Failure	Fire	Structural Failure	Any Casualty[15]	Minor Spill
Tank Barge	0.37 (1 in 2.7)	0.00	0.74 (1 in 1.4)	0.00	0.00	0.59 (1 in 1.7)	**1.7 (1 in 0.56)**	0.22 (1 in 4.5)
Tanker	0.074 (1 in 14)	0.00	0.15 (1 in 6.8)	0.00	0.00	0.00	**0.22 (1 in 4.5)**	0.074 (1 in 14)
Cargo Ship	0.074 (1 in 14)	0.00	0.30 (1 in 3.4)	0.074 (1 in 14)	0.00	0.52 (1 in 1.9)	**0.96 (1 in 1.04)**	0.074 (1 in 14)
Freight Barge	0.59 (1 in 1.7)	0.15 (1 in 6.8)	0.67 (1 in 1.5)	0.00	0.00	0.074 (1 in 14)	**2.1 (1 in 0.5)**	0.37 (1 in 2.7)
Towing Vessel	0.52 (1 in 1.9)	0.00	0.15 (1 in 6.8)	0.15 (1 in 6.8)	0.22 (1 in 4.5)	2.5 (1 in 0.4)	**3.6 (1 in 0.28)**	0.44 (1 in 2.3)
Any Vessel	**1.6 (1 in 0.6)**	**0.15 (1 in 6.8)**	**2.0 (1 in 0.5)**	**0.22 (1 in 4.5)**	**0.22 (1 in 4.5)**	**4.4 (1 in 0.23)**	**8.6 (1 in 0.12)**	**1.2 (1 in 0.8)**

The casualty rates that are "0.00" indicate only that this type of casualty did not occur during the time period of 2002 through 2015. This does not indicate that it would be impossible for such an event to occur (e.g., for there to be a tank barge collision). This is the major limitation in using such a small data set. Extending the casualty data to a larger time frame would not take into account the improvements in safety in operations that has been observed in the maritime industry in the last 20 years or so. Casualty rates per vessel transit are useful for making predictions for future rates when there may be different levels of traffic than there are currently. The rates in Table 25 are based on 2015 Hudson River vessel traffic data.

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[13] Excludes minor spills not otherwise associated with a casualty.

[14] When the annual frequency is greater than 1.0, the probability is 1 in a number less than 1. For example a 1 in 0.5 chance, means that there are likely to be two incidents per year, or one every 0.5 year (six months), on average.

[15] Excludes minor spills not otherwise associated with a casualty.

Factors Affecting Hudson River Vessel Casualties: Ice

Each waterway has features and conditions that affect the likelihood of an accident. For the Hudson River, ice is one of those factors.[16] Ice can affect vessel casualty probabilities in several ways. First, floating ice can cause damage to vessels, though this is generally limited to larger icebergs, at least for deep-draft vessels. However, smaller vessels might be damaged by ice. The presence of ice also creates the potential for casualties when vessels are stuck or are inhibited in their movements.

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. Ice conditions vary annually, but, as an example, the conditions on 15 February 2017 were as shown in Table 26 and Table 27.

Table 26: Ice Conditions by Section on Hudson River on 15 February 2017

Location	Ice Type	Form	Thickness	Coverage[17]
George Washington Bridge[18]	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[19]	Fast	Brash	6–8 inches	40%

Table 27: 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%

Areas of the Hudson River north of Spuyten Duyvil that are considered to be "problem areas" with respect to ice are identified as (Figure 13):[20]

- Port of Albany to Troy Locks (Albany, NY, to Troy, NY);
- World's End (Hudson Highlands near West Point, NY);

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[16] See also Appendix B, and Appendix A in HROSRA Volume 1 (definitions of different types of ice).
[17] The percentage of water surface covered by ice to the total surface area at a specific location.
[18] All locations south of the George Washington Bridge were likewise open.
[19] Locations above Albany to Troy were not observed.
[20] Source: *Sector New York 2016-2017 Ice Breaking Season.*

- Crum Elbow (near Hyde Park, NY);
- Silver Point (near Alsen, NY); and
- Middle Ground Flats (near Hudson, NY).

Figure 13: Ice Problem Areas on Hudson River

There are no reliable data on the effect of the presence of ice on the likelihood of vessel casualties. It will just be noted that there will be times of the year where there may be problems associated with ice. At the same time, the vessel traffic may be reduced at these times as well, decreasing the likelihood again.

Factors Affecting Hudson River Vessel Casualties: Fog and Visibility

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.[21] The Hudson River Valley has specific conditions that promote the formation of widespread "radiation fog" related to the turbulent change in the

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[21] Cushing 2016.

surface layer and controls of heat and moisture advection produced by nocturnal boundary layer flows. This type of fog is particularly difficult to predict.[22]

Fog events in the Hudson River occur most frequently during the warm season months (May through October) and are tied to radiational cooling effects within the planetary boundary layer.[23] 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),[24] it was noted that, "Waterway users almost unanimously agreed that the fog, ice, and snow continue to complicate navigation in the winter months." Mist and lighter fog increases the likelihood of collisions by nearly three times. Thick fog has been shown to increase the likelihood of collisions by 59 times.[25]

Visibility can also be affected by blind curves in the river. There are a number of these locations on the Hudson River where visibility is compromised even in otherwise clear-weather situations, including:

- Saugerties Lighthouse (Figure 14);
- Jones Point (Haverstraw Bay);
- Bear Mountain Bridge; and
- Constitution Island (World's End) (Figure 15).

Figure 14: Blind Curve at Saugerties Light

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[22] Fitzjarrald and Lala 1989.
[23] Lee 2015.
[24]USCG performs a WAMS for the Hudson River every five years, and whenever they establish a federal anchorage.
[25] Lewison 1980; Det Norske Veritas 1999; Det Norske Veritas 2011b.

Figure 15: Hudson Highlands Blind Curve Locations

According to several vessel casualty studies, poor visibility due to fog (or other factors such as blind curves) increases the frequency of collisions by a factor of nearly seven.[26] The increase in collision frequency would apply during periods of fog and in locations with blind curves.

Factors Affecting Hudson River Vessel Casualties: Close Quarters

The Hudson River becomes narrower north of Kingston, especially north of Germantown. This generally limits larger vessel traffic to single lanes of traffic.

At Catskill, the river narrows to about a quarter-mile width. Just north of Athens, the width is 0.2 mile. There are several other locations northward that are narrower than that, including the Port of Albany where the river has a width of about 0.13 miles. The channel for deeper-draft vessels is roughly half of that width.

In addition, there are a number of locations that may temporarily present close quarters for vessel passings, such as the bridge construction in the Tappan Zee. Occasional construction projects, regattas, or other activities may also present an increased risk for vessel accidents. The issue of passing in close quarters also presents itself with the proposed anchorages, as discussed below.

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[26] Lewison 1980; Det Norske Veritas 2011b; Det Norske Veritas 1999.

Collisions are more frequent in narrower rivers. In one series of studies, it was found that in rivers that are less than 0.3 mile wide, the collision rate is 4.2 times that of wider rivers (0.3–1.6 miles wide). For wider estuaries (wider than 1.6 miles), the collision rate is significantly lower still–30% of the collision rate of wide rivers and 7% of the collision rate of narrower rivers.[27] It would be logical to assume that collisions are much more likely to occur in narrower parts of the Hudson River.

Factors Affecting Hudson River Vessel Casualties: Lack of VTS and TSS

The purpose of a Vessel Traffic Service (VTS) is to provide active monitoring and navigational advice for vessels in particularly confined and busy waterways. Traffic separation schemes (TSS) are used in busy waterways, often in conjunction with VTS, to reduce accidents. There is currently no VTS covering the Hudson River above the Holland Tunnel in lower Manhattan. The area of operations for VTS on the Hudson River does not extend into the study area. It is limited to the areas shown in Figure 16.

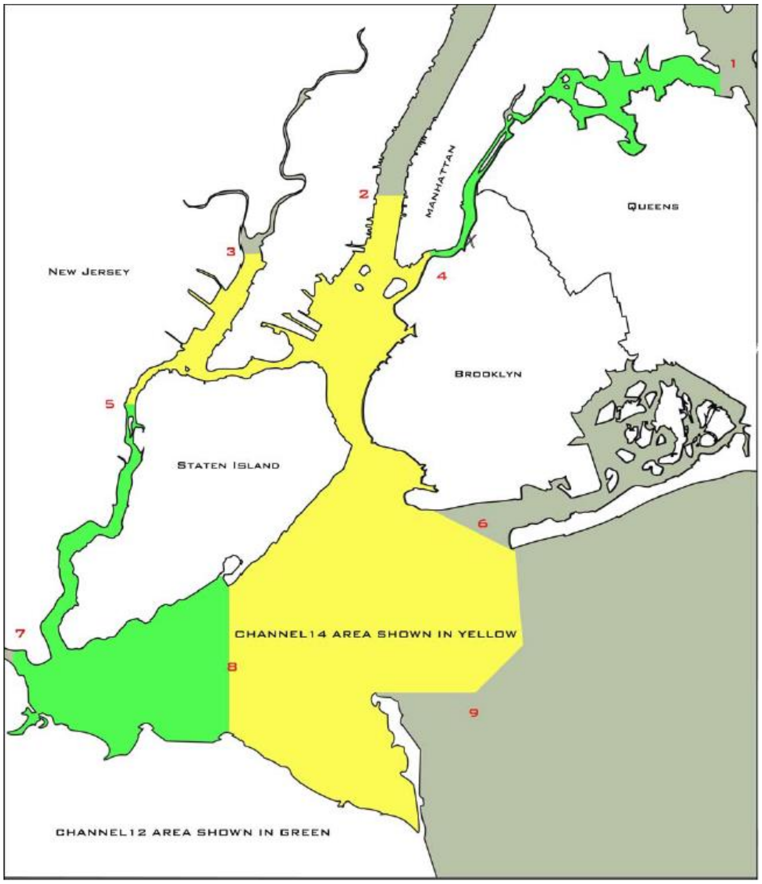

Figure 16: Area of Operations for Vessel Traffic Service New York[28]

Besides anecdotal evidence that VTS is effective in reducing accidents and near-misses, there are risk models that quantified the benefits. For example, one analysis has determined that under good visibility, VTS can reduce collisions by 19%. Under poor visibility conditions, the reduction is slightly higher–

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[27] Lewison 1980; Det Norske Veritas 2011b; Det Norske Veritas 1999.

[28] Source: *US Coast Guard Vessel Traffic Service New York User's Manual* Revised July 2010.

20%.[29] Traffic separation schemes (TSS) have been shown to reduce head-on collisions by 39% and crossing collisions by 14%.[30] Other studies have found considerably higher risk reduction factors of two to three.[31] The actual effectiveness depends on the patterns of vessel traffic and waterway configuration.[32] By not having VTS and TSS, the Hudson River does not have this advantage of risk reduction.[33]

Pilotage in the Hudson River

Pilotage is another factor that can have a significant effect on the rate of casualties. Compulsory pilotage decreases vessel casualties by at least 75%.[34] [The regulations regarding pilotage in the US and in the Hudson in particular are presented in Appendix C.]

The Hudson River Pilots Association has three Full Branch and two Deputy Pilots working on the Hudson River. In addition, there are five Sandy Hook Pilots licensed for the Lower Hudson River as Transport Pilots, available to assists the Hudson River Pilots Association, during periods of increased vessel activity. Records of the Board of Commissioners of Pilots of the State of New York indicate that pilots were assigned to vessels on the Hudson River as shown in Table 28.

Table 28: Hudson River-Licensed Pilot Assignments by Year

Year	Ship Assignments	Pilots	Ship Assignments/Pilot
2008	878	8	110
2009	718	7.5	96
2010	520	7	74
2011	480	6	80
2012	514	6	86
2013	656	6	109
2014	626	6	104
2015	560	6	94
2016	562	8	70

In records of the Board of Commissioners of Pilots of the State of New York on vessel casualties for the years 2010 through 2017 (excluding the year 2015, as the Annual Report is not available) with regard to vessel incidents are summarized in Table 29. The safety record for piloted vessels is very good. Overall, for the ship assignments during 2010 through 2016, 3.4% had vessel incidents. Of those incidents, 61% were found to involve no fault on the part of the state pilot, and in 33% of the incidents, the pilot was not actively involved in piloting at the time of the accident.

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[29] Fowler and Sørgård 2000.
[30] Przywarty 2009a, 2009b, based on MacDuff 1974.
[31] Reviewed in Larsen 1993; USCG 1993.
[32] NRC 1993; Young 1994; Young 1995.
[33] This issue is discussed further in HROSRA Volume 6.
[34] Lewison 1980; Det Norske Veritas 2011b; Det Norske Veritas 1999.

Table 29: New York Pilots Vessel Incidents[35]

Year	Total Number Incidents	Board Actions/Findings					
		No Fault on Part of State Pilot	State Pilot not at Controls[36]	Under Investigation	License Revoked	Disciplinary Hearing	Letter of Caution
2010	17	11	6	0	0	0	0
2011	14	6	8	0	1[37]	0	0
2012	19	11	7	1[38]	0	1[39]	0
2013	15	11	2	1	0	1[40]	1
2014	27	19	6	2	0	0	0
2015	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2016	22	11	9	2	0	0	0

Crew Fatigue and Training

Fatigue and training are other issues that have been considered with regard to increasing vessel accidents. There is no particular reason to attribute greater issues of crew fatigue and training in the Hudson River relative to other locations. However, changes in regulations regarding crew endurance may have been helping to decrease accidents from those seen in previous decades. [See also Appendix D.]

Historically, most transportation accidents are attributed to human error. There does not appear at this time, a definitive indication of an industry wide crew fatigue problem. On the other hand incidents attributed to operator or personnel error due to fatigue do from time to time arise. One such incident occurred on the Hudson River on 12 March 2016. The incident involved the tug *Specialist* at the Tappan Zee Bridge, Pier 31 in Tarrytown, New York. Three fatalities occurred in this incident.

The National Transportation Safety Board's (NTSB) report (Accident # DCA16FM033), dated May 11, 2017, found that the *"probable cause of the collision and sinking of the Specialist was inadequate manning, resulting in fatigued crewmembers navigating three tugboats with obstructed visibility due to the size of the crane on the barge they were towing and the location of the tugboats alongside the barge."*

The NTSB report included the following information:

> *"According to statements and evidence, crewmembers aboard the Specialist and the Realist had likely not received more than 4–5 hours of uninterrupted sleep in at least 3 days leading up to the accident. In addition to extended wakefulness or chronic sleep restriction, the crew was dealing with adverse weather conditions, strong waterway currents, and restricted visibility, which*

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[35] Based on data in Board of Commissioners of Pilots of the State of New York Annual Reports. No report was available for the year 2015.

[36] This means that either the Pilot was not steering (very rarely steers) or not up on the bridge or not actively piloting the vessel at the time of the incident; it could be a dispute between Pilot and Master, or Master deciding to pilot his vessel himself.

[37] Not related to specific vessel incident; based on violation of Board regulations.

[38] Investigation for grounding of T/V *Stena Primorsk*. This case was finally found to have no fault on part of the State Pilot.

[39] Not related to specific vessel incident; pilot-in-training resigned.

[40] Not related to specific vessel incident.

> *increased their overall workload and the demands on their attention, thus compounding the effects of fatigue. Research indicates that performance consistently declines beyond 2 hours of continued monitoring or vigilance, and that it is difficult to perform at a safe level after 4–5 hours of continuous vigilance.*[41] *Attention starts to wane when fatigue sets in."*

There are various studies and ample anecdotal evidence that indicate or suggest that improvements in the training of marine vessel crews decrease the likelihood of vessel casualties due to the reduced incidence of human errors.[42] The most noteworthy changes in vessel crew training came with the implementation of the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW 1978). This convention, which set qualification standards for masters, officers, and watch personnel on seagoing merchant ships, first entered into force in 1984 with significant amendments in 1995 that entered into force in 2002 (STCW 1995); additional amendments entered into force in 2012.

Proposed Increased Anchorages for Hudson River

Since 2015, there has been great public concern about a proposal for establishing additional anchorages for tank vessels and cargo vessels on the Hudson River. This issue is explored briefly herein with regard to where these anchorage could potentially affect the likelihood of spill.

In 2015, the USCG Sector New York issued Marine Safety Information Bulletin MSIB–(2015-014), "Hudson River Anchorage Grounds,"[43] in response to "reports of commercial vessels, including tugs and barges, anchored outside designated anchorage areas along the Hudson River."

In this bulletin, mariners were instructed that, as per 33 CFR §110.155(1)(2), anchorage outside of designated anchorage grounds is impermissible except in cases of emergency, and only then if the vessel operator contacts a designated official to inform them of the emergency. Barring such action, vessel operators are exposed to civil penalties of up to $40,000. As a result, mariners face a choice of continuing on until poor conditions deteriorate to emergency status, or face civil penalties. Additionally, lack of designated anchorage grounds results in greater potential for vessels to anchor in sensitive areas.

According to 33 CFR §110.155(1)(2), the only approved anchorages on the lower Hudson River are: Anchorage No. 16;[44] Anchorage No. 17;[45] Anchorage No. 18-A;[46] Anchorage No. 18;[47] Anchorage No. 19 East;[48] and Anchorage No. 19 West[49] (see also Figure 17 and Figure 18).

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[41] Richter et al. 2005.

[42] Wang and Zhang 2000; Grabowski 2013.

[43] https://homeport.uscg.mil/cgi-bin/st/portal/uscg_docs/MyCG/Editorial/20151109/MSIB-Hudon%20River%20Anchorage_2.pdf?id=a19f2f528cb899e4cb6e480f674175f79ca8229e&user_id=423436af395bdfc68adc7ccf66927ee8

[44] North of a line on a range with the north side of the north pier of the Union Dry Dock and Repair Company Shipyard, Edgewater, New Jersey; west of a line ranging 25° from a point 120 yards east of the east end of said pier to a point (500 yards from the shore and 915 yards from the Fort Lee flagpole) on a line ranging approximately 100°22′ from the Fort Lee flagpole toward the square chimney on the Medical Center Building at 168th Street, Manhattan; and south of said line ranging between the Fort Lee flagpole and the square chimney on the Medical Center Building. [When the use of Anchorage No. 16 is required by naval vessels, the vessels anchored therein shall move when the Captain of the Port directs them.]

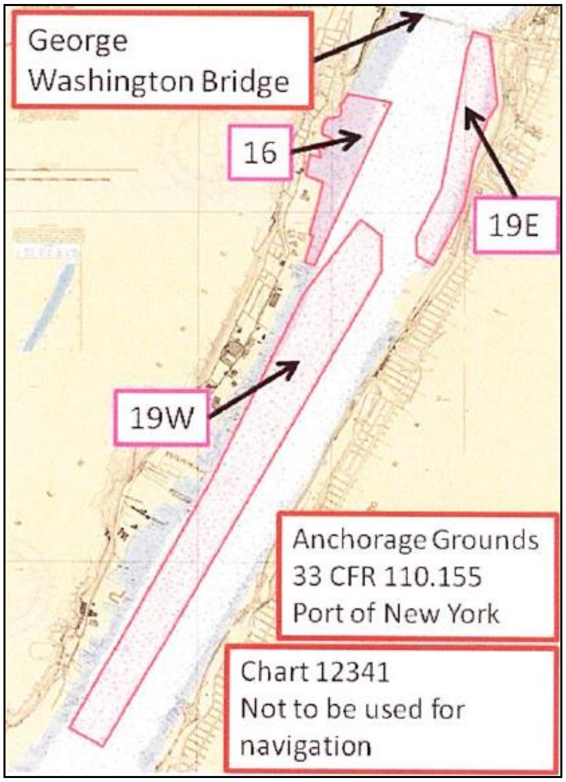

Figure 17: Current Anchorages South of George Washington Bridge

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[45] All waters of the Hudson River bound by the following points: 40°56′26.66″ N, 073°55′12.06″ W; thence to 40°56′22.54″ N, 073°54′49.77″ W; thence to 40°55′56.00″ N, 073°54′58.00″ W; thence to 40°55′54.15″ N, 073°54′46.96″ W; thence to 40°54′18.43″ N, 073°55′21.12″ W; thence to 40°52′27.59″ N, 073°56′14.32″ W; thence to 40°51′34.20″ N, 073°56′52.64″ W; thence to 40°51′20.76″ N, 073°57′31.75″ W; thence along the shoreline to the point of origin (NAD 83). [When the use of Anchorage No. 17 is required by naval vessels, the vessels anchored therein shall move when the Captain of the Port directs them.]

[46] East of lines bearing 8° from the northwest corner of the crib icebreaker north of the New York Central Railroad Company drawbridge across Spuyten Duyvil Creek (Harlem River) to a point 250 yards offshore and on line with the New York Central Railroad signal bridge at the foot of West 231st Street, extended, at Spuyten Duyvil, Bronx, New York; thence bearing 19° to the channelward face of the Mount St. Vincent Dock at the foot of West 261st Street, Riverdale, Bronx, New York. [(i) When the use of Anchorage No. 18-A is required by naval vessels the vessels anchored therein shall move when the Captain of the Port directs them.]

[47] All waters of the Hudson River bound by the following points: 40°56′54.0″ N, 073°54′40.0″ W; thence to 40°56′51.0″ N, 073°54′24.0″ W; thence to 40°55′53.0″ N, 073°54′40.0″ W; thence to 40°55′56.0″ N, 073°54′58.0″ W; thence to the point of origin (NAD 83). [This anchorage ground is reserved for use by ships only.]

[48] All waters of the Hudson River bound by the following points: 40°49′42.6″ N, 073°57′14.7″ W; thence to 40°49′45.9″ N, 073°57′22.0″ W; thence to 40°49′52.0″ N, 073°57′22.0″ W; thence to 40°50′08.3″ N, 073°57′10.8″ W; thence to 40°50′55.4″ N, 073°56′59.7″ W; thence to 40°51′02.5″ N, 073°56′57.4″ W; thence to 40°51′00.8″ N, 073°56′49.4″ W; thence along the shoreline to the point of origin.

[49] All waters of the Hudson River bound by the following points: 40°46′56.3″ N, 073°59′42.2″ W; thence to 40°47′36.9″ N, 073°59′11.7″ W; thence to 40°49′31.3″ N, 073°57′43.8″ W; thence to 40°49′40.2″ N, 073°57′37.6″ W; thence to 40°49′52.4″ N, 073°57′37.6″ W; thence to 40°49′57.7″ N, 073°57′47.3″ W; thence to 40°49′32.2″ N, 073°58′12.9″ W; thence to 40°49′00.7″ N, 073°58′33.1″ W; thence to 40°48′28.7″ N, 073°58′53.8″ W; thence to 40°47′38.2″ N, 073°59′31.2″ W; thence to 40°47′02.7″ N, 073°59′57.4″ W; thence to the point of origin.

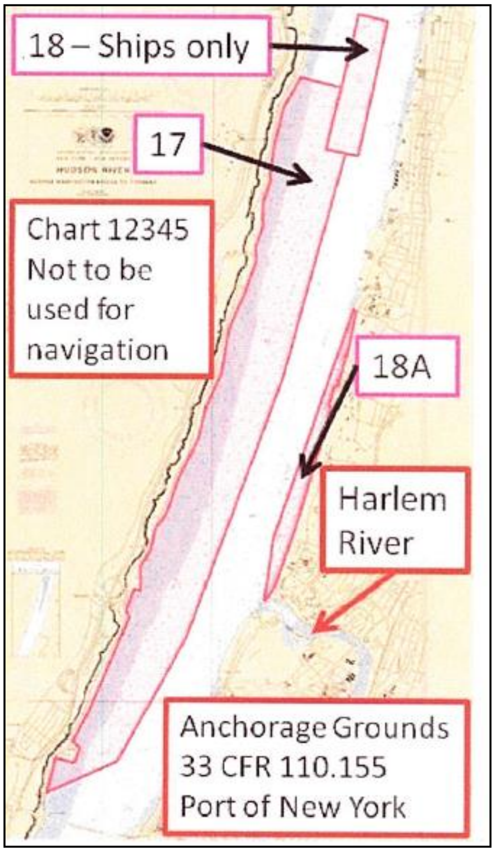

Figure 18: Current Anchorage North of George Washington Bridge to Yonkers

The following regulations apply to the use of Anchorages 19 East and 19 West:

- No vessel may conduct lightering operations in these anchorage grounds without permission from the Captain of the Port. When lightering is authorized, the Captain of the Port New York must be notified at least four hours in advance of a vessel conducting lightering operations as required by 156.118 of this title.
- Any vessel conducting lightering or bunkering operations shall display by day a red flag (46 CFR §35.30-1; Pub 102; International Code of Signals signaling instructions) at its mast head or at least 10 feet above the upper deck if the vessel has no mast, and by night the flag must be illuminated by spotlight. These signals shall be in addition to day signals, lights and whistle signals as required by rules 30 (33 USC §2030 and 33 CFR §83.30) and 35 (33 USC §2035 and 33 CFR §83.35) of the Inland Navigation Rules when at anchor in a general anchorage area.
- Within an anchorage, fishing and navigation are prohibited within 500 yards of an anchored vessel displaying a red flag.
- These anchorage grounds are only authorized for use by tugs and/or barges.
- No vessel may occupy this anchorage ground for a period of time in excess of 96 hours without prior approval of the Captain of the Port.
- No vessel may anchor in Anchorage No. 19 East or No. 19 West without permission from the Captain of the Port.

- Each vessel shall report its position within Anchorage No. 19 East or No. 19 West to the Captain of the Port immediately after anchoring.

An additional anchorage is designated west of Hyde Park (Figure 19): Anchorage No. 19-A.[50]

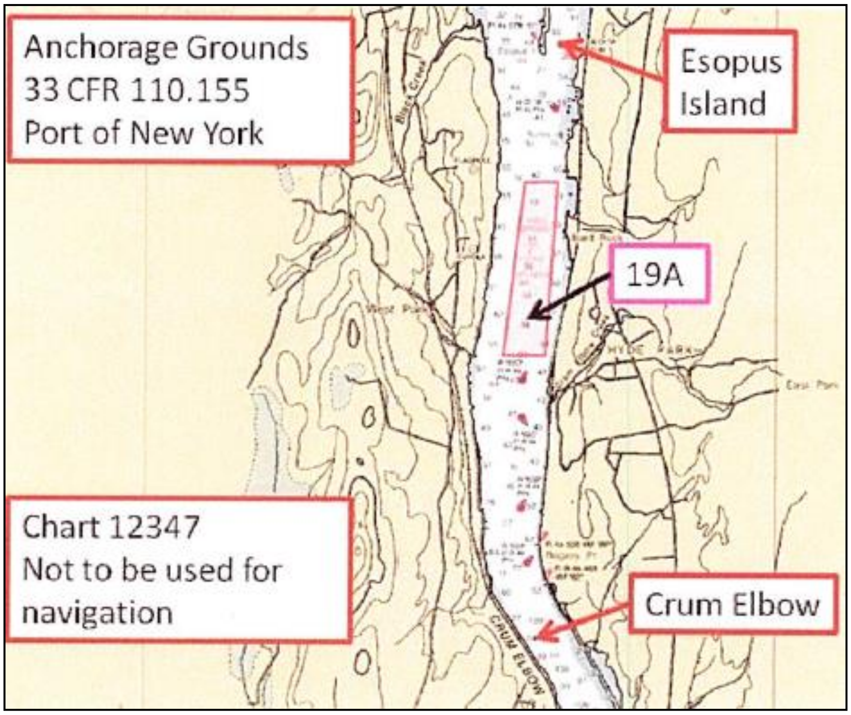

Figure 19: Current Anchorage off Hyde Park

The restrictions for Anchorage 19-A are:

- No vessel may anchor in Anchorage 19-A from December 16 to the last day of February without permission from the Captain of the Port, New York.
- No vessel less than 20 meters in length may anchor in Anchorage 19-A without prior approval of the Captain of the Port, New York.

Subsequent to the issuance of the MSIB 2015-014, on January 21, 2016, the Maritime Association of the Port of New York and New Jersey's Tug and Barge Committee submitted a letter to USCG 1st District, requesting USCG to establish 10 additional federal anchorages on the Hudson River, adding 43 anchorage berths. The letter listed the priorities of the contemplated anchorages as follows:

- Priority #1: Kingston Hub (8 berths)
    - Port Ewen (1 berth)
    - Big Rock Point (4 berths)
    - Kingston Flats (3 berths)

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[50] An area located west of Hyde Park enclosed by the coordinates starting at 41°48′35″ N 073°57′00″ W; to 41°48′35″ N 073°56′44″ W; to 41°47′32″ N 073°56′50″ W; to 41°47′32″ N 073°57′10″ W; thence back to 41°48′35″ N 073°57′00″ W (NAD 1983).

- Priority #2: Newburgh Hub (8 berths)
    - Newburgh (5 berths)
    - Roseton (3 berths)
- Priority #3: Yonkers Hub (16 berths)
    - Yonkers Extension (16 berths)
- Priority #4: Tompkins Cover (3 berths)
- Priority #5: Milton (2 berths)
- Priority #6: Marlboro (3 berths)
- Priority #7: Montrose Point (3 berths)

On 9 June 2016, the USCG published an Advance Notice of Proposed Rulemaking (ANPRM) in the *Federal Register* (Vol. 81, No. 111).[51] The ANPRM stated that the USCG was considering establishing new anchorage grounds on the Hudson River between Yonkers and Kingston "after receiving requests suggesting that anchorage grounds may improve navigation safety along an extended portion of the Hudson River, which currently has no anchorage grounds, allowing for a safer and more efficient flow of vessel traffic." The requests had come from the Port of New York/New Jersey Tug and Barge Committee, the Hudson River Port Pilot's Association, and American Waterways Operators. The anchorages were to accommodate a variety of vessel types and configurations at depths of 21 to 65 feet, and "would not interfere with the areas where vessels have historically transited the Hudson River."

The contemplated additional anchorages are summarized in Table 30 and pictured in Figure 20 through Figure 29.[52] The anchorages are all designated as "long-term," which differentiates them from "temporary" anchorages, such as those that are set up during special circumstances, such as boat races, construction activities, fireworks launching, etc. Typical long-term anchorages are limited to 96 hours (four days).

Table 30: Contemplated/Proposed Hudson River Anchorages (Docket USCG-2016-0132)

Anchorage	Berths	Vessel Swing Radius	Draft	Acres
Yonkers Extension	16	1,200 ft	< 35 ft	715. 24
Montrose Point	3	1,400 ft	< 26 ft	127. 10
Tomkins Cove	3	1,200 ft	< 40 ft	98. 85
Newburgh	4	1,800 ft	North: < 32 ft; South: < 22 ft	445. 34
Roseton	3	1,700 ft	< 40 ft	305. 00
Marlboro	3	1,800 ft	< 35 ft	154. 80
Milton	2	1,200 ft	< 40 ft	74. 07
Big Rock Point	4	1,200 ft	< 35 ft	207. 62
Port Ewen	1	1,200 ft	< 30 ft	46. 84
Kingston Flats South	3	1,800 ft (2); 1,300 ft (1)	< 22 ft	279. 00

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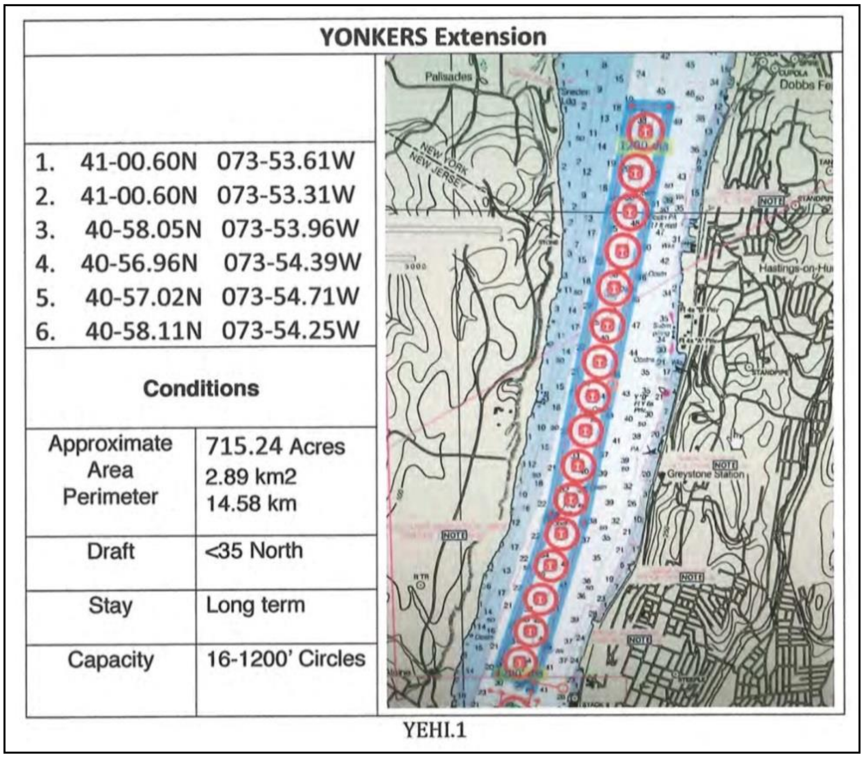
[51] Docket Number USCG-2016-0132.

[52] Note that in the figures there are swing circles that show to possible location of tank barges, tankers, or cargo vessels. These circles–1,200 to 1,800 feet in diameter indicate the greatest extent to which an anchored vessel might potentially "swing." The vessels themselves would take up only a small portion of these circles as they are not longer than about 600 feet.



YONKERS Extension

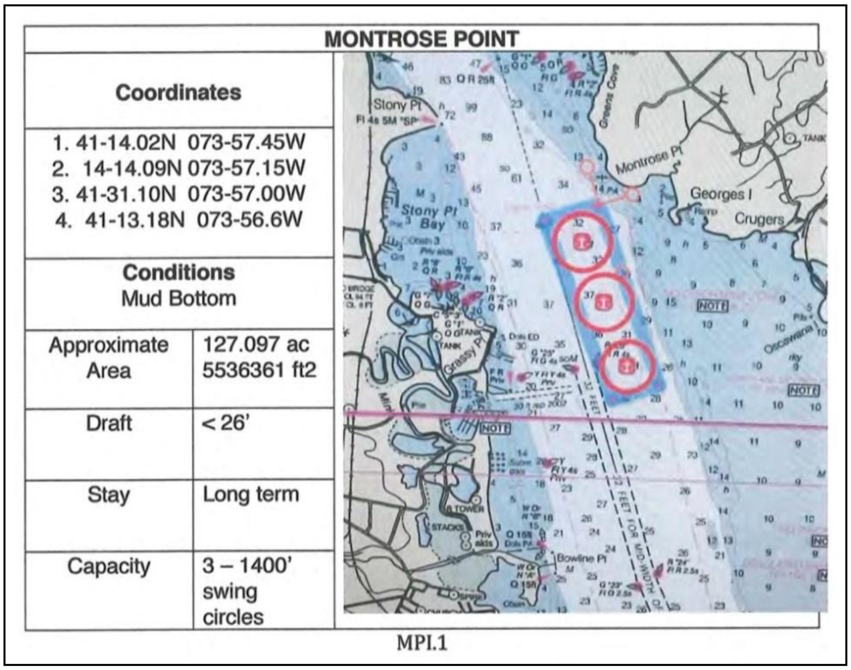
1.	41-00.60N	073-53.61W
2.	41-00.60N	073-53.31W
3.	40-58.05N	073-53.96W
4.	40-56.96N	073-54.39W
5.	40-57.02N	073-54.71W
6.	40-58.11N	073-54.25W

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 20: Contemplated/Proposed Yonkers Extension Anchorage Ground



MONTROSE POINT

Coordinates

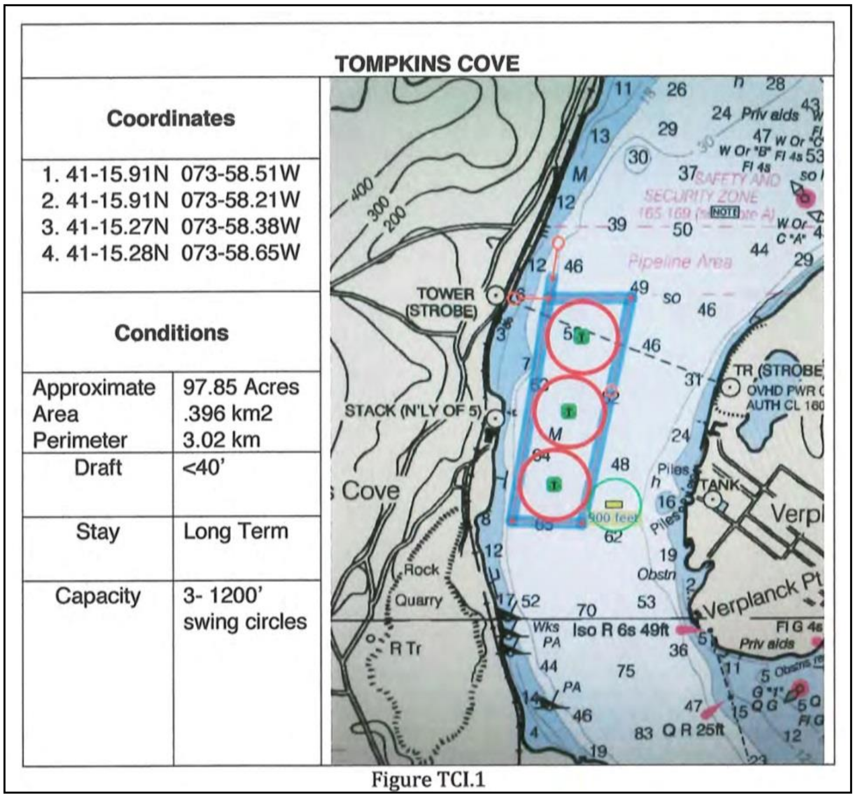
1.	41-14.02N	073-57.45W
2.	14-14.09N	073-57.15W
3.	41-31.10N	073-57.00W
4.	41-13.18N	073-56.6W

Conditions
Mud Bottom

Approximate Area	127.097 ac 5536361 ft2
Draft	< 26'
Stay	Long term
Capacity	3 – 1400' swing circles

MPI.1

Figure 21: Contemplated/Proposed Montrose Point Anchorage Ground

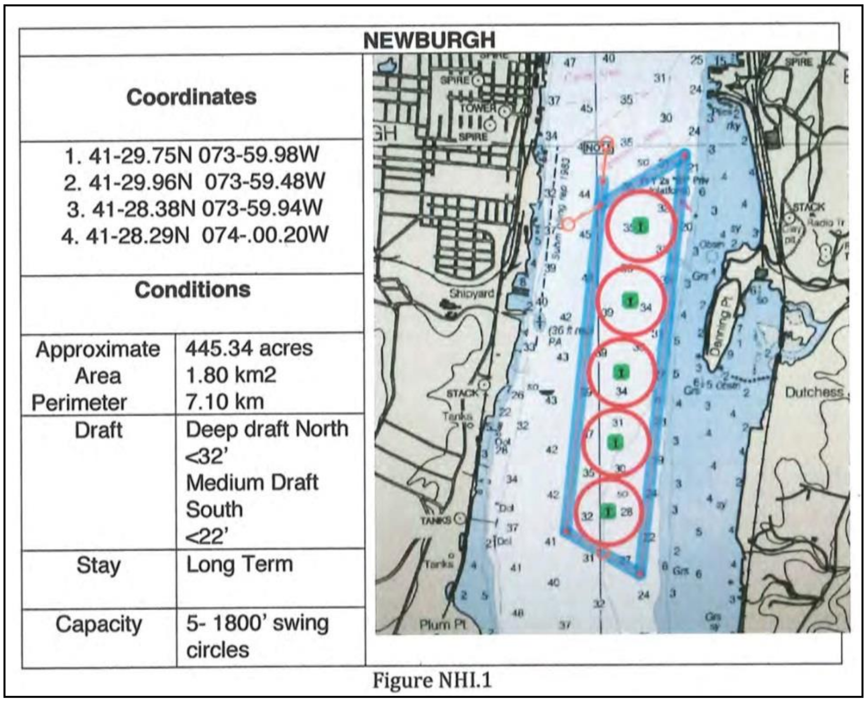


TOMPKINS COVE

Coordinates	
1. 41-15.91N 073-58.51W 2. 41-15.91N 073-58.21W 3. 41-15.27N 073-58.38W 4. 41-15.28N 073-58.65W	
Conditions	
Approximate Area Perimeter	97.85 Acres .396 km2 3.02 km
Draft	<40’
Stay	Long Term
Capacity	3- 1200’ swing circles

Figure TCI.1

Figure 22: Contemplated/Proposed Tompkins Cove Anchorage Ground

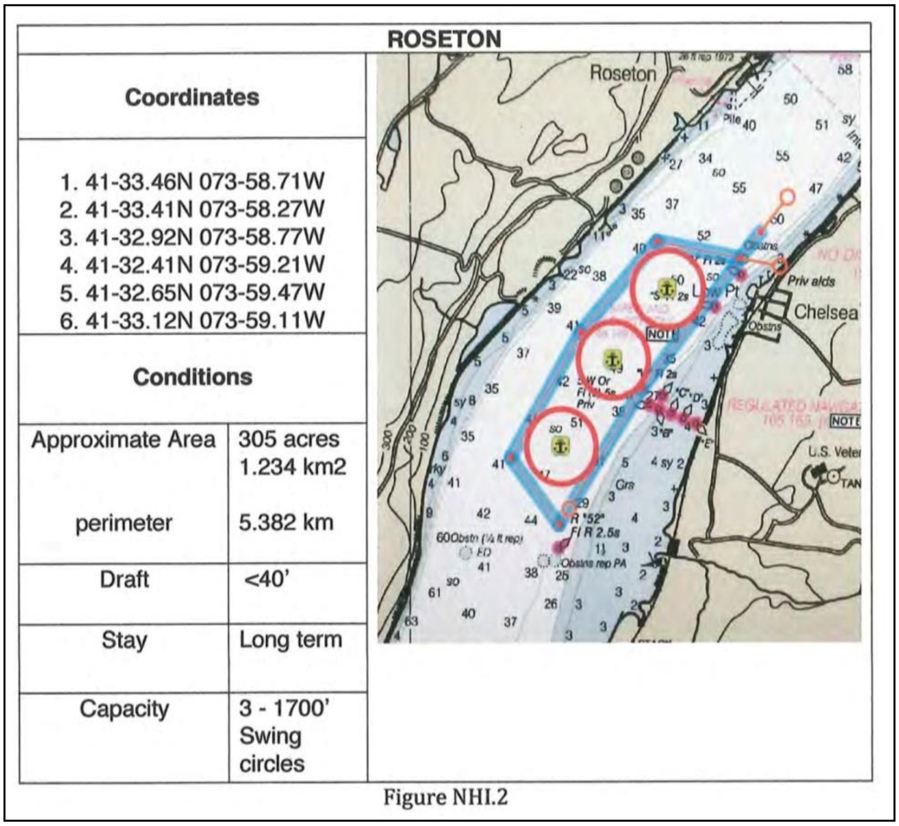


NEWBURGH

Coordinates	
1. 41-29.75N 073-59.98W 2. 41-29.96N 073-59.48W 3. 41-28.38N 073-59.94W 4. 41-28.29N 074-.00.20W	
Conditions	
Approximate Area Perimeter	445.34 acres 1.80 km2 7.10 km
Draft	Deep draft North <32’ Medium Draft South <22’
Stay	Long Term
Capacity	5- 1800’ swing circles

Figure NHI.1

Figure 23: Contemplated/Proposed Newburgh Anchorage Ground

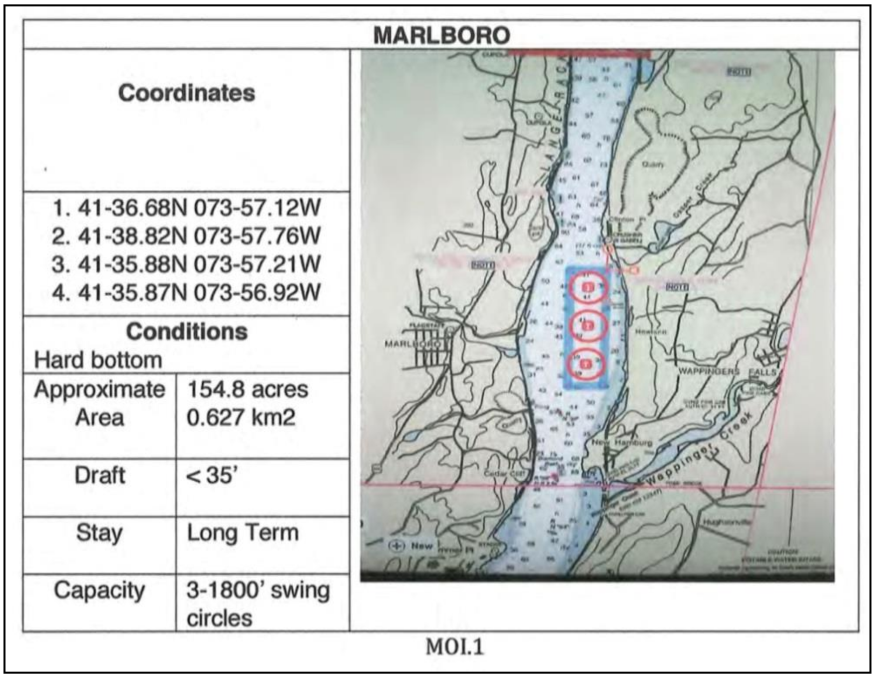


ROSETON

Coordinates	
1. 41-33.46N 073-58.71W 2. 41-33.41N 073-58.27W 3. 41-32.92N 073-58.77W 4. 41-32.41N 073-59.21W 5. 41-32.65N 073-59.47W 6. 41-33.12N 073-59.11W	
Conditions	
Approximate Area	305 acres 1.234 km2
perimeter	5.382 km
Draft	<40'
Stay	Long term
Capacity	3 - 1700' Swing circles

Figure NHI.2

Figure 24: Contemplated/Proposed Roseton Anchorage Ground

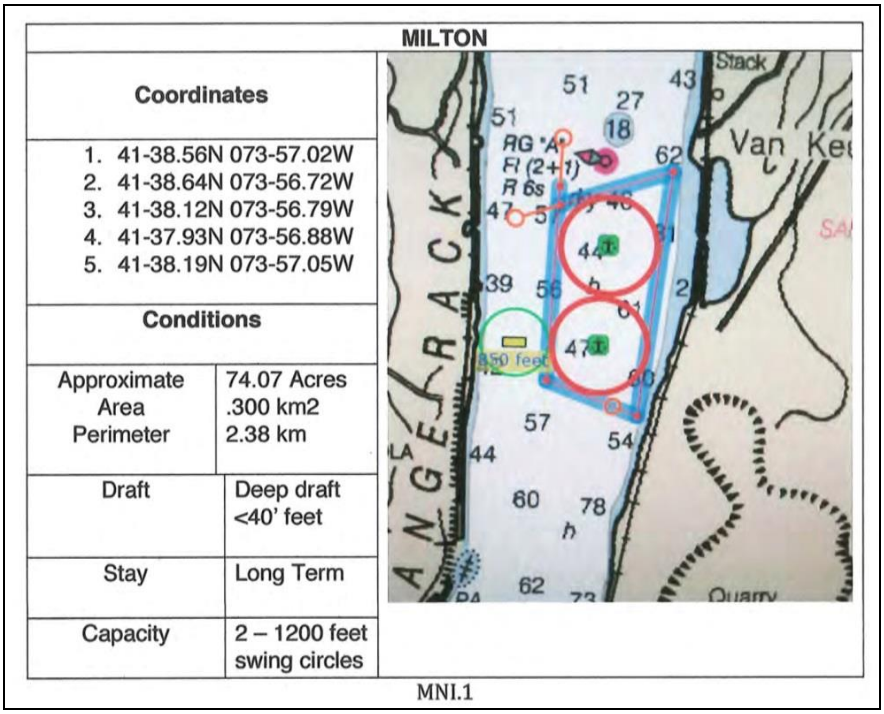


MARLBORO

Coordinates	
1. 41-36.68N 073-57.12W 2. 41-38.82N 073-57.76W 3. 41-35.88N 073-57.21W 4. 41-35.87N 073-56.92W	
Conditions Hard bottom	
Approximate Area	154.8 acres 0.627 km2
Draft	< 35'
Stay	Long Term
Capacity	3-1800' swing circles

MOI.1

Figure 25: Contemplated/Proposed Marlboro Anchorage Ground

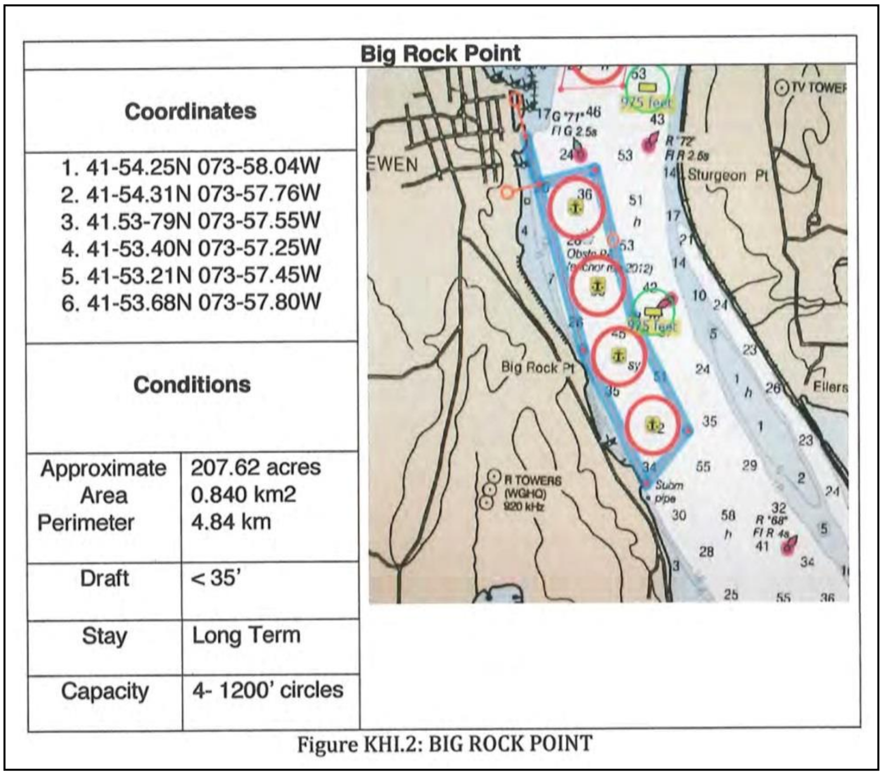


MILTON

Coordinates	
1. 41-38.56N 073-57.02W 2. 41-38.64N 073-56.72W 3. 41-38.12N 073-56.79W 4. 41-37.93N 073-56.88W 5. 41-38.19N 073-57.05W	
Conditions	
Approximate Area Perimeter	74.07 Acres .300 km2 2.38 km
Draft	Deep draft <40' feet
Stay	Long Term
Capacity	2 – 1200 feet swing circles

MNI.1

Figure 26: Contemplated/Proposed Milton Anchorage Ground

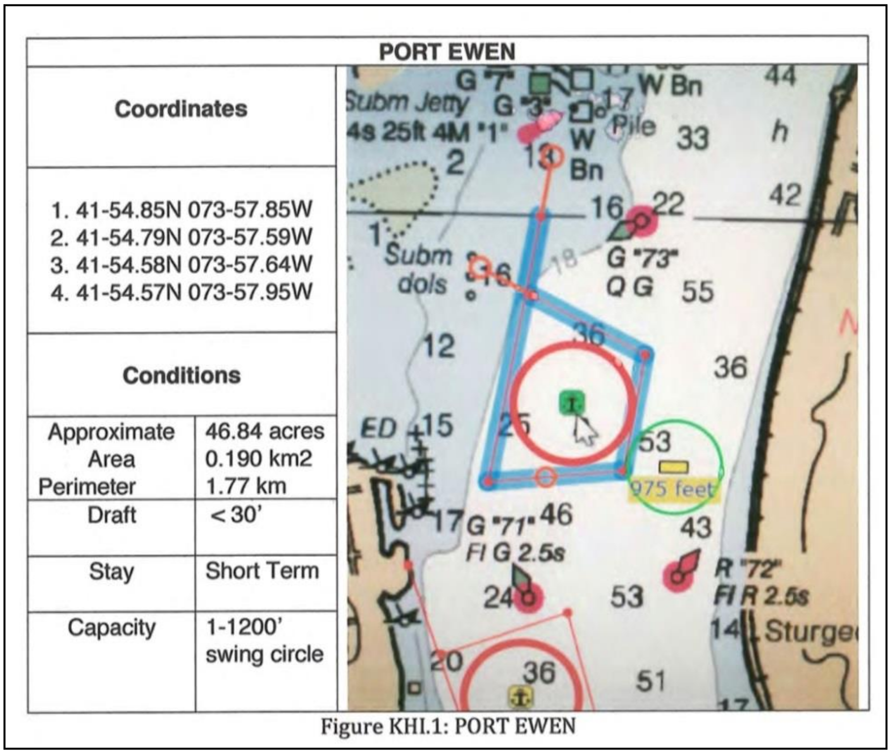


Big Rock Point

Coordinates	
1. 41-54.25N 073-58.04W 2. 41-54.31N 073-57.76W 3. 41.53-79N 073-57.55W 4. 41-53.40N 073-57.25W 5. 41-53.21N 073-57.45W 6. 41-53.68N 073-57.80W	
Conditions	
Approximate Area Perimeter	207.62 acres 0.840 km2 4.84 km
Draft	< 35'
Stay	Long Term
Capacity	4- 1200' circles

Figure KHI.2: BIG ROCK POINT

Figure 27: Contemplated/Proposed Big Rock Point Anchorage Ground

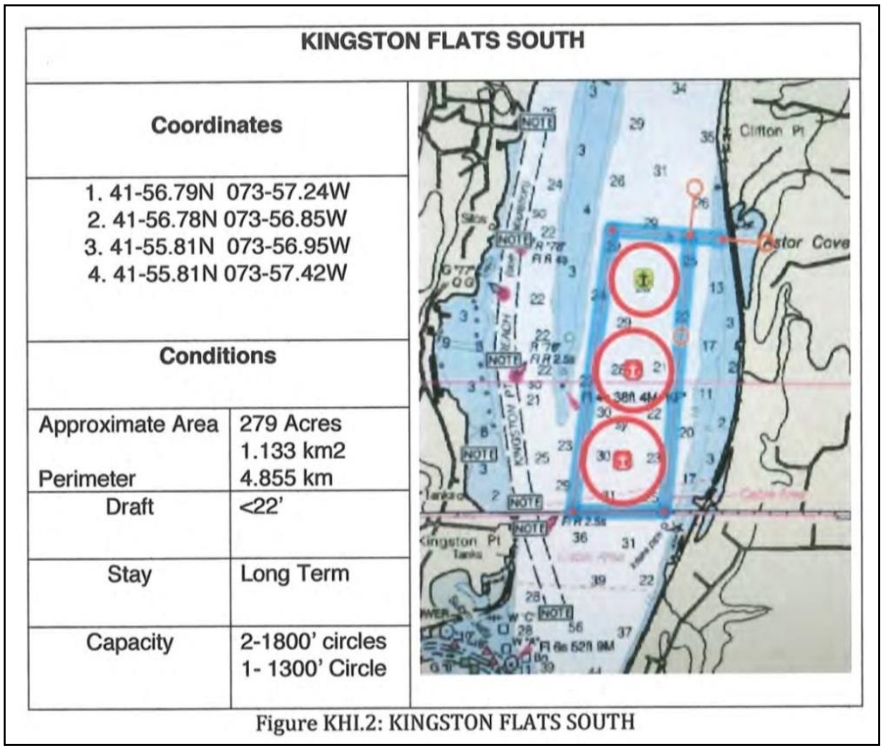


PORT EWEN

Coordinates	
1. 41-54.85N 073-57.85W 2. 41-54.79N 073-57.59W 3. 41-54.58N 073-57.64W 4. 41-54.57N 073-57.95W	
Conditions	
Approximate Area Perimeter	46.84 acres 0.190 km2 1.77 km
Draft	< 30’
Stay	Short Term
Capacity	1-1200’ swing circle

Figure KHI.1: PORT EWEN

Figure 28: Contemplated/Proposed Port Ewen Anchorage Ground



KINGSTON FLATS SOUTH

Coordinates	
1. 41-56.79N 073-57.24W 2. 41-56.78N 073-56.85W 3. 41-55.81N 073-56.95W 4. 41-55.81N 073-57.42W	
Conditions	
Approximate Area Perimeter	279 Acres 1.133 km2 4.855 km
Draft	<22’
Stay	Long Term
Capacity	2-1800’ circles 1- 1300’ Circle

Figure KHI.2: KINGSTON FLATS SOUTH

Figure 29: Contemplated/Proposed Kingston Flats South Anchorage Ground

The regulatory authority for establishing anchorages comes from 33 US Code §471:

> “The Secretary of Homeland Security is authorized, empowered, and directed to define and establish anchorage grounds for vessels in all harbors, rivers, bays, and other navigable waters of the United States whenever it is manifest to the said Secretary that the maritime or commercial interests of the United States require such anchorage grounds for safe navigation and the establishment of such anchorage grounds shall have been recommended by the Chief of Engineers, and to adopt suitable rules and regulations in relation thereto; and such rules and regulations shall be enforced by the Coast Guard under the direction of the Secretary of Transportation: Provided, That at ports or places where there is no Coast Guard vessel available such rules and regulations may be enforced by the Chief of Engineers under the direction of the Secretary of Homeland Security.”

Potential Changes in Vessel Spills with Proposed Increased Anchorages

The extent to which the anchorages proposed for the Hudson River would affect vessel casualty rates and thus spills is uncertain. An anchorage provides a location for a vessel to moor, for a period of time. One or more moored vessels may be located in these newly established anchorages at any given time. Vessels requiring mooring for safety reasons do so presently, both within designated anchorages if possible under the specific circumstances, and as needed elsewhere. Hence, if the requirement for mooring is unchanged, the effect of establishing additional anchorages is concentrating ships in designated locations. Establishment of additional anchorages could also have the potential of increasing the practice of mooring due to the availability of additional designated anchorages.

Ships approaching, and at anchor, will conduct a range of navigational, mooring and unmooring, and shipboard operations. These may include troubleshooting, repair, provisioning and materials transfer, etc. All of these activities have an associated baseline risk. The effect of locating a greater number of ships at the proposed anchorages is to expose adjacent ships to one other’s operational risk.

Vessels at anchor are a potential collision and allision “target” for other transiting vessels that pass the anchorage. Some of the anchorages, if fully utilized, might create closer quarters for passing based on the maps (Figure 20 through Figure 29), though none of the contemplated anchorage locations are at the narrowest parts of the river.

The hypothetical net change in collision/allision risk due to concentrating multiple vessels at designated new anchorages is that the collision/allision target(s) are larger, resulting in increased likelihood at that anchorage location. However, this could be offset by the reduction in collision/allision with vessels anchored for safety reasons outside designated anchorages.

The potential also exists to increase collision and allision at anchorage, by increasing the possibility for multiple ships at a single anchorage with the associated close proximity maneuvering requirements. The clustering of multiple ships concentrates collision and allision targets.

Grounding, capsize, structural failure, process leaks (onboard), and cargo transfer leaks remain unaffected by the establishment of additional anchorages.

The risk of accidents for vessels in anchorages differs from the risk of accidents while underway, though the issue is not necessarily straightforward. The circumstances of each specific waterway, including its traffic makeup, congestion, visibility conditions, and configuration, will determine the actual risk.

Ultimately, the question with regard to anchorages is not whether accidents are more or less likely to occur when vessels are in anchorages, but whether a vessel that is in transit (i.e., underway) is more or less likely to be in an accident if it continues while under distress or if it seeks *temporary* refuge in an anchorage.

When vessels are in anchorages that are in close proximity to more constrained waterways, it is more likely that a stationary vessel may be involved in an allision during the time that it is in the anchorage and that the passing vessels are transiting past the anchorages may allide with the vessels in the anchorage. These incidents could potentially result in spillage, depending on the force of the allision.

If the anchorages are to be used to “store oil” in tank barges for longer time periods and the overall moving vessel traffic stays the same or increases, the likelihood of a tank vessel being struck by another while maneuvering in the anchorage area or be struck by another vessel that is underway and leaves the channel adjacent to the anchorage would naturally increase with the presence of anchorages. However, there is no evidence at present that the anchorages would be used in such a manner.

Quantification of Anchorage Effect on Accident and Spill Risk

Quantifying the potential increase (or decrease) in vessel accident (and spill) risk with the establishment of additional anchorages, such as those proposed in Table 30 (Figure 20 through Figure 29) for the Hudson River, would require an extensive vessel traffic modeling study. The specific navigational conditions (tides, bathymetry, vessel channel, shoreline configuration), and assumed variations in vessel traffic levels, and specific regulations (numbers of vessels, maximum time at anchor, etc.) for the Hudson River would need to be incorporated into the model. In addition, an approximation of the decision-making of the vessel operators with respect to the location, circumstances, duration, and timing of anchoring would need to be incorporated. Vessel accident (and spillage) rates with and without the additional anchorages (or with variations in the numbers and/or locations of anchorages) could then be evaluated.

There are no known studies in which the accident rates with and without anchorages, or before and after the establishment and implementation of anchorages, have been compared that could be used as proxies for the Hudson River situation.

Some studies have generally indicated a *reduced* rate of accidents in anchorages relative to other areas in port and waterways. For example, in UK ports, 45% of accidents occur in berthing areas, 15.7% occur in harbor approaches, and only 0.5% of accidents occur in anchoring areas (anchorages).[53] In a study for Hong Kong Harbor, the rate of accidents overall were found to be 0.00335 per port visit, whereas in anchorages, they were 0.000402 per port visit.[54]

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[53] UK Dept of Transport 2010.

[54] Yip 2008.

Researchers in another study on the Hong Kong Harbor concluded that the locations of anchorages with respect to vessel traffic lanes could increase the number of accidents and that anchorage locations should be considered with this in mind.[55] A shortage of anchorage spaces was identified as a factor that increases the risk for vessel accidents in the Delaware River and Bay.[56]

A 2002 study on the navigational hazards on the Lower Mississippi River showed that presence of floating anchorages significantly decreased the rate of allisions and groundings even in narrow river areas.[57] The researchers in this study discussed their findings regarding the anchorages with the USCG Chief of the Office of Vessel Traffic Management who suggested that when pilots approach known hazards (such as charted anchorages), their level of alert rises. This extra care, coupled with mitigation by USCG and ACOE, might account for the effect of anchorages reducing accidents even in narrow river sections where they might otherwise be considered navigational risks. This observation is supported by other research studies that indicate that stress and the resulting greater caution, at least under some circumstances, may reduce risk.[58]

Certain circumstances may increase the risk at anchorages. For the Mississippi River, there is a particular concern regarding anchoring in high-water conditions. The risk of dragging anchor is substantially increased during periods of high water and strong currents. The USCG advises mariners to adhere to USCG advisories and pilot association guidance for prevailing conditions and be able to respond effectively during an anchor-dragging situation.[59] The risks of anchoring during high water were illustrated by the January 2016 collision between the cargo vessel Manizales and the bulk carrier Zen-Noh Grain Pegasus at the Belmont Anchorage near Hester, Louisiana, and other historical cases.[60] While there are times of higher water (generally in spring) in the Hudson River, the flooding levels are not nearly those of the Mississippi River, where spring flooding often approaches and occasionally exceeds 40 feet.

Accidents within an anchorage or fleeting area may also be a concern. Collisions and allisions may occur during maneuvering in close quarters, which frequently occurs at anchorages, as well as at docks and in other congested areas in a port. In a study conducted for the Puget Sound, tank barges were found to have an accident rate that is 5.3 times higher for maneuvering than for being in transit (0.000912 per transit day versus 0.000171 per transit day).[61] In the same study, non-impact incidents (e.g., excluding collisions, allisions, and groundings) for tankers were found to be 16 times more likely while underway as opposed to being in an anchorage (0.00282 per transit day versus 0.000179 per transit day). For tank barges, the accident rate while underway was four times as high as in anchorages (0.000426 per transit day versus 0.000179 per transit day). Non-impact accidents generally do not present the same risk for spills as impact accidents where hull breaches are more likely due to the force involved.

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[55] BMT 2004.

[56] Altiok 2012.

[57] Woodell et al. 2002.

[58] LaPorte 1996.

[59] According to the NTSB (2017), "Mariners should consider measures such as increasing the scope of anchor chains, stationing navigation and engineering watches, keeping propulsion and steering systems at the ready, and retaining a pilot on board."

[60] NTSB 2017.

[61] The Glosten Associates et al. 2013.

Vessel Encounters on the Hudson River

For collisions and allisions, accident rates are dependent on the frequency of encounters (i.e., the number of times a vessel comes into the vicinity of other vessels) along its journey. The encounter rate is dependent on both the vessel traffic (numbers of vessels) and the space through which the vessels are transiting. In some busy ports, these encounters are very frequent, increasing the likelihood of an accident. In other waterways with lower levels of vessel traffic, the actual encounters are infrequent.

For the Hudson River, the encounter rate was calculated based on available transit data. With most larger vessels traveling at about 10–12 kts (12–15 mph), the transit through the 115-mile study area would be expected to take place over the course of about 8–10 hours, assuming no stops or slow-downs. In actual practice, the vessels do anchor to await berths or pilots, dock, and slow down along each transit. According to anecdotal information from pilots on the Hudson River, transits to and from the Port of Albany generally take place on separate days–i.e., each transit would take place over one day.

If each vessel transit (up- or down-river) takes place over the course of 24 hours, the vessels are assumed to spend 10 hours underway, two hours at anchor or slowed down; and 12 hours at dock. If each transit involves 10 hours of actual motion, there are 14,410 hours of deep-draft vessels in transit each year, and 143,440 hours of shallow-draft vessels in transit, or a total of 157,850 hours of vessels underway in the Hudson River study area.

Each year, there are 1,441 deep-draft and 14,334 shallow-draft vessel transits (Table 21). Every day, there are about 43 vessel transits–roughly 22 up-river and 22 down-river transits. (Half of these transits would involve cargo-laden vessels.)

Annually, there are an estimated 300 vessel-to-vessel pairwise encounters within one-quarter mile in the Hudson River study area (Table 31). This does not mean that there would be collisions or other accidents, only that the vessels might be within one quarter-mile of each other potentially requiring some kind of evasive or avoidance maneuvering.

Table 31: Estimated Annual Vessel Encounters within One-Quarter Mile on Hudson River

Vessel Type	Cargo Ship Deep	Cargo Ship Shallow	Cargo Barge Deep	Cargo Barge Shallow	Tanker	Tow/ Tug Deep	Tow/ Tug Shallow	Tank Barge Deep	Tank Barge Shallow	Total
Cargo Ship Deep	0.05	1.94	0.06	0.68	0.02	0.07	0.53	0.19	0.43	**4**
Cargo Ship Shallow	1.94	71.22	2.32	25.06	0.59	2.41	19.61	6.88	15.69	**146**
Cargo Barge Deep	0.06	2.32	0.08	0.82	0.02	0.08	0.64	0.22	0.51	**5**
Cargo Barge Shallow	0.68	25.06	0.82	8.82	0.21	0.85	6.90	2.42	5.52	**51**

Table 31: Estimated Annual Vessel Encounters within One-Quarter Mile on Hudson River

Vessel Type	Cargo Ship Deep	Cargo Ship Shallow	Cargo Barge Deep	Cargo Barge Shallow	Tanker	Tow/ Tug Deep	Tow/ Tug Shallow	Tank Barge Deep	Tank Barge Shallow	Total
Tanker	0.02	0.59	0.02	0.21	0.00	0.02	0.16	0.06	0.13	**1**
Tow/ Tug Deep	0.07	2.41	0.08	0.85	0.02	0.08	0.66	0.23	0.53	**5**
Tow/ Tug Shallow	0.53	19.61	0.64	6.90	0.16	0.66	5.40	1.89	4.32	**40**
Tank Barge Deep	0.19	6.88	0.22	2.42	0.06	0.23	1.89	0.66	1.52	**14**
Tank Barge Shallow	0.43	15.69	0.51	5.52	0.13	0.53	4.32	1.52	3.45	**32**
Total	**4**	**146**	**5**	**51**	**1**	**5**	**40**	**14**	**32**	**298**

Note that for half of the tank vessel (tanker and tank barge) transits there would be no oil cargo, only bunker fuel. Vessel-to-vessel encounters with loaded tank vessels are shown in Table 32. There are an estimated 24 half-mile vessel encounters with loaded tank vessels each year. There would be about two close encounters between loaded tank vessels.

Table 32: Estimated Annual Loaded Tank Vessel Encounters within One-Quarter Mile

Vessel Encountered	Loaded Tank Vessel Type			
	Loaded Tanker	Loaded Tank Barge Deep	Loaded Tank Barge Shallow	Total
Loaded Tanker	0.001	0.014	0.032	**0.048**
Loaded Tank Barge Deep	0.014	0.166	0.379	**0.559**
Loaded Tank Barge Shallow	0.032	0.379	0.864	**1.275**
Empty Tanker	0.001	0.014	0.032	**0.048**
Empty Tank Barge Deep	0.014	0.166	0.379	**0.559**
Empty Tank Barge Shallow	0.032	0.379	0.864	**1.275**
Cargo Ship Deep	0.008	0.093	0.213	**0.315**
Cargo Ship Shallow	0.294	3.440	7.843	**11.576**
Cargo Barge Deep	0.006	0.068	0.155	**0.228**
Cargo Barge Shallow	0.103	1.210	2.760	**4.073**
Tow/ Tug Deep	0.010	0.117	0.266	**0.392**
Tow/ Tug Shallow	0.081	0.947	2.160	**3.188**
Total	**0.597**	**6.994**	**15.945**	**23.536**

The encounter estimates are actually over-estimating the rate of encounters because most of the loaded tank vessel traffic goes in one direction only at this time. The loaded tank vessels would therefore only be likely to encounter another vessel about 87 times per year (i.e., removing the loaded-loaded encounters in Table 32).

Application of Previous Vessel Casualty Studies

Casualty rates from previous studies that were conducted for other locations or globally, based on either historical data or modeling, were evaluated as a comparison and for potential use in the projections for the Hudson River. Appendix A provides a synopsis of a large number of vessel casualty studies that have been conducted worldwide and in specific locations.

Many of the studies focus on the number of accidents per ship-year (operating a ship for one year). These data are useful for risk management and insurance purposes for large international ship operators. For analyzing a smaller waterway (e.g., a port or river), per transit data are more applicable, although it is possible to estimate the number of transits per year per vessel for extrapolation purposes.

The studies on encounter accidents (collisions and allisions) and groundings are most important in that these incidents are the ones that would have the potential to cause the largest oil outflow (the largest volume of spillage). The frequencies of encounter accidents are dependent on:

- Vessel traffic and density;
- Channel width and configuration;
- Traffic separation schemes in shipping lanes;
- Vessel traffic service (VTS) availability and usage;
- Visibility;
- Competence of operators to make evasive maneuvers in the event of an encounter; and
- Size of vessels, which determines the ability and space or distance to make evasive maneuvers.

For groundings, there are other considerations. Except in the case of a grounding that occurs because of an evasive maneuver, the usual causes of powered groundings[62] are related to:

- Presence of submerged navigational hazards;
- Unfamiliarity of the vessel operator with charted navigational hazards (often due to the lack of compulsory pilotage); and
- Steering failure.

In the case of drift groundings,[63] storms and onshore winds, as well as the distance to shore (or submerged navigational hazards) are important factors. Steering or engine power failure may also be involved in some cases. When a vessel hits a soft (e.g., sandy) bottom, it is called a soft grounding whether or not it was a powered or drift grounding. These incidents are often not serious and are much less likely to cause a hull rupture and spill. The vessel may require towing or waiting until higher tide. A hard grounding occurs when the vessel strikes a hard submerged object (e.g., a rock). This type of incident is more likely

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[62] Groundings that occur when the vessel is being intentionally moved forward.
[63] Groundings that occur as a result of the inability to control the vessel during a heavy storm or onshore winds.

to cause hull damage and the potential for spillage. When a vessel is involved in a drift grounding and hits a rocky shore or shoreline structures (e.g., piers), there may also be significant hull damage, increasing the likelihood of spillage.

A large number of studies (using historical data or modeling)[64] have taken these types of geographic factors into account to determine rates of impact accidents (collisions, allisions, and groundings.)

The main advantage of using previous vessel casualty data or models is that there is a higher degree of accuracy for estimating low-frequency events that have relatively long return periods. The disadvantage is that there are apt to be specific characteristics of a waterway that may affect the rate of accidents (the exceptions to the rule).

Calculation Approach for Hudson River Vessel Casualty Rates

To the extent that the Hudson River casualty data (as summarized in Table 22 through Table 25) were reasonable, they were applied. However, for certain types of accidents, other casualty rates were applied. In these cases, the rates were modified, to the extent possible, to reflect mitigating circumstances and conditions on the Hudson River.

Hudson River-specific vessel grounding data were applied in that the relative frequency of groundings within the specific geographic and bathymetric configurations of the river would likely have yielded the number of groundings that might occur. A brief comparison between the Hudson grounding rate and that of other analogous waterways was conducted.

The historical data most likely are sufficient to determine the likelihood of future allision incidents. Allisions generally occur during maneuvers at docks or around obstructions. While there have been a number of allisions, there have been very few collision accidents in the Hudson River. This is likely because the time period considered is not long enough. The other factor considered is that collisions are very much related to the traffic density or congestion because of the changes in encounter rates. Rates of corrective actions (e.g., evasive maneuvers), human error, and steering failure, all of which factor into the likelihood of collisions, are all relatively well established in maritime studies. Therefore, for collisions, the preferred approach was to apply collision models (algorithms) modified to Hudson River conditions.

Other types of casualties, including those related to fire, structural failure, or equipment failure, are generally not dependent on waterway characteristics or vessel traffic. The rates of these types of casualties are affected by the maintenance and quality of the vessels and the training of the operators. For these, data from other studies were used to supplement the Hudson data after a comparison was conducted.

As a conservative measure, the higher of the vessel casualty rates was assumed in comparisons between Hudson and other data. All data were calculated as per-vessel transit so that the data could be applied to current as well as other future potential vessel traffic. ***Note that vessel casualties do not necessarily result in spills. The probability of spillage in the event of a casualty is calculated in later sections of this chapter.***

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[64] Appendix A Table 99 through Table 102.

Calculation of Vessel Collision Frequencies

The likelihood of a collision in the Hudson River was calculated based on the basic collision model:[65]

$$N_{coll} = N_E \cdot P_C$$

Where: N_{coll} = number of collisions

N_E = number of pairwise encounters (vessel-to-vessel encounters)

P_C = probability of failing to avoid collision course due to technical failure or human error

This equation was converted into a time-dependent version:

$$\frac{N_{coll}}{t} = \frac{N_E}{t} \cdot P_C$$

Where: t = time (in years)

The collision rate (per year) should also be modified with factors that increase (M) or decrease (R) the likelihood of collisions that are relevant to the specific water (in this case, the Hudson River study area), which changes the equation to:

$$\frac{N_{coll}}{t} = \left\{ \left[\frac{N_E}{t} \cdot P_C \right] \cdot \left[\sum M_i \right] \right\} - \left\{ \left[\frac{N_E}{t} \cdot P_C \right] \cdot \left[\sum R_i \right] \right\}$$

$$\frac{N_{coll}}{t} = \left[\frac{N_E}{t} \cdot P_C \right] \cdot \left\{ \left[\sum M_i \right] - \left[\sum R_i \right] \right\}$$

Based on the data in Table 31 and Table 32, for the Hudson River, N_E, the number of pairwise encounters with loaded tank vessels is 24 per year. For other vessels that could potentially spill bunker fuel (including tank vessels), the annual encounter number is about 300.

The average probability of the failure of collision avoidance (P_c), is about 0.0005.[66]

The modifiers[67] relevant to the Hudson River (M_H) are:

- M_{WIDTH} = 4.2 for narrow river (applied to 0.25 of river mileage); 1.0 for wide river (applied to 0.75 of river mileage)
- $R_{PILOTAGE}$ = 0.51 for compulsory pilotage (for 0.035 transits)[68]
- $M_{VISIBILITY}$ = 6.9 for fog and other visibility factors for 0.2 part of river mileage-time

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[65] Fujii and Shiobara 1971; MacDuff 1974; Motewka et al. 2010.

[66] MacDuff 1974; Fowler and Sørgård 2000; Otto et al. 2002; Rosqvist et al. 2002; Przywarty 2009.

[67] Lewison 1980; Det Norske Veritas 2011b; Det Norske Veritas 1999.

[68] Based on average 560 state-piloted transits (Table 28) assigned to 15,785 annual trips (Table 21).

The modifiers were summed as follows:

$$M_H = (M_{WIDTH} + M_{VISIBILITY}) \cdot R_{PILOTAGE}$$
$$M_{WIDTH-H} = (0.25 \cdot M_{NARROW}) + (0.75 \cdot M_{WIDE})$$
$$M_{VISIBILITY-H} = 0.2 \cdot M_{VISIBILITY}$$
$$R_{PILOTAGE-H} = 0.035 \cdot R_{PILOTAGE}$$
$$M_H = 3.16$$

The estimated number of collisions for the Hudson River study area, based on these assumptions, is:

$$\frac{N_{coll}}{t} = \left[\frac{N_E}{t} \cdot P_C\right] \cdot \left\{\left[\sum M_i\right] - \left[\sum R_i\right]\right\}$$
$$\frac{N_{coll-TANKS}}{year} = (24 \cdot 0.0005) \cdot 3.16$$
$$\frac{N_{coll-TANKS}}{year} = 0.038$$
$$\frac{N_{coll-ALL}}{year} = (300 \cdot 0.0005) \cdot 3.16$$
$$\frac{N_{coll-ALL}}{year} = 0.47$$

In other words, there would be expected to be 0.038 collisions involving loaded tank vessels per year–or one collision every 26 years. For all vessels that carry oil as bunker fuel, it would be expected that there are 0.47 incidents per year or one incident every two years. ***Note that the occurrence of a collision does not imply that there will necessarily be a spill.***

These estimates are based on pairwise encounter rates (within one-quarter mile) for current vessel traffic. If vessel traffic were to change (i.e., increase or decrease), the probabilities of collisions would also change. Collision probability is based on the concept that vessel density (the number of vessels in a given area) is the driving factor, since vessel density affects the potential encounter rate. This approach is useful for determining the increase in likelihood of collisions with increases in overall vessel traffic.

Based on an analysis conducted on vessel collisions and vessel density in the Puget Sound,[69] the following relationship between vessel density and expected collisions was developed:

$$CR_d = 0.00003d^{1.19}$$

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[69] Based on Judson 1992; applied in: The Glosten Associates et al. 2013; Herbert Engineering et al. 2014.

Where: d = vessel density (number of vessels per square mile)

CR_d = collision rate (expected collisions per vessel transit) at vessel density, d.

The relationship between vessel density and collision rate can be seen in Figure 30.

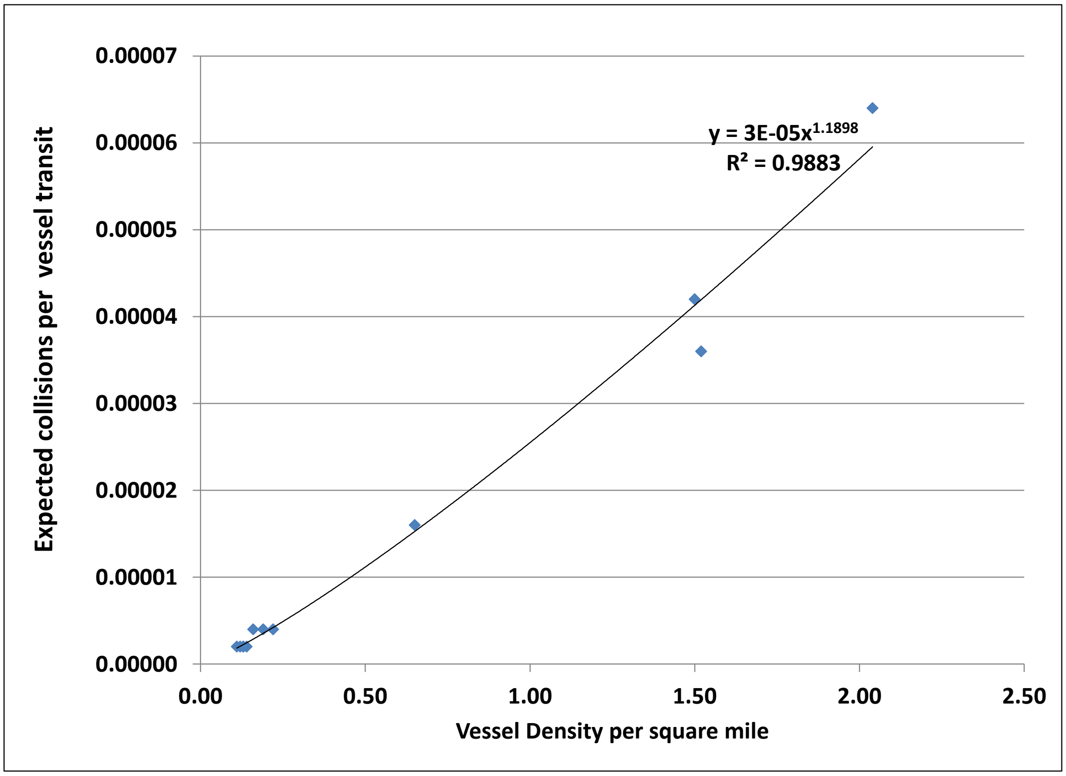

Figure 30: Expected Collisions by Vessel Density[70]

As a check, this formula was applied to the Hudson River data. The calculation is based on a vessel density. For the 44 vessels that are on the river at any one time over the approximately 115 square-mile area of study area, of which about one-half of which comprises the channel and navigable areas, the density is 0.76 vessels per square mile. Based on this, the collision frequency of 0.00005 per vessel transit might be expected. With 15,785 annual vessel transits in the Hudson, there would be estimated to be 0.34 collisions per year–or one collision every three years. This is a lower predicted frequency than predicted by the first method. The increased number of potential collisions is attributable to the adjustments made to the potential probability due to factors of visibility and width.

Based on the original equation:

$$\frac{N_{coll}}{t} = \left[\frac{N_E}{t} \cdot P_C\right] \cdot \left\{\left[\sum M_i\right] - \left[\sum R_i\right]\right\},$$

---

[70] Equation developed from data on vessel density and collision rates extrapolated from Judson 1992.

the increase in collisions is directly proportional to the number of pairwise vessel encounters (N_A). The encounters are based on the numbers of vessels going in either direction along with the likelihood that any two vessels will simultaneously be in the same quarter-mile length of the shipping channel (“block”).

The probability that one vessel will be in a certain “block” over the course of a year is the equivalent of the number of annual vessel trips divided by the number of blocks. The probability that two vessels will be in the same block is that probability squared. (Probabilities of two things happening concurrently are the product of the two independent probabilities.) Assuming that time, *t*, is one year:

$$N_E = P_{VESSEL-UP} \cdot P_{VESSEL-DOWN}$$

$$P_{VESSEL-UP} = \frac{trips_{UP}}{N_{blocks}}$$

$$P_{VESSEL-DOWN} = \frac{trips_{DOWN}}{N_{blocks}}$$

$$N_E = \frac{trips_{UP}}{N_{blocks}} \cdot \frac{trips_{DOWN}}{N_{blocks}}$$

The trips need to be divided into up-river and down-river transits–$trips_{UP}$ and $trips_{DOWN}$. This can be roughly the number of total trips divided by two (as in Table 19). If the number of annual trips changes (i.e., more trips with greater vessel traffic, fewer trips with less traffic), the number of encounters (N_E) changes. Assuming the number of trips up and down are equivalent:

$$N_E = \frac{trips_{UP}}{N_{blocks}} \cdot \frac{trips_{DOWN}}{N_{blocks}}$$

$$trips_{UP} = trips_{DOWN} = \frac{transits_{TOTAL}}{2}$$

$$N_{blocks-Hudson} = 460$$

$$N_E = \frac{(0.5 \cdot transits_{TOTAL})^2}{460^2}$$

$$N_E = \frac{0.25 \cdot (transits_{TOTAL})^2}{211600}$$

$$N_E = 0.0000012 \cdot (transits_{TOTAL})^2$$

For loaded tank vessel traffic alone, the transits have to be divided into loaded tanker traffic versus all other traffic (including empty tank vessels) that might be encountered.

$$N_E = \frac{trips_{TANK}}{N_{blocks}} \cdot \frac{trips_{OTHER}}{N_{blocks}}$$

$$N_{blocks-Hudson} = 460$$

$$N_E = \frac{(trips_{TANK-LOADED} \cdot trips_{OTHER})^2}{460^2}$$

$$trips_{TANK-LOADED} = 0.5 \cdot trips_{TANK}$$

$$trips_{OTHER} = 0.5 \cdot transits_{TOTAL}$$

$$N_E = \frac{(0.5 \cdot trips_{TANK}) \cdot (0.5 \cdot transits_{TOTAL})}{211600}$$

$$N_E = \frac{0.25(trips_{TANK} \cdot transits_{TOTAL})}{211600}$$

$$N_E = 0.0000012 \cdot (trips_{TANK} \cdot transits_{TOTAL})$$

Applying these equations that calculate encounters to the original equation that multiplies encounters by the likelihood of avoidance and modifies for mitigating factors, and varying vessel traffic assumptions (Table 33), the collision rates for the Hudson River were estimated a summarized in Table 34 and Figure 31. (Loaded tank vessels are analyzed separately as they have the potential to spill cargo.) Increases and decreases in tank vessel traffic assume that all other traffic stays the same, though the overall number, which includes the tank vessel traffic, would change. ***Note that these are not necessarily spills. Spill rates per collision are calculated in another part of this chapter.***

Table 33: Hudson River Vessel Traffic Assumptions for Modeling

Vessel Traffic Assumptions		Numbers of Loaded Tank Vessels			Total Vessels
		Tankers	Tank Barges	Total Tank Vessels	
1	**Current Traffic**[71]	**32**	**1,230**	**1,262**	**15,785**
2	**50% Overall Decrease**	16	615	**631**	**7,893**
3	**10% Overall Decrease**	29	1,107	**1,136**	**14,207**
4	**50% Decrease in Tank Vessels**	16	615	**631**	**14,523**
5	**20% Decrease in Tank Vessels**	26	984	**1,010**	**15,280**
6	**10% Decrease in Tank Vessels**	29	1,107	**1,136**	**15,533**
7	**10% Increase in Tank Vessels**	35	1,353	**1,388**	**16,037**
8	**20% Increase in Tank Vessels**	39	1,476	**1,515**	**16,290**
9	**50% Increase in Tank Vessels**	48	1,845	**1,893**	**17,047**
10	**10% Overall Increase**	35	1,353	**1,388**	**17,364**
11	**100% Increase in Tank Vessels**	64	2,460	**2,524**	**18,309**
12	**20% Overall Increase**	39	1,476	**1,515**	**18,942**
13	**200% Increase in Tank Vessels**	128	4,920	**5,048**	**23,357**
14	**50% Overall Increase**	48	1,845	**1,893**	**23,678**
15	**100% Overall Increase (Doubling)**	64	2,460	**2,524**	**31,570**

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[71] Based on Table 19.

Table 34: Predicted Collision Frequency for Hudson River by Vessel Traffic

Vessel Traffic Assumptions		Estimated Annual Number of Collisions		
		Loaded Tank Vessels (Oil Cargo Spill Potential)		Overall Vessel[72] (Bunker Fuel Spill Potential)
		Tankers	Tank Barges	All Vessels
1	Current Traffic	**0.0005**	**0.0184**	**0.4724**
2	50% Overall Decrease	0.0001	0.0046	0.1181
3	10% Overall Decrease	0.0004	0.0149	0.3827
4	50% Decrease in Tank Vessels	0.0002	0.0085	0.3999
5	20% Decrease in Tank Vessels	0.0004	0.0143	0.4427
6	10% Decrease in Tank Vessels	0.0004	0.0163	0.4575
7	10% Increase in Tank Vessels	0.0005	0.0206	0.4876
8	20% Increase in Tank Vessels	0.0006	0.0228	0.5031
9	50% Increase in Tank Vessels	0.0008	0.0298	0.5510
10	10% Overall Increase	0.0006	0.0223	0.5717
11	100% Increase in Tank Vessels	0.0011	0.0427	0.6356
12	20% Overall Increase	0.0007	0.0265	0.6803
13	200% Increase in Tank Vessels	0.0028	0.1090	1.0344
14	50% Overall Increase	0.0011	0.0414	1.0630
15	100% Overall Increase (Doubling)	0.0019	0.0737	1.8897

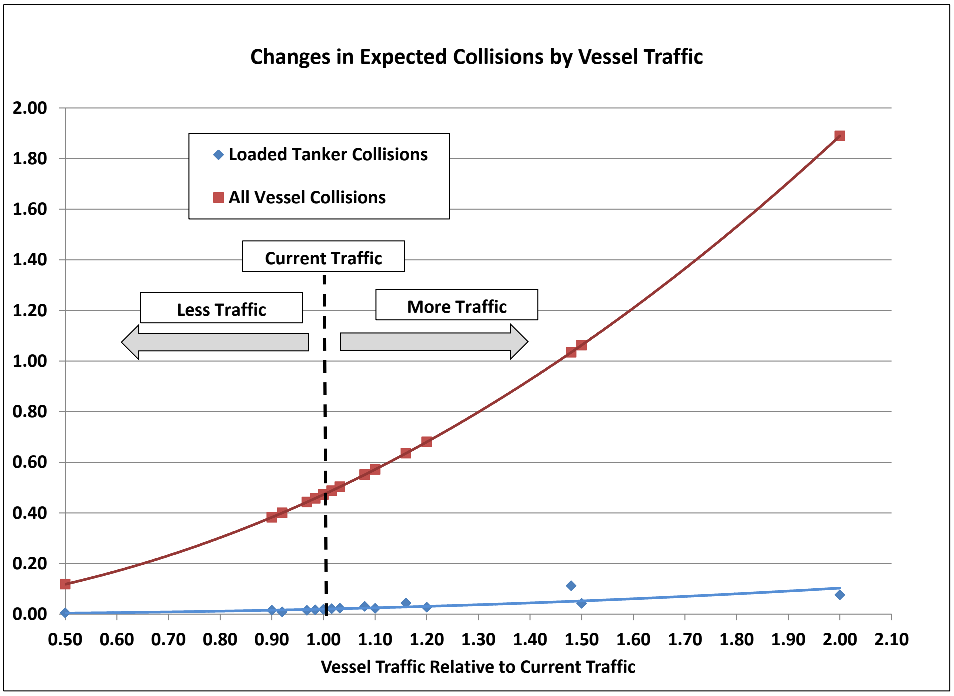

Figure 31: Changes in Expected Collisions based on Vessel Traffic Assumptions

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[72] "1 in 1" or 1 in [<1] probability means that it is likely that there would be at least one incident per year.

Assumptions for Other Vessel Casualty Frequencies

The probability of allisions was estimated to be 0.00036 per vessel trip (based on the data in Table 24). There are no reliable data for comparison. The likelihood of allisions between would increase with more vessel congestion, although the likelihood of two vessels encountering each other such as in an anchorage is captured under collisions. For allisions with docks and other structures, the probability is linearly related to vessel number.

For groundings, the existing historical data (from Table 24) for the Hudson River shows an average grounding rate of 0.00059 per transit. For tankers, the rate is considerably higher–0.0023 per transit. For tank barges, which have a lower draft, the rate is 0.0003 per transit. This is apt to be a relatively good indicator of the likelihood of future groundings given the particular geography of the Hudson River. The rates for the Hudson River are generally higher than estimated in other studies, which range from about 0.0001 to 0.0002 per transit.

For fires on board the vessel,[73] the probability is very low, based on Hudson River data (Table 24)–averaging 0.000019 per transit–or 0.3 fires per year, as estimated by the Hudson data. The only data available for fires on vessels are based on ship-years.[74] The average is about 0.00015 per ship-year. If the Hudson River vessel transits are based on one-day trips, there are 15,785 trips across 365 days or 43 ship-years. This would predict an estimated 0.006 fires per year, based on the ship-year methodology. In this case, the higher probability was selected for application in this study. Note that fire casualties do not indicate fires that occur as the result of spillage, rather fires that occur in engines or elsewhere on board a vessel that might cause a spill.

For structural failures and mechanical failures, the Hudson River data (Table 24) were applied as they are relatively close to data from other regions.[75] The structural failure rate is assumed to be 0.00031 per transit, and the equipment failure rate was assumed to be 0.000014 per transit.

In addition, the Hudson River data (Table 24) indicated a rate of casualties that resulted in minor spillage of 0.00032 per transit.

Application of Other Vessel Casualty Rates to Hudson River Traffic

The annual traffic data (as in Table 21) were applied to each of the non-collision casualty rates to determine the expected annual numbers of incidents and the annual probabilities (or chances of occurrence) based on different traffic assumptions. The results are shown in Table 35 for allisions, Table 36 for groundings, Table 37 for fires, Table 38 for structural failure, and Table 39for equipment failure. In addition, the results for miscellaneous small spills, the results are shown in Table 40***. Except for the minor spill casualties in Table 40 the data indicate casualties and not necessarily spills. The likelihood of spills as a result of casualties is analyzed in following section.***

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[73] Note that this does not indicate fires that occur as the result of spillage, rather fires that occur in engines or elsewhere on board a vessel that might cause a spill.

[74] See Appendix A. Det Norske Veritas 2011b; Selway et al. 1999; Ulusçu et al. 2008.

[75] The Glosten Associates et al. 2013; See also Appendix A.

Table 35: Predicted Allision Frequency for Hudson River by Vessel Traffic

Vessel Traffic Assumptions		**Estimated Annual Number of Allisions**		
		Loaded Tank Vessels (Oil Cargo Spill Potential)		**Overall Vessel (Bunker Fuel Spill Potential)**
		Tankers	**Tank Barges**	**All Vessels**
1	**Current Traffic**	**0.0114**	**0.4430**	**5.6826**
2	**50% Overall Decrease**	0.0057	0.2215	2.8415
3	**10% Overall Decrease**	0.0102	0.3987	5.1145
4	**50% Decrease in Tank Vessels**	0.0057	0.2215	5.2283
5	**20% Decrease in Tank Vessels**	0.0091	0.3545	5.5008
6	**10% Decrease in Tank Vessels**	0.0102	0.3987	5.5919
7	**10% Increase in Tank Vessels**	0.0125	0.4872	5.7733
8	**20% Increase in Tank Vessels**	0.0136	0.5318	5.8644
9	**50% Increase in Tank Vessels**	0.0170	0.6644	6.1369
10	**10% Overall Increase**	0.0125	0.4872	6.2510
11	**100% Increase in Tank Vessels**	0.0227	0.8859	6.5912
12	**20% Overall Increase**	0.0136	0.5318	6.8191
13	**200% Increase in Tank Vessels**	0.0454	1.7718	8.4085
14	**50% Overall Increase**	0.0170	0.6644	8.5241
15	**100% Overall Increase (Doubling)**	0.0227	0.8859	11.3652

Table 36: Predicted Grounding Frequency for Hudson River by Vessel Traffic

Vessel Traffic Assumptions		**Estimated Annual Number of Groundings**		
		Loaded Tank Vessels (Oil Cargo Spill Potential)		**Overall Vessel (Bunker Fuel Spill Potential)**
		Tankers	**Tank Barges**	**All Vessels**
1	**Current Traffic**	**0.0726**	**0.3691**	**9.3132**
2	**50% Overall Decrease**	0.0363	0.1846	4.6569
3	**10% Overall Decrease**	0.0653	0.3323	8.3821
4	**50% Decrease in Tank Vessels**	0.0363	0.1846	8.5686
5	**20% Decrease in Tank Vessels**	0.0581	0.2954	9.0152
6	**10% Decrease in Tank Vessels**	0.0653	0.3323	9.1645
7	**10% Increase in Tank Vessels**	0.0798	0.4060	9.4618
8	**20% Increase in Tank Vessels**	0.0871	0.4431	9.6111
9	**50% Increase in Tank Vessels**	0.1088	0.5537	10.0577
10	**10% Overall Increase**	0.0798	0.4060	10.2448
11	**100% Increase in Tank Vessels**	0.1451	0.7383	10.8023
12	**20% Overall Increase**	0.0871	0.4431	11.1758
13	**200% Increase in Tank Vessels**	0.2903	1.4765	13.7806
14	**50% Overall Increase**	0.1088	0.5537	13.9700
15	**100% Overall Increase (Doubling)**	0.0227	0.8859	11.3652

Table 37: Predicted Fire Casualty Frequency for Hudson River by Vessel Traffic

Vessel Traffic Assumptions		Estimated Annual Number of Fire Casualties		
		Loaded Tank Vessels (Oil Cargo Spill Potential)		Overall Vessel (Bunker Fuel Spill Potential)
		Tankers	Tank Barges	All Vessels
1	**Current Traffic**	**0.0006**	**0.0234**	**0.2999**
2	**50% Overall Decrease**	0.0003	0.0117	0.1500
3	**10% Overall Decrease**	0.0005	0.0210	0.2699
4	**50% Decrease in Tank Vessels**	0.0003	0.0117	0.2759
5	**20% Decrease in Tank Vessels**	0.0005	0.0187	0.2903
6	**10% Decrease in Tank Vessels**	0.0005	0.0210	0.2951
7	**10% Increase in Tank Vessels**	0.0007	0.0257	0.3047
8	**20% Increase in Tank Vessels**	0.0007	0.0281	0.3095
9	**50% Increase in Tank Vessels**	0.0009	0.0351	0.3239
10	**10% Overall Increase**	0.0007	0.0257	0.3299
11	**100% Increase in Tank Vessels**	0.0012	0.0468	0.3479
12	**20% Overall Increase**	0.0007	0.0281	0.3599
13	**200% Increase in Tank Vessels**	0.0024	0.0935	0.4438
14	**50% Overall Increase**	0.0009	0.0351	0.4499
15	**100% Overall Increase (Doubling)**	0.0012	0.0468	0.5998

Table 38: Predicted Structural Failure Frequency for Hudson River by Vessel Traffic

Vessel Traffic Assumptions		Estimated Annual Number of Structural Failures		
		Loaded Tank Vessels (Oil Cargo Spill Potential)		Overall Vessel (Bunker Fuel Spill Potential)
		Tankers	Tank Barges	All Vessels
1	**Current Traffic**	**0.0098**	**0.3814**	**4.8934**
2	**50% Overall Decrease**	0.0049	0.1907	2.4468
3	**10% Overall Decrease**	0.0088	0.3434	4.4042
4	**50% Decrease in Tank Vessels**	0.0049	0.1907	4.5021
5	**20% Decrease in Tank Vessels**	0.0078	0.3053	4.7368
6	**10% Decrease in Tank Vessels**	0.0088	0.3434	4.8152
7	**10% Increase in Tank Vessels**	0.0108	0.4195	4.9715
8	**20% Increase in Tank Vessels**	0.0117	0.4579	5.0499
9	**50% Increase in Tank Vessels**	0.0147	0.5722	5.2846
10	**10% Overall Increase**	0.0108	0.4195	5.3828
11	**100% Increase in Tank Vessels**	0.0196	0.7629	5.6758
12	**20% Overall Increase**	0.0117	0.4579	5.8720
13	**200% Increase in Tank Vessels**	0.0391	1.5258	7.2407
14	**50% Overall Increase**	0.0147	0.5722	7.3402
15	**100% Overall Increase (Doubling)**	0.0196	0.7629	9.7867

Table 39: Predicted Equipment Failure Frequency for Hudson River by Vessel Traffic

Vessel Traffic Assumptions		Estimated Annual Number of Equipment Failures		
		Loaded Tank Vessels (Oil Cargo Spill Potential)		Overall Vessel (Bunker Fuel Spill Potential)
		Tankers	Tank Barges	All Vessels
1	**Current Traffic**	**0.0004**	**0.0172**	**0.2210**
2	**50% Overall Decrease**	0.0002	0.0086	0.1105
3	**10% Overall Decrease**	0.0004	0.0155	0.1989
4	**50% Decrease in Tank Vessels**	0.0002	0.0086	0.2033
5	**20% Decrease in Tank Vessels**	0.0004	0.0138	0.2139
6	**10% Decrease in Tank Vessels**	0.0004	0.0155	0.2175
7	**10% Increase in Tank Vessels**	0.0005	0.0189	0.2245
8	**20% Increase in Tank Vessels**	0.0005	0.0207	0.2281
9	**50% Increase in Tank Vessels**	0.0007	0.0258	0.2387
10	**10% Overall Increase**	0.0005	0.0189	0.2431
11	**100% Increase in Tank Vessels**	0.0009	0.0345	0.2563
12	**20% Overall Increase**	0.0005	0.0207	0.2652
13	**200% Increase in Tank Vessels**	0.0018	0.0689	0.3270
14	**50% Overall Increase**	0.0007	0.0258	0.3315
15	**100% Overall Increase (Doubling)**	0.0009	0.0345	0.4420

Table 40: Predicted Minor Spill Casualties for Hudson River by Vessel Traffic

Vessel Traffic Assumptions		Estimated Annual Number of Minor Spill Casualties		
		Loaded Tank Vessels (Oil Cargo Spill)		Overall Vessel (Bunker Fuel Spill)
		Tankers	Tank Barges	All Vessels
1	**Current Traffic**	**0.0101**	**0.3937**	**5.0512**
2	**50% Overall Decrease**	0.0050	0.1969	2.5258
3	**10% Overall Decrease**	0.0091	0.3544	4.5462
4	**50% Decrease in Tank Vessels**	0.0050	0.1969	4.6474
5	**20% Decrease in Tank Vessels**	0.0081	0.3151	4.8896
6	**10% Decrease in Tank Vessels**	0.0091	0.3544	4.9706
7	**10% Increase in Tank Vessels**	0.0111	0.4331	5.1318
8	**20% Increase in Tank Vessels**	0.0121	0.4727	5.2128
9	**50% Increase in Tank Vessels**	0.0151	0.5906	5.4550
10	**10% Overall Increase**	0.0111	0.4331	5.5565
11	**100% Increase in Tank Vessels**	0.0202	0.7875	5.8589
12	**20% Overall Increase**	0.0121	0.4727	6.0614
13	**200% Increase in Tank Vessels**	0.0404	1.5750	7.4742
14	**50% Overall Increase**	0.0151	0.5906	7.5770
15	**100% Overall Increase (Doubling)**	0.0202	0.7875	10.1024

Probability of Oil Spillage with Vessel Casualties

With regard to a vessel accident turning into a spill (of any volume–small to very large), there are well-documented data and studies that provide valuable insights. For non-tank vessels (cargo ships that do not carry oil as cargo and can thus only spill bunker fuel), the probability of a bunker spill given an accident are shown in Table 41. The implementation schedule for double hulls on bunker tanks is in Table 42.

Table 41: Bunker Spill Probabilities for All Piloted Vessels[76]

Incident Type	Hull	Bunker Spill Probability (Worldwide Data)
Collision	**Single**	0.05000
	Double	0.02000
Allision	**Single**	0.05000
	Double	0.02000
Grounding	**Single**	0.05000
	Double	0.02000
Other, Non-Impact Error	**Single**	0.20000
	Double	0.20000
Transfer Error	**Single**	0.92000
	Double	0.92000

Table 42: Implementation of Double-Hulls for Bunker Tanks

Years	World Fleet	
	Probability of Double Hull	Probability of Single Hull
2018	0.41	0.59
2019	0.45	0.55
2020	0.50	0.50
2021	0.54	0.46
2022	0.59	0.41
2023	0.63	0.37
2024	0.68	0.32
2025	0.72	0.28
2030	0.75	0.25
2027	0.82	0.18
2028	0.88	0.12
2029	0.95	0.05
2030	1.00	0.00

For tank vessels, the probabilities of spillage are in Table 43. Since all tankers are *required* to have double hulls by 2015, for future spillage rates, the double-hulled probability should be applied. Tank barges in operation in the Hudson River likewise are all reported to have double hulls. For bunker tanks, it is assumed that 50% of the tanks would be double-hulled. Spill frequency will decrease over time.

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[76] Etkin and Michel 2003; Michel and Winslow 1999, 2000; Barone et al. 2007; Herbert Engineering et al. 2003.

Table 43: Cargo Spill Probabilities for Tankers and Tank Barges[77]

Vessel Type	Incident Type	Cargo Spill Probability in Incident, *P(CS)*
Small Tanker	**Collision**	0.15
	Allision	0.15
	Grounding	0.18
	Other, Non-Impact Error	0.40
	Transfer Error	0.92
Tank Barge	**Collision**	0.13
	Allision	0.13
	Grounding	0.22
	Other, Non-Impact Error	0.40
	Transfer Error	0.92

Based on the probabilities of spillage associated with vessel casualties, the annual expected numbers of spills (*of any volume–not necessarily large spills*) for the different types of casualties were calculated as shown in Table 44 through Table 50.

Table 44: Predicted Annual Spill Frequencies due to Collision

Vessel Traffic Assumptions		Loaded Tank Vessels (Oil Cargo Spills)		Overall Vessel (Bunker Fuel Spills)
		Tankers	Tank Barges	All Vessels
1	**Current Traffic**	**0.000075**	**0.002392**	**0.014172**
2	**50% Overall Decrease**	0.000015	0.000598	0.003543
3	**10% Overall Decrease**	0.000060	0.001937	0.011481
4	**50% Decrease in Tank Vessels**	0.000030	0.001105	0.011997
5	**20% Decrease in Tank Vessels**	0.000060	0.001859	0.013281
6	**10% Decrease in Tank Vessels**	0.000060	0.002119	0.013725
7	**10% Increase in Tank Vessels**	0.000075	0.002678	0.014628
8	**20% Increase in Tank Vessels**	0.000090	0.002964	0.015093
9	**50% Increase in Tank Vessels**	0.000120	0.003874	0.016530
10	**10% Overall Increase**	0.000090	0.002899	0.017151
11	**100% Increase in Tank Vessels**	0.000165	0.005551	0.019068
12	**20% Overall Increase**	0.000105	0.003445	0.020409
13	**200% Increase in Tank Vessels**	0.000420	0.014170	0.031032
14	**50% Overall Increase**	0.000165	0.005382	0.031890
15	**100% Overall Increase (Doubling)**	0.000285	0.009581	0.056691

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[77] Based on Yip et al. 2011b; Rawson and Brown 1998; NRC 1998; NRC 2001; IMO 1995; Etkin et al. 2002.

Table 45: Predicted Annual Spill Frequencies due to Allision

Vessel Traffic Assumptions		Loaded Tank Vessels (Oil Cargo Spills)		Overall Vessel (Bunker Fuel Spills)
		Tankers	**Tank Barges**	**All Vessels**
1	**Current Traffic**	**0.001710**	**0.057590**	**0.170478**
2	**50% Overall Decrease**	0.000855	0.028795	0.085245
3	**10% Overall Decrease**	0.001530	0.051831	0.153435
4	**50% Decrease in Tank Vessels**	0.000855	0.028795	0.156849
5	**20% Decrease in Tank Vessels**	0.001365	0.046085	0.165024
6	**10% Decrease in Tank Vessels**	0.001530	0.051831	0.167757
7	**10% Increase in Tank Vessels**	0.001875	0.063336	0.173199
8	**20% Increase in Tank Vessels**	0.002040	0.069134	0.175932
9	**50% Increase in Tank Vessels**	0.002550	0.086372	0.184107
10	**10% Overall Increase**	0.001875	0.063336	0.187530
11	**100% Increase in Tank Vessels**	0.003405	0.115167	0.197736
12	**20% Overall Increase**	0.002040	0.069134	0.204573
13	**200% Increase in Tank Vessels**	0.006810	0.230334	0.252255
14	**50% Overall Increase**	0.002550	0.086372	0.255723
15	**100% Overall Increase (Doubling)**	0.003405	0.115167	0.340956

Table 46: Predicted Annual Spill Frequencies due to Grounding

Vessel Traffic Assumptions		Loaded Tank Vessels (Oil Cargo Spills)		Overall Vessel (Bunker Fuel Spills)
		Tankers	**Tank Barges**	**All Vessels**
1	**Current Traffic**	**0.013068**	**0.081202**	**0.279396**
2	**50% Overall Decrease**	0.006534	0.040612	0.139707
3	**10% Overall Decrease**	0.011754	0.073106	0.251463
4	**50% Decrease in Tank Vessels**	0.006534	0.040612	0.257058
5	**20% Decrease in Tank Vessels**	0.010458	0.064988	0.270456
6	**10% Decrease in Tank Vessels**	0.011754	0.073106	0.274935
7	**10% Increase in Tank Vessels**	0.014364	0.089320	0.283854
8	**20% Increase in Tank Vessels**	0.015678	0.097482	0.288333
9	**50% Increase in Tank Vessels**	0.019584	0.121814	0.301731
10	**10% Overall Increase**	0.014364	0.089320	0.307344
11	**100% Increase in Tank Vessels**	0.026118	0.162426	0.324069
12	**20% Overall Increase**	0.015678	0.097482	0.335274
13	**200% Increase in Tank Vessels**	0.052254	0.324830	0.413418
14	**50% Overall Increase**	0.019584	0.121814	0.419100
15	**100% Overall Increase (Doubling)**	0.004086	0.194898	0.340956

Table 47: Predicted Annual Spill Frequencies due to Fire Casualty

Vessel Traffic Assumptions		Loaded Tank Vessels (Oil Cargo Spills)		Overall Vessel (Bunker Fuel Spills)
		Tankers	Tank Barges	All Vessels
1	Current Traffic	**0.000240**	**0.009360**	**0.059980**
2	50% Overall Decrease	0.000120	0.004680	0.030000
3	10% Overall Decrease	0.000200	0.008400	0.053980
4	50% Decrease in Tank Vessels	0.000120	0.004680	0.055180
5	20% Decrease in Tank Vessels	0.000200	0.007480	0.058060
6	10% Decrease in Tank Vessels	0.000200	0.008400	0.059020
7	10% Increase in Tank Vessels	0.000280	0.010280	0.060940
8	20% Increase in Tank Vessels	0.000280	0.011240	0.061900
9	50% Increase in Tank Vessels	0.000360	0.014040	0.064780
10	10% Overall Increase	0.000280	0.010280	0.065980
11	100% Increase in Tank Vessels	0.000480	0.018720	0.069580
12	20% Overall Increase	0.000280	0.011240	0.071980
13	200% Increase in Tank Vessels	0.000960	0.037400	0.088760
14	50% Overall Increase	0.000360	0.014040	0.089980
15	100% Overall Increase (Doubling)	0.000480	0.018720	0.119960

Table 48: Predicted Annual Spill Frequencies due to Structural Failure

Vessel Traffic Assumptions		Loaded Tank Vessels (Oil Cargo Spills)		Overall Vessel (Bunker Fuel Spills)
		Tankers	Tank Barges	All Vessels
1	Current Traffic	**0.003920**	**0.152560**	**0.978680**
2	50% Overall Decrease	0.001960	0.076280	0.489360
3	10% Overall Decrease	0.003520	0.137360	0.880840
4	50% Decrease in Tank Vessels	0.001960	0.076280	0.900420
5	20% Decrease in Tank Vessels	0.003120	0.122120	0.947360
6	10% Decrease in Tank Vessels	0.003520	0.137360	0.963040
7	10% Increase in Tank Vessels	0.004320	0.167800	0.994300
8	20% Increase in Tank Vessels	0.004680	0.183160	1.009980
9	50% Increase in Tank Vessels	0.005880	0.228880	1.056920
10	10% Overall Increase	0.004320	0.167800	1.076560
11	100% Increase in Tank Vessels	0.007840	0.305160	1.135160
12	20% Overall Increase	0.004680	0.183160	1.174400
13	200% Increase in Tank Vessels	0.015640	0.610320	1.448140
14	50% Overall Increase	0.005880	0.228880	1.468040
15	100% Overall Increase (Doubling)	0.007840	0.305160	1.957340

Table 49: Predicted Annual Spill Frequencies due to Equipment Failure

Vessel Traffic Assumptions		Loaded Tank Vessels (Oil Cargo Spills)		Overall Vessel (Bunker Fuel Spills)
		Tankers	Tank Barges	All Vessels
1	Current Traffic	**0.000160**	**0.006880**	**0.044200**
2	50% Overall Decrease	0.000080	0.003440	0.022100
3	10% Overall Decrease	0.000160	0.006200	0.039780
4	50% Decrease in Tank Vessels	0.000080	0.003440	0.040660
5	20% Decrease in Tank Vessels	0.000160	0.005520	0.042780
6	10% Decrease in Tank Vessels	0.000160	0.006200	0.043500
7	10% Increase in Tank Vessels	0.000200	0.007560	0.044900
8	20% Increase in Tank Vessels	0.000200	0.008280	0.045620
9	50% Increase in Tank Vessels	0.000280	0.010320	0.047740
10	10% Overall Increase	0.000200	0.007560	0.048620
11	100% Increase in Tank Vessels	0.000360	0.013800	0.051260
12	20% Overall Increase	0.000200	0.008280	0.053040
13	200% Increase in Tank Vessels	0.000720	0.027560	0.065400
14	50% Overall Increase	0.000280	0.010320	0.066300
15	100% Overall Increase (Doubling)	0.000360	0.013800	0.088400

Table 50: Predicted Annual Spill Frequencies due to Minor Spill Casualty

Vessel Traffic Assumptions		Loaded Tank Vessels (Oil Cargo Spills)		Overall Vessel (Bunker Fuel Spills)
		Tankers	Tank Barges	All Vessels
1	Current Traffic	**0.010**	**0.394**	**5.051**
2	50% Overall Decrease	0.005	0.197	2.526
3	10% Overall Decrease	0.009	0.354	4.546
4	50% Decrease in Tank Vessels	0.005	0.197	4.647
5	20% Decrease in Tank Vessels	0.008	0.315	4.890
6	10% Decrease in Tank Vessels	0.009	0.354	4.971
7	10% Increase in Tank Vessels	0.011	0.433	5.132
8	20% Increase in Tank Vessels	0.012	0.473	5.213
9	50% Increase in Tank Vessels	0.015	0.591	5.455
10	10% Overall Increase	0.011	0.433	5.557
11	100% Increase in Tank Vessels	0.020	0.788	5.859
12	20% Overall Increase	0.012	0.473	6.061
13	200% Increase in Tank Vessels	0.040	1.575	7.474
14	50% Overall Increase	0.015	0.591	7.577
15	100% Overall Increase (Doubling)	0.020	0.788	10.102

Vessel Spill Volumes for Collisions, Allisions, and Groundings

These probabilities only indicate whether there will be a spill of *any volume*. Most spills are quite small and only a very small percentage is large. Spill volume will depend on the accident circumstances, vessel capacity and loaded volume. The type of oil affects the way in which it flows out. For double-hulled tank barges involved in impact accidents, the probabilities of different outflow percentages are as in Table 51.

Table 51: Oil Outflow Probability for Double-Hull Tank Barges in Impact Accidents

% Cargo Outflow (Adjusted)	Probability[78]	Cumulative Probability
0.001%	0.180	0.1800
0.01%	0.220	0.4000
0.03%	0.200	0.6000
0.2%	0.110	0.7100
0.5%	0.090	0.8000
1%	0.070	0.8700
3%	0.060	0.9300
7.5%	0.030	0.9600
15%	0.020	0.9800
23%	0.018	0.9980
50%	0.002	1.0000

Outflow modeling has demonstrated that the volumes of outflows for the very largest incidents involving tankers and tank barges would be reduced by 50% with double hulls. Note also that this is independent of the probability of spillage occurring with an impact accident. Double hulls on tankers accomplish two things: reduction of the probability of any spillage occurring in the first place, and reduction of the volume of spillage for the very largest incidents by 50%. This is not the case for double hulls on bunker tanks, for which there is a reduction in the probability of spillage occurring in an impact accident, but there is no reduction in spillage volume with large incidents. The percentage oil outflow probabilities from tankers (Table 52) is based on international studies of the amount of oil actually spilled compared with the adjusted capacity of the vessel, which was verified by existing oil outflow models developed for the International Maritime Organization (IMO).[79]

Table 52: Oil Outflow Probability for Double-Hull Tankers in Impact Accidents

% Cargo Outflow	Probability	Cumulative Probability
0.002%	0.3589	0.3589
0.02%	0.1400	0.4989
0.05%	0.1200	0.6189
0.2%	0.1110	0.7299
0.7%	0.0900	0.8199

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[78] Based on Etkin 2001; Etkin 2002; Etkin 2003; Etkin and Neel 2001; Etkin and Michel 2003; Etkin et al. 2009; Rawson and Brown 1998; Yip et al. 2011b; NRC 1998; NRC 2001. (Oil outflow percentage probabilities were derived from analyses of international data on oil spillage (actual spillage versus adjusted capacity).

[79] Rawson and Brown 1998; Yip et al. 2011b; NRC 1998; NRC 2001.

Table 52: Oil Outflow Probability for Double-Hull Tankers in Impact Accidents		
% Cargo Outflow	**Probability**	**Cumulative Probability**
1.3%	0.0800	0.8999
3.1%	0.0700	0.9699
20%	0.0300	0.9999
50%	0.0001	1.0000

The bunker outflow probabilities for impacts accidents are shown in Table 53.

Table 53: Bunker Outflow Probability from All Vessel Impact Accidents		
% Bunker Outflow	**Probability *P*[80]**	**Cumulative Probability**
0.01%	0.23	0.2300
0.03%	0.17	0.4000
0.15%	0.14	0.5400
1.6%	0.10	0.6400
4.3%	0.09	0.7300
10%	0.08	0.8100
16%	0.06	0.8700
33.3%	0.05	0.9200
59%	0.04	0.9600
100%	0.04	1.0000

Spill Volumes for Non-Impact Casualties

The oil outflow for non-impact casualties, including structural failure, equipment failure, and fire tends to be smaller than that for impact-related events, as shown in Table 54 for tankers, in Table 55 for tank barges, and Table 56 for bunker tanks.[81]

Table 54: Oil Outflow Probability for Non-Impact Incidents in Tankers		
% Cargo Outflow (Adjusted)	**Probability**	**Cumulative Probability**
0.01%	0.50	0.5000
0.02%	0.15	0.6500
0.06%	0.11	0.7600
0.16%	0.08	0.8400
0.54%	0.08	0.9200
11.50%	0.08	1.0000

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[80] Etkin and Michel 2003; Etkin 2001; Etkin 2002; Herbert Engineering et al. 2003; Michel and Winslow 1999, 2002; Barone et al. 2007; Yip et al. 2011a.

[81] Based on Etkin and Michel 2003; Etkin 2001; Etkin 2002.

Table 55: Oil Outflow Probability for Double-Hull Tank Barges in Non-Impact Incidents

% Cargo Outflow (Adjusted)	Probability	Cumulative Probability
0.0005%	0.450	0.4500
0.001%	0.120	0.5700
0.002%	0.100	0.6700
0.004%	0.080	0.7500
0.01%	0.070	0.8200
0.02%	0.060	0.8800
0.04%	0.040	0.9200
0.1%	0.030	0.9500
0.6%	0.020	0.9700
1.8%	0.014	0.9840
6.3%	0.004	0.9880
14.3%	0.004	0.9920
18.6%	0.004	0.9960
27%	0.004	1.0000

Table 56: Bunker Outflow Probability from All Vessel Non-Impact Incidents

% Bunker Outflow (Adjusted)	Probability	Cumulative Probability
0.001%	0.20	0.2000
0.003%	0.15	0.3500
0.008%	0.13	0.4800
0.015%	0.11	0.5900
0.06%	0.09	0.6800
0.1%	0.08	0.7600
0.8%	0.04	0.8000
3%	0.04	0.8400
12%	0.04	0.8800
36%	0.04	0.9200
40%	0.02	0.9400
71%	0.02	0.9600
91%	0.02	0.9800
100%	0.02	1.0000

Summary of Vessel Casualty Spill Probabilities by Volume

Based on current vessel traffic, the expected numbers and probabilities of spills related to vessel casualties for tank vessels (tankers and tank barges) were calculated and summarized in Table 57. Expected bunker spill frequencies and volumes were calculated and summarized in Table 58.

Bunker spills and oil cargo spills were combined in Table 59. About seven spills can be expected annually from vessels on the Hudson River based on current traffic patterns.

Table 57: Annual Frequency of Cargo Spills from Tank Vessels (Current Vessel Traffic)

Spill Volume (bbl)	Annual Spills			Annual Probability		
	Tankers	Tank Barges	Total Tank Vessels	Tankers	Tank Barges	Total Tank Vessels
<1	0.010	0.470	**0.480**	1 in 100	1 in 2	**1 in 2**
1–9	0.005	0.076	**0.081**	1 in 200	1 in 13	**1 in 12**
10–99bbl	0.005	0.088	**0.093**	1 in 200	1 in 11	**1 in 11**
100–999	0.004	0.037	**0.041**	1 in 250	1 in 27	**1 in 24**
1,000–9,999	0.003	0.021	**0.024**	1 in 333	1 in 48	**1 in 42**
10,000– 99,999	0.001	0.011	**0.012**	1 in 1,000	1 in 91	**1 in 83**
100,000+	0.0000015	0.0000000	**0.0000015**	1 in 666,667	0	**1 in 666,667**
Total	**0.029**	**0.703**	**0.732**	**1 in 34.5**	**1 in 1.4**	**1 in 1.4**

Table 58: Annual Frequency of Bunker Spills (Current Vessel Traffic)[82]

Spill Volume (bbl)	Annual Spills	Annual Probability
<1	3.176	1 in 0.31
1–9	0.392	1 in 2.55
10–99bbl	0.172	1 in 5.80
100–999	0.183	1 in 5.48
1,000–9,999	0.118	1 in 8.45
10,000– 99,999	0.031	1 in 32.32
100,000+	0.000	0
Total	**4.073**	**1 in 0.25**

Table 59: Annual Frequency of Vessel Oil Spills (Based on Current Vessel Traffic)

Spill Volume (bbl)	Annual Spills	Annual Probability
<1	3.656	1 in 0.27
1–9	0.473	1 in 2.11
10–99bbl	0.265	1 in 3.77
100–999	0.224	1 in 4.46
1,000–9,999	0.142	1 in 7.04
10,000– 99,999	0.043	1 in 23.26
100,000+	0.0000015	1 in 666,667
Total	**4.805**	**1 in 0.21**

Changes in vessel traffic will, of course, affect the potential numbers of spills. In addition, any changes related to spill prevention could also affect the potential numbers of spills. The predicted probabilities of spills of different volumes based on hypothetical future vessel traffic assumptions are shown in Table 60. The majority of spills (86%) are of less than 10 bbl. The distribution of spills by volume for current traffic is shown in Figure 32. The estimated annual frequencies of spills of 10 bbl or more are in Table 61.

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[82] Bunker capacities assumed to be 14,000 bbl for dry cargo ships and tankers; and 500 bbl for tank barges, tow/tugs and dry cargo barges. Bunkers for barges are in tow/tug boats associated with barges.

Table 60: Predicted Annual Spill Frequencies based on Vessel Traffic Changes

Vessel Traffic Assumption	Estimated Annual Number of Spills by Volume Category (bbl)							
	<1	1	10	100	1,000	10,000	100,000	Total
Current Traffic	3.66	0.47	0.27	0.22	0.14	0.044	0.0000015	**4.81**
50% Overall Decrease	1.83	0.24	0.13	0.11	0.07	0.022	0.0000007	**2.40**
10% Overall Decrease	3.29	0.43	0.24	0.20	0.13	0.039	0.0000013	**4.32**
50% Decrease Tank Vessels	3.16	0.40	0.20	0.19	0.12	0.035	0.0000007	**4.11**
20% Decrease Tank Vessels	3.46	0.44	0.24	0.21	0.13	0.040	0.0000012	**4.53**
10% Decrease Tank Vessels	3.56	0.46	0.25	0.22	0.14	0.042	0.0000013	**4.67**
10% Increase Tank Vessels	3.75	0.49	0.28	0.23	0.15	0.045	0.0000016	**4.94**
20% Increase Tank Vessels	3.85	0.50	0.29	0.24	0.15	0.047	0.0000018	**5.08**
50% Increase Tank Vessels	4.15	0.55	0.33	0.26	0.17	0.053	0.0000022	**5.50**
10% Overall Increase	4.02	0.52	0.29	0.25	0.16	0.048	0.0000016	**5.29**
100% Increase Tank Vessels	4.64	0.62	0.39	0.29	0.19	0.061	0.0000030	**6.19**
20% Overall Increase	4.39	0.57	0.32	0.27	0.17	0.052	0.0000018	**5.77**
200% Increase Tank Vessels	6.62	0.91	0.63	0.44	0.28	0.097	0.0000059	**8.97**
50% Overall Increase	5.49	0.71	0.40	0.34	0.22	0.066	0.0000022	**7.22**
100% Overall Increase	7.27	0.89	0.51	0.42	0.26	0.085	0.0000080	**9.44**

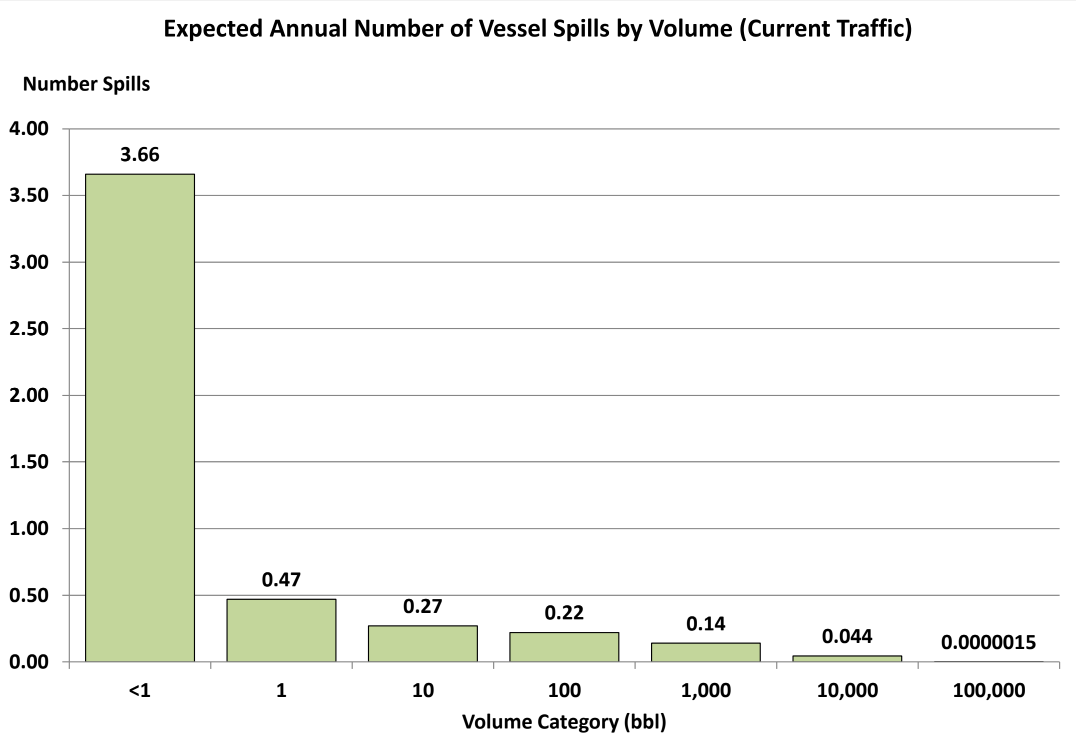

Figure 32: Expected Number of Vessel Spills by Volume (Current Traffic)

Table 61: Predicted Annual Larger Spill Frequencies based on Vessel Traffic Changes

Vessel Traffic Assumption	Estimated Annual Number of Spills by Volume Category (bbl)					
	10	**100**	**1,000**	**10,000**	**100,000**	**Total**
Current Traffic	**0.27**	**0.22**	**0.14**	**0.044**	**0.0000015**	**0.68**
50% Overall Decrease	0.13	0.11	0.07	0.022	0.0000007	**0.34**
10% Overall Decrease	0.24	0.20	0.13	0.039	0.0000013	**0.61**
50% Decrease Tank Vessels	0.20	0.19	0.12	0.035	0.0000007	**0.55**
20% Decrease Tank Vessels	0.24	0.21	0.13	0.040	0.0000012	**0.63**
10% Decrease Tank Vessels	0.25	0.22	0.14	0.042	0.0000013	**0.65**
10% Increase Tank Vessels	0.28	0.23	0.15	0.045	0.0000016	**0.70**
20% Increase Tank Vessels	0.29	0.24	0.15	0.047	0.0000018	**0.73**
50% Increase Tank Vessels	0.33	0.26	0.17	0.053	0.0000022	**0.80**
10% Overall Increase	0.29	0.25	0.16	0.048	0.0000016	**0.74**
100% Increase Tank Vessels	0.39	0.29	0.19	0.061	0.0000030	**0.93**
20% Overall Increase	0.32	0.27	0.17	0.052	0.0000018	**0.81**
200% Increase Tank Vessels	0.63	0.44	0.28	0.097	0.0000059	**1.44**
50% Overall Increase	0.40	0.34	0.22	0.066	0.0000022	**1.02**
100% Overall Increase	0.51	0.42	0.26	0.085	0.0000080	**1.28**

The likelihood of a spill of 100,000 bbl or more is about 1 in 670,000 with current vessel traffic. With increased overall traffic, and, in particular with increases in tank vessels, this probability increases to as much as 1 in 125,000. With decreased traffic, the probability likewise decreases (Figure 33 and Table 62).

Table 62: Expected Frequencies of 100,000-bbl+ Vessel Spills by Traffic Assumption

Traffic	Annual Frequency	Annual Probability
50% Overall Decrease	0.0000007	1 in 1,428,571
50% Decrease TV	0.0000007	1 in 1,428,571
20% Decrease TV	0.0000012	1 in 833,333
10% Overall Decrease	0.0000013	1 in 769,231
10% Decrease TV	0.0000013	1 in 769,231
Current Traffic	**0.0000015**	**1 in 666,667**
10% Increase TV	0.0000016	1 in 625,000
10% Overall Increase	0.0000016	1 in 625,000
20% Increase TV	0.0000018	1 in 555,556
20% Overall Increase	0.0000018	1 in 555,556
50% Increase TV	0.0000022	1 in 454,545
50% Overall Increase	0.0000022	1 in 454,545
100% Increase TV	0.000003	1 in 333,333
200% Increase TV	0.0000059	1 in 169,492
100% Overall Increase	0.0000080	1 in 125,000

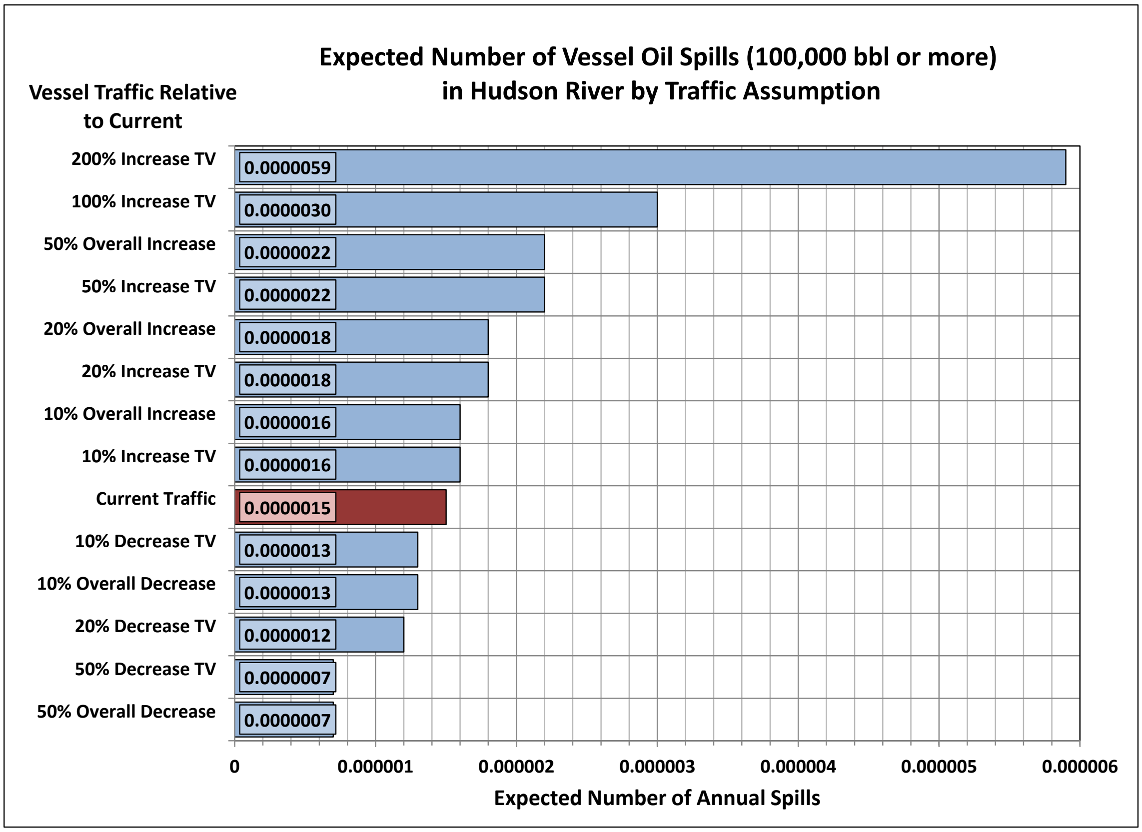

Figure 33: Expected Number of Vessel Spills 100,000 bbl or More by Traffic Assumption

Vessel Transfer Spill Rates

Oil spills can occur due to errors or equipment failures during transfer operations to or from a vessel. These operations include:

- Fueling or bunkering where the vessel takes on fuel at a fuel dock;
- Taking on (loading) or unloading cargo oil at a terminal;
- Transfer of oil cargo or “lightering” from a larger tank vessel to a smaller one; and
- Fueling or bunkering of a vessel from a fuel barge.

The first two types of operations are common in the Hudson River. These transfer operations occur at fuel docks, marinas, and oil terminals. Another barge was brought in to lighter (or remove the oil) from the grounded barge onto another tank barge (Figure 34).

With various transfer spill prevention regulations and improvements in safety practices at docksides and oil terminals, there has been a significant reduction in the rate of transfer spills from large vessels (over 300 GRT). Between 1985 and 2004, there was a 96% reduction in the number of transfer-related spills in the US.[83] These reductions have been particularly high in jurisdictions that have strict transfer regulations, including Washington State and California.

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[83] Etkin 2006a.

Figure 34: Tank Barge Lightering after Grounding at Catskill, NY, April 2017[84]

A conservative[85] estimate of transfer-related spills is a 0.0004 probability of a spill during every transfer operation, or one spill for every 2,500 transfer operations. With the implementation of strict standards to reduce spillage during transfer operations, the spillage rate may be reduced to about a 0.00026 probability of a spill during every transfer operation, or one spill every 3,850 transfer operations.[86] Assuming that there is one transfer operation for every loaded tank barge and tanker transit on the Hudson River and about 1,262 loaded tank vessel transits annually (Table 19), there are estimated to be one spill of oil cargo every other year based on conservative measures. With increased safety standards, this rate may be brought down to one spill of oil cargo every three years. These could be spills as small as one gallon. For bunkering- or fueling-related spills for large vessels, which includes tank vessels, one can assume that the vessels bunker once every other round-trip transit, or once in four trips. If there are about 7,000 trips per year, there would be about 1,750 bunkering operations annually. There would be expected to be 0.5 to 0.7 bunkering spills per year–or one bunkering spill every 1.4 to two years. Again, these spills tend to be very small.[87]

Vessel Transfer Spill Volumes

Generally, spills due to transfer errors are smaller than the spills that might occur with impact accidents (collisions, allisions, and groundings). The data shown in Table 63 and Figure 35 are the spill volumes associated with a large number of transfer-related spills reported in US waters.

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[84] Photo: Paul Buckowski, *Albany Times Union* (https://www.timesunion.com/7dayarchive/article/Barge-hauling-gas-runs-aground-in-Hudson-River-11049029.php#photo-12667926)

[85] i.e., tending to overestimate the risk.

[86] Det Norske Veritas (2011b) estimated a spillage rate of 0.00019 spills per crude oil transfer and 0.00018 for petroleum product spills.

[87] This does not include spills during fueling of smaller vessels, which are covered elsewhere in this report.

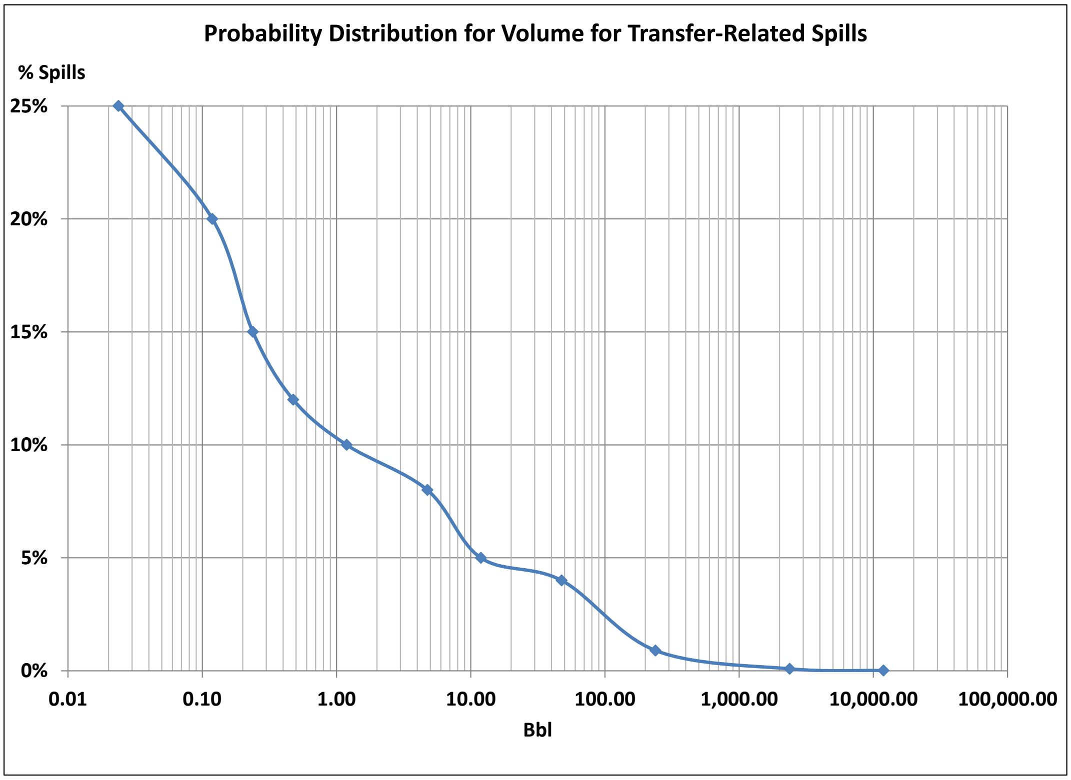

Figure 35: Probability Distribution of Spill Volume for Transfer-Related Oil Spills

Table 63: Spill Volumes for Transfer-Related Incidents[88]

Spill Volume	Probability	Cumulative Probability
<1 bbl	0.72	0.7200
1–9 bbl	0.18	0.9000
10–99bbl	0.09	0.9900
100–999 bbl	0.009	0.9990
1,000–9,999 bbl	0.0009	0.9999
10,000 bbl +	0.0001	1.0000

While the maximum observed transfer-related spillage is 500,000 gallons (11,905 bbl), the maximum for a particular vessel's bunker spillage when the vessel contains less than 500,000 gallons in bunker fuel would naturally be the bunker capacity of the vessel. Sixty percent of spills are 10 gallons (0.24 bbl) or less. Ninety percent of spills are 200 gallons (5 bbl) or less.[89]

Based on this distribution of spill volumes and the probabilities of transfer spills, the expected annual number of transfer spills by volume was estimated as shown in Table 64 and Table 65, based on conservative assumptions and with the implementation of transfer regulations. Note that NYSDEC does

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[88] Based on Etkin 2006.

[89] Etkin 2006.

have a licensing requirement for major petroleum facilities,[90] which generally corresponds to SPCC regulations. However, there are no specific regulations regarding oil transfer operations such as exist in California and Washington.

Table 64: Estimated Annual Transfer Spills in Hudson River (Conservative)

Spill Volume (bbl)	Annual Spill Rate (Annual Probability)					
	Oil Cargo Transfer		Bunkering		Total	
	Annual Spills	Annual Probability	Annual Spills	Annual Probability	Annual Spills	Annual Probability
<1 bbl	0.365	1 in 3	0.514	1 in 2	0.86	1 in 1
1-9 bbl	0.09	1 in 11	0.126	1 in 8	0.216	1 in 5
10-99bbl	0.045	1 in 22	0.063	1 in 16	0.108	1 in 9
100-999 bbl	0.0045	1 in 222	0.0063	1 in 159	0.011	1 in 91
1,000-9,999 bbl	0.00045	1 in 2,222	0.00063	1 in 1,587	0.0011	1 in 909
10,000 bbl +	0.00005	1 in 20,000	0.00007	1 in 14,286	0.00012	1 in 8,333
Total	**0.505**	**1 in 2**	**0.71**	**1 in 1**	**1.19622**	**1 in 1**

Table 65: Estimated Annual Transfer Spills in Hudson River (with Transfer Regulations)

Spill Volume (bbl)	Annual Spill Rate (Annual Probability)					
	Oil Cargo Transfer		Bunkering		Total	
	Annual Spills	Annual Probability	Annual Spills	Annual Probability	Annual Spills	Annual Probability
<1 bbl	0.239	1 in 4	0.365	1 in 3	0.6	1 in 2
1-9 bbl	0.059	1 in 17	0.09	1 in 11	0.149	1 in 7
10-99bbl	0.03	1 in 33	0.045	1 in 22	0.075	1 in 13
100-999 bbl	0.003	1 in 333	0.0045	1 in 222	0.0075	1 in 133
1,000-9,999 bbl	0.0003	1 in 3,333	0.00045	1 in 2,222	0.00075	1 in 1,333
10,000 bbl +	0.000033	1 in 30,303	0.00005	1 in 20,000	0.000083	1 in 12,048
Total	**0.331**	**1 in 3**	**0.505**	**1 in 2**	**0.832**	**1 in 1**

Pre-Booming during Transfer Operations

In addition to specific safety measures taken to reduce the likelihood of a transfer-related spill, regulations may specific that transfer operations be conducted with vessels "pre-boomed." This means that a containment boom is used to encircle the vessel or otherwise contain any spilled oil up against the dock where it may be more easily removed with vacuum pumps or skimmers.

This measure does not prevent oil from spilling, but may, under certain conditions, prevent the spread of the oil beyond the containment area. There are limitations to this protection strategy, however. First, the containment boom will not be completely effective if the currents in the area exceed 0.7 knots. The effectiveness reduces quickly as the current velocity exceeds this value.

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[90] Article 12 of Navigation Law, 6 NYCRR Part 610 and 17 NYCRR Part 30.

Secondly, pre-booming can be dangerous during the handling of particularly volatile products, such as gasoline, and, possibly, Bakken crude oil. The volatile vapors from the spilled oil could build up in the event of a spill increasing the likelihood of a fire or explosion. *The lack of boom placement around a vessel does not necessarily indicate negligence on the part of the operator. The placement of boom around vessels during transfer operations needs to follow regulatory requirements and reflect best practice.*

Potential Oil Spillage in Hudson River: Recreational Vessels

Smaller vessels, including recreational vessels, workboats, and fishing vessels are also potential sources of oil spillage. Nationally, there has been a 74% decrease since the 1970s, and a 52% reduction since the 1990s, in the annual volume of oil spilled from these types of vessels.[91] Overall, about one bbl of oil spills each year for every 2,900 vessels.

Hudson River Recreational Vessels

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 66. 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.[92]

In HROSRA Volume 1, these vessels were mentioned as potential resources that may be oiled in the event of a spill, as well as a means to demonstrate the degree to which recreational boating is an important and valued cultural activity in the Hudson River. At the same time, each of these boats is a potential spill *source* as well.[93]

Table 66: 2016 Vessel Registrations by County and Length[94]

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**

Estimated Oil Spillage from Recreational Vessels

According to the ORPHP,[95] there are about 20 reportable boating accidents[96] per year in the Hudson River. Generally, about 80% of these accidents include some kind of damage to the boat, which could

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[91] From ERC database.

[92] For example, Westchester County has shorelines along the Long Island Sound in addition to the Hudson River.

[93] The potential for smaller personal watercraft and outboard motor boats operating with gasoline in two-stroke engines to contribute to oil inputs to the river is described in another section of this report.

[94] NYS ORPHP 2017.

[95] NY ORPHP 2017.

conceivably cause a spill of fuel. Therefore, there are about 16 potential spills per year. In addition to accident-related spillage, there are also spills relating to transfers during fuel operations.

Most recreational vessels have fuel tanks of 0.5 to 3 bbl. The largest yachts can hold as much as 250 bbl. The estimated total annual volume of oil spillage from recreational vessels in the Hudson River is about 20 bbl. This is based on the number of vessel registrations and the US average per-boat spill rate of 0.00034 bbl/year per vessel. With an estimated 16 annual accidents, this comes to about 1.3 bbl per accident. There would be smaller volumes of spillage for smaller vessels, and more for larger ones.

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[96] Including incidents that result in the loss of life, injuries requiring more than basic first aid, and total property damage to any one party in excess of $1,000.

Potential Oil Spillage along Hudson River: Railroad

Trains can be sources of oil spillage into the Hudson River in two main ways–spills of oil cargo from tank cars carrying crude oil and/or refined oil products, and spills of fuels and lubricants from locomotives. *Note that since this study focuses on oil spill risks to the Hudson River, it does not include analyses of risks to inland areas from the transport of oil.*

Commuter Railroad Lines on Hudson River Eastern Shore

Significant distances along both the eastern and western banks of the Hudson River are covered with railroad tracks, which often run within yards of the high tide line (see for example Figure 36). The Hudson Line of the Metro-North commuter rail of the Metropolitan Transportation Authority (MTA) runs along the eastern bank of the river between Spuyten Duyvil and Poughkeepsie (Figure 37).[97] The Hudson Line has 24 stations from Spuyten Duyvil to Poughkeepsie. The line is electrified (with third rails) to Croton-Harmon Station. Trains traveling from Grand Central Terminal (in Manhattan) to stations beyond Croton-Harmon as far as Poughkeepsie are pulled or pushed by diesel-powered locomotives.[98]

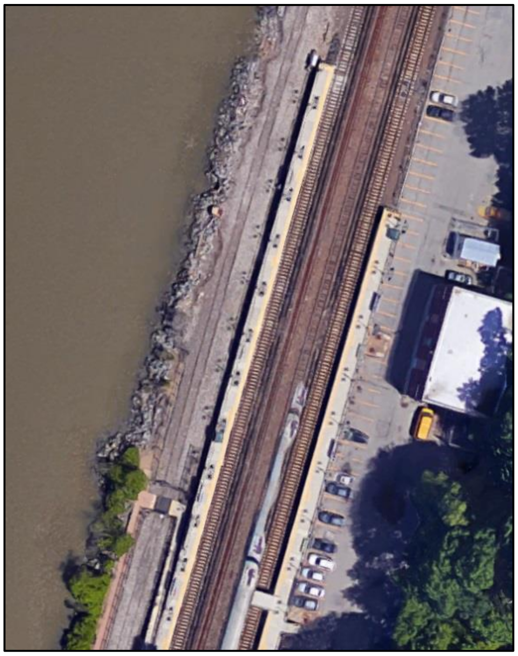

Figure 36: Metro-North Hudson Line Tracks at Riverdale Station

There are 32 southbound and 31 northbound diesel-powered trains operating each weekday, with fewer trains on weekends and holidays. Each diesel locomotive[99] carries between 1,800 to 2,400 gallons (43 to

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[97] South of Spuyten Duyvil, the Hudson Division runs along the Harlem River on the Bronx (east) side before crossing over to the island of Manhattan near East 132nd Street in Harlem.

[98] The diesel locomotives are located at the northern end of the train. They push the trains south to Grand Central Terminal and pull the trains on the northward transit. The diesel locomotives are equipped with third-rail shoes for electric operation in the Park Avenue to Grand Central Terminal tunnel. Completely electrified trains operate only between Grand Central Terminal and Croton-Harmon station.

[99] GE P32AC-DM model.

57 bbl) of diesel fuel plus 410 gallons (9.8 bbl) of lubricants. The maximum oil spillage from a Metro-North train locomotive is 67 bbl.

Figure 37: Metro-North Railroad Line Map

Amtrak Passenger and Freight Rail Service on Hudson River Eastern Shore

The eastern-side tracks are used by both Amtrak for long-distance passenger train service[100] and by CSX operating partners for freight traffic. The Amtrak and freight trains go to Albany and beyond.

The Amtrak trains go as far as Albany-Rensselaer (on the eastern shore) before splitting off to the east, north, and west. Along the Hudson corridor, there are stations in New York City and six stations between Yonkers and Albany-Rensselaer (Figure 38). The total mileage along the Hudson River is about 133 miles. There are 15 passenger trains in each direction (northbound and southbound) on most days or about

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[100] Amtrak trains follow tracks that turn westward at the confluence of the Harlem and Hudson Rivers at Spuyten Duyvil and run along the eastern shore of the Hudson River before going into various tunnels.

10,000 trains per year. The Amtrak passenger trains are pulled by diesel locomotives. Amtrak locomotives[101] have a fuel capacity of 2,200 gallons (52 bbl) of diesel fuel, as well as 410 gallons (9.8 bbl) of lubricants. Most Amtrak trains are pulled by two locomotives. The maximum amount of oil carried by a single Amtrak train is 124 bbl.

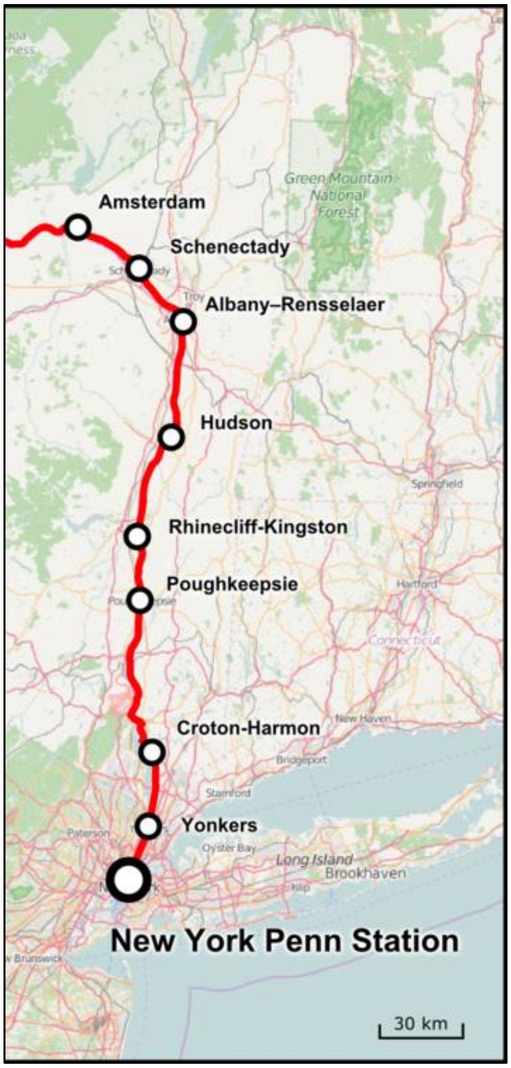

Figure 38: Amtrak Stations along Hudson River Eastern Shore

The freight rail service on the eastern shore does not include the transport of unit trains of tank cars carrying crude oil or ethanol. There are currently about five freight trains per day (about 1,800 per year). Freight trains would have one or two locomotives depending on the length of the train. The amount of fuel carried on each locomotive is approximately 131 bbl. The maximum spillage could therefore be 262 bbl.

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[101] GE Genesis P42DC model.

Freight Rail Service on the Western Hudson Shore

The CSX-owned railroad line on the western side of the Hudson River is called the River Subdivision. It runs along the shore from just south of Haverstraw north (Milepost 38.5) to West Park (Milepost 78.1), which is across the river from Hyde Park. Here begins a more inland route going north. The shore-side rails run approximately 39.6 miles with occasional tunnels and short sections that are not directly on the shore (e.g. small peninsulas) (Figure 39).

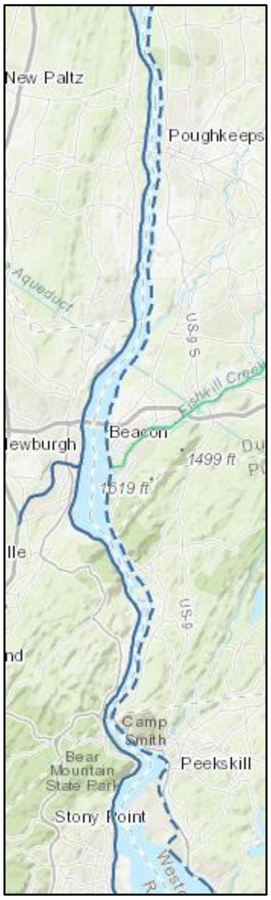

Figure 39: CSX River Subdivision on Western Shore of Hudson River[102]

The River Subdivision is used exclusively for freight traffic. There is no longer any passenger service on this line. Freight traffic consists mostly of intermodal (i.e., shipping containers that can be transferred to trucks or ships), mixed-commodity, and TOFC (trailer or flat car) trains. These freight trains number about 30 to 40 trains per day on weekdays, 36 to 48 trains on Saturdays, and 16 to 28 trains on Sundays. Included in those train numbers are two to four daily ethanol unit trains (half loaded and half empty). Currently, there are no regular crude oil unit trains.[103] The total weekly freight traffic on the River Subdivision is about 200 to 275 trains–or 10,500 to 14,300 trains annually.[104] These longer freight trains

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[102] https://www.csx.com/index.cfm/customers/maps/csx-system-map/

[103] Crude oil trains are discussed in greater detail in the next section.

[104] https://en.wikipedia.org/wiki/River_Subdivision_(CSX_Transportation)

generally have two to four locomotives carrying a total of 262 to 525 bbl of diesel. Regardless of whether the freight cars are loaded or empty, there would be locomotives carrying diesel fuel. For the ethanol unit trains each carrying 50 to 100 tank cars, there could be a total of 32,500 to 65,000 bbl of ethanol being transported (one way) on 365 to 730 trains per year.[105]

Crude-by-Rail (CBR) Transport along Hudson River

In January 2014, Governor Andrew M. Cuomo issued Executive Order 125 directing state agencies to immediately conduct a coordinated review of New York State's crude oil incident prevention and response capacity based public concern mainly about the risk of transport of crude oil by rail, but also by vessel. There had been a dramatic increase in the crude-by-rail (CBR) transport through the state. In April 2014, the New York State Department of Environmental Conservation (NYDEC) and other agencies[106] issued a report that concluded that the state faced a particular risk as a major conduit for the crude oil boom, particularly from North Dakota Bakken crude, but also from diluted bitumen from Alberta. There was oil being transported both by unit trains down the western Hudson River shore (River Subdivision) and by tank barge down the river after being offloaded from unit trains in Albany (Figure 40).

Figure 40: Crude Oil Transportation Corridor in New York State[107]

The increase in CBR traffic–which totaled 15 to 30 loaded trains per week–corresponded to the increase in rail loadings in North Dakota that began in 2012 (Figure 42). Beginning in 2011, crude oil producers in the Bakken (North Dakota) began to largely depend on railroads to transport a significant share of their output to market simply because there was insufficient pipeline capacity to move the crude oil out of the

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[105] Ethanol spills are not addressed in this report.

[106] NYDEC 2014.

[107] NYDEC 2014.

area to markets. The CBR routes from the Bakken formation in both the US and Canada to refineries in St. John, New Brunswick, and New Jersey are shown in Figure 41.

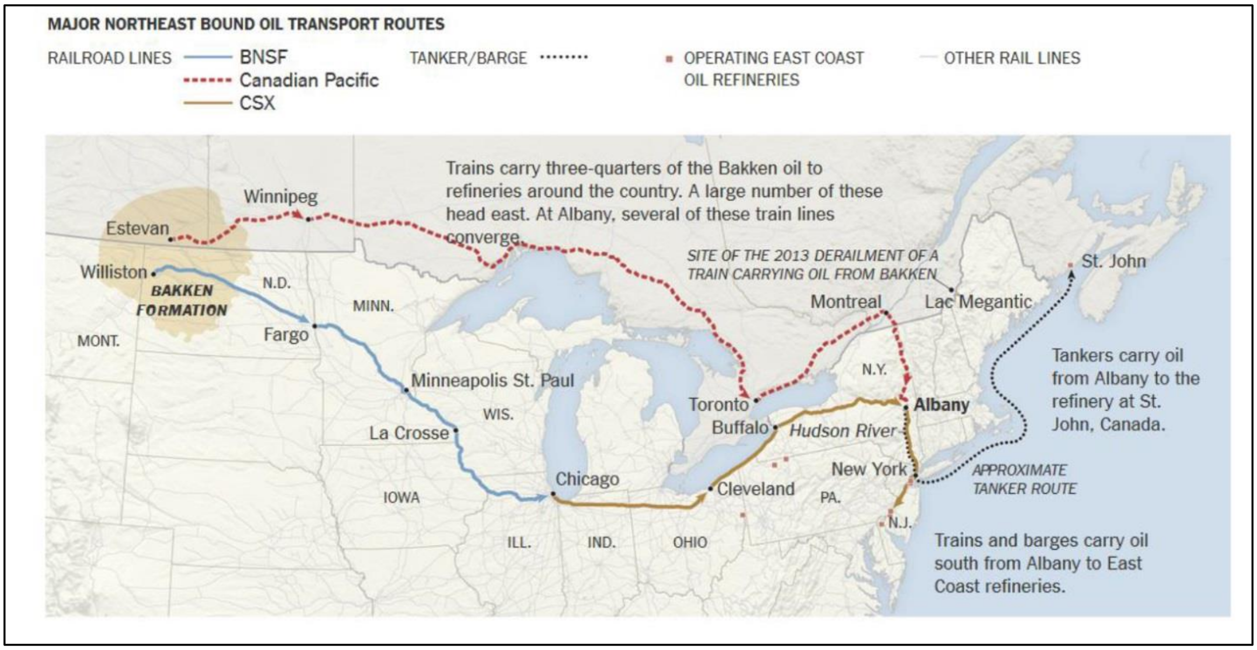

Figure 41: Major Northeast-Bound Oil Transport Routes[108]

Crude-by-rail loadings in North Dakota have been on the decline since they peaked in March 2014, as new pipeline capacity and lower crude production began to chip away at the volumes (Figure 43).

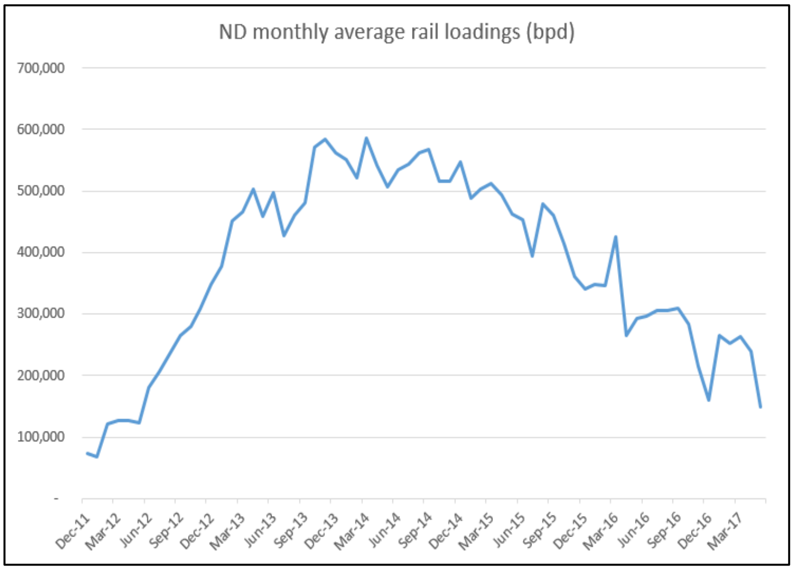

Figure 42: North Dakota Average Rail Loadings (Barrels per Day)[109]

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[108] Cushing 2016.

[109] https://www.genscape.com/blog/north-dakota-crude-rail-loadings-plummet-dapl-startup-imminent

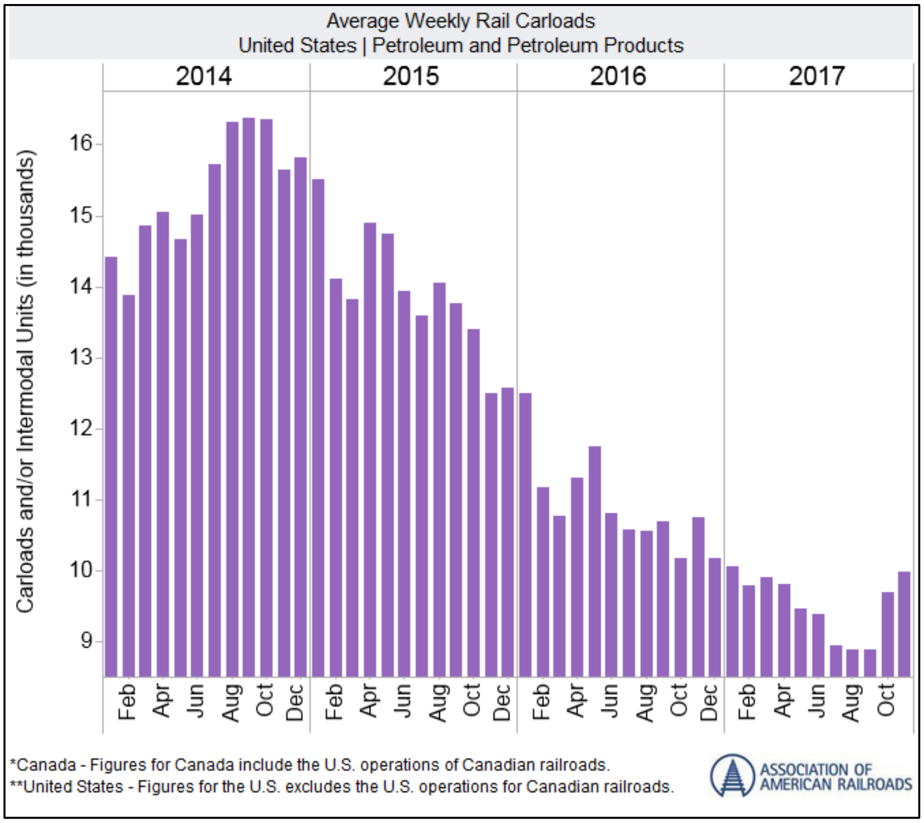

Figure 43: Average Weekly US National Rail Traffic Data: Petroleum[110]

Oil produced at remote locations has little-to-no value unless those barrels can be efficiently and cost-effectively transported to market. The Bakken region in western North Dakota and eastern Montana provides a specific example of a production area having insufficient transportation infrastructure to move the production to where the demand for that product is located. For many years prior to the shale oil revolution, long-existing pipeline capacity out of the Bakken could handle the modest volumes of conventional oil being produced there.

By 2011, Bakken tight/shale oil production had begun a steep, rapid rise, quickly outstripping available pipeline capacity which resulted in pipeline congestion and significant price discounting while Bakken producers and midstream (pipeline) companies scrambled to develop alternative routes to market. The initial solution to the lack of transportation infrastructure was the development of rail loading terminals which could be constructed quickly and at relatively modest costs, and those rail loading terminals could use existing infrastructure, e.g., the nation's railroads, to transport the crude to markets.

Crude-by-rail (CBR) also allows for destination flexibility, similar to vessel transportation; in other words, if a producer could achieve higher netbacks (the crude sale price minus transportation costs from the wellhead) from railing its crude to the East Coast or the West Coast (neither of which is connected to

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[110] Source: American Association of Railroads.

crude producing regions via pipeline) instead of the Midwest or the Gulf Coast then it was feasible to load it on rail cars and ship it to the East or West Coast. In all, 21 bulk storage and rail loading terminals were built in the Bakken crude production area. [Note that the estimated total daily capacity is the equivalent of 9 to 11 CBR unit trains, depending on loading and train length.]

Table 67: PADD 1 Crude-by-Rail Offloading

Crude-by-Rail Terminal/Operator/Owner(s)	Location	Estimated Capacity (bbl/day)
Enbridge Rail/Canopy Prospecting/Eddystone Rail Company	Philadelphia, PA	60,000
Buckeye Partners LP/Albany NY Terminal	Albany, NY	135,000
Carlyle Refinery/Philadelphia Energy Solutions	Philadelphia, PA	140,000
Global Partners LP	Albany, NY	160,000
NuStar Energy LP	Paulsboro, NJ	30,000
PBF Energy	Delaware City, DE	110,000
Plains All American Pipeline LP	Yorktown, VA	130,000
Sunoco/Eagle Point Terminal	Eagle Point, NJ	20,000
Total		**785,000**

Shifts in CBR Transport Patterns

The steady reduction in national CBR transport that began to occur in 2014 that resulted in a 50% reduction by 2017 affected New York by virtually ending the CBR transport in the state by late 2015 (. Much of this reduction in the use of rail to transport crude oil is due to the shift to pipelines and a shift in refinery usage in the Northeast. As of 1 June 2017, the 470,000 to 570,000 bbl/day Dakota Access Pipeline (DAPL) commenced operation. DAPL's capacity enables producers to further reduce their use of CBR transport.

Table 68: Changes in Crude-by-Rail Oil Movements to Northeast[111]

Movement[112]	Thousand Bbl/Day (CBR Train Equivalents/Day)							
	June 2010	**June 2014**	**June 2015**	**June 2016**	**May 2017**	**June 2017**	**Sept 2017**	**Oct 2017**
North Dakota to Northeast (NJ)	3.25 Tbbl/day	335.4 Tbbl/day	382.2 Tbbl/day	151.45 Tbbl/day	49.4 Tbbl/day	79.3 Tbbl/day	6.5 Tbbl/day	57.2 Tbbl/day
	0.05 trains/day	5.16 trains/day	5.88 trains/day	2.33 trains/day	0.76 trains/day	1.22 trains/day	0.1 trains/day	0.88 trains/day
Canada to Northeast (NJ)	0 Tbbl/day	90.35 Tbbl/day	24.05 Tbbl/day	0 Tbbl/day	20.15 Tbbl/day	0.65 Tbbl/day	17.55 Tbbl/day	13 Tbbl/day
	0 trains/day	1.39 trains/day	0.37 trains/day	0 trains/day	0.31 trains/day	0.01 trains/day	0.27 trains/day	0.2 trains/day

Today, there are fewer shipments of crude oil by rail from the Midwest (PADD 2) Bakken production fields to the East Coast (PADD 1) refineries (Figure 44). Crude oil shipments by rail have generally decreased for several reasons, including narrowing price differences between domestic and imported

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[111] US Energy Information Administration (EIA) data.

[112] Note that not all movements from North Dakota transit through New York; some go through Pennsylvania.

crude oil, the opening of new crude oil pipelines, and declining domestic production in the Midwest and Gulf Coast onshore regions (Figure 45) as well as refinery production reductions due to refinery closures.

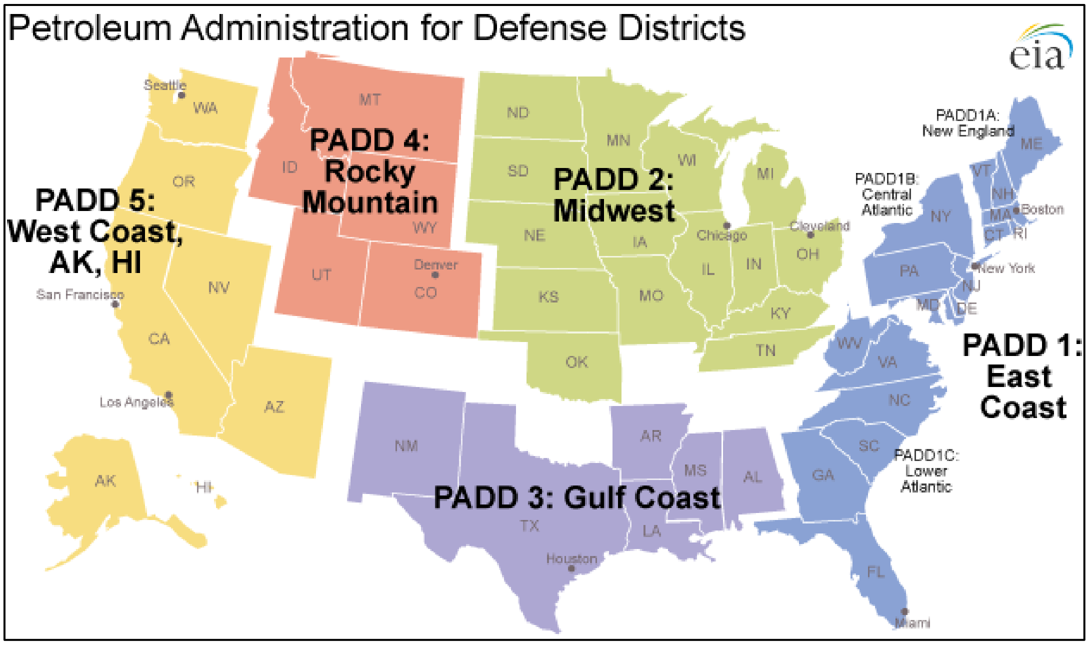

Figure 44: PADD District Map[113]

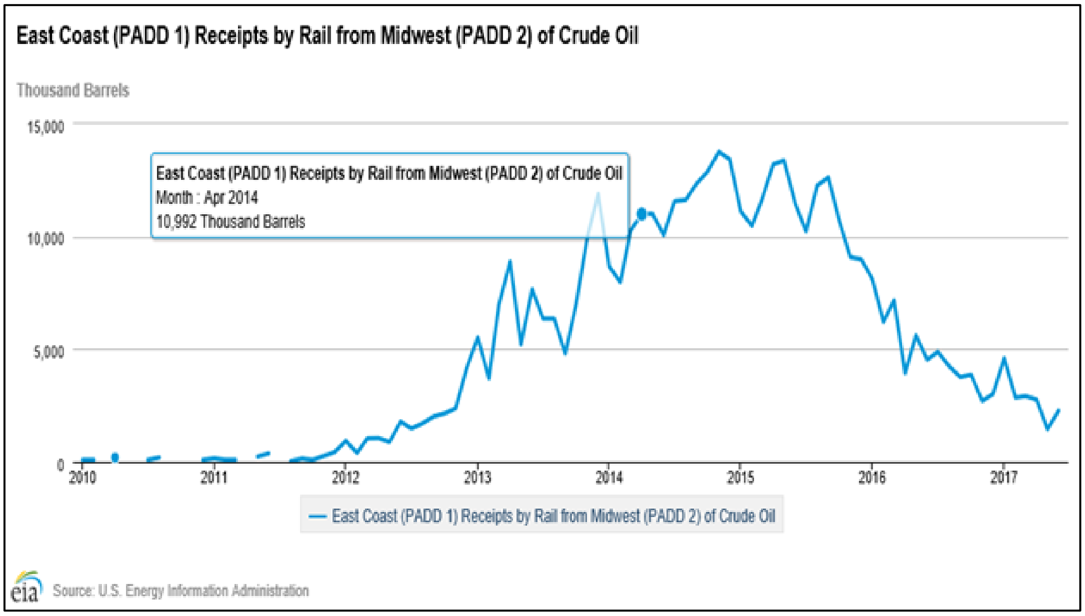

Figure 45: East Coast Receipts of Crude Oil by Rail from Midwest[114]

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[113] US Energy Information Administration.

[114] Source: US Energy Information Administration

Market Forces Driving Crude Oil Transport

The economics of CBR transportation depends largely on the relationship between the prices of domestic and international crude oils including transportation costs. Domestic crude oils priced in the Midwest and western Texas are no longer heavily discounted relative to imported crude oils priced in the North Sea although that pricing spread fluctuates from time to time benefiting one crude over another causing refiners to alternate supply. The narrower the spread between domestic and imported crude oils, the more likely US coastal refiners will choose to run imported crudes rather than domestic supplies shipped by rail. One should also be cognizant that pricing is not the only criteria a refiner looks at, the type of crude or the crude slate, is also a consideration since some refineries are designed to run heavy crude, while others are optimally engineered to run lighter crudes.

Each refinery has a programming model of their facility that reflects their specific capacities, limitations, and processing options (e.g., ability to maximize gasoline yield and diesel yield). These refinery configurations allow the refiner to evaluate specific crude supply options by entering the estimated crude oil cost, crude oil characteristics (percentages of naphtha, kerosene, other distillates, or molecules in the crude oil), and the estimated and wholesale (spot) market prices for the refinery products.

Generally, refineries evaluate crude oils available to them based on their location and available crude oil supply. Refiners in PADD 1 focus on purchasing the cheapest foreign low-sulfur or sweet crudes they can, and select the crude oil that provides them the best product yield for the crude price. For example, PADD 1 refiners have been acquiring railcar supply of Bakken crude from North Dakota because, even with relatively high railcar shipping costs, Bakken crude arrives on the East Coast at a much lower price than other crude oil with similar characteristics imported from Africa. However, as we have seen herein, the continual fluctuation of the spread between domestic and foreign supply provides these PADD 1 refineries to alternate crude oil supply to take advantage of the most optimal crude slate and pricing at various times (Figure 46).

But economic conditions changed and the pricing differential between WTI and Brent dropped. Over the years, incremental pipeline capacity out of the Bakken has been significantly added, thus growth in pipeline capacity, resulted in a narrowing in the “spread” between domestic and imported oil, and other factors have led to a sharp decline in rail shipments of crude oil.

Crude purchases and supply will change based on worldwide market pricing with the added transportation costs. In January 2017, For example, a January 2017 Reuters article stated that US East Coast refiners are on a Brazilian crude buying spree, displacing West African cargoes as producers such as Royal Dutch Shell and Norway’s Statoil sell rising output from fields off Brazil’s coast.[115] The strong February 2017 numbers follow a surge in Brazilian oil shipments into the region that started last September that pushed the annual figure for all of 2016 past 2012 volumes. The lower price of West African crude caused an increase in the volume shipped. Brazilian medium grades compete with some African crudes, especially those from Angola. Brazilian crude was once a mainstay on the US East Coast, averaging roughly 50,000 bpd in 2009, on the eve of the shale revolution that upended trade routes. US Bakken crude pushed out foreign imports on the East Coast from 2010 until 2015, but the reliance on domestic supplies proved short-lived.

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[115] Renshaw and Parraga 2017.

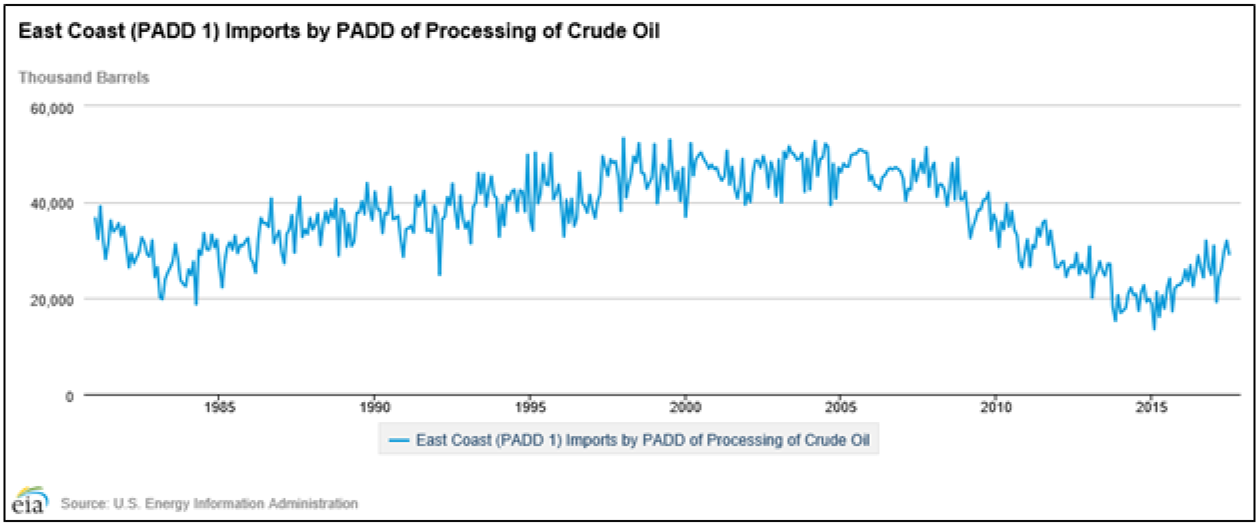

Figure 46: East Coast PADD 1 Crude Oil Foreign Imports[116]

In a *Morningstar Commodities Research* article in July 2017[117], it was explained that the three largest East Coast refineries in PADD 1, have been on a "roller coaster ride" over the past decade. Prior to the advent of shale crude, they were under constant threat of closure as a result of shrinking margins in an oversupplied North Atlantic market. Shale crude bought discounts for domestic barrels that made rail deliveries to these refineries viable and gave them a new lease of life. But these discounts narrowed as new pipeline infrastructure came on line, making rail shipments to the East Coast too expensive.

Bakken discounts narrowed in 2015 as new pipeline capacity reduced takeaway congestion out of North Dakota. The unexpected repeal of 1970s-era US crude export regulations in December 2015 further eroded price discounts for domestic crude. As a result, rail volumes from North Dakota to the East Coast fell from a peak 458,000 bbl/day, in November 2014, to 90,000 bbl/day by March 2017, according to the US Energy Information Administration. Refiners reduced their rail shipments to minimum committed volumes, and wrote off their investments in terminals. Rail shipments to the East Coast remain uneconomical this year, as witnessed by the shuttering of the Eddystone terminal in Philadelphia in February after a fall in oil prices made it uneconomical to deliver the crude to the East Coast combined with a contractual dispute. It remains to be seen what the long term situation will be with Eddystone terminal.

In April 2017, Philadelphia Energy Solutions (PES) Inc., the largest refiner on the US East Coast, stated that it would not be taking any rail deliveries of North Dakota's Bakken crude oil in June, which is considered by market observers to be a sign that the impending start of the Dakota Access Pipeline is upending trade flows.

At its peak, PES would have routinely taken about three miles' worth of trains filled with Bakken oil daily. But after the $3.8 billion Dakota Access Pipeline began interstate crude oil delivery on 14 May

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[116] Source: US Energy Information Administration

[117] *Morningstar Commodities Research* article July 3, 2017, Sandy Fielden, "East Coast Refineries Recover from Shale Loss"

2017, it was considered to be more lucrative for producers to transport oil to refineries in the US Gulf Coast via this route. According to oil market analysts, unless there's an unforeseen event, like a supply disruption, there will be no economic incentive to rail Bakken to the East Coast.

It should be noted, that crude oil demand for PADD 1 refineries have been negatively impacted by the closure of the following refineries with approximate throughput of 469,000 bpd or about 29% of the PADD 1 capacity. Due to continuing economic conditions and environmental regulations, it is extremely doubtful that any significant additional refinery capacity would come on line to replace the capacity lost, which includes:

- Sunoco Eagle Point, NJ, 145,000 bpd capacity, closed 2/10
- Sunoco Marcus Hook, PA, 178,000 bpd capacity, closed 12/11
- Western Refining, Yorktown, VA, 66,000 bpd capacity, closed 12/11
- Chevron Perth Amboy, NJ, 80,000 bbl/day capacity, closed 7/12

Refineries still operating:[118]

- **Delaware City Refinery (190,000 bbl/day):** PBF Energy Partners, Crude is supplied via barges on the Delaware river and via rail; PBF signed an agreement with Continental Resources to supply the refinery with Bakken crude oil; 2013 - Railway crude unloading facilities completed
- **Bayway Linden Refinery (238,000 bbl/day):** The refinery processes mainly light, low-sulfur crude oil; Crude oil is supplied to the refinery by tanker, primarily from the North Sea, Canada and West Africa; From 2013, Global Partners will use its rail transloading, logistics and transportation system to deliver crude oil from the Bakken region; 2013 - Phillips 66 signs a 5 year supply agreement with Global Partners for Bakken Crude
- **Nustar Paulsboro Refinery (74,000 bbl/day):** The refinery purchases heavy crude from Petróleos de Venezuela S.A but terminated that supply contract in 2014; In 2012 NuStar planned to start importing heavy crude from Canada by rail; 2014 - Lindsay Goldberg acquired the refinery.
- **Paulsboro Refinery (160,000 bbl/day):** PBF Energy, Receives a variety of feedstocks from its deepwater access on the Delaware River including sour crudes such as Arab Light, Arab Heavy, Hamaca, Urals and Kirkuk
- **Philadelphia Refinery (335,000 bbl/day):** Carlyle Group and Sunoco Joint Venture. Most of the crude oil processed at Sunoco's refineries is light-sweet crude oil; The refinery processes crude oils supplied from foreign sources; Approximately 60 percent of Sunoco's crude oil supply for its Philadelphia and Marcus Hook refineries during 2010 came from Nigeria; The refinery is also processing a small amount of Bakken Crude
- **Trainer Refinery (190,000 bbl/day):** Monroe Energy (Delta), Trainer Refinery processes mainly light, low-sulfur crude oil; Trainer receives crude oil from West and North Africa and Canada; At least a third of the crude is to be supplied by the Bakken; 2013 - The refinery receives its first delivery of Bakken Crude; 2014 - Bridger signs 5 year agreement to supply Bakken Crude

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[118] Source: A Barrel Full website, http://abarrelfull.wikidot.com/home. Note that some crude oil supply information may be dated.

Market analysts[119] continue to opine that by returning to a slate of imported crude, the largest East Coast refiners in theory reverted to the same economic dilemma they faced between 2009 and 2012. At that time, larger refineries in the region struggled to break even, several plants with approximately 390,000 bbl/day capacity were closed, and plans were advanced to close the two Philadelphia refineries now operated by PES and Monroe Energy (part of Delta Airlines). Along with rivals in the Atlantic Basin, these refineries relied on relatively expensive light sweet crude feedstock and sold refined products into a market where demand was static or shrinking. With no real progress having been made to address overcapacity in the Atlantic Basin since 2012, all the signs indicated that the three largest East Coast refineries, which are configured to process light sweet crude, would once again be vulnerable to closure after losing the advantage of cheap domestic shale crude delivered by rail.

Short-Term Changes in Oil Movement

While there appear to be general changes away from bringing crude oil through the Hudson River (by rail or tank vessel), there are unpredictable circumstances that may cause a short-term, or potentially future longer-term, shift back to crude oil transport through the river.

An example of this is the effect of the recent Hurricanes in the Gulf of Mexico and Caribbean Sea (Harvey, Jose, and Maria). According to a 25 September 2017 Bloomberg News report there may be temporary shifts in the transport of crude oil to refineries in the Northeast, including the temporary use of crude oil trains:[120]

> *At least two East Coast refineries are making less gasoline and diesel as rough Atlantic seas hamper the transfer of crude oil from ships to barges for delivery to the facilities, people familiar with operations say.*
>
> *Philadelphia Energy Solutions Inc., which operates the largest oil-refining complex serving the New York Harbor market, was said to cut rates about 20 percent. Delta Air Lines Inc.'s Monroe Trainer in Pennsylvania ran out of crude and had to put its crude units into circulation limbo, heated but not processing. Unless supply is replenished within a few days, Trainer will run vacuum gasoil through the crude units to keep them running and to provide feedstock for processing units like the fluid catalytic crackers.*
>
> *"Product prices are rallying in response to refinery run cuts on the East Coast, which will result in lower product availability in the short term," Andy Lipow, president of Lipow Oil Associates LLC in Houston, said in a phone interview Monday.*
>
> *Using feedstocks like gasoil instead of crude would further limit the amount of fuel a refinery can produce and deplete East Coast inventories that were already run down after Hurricanes Harvey and Irma. Gasoline and diesel futures surged Monday, with diesel reaching a two-year high and*

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[119] *Morningstar Commodities Research* article July 3, 2017, Sandy Fielden, "East Coast Refineries Recover from Shale Loss"

[120] https://www.bloomberg.com/news/articles/2017-09-25/rough-seas-slow-crude-deliveries-to-u-s-east-coast-refineries

> *gasoline touching levels last seen right after Harvey shut almost a quarter of US refining capacity.*
>
> *Philadelphia Energy also ordered as many as eight train loads of Bakken crude from North Dakota to supplement crude quickly at its 335,000 barrel-a-day refinery. Crude from the Great Plains is looking more attractive to coastal refiners as US benchmark West Texas Intermediate crude sank to the steepest discount since 2015 to Brent, the international marker. The Trainer refinery was forced to cut rates after running above its 185,000 barrel-a-day nameplate capacity last week.*
>
> *Large swells generated by Hurricane Maria are affecting most of the East Coast of the United States, according to the National Hurricane Center advisory at 8am Eastern time Tuesday. At the mouth of Delaware Bay, waves were forecast to build Monday and Tuesday, peaking at about 10 feet on Sept. 27 as Hurricane Maria moves north.*
>
> *The storm, which devastated Puerto Rico last week, was forecast Monday to graze the North Carolina coast before turning east in the Atlantic. It will create rough seas along the East Coast as it passes. A wave of 3.6 feet was reported at 6 p.m. local time Monday at the mouth of Delaware Bay, according to the National Data Buoy Center's website. Over the weekend, waves at the buoy, about 30 miles from Cape May, New Jersey, had reached 5.2 feet.*
>
> *Texas refineries, including Exxon Mobil Corp.'s Beaumont and Total SA's Port Arthur are still trying to restore normal operations after Harvey's Aug. 25 landfall.*
>
> *"Contributing to the price rally is the fact that Texas Gulf Coast refineries haven't fully restored operations since Hurricane Harvey," Lipow said.*

Crude-by-Rail Accidents

The period of CBR transport along the Hudson River and through the state in general caused considerable concern about the possibility of an accident that would cause spillage and/or fire and explosions. These concerns were driven by media reports about CBR accidents. There were a number of CBR accidents that occurred during 2013–2016, as summarized in Table 69.

The occurrence of these accidents in apparent rapid succession when there had been no publicized oil rail accidents in previous years heightened concerns about continuously increasing risks of CBR accidents. Clearly, the July 2013 Lac-Mégantic accident in Quebec was of greatest concern given that there were 47 fatalities. But even incidents involving smaller volumes of spillage, especially those that involved fire, have created apprehension about CBR traffic through populated areas. The consequences of any CBR accident would be dependent on the volume spilled, whether ignition occurred, and the specific location involved, especially with regard to the proximity to populated areas.

Table 69: Notable CBR US and Canadian Accidents with Spillage during 2013–2016[121]

CBR Incident	Accident Date	Outcome Synopsis
Parkers Prairie, Minnesota	27 March 2013	• 14 tank cars derailed • 1 car ruptured • 714 bbl spilled • No fire • Minimal damage due to frozen ground
Calgary, Alberta	3 April 2013	• 7 tank cars derailed • 2 tank cars released oil • Fire (put out by local firefighters) • 640 bbl spilled
Lac-Mégantic, Quebec	5 July 2013	• 63 tank cars derailed • 37,719 bbl spilled • 47 fatalities • 2,000 people evacuated • Extensive damage to town
Gainford, Alberta	19 October 2013	• 9 propane cars derailed • 4 crude cars derailed • 3 propane cars burned • No crude burned • One home damaged
Aliceville, Alabama	7 November 2013	• 30 tank cars derailed • 12 tank cars burned • 10,846 bbl spilled • No injuries • Fire • Wetland impact
Casselton, North Dakota	30 December 2013	• Collision • 20 crude cars derailed • Explosion/fire • > 9,524 bbl spilled • 1,400 residents evacuated • No injuries
Plaster Rock, New Brunswick	7 February 2014	• 5 tank cars derailed • 5 tank cars burned • 45 homes evacuated • 3,000 bbl spilled • 45 homes evacuated • No injuries • No fire
Vandergrift, Pennsylvania	13 February 2014	• 19 tank cars derailed • 4 tank cars spilled oil • 108 bbl spilled • No fire • No injuries
Lynchburg, Virginia	30 April 2014	• 15 tank cars derailed • 3 tank cars burned • 1,190 bbl spilled

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[121] Etkin et al. 2015b.

Table 69: Notable CBR US and Canadian Accidents with Spillage during 2013–2016[121]

CBR Incident	Accident Date	Outcome Synopsis
		• Immediate area evacuated • Some oil in river • No injuries
LaSalle, Colorado	9 May 2014	• 6 tank cars derailed • 1 tank car spilled oil • 155 bbl spilled • Spill contained in ditch • No fire
Mount Carbon, West Virginia	16 February 2015	• 27 tank cars derailed • 14 tank cars burned • 9,800 bbl spilled • Oil entered Kanawha River • Drinking water source for two counties affected
Gogama, Ontario	14 February 2015	• 35 tank cars derailed • 7 tank cars caught fire • 4,900 bbl spilled
Gogama, Ontario	7 March 2015	• 69 tank cars derailed • 7 tank cars caught fire • 4,709 bbl spilled
Mosier, Oregon	3 June 2016	• 11 tank cars derailed • Several cars burned • 1,000 bbl spilled • Some oil entered Columbia River

Lac-Mégantic Incident

The 5 July 2013 incident at Lac-Mégantic, Quebec represented a "perfect storm" of failures that contributed to the accident and its consequences. This particular set of circumstances would not be expected to occur in the US due to regulations and railroad operating practices in place, most importantly:

- A train would not be left unattended in this manner;
- The locomotive conditions in this incident would not be considered acceptable; and
- A train with hazardous cargo would not be operated by a single person.

The use of safer tank cars (as per DOT-117 specifications) and the lower volatility of conditioned Bakken crude would also significantly reduce the probability that this series of events could recur in this manner. A synopsis of the event and an analysis of the spillage is presented here so that the volumes applied in the impacts modeling can be benchmarked against it.

For the Lac-Mégantic incident, the volume of oil can be accounted for in three phases. There were 72 DOT-111 cars loaded with a reported 7.7 million liters (48,432 bbl) of Bakken crude with each car holding about 672.66 bbl (28,252 gallons). A total of 63 tank cars derailed (holding about 42,378 bbl)–87.5% of the train's tank cars. A total of about 37,739 bbl of oil were reported to have been released from the tank cars.[122] Only four cars released no oil (2,961 bbl). An additional 1,964 bbl of oil were removed from damaged cars that did not entirely release their contents. About 100,000 liters (629 bbl) ended up in Mégantic Lake and the Chaudière River by way of surface flow, underground infiltration, and sewer systems. An undetermined amount of oil saturated nearly 77 acres of land.

Of the 63 derailed cars, 37 cars (holding approximately 24,888 bbl) had a breached shell due to impact damage; of these, 21 cars had "large" breaches, 12 had "medium" breaches, and four had "small" breaches. The remaining 26 cars had no breach, although 22 of the non-breached cars had at least some denting. Only four derailed cars had no discernible damage (Figure 47).

There appeared to be three types of releases from the derailed tank cars:

- **Phase 1A (Instantaneous Derailment-Damage-Related Releases):** Twenty-one cars *nearly instantaneously* released their entire contents (14,126 bbl) due to the size of the breaches (of a large size commensurate with car diameter);
- **Phase 1B (Subsequent Derailment-Damage-Related Releases):** An additional 12,177 bbl of oil were subsequently released from about 18 cars with lesser degrees of damage; and
- **Phase 2 (Burn-Through- and Thermal-Tear-Related Releases):** Four cars released 2,691 bbl of oil due to thermal tears that occurred as a result of the fire 20 minutes or longer after the initial releases; 13 cars later experienced localized loss of contents due to burn-through[123] (8,745 bbl).

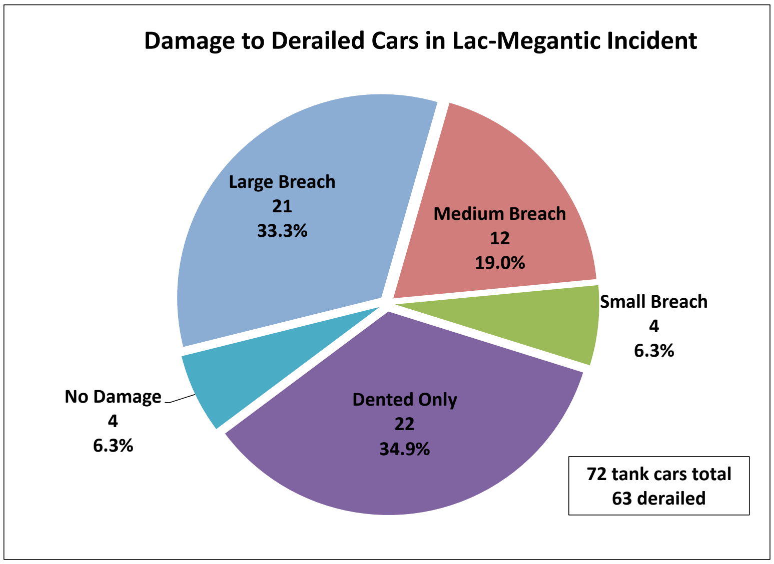

Figure 47: Damage to Derailed Cars in Lac-Mégantic Incident[124]

During the response operations, 740,000 liters (4,654 bbl) of crude oil were recovered from the derailed tank cars, of which 2,691 bbl were removed from the four non-damaged cars. About 1,963 bbl that

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[122] TSB Canada 2014b. Note that with approximations and rounding in the TSB Canada report and conversions from liters to gallons to barrels, there are some rounding discrepancies.
[123] Burn-through is a perforation of the tank shell caused by fire damage.
[124] Based on data in TSB Canada 2014b.

remained in damaged cars (nearly three cars-worth of oil) were also removed. The “mass balance” of the contents of the train is illustrated in Figure 48.

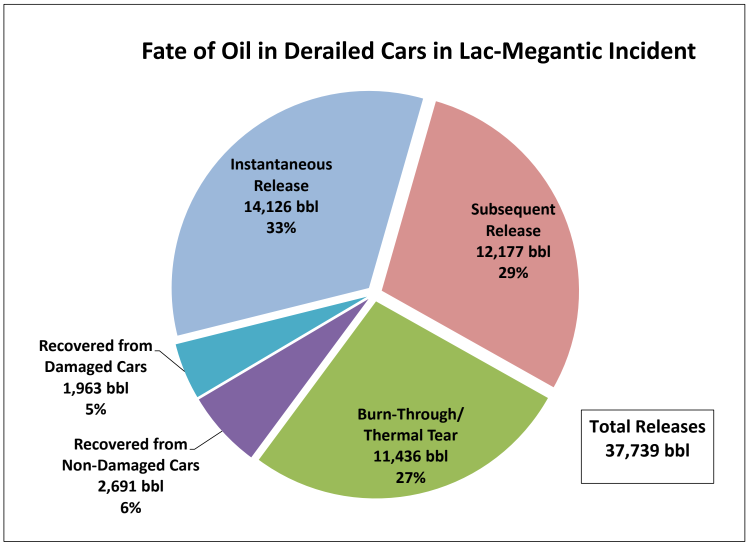

Figure 48: Fate of Oil in Derailed Cars (Mass Balance) in Lac-Mégantic Incident

While about 37,739 bbl of oil were ultimately lost from Train MMA-002, the sequence of releases should be considered with respect to the likelihood of all of the events occurring in the future. The initial and subsequent releases were likely due to damages from the derailment itself (26,303 bbl). The burn-through and thermal-tear releases (11,436 bbl) were secondarily caused by the fire. The former releases may have been reduced by better tank car designs. The latter releases would likely have been reduced by the improved thermal protection in DOT-117 cars.

The accident investigation for the Lac-Mégantic incident revealed several key factors that caused and ultimately affected the outcome, and which have a bearing on the analysis of potential future incidents that may occur with regard to the Vancouver Energy Distribution Terminal CBR traffic:[125]

- The train (MMA-002) had been under the control of a sole operator;
- The train was parked unattended on a main line on a descending grade with the securement of the train reliance on a locomotive that was not in proper operating condition;
- There were significant braking failures (*e.g.*, seven hand brakes that were applied to secure the train were insufficient to hold the train with the additional braking force from the locomotive’s independent brakes; and the hand brakes had not been properly tested for effectiveness);
- The train was left unattended despite its abnormal condition (*i.e.*, there had been significant indications of mechanical problems with the lead locomotive);
- The lead locomotive had a non-standard repair that allowed oil to accumulate in the turbocharger and exhaust manifold, resulting in a fire; the fire precipitated the locomotive’s engine being shut down, which removed the braking ability of the locomotive; no additional locomotive was started to provide braking power;

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[125] For a thorough analysis refer to TSB Canada 2014b.

- DOT-111 tank cars did not withstand shell damage and had inadequate thermal protection; and
- The volatility of the oil (unconditioned Bakken crude) contributed greatly to the fire, which caused the damages, including fatalities and injuries (the oil had been improperly classified with regard to hazard).

Fire/Explosion-Caused Rail Accidents

Among the different types of freight railroad accidents considered in the analysis of baseline accident rates, there is a category of "fire/explosion" accidents. These rail accidents are ones in which there is a fire and/or explosion that occurs on a train in transit for which the fire and/or explosion is the primary classification of the accident. This would include accidents in which there is a fire or explosion on a locomotive, or perhaps a fire in a freight car, such as a fire in a car containing grain cargo, or even a tank car containing hazardous materials. This is not the same as the ignition of oil after the train derails and has released oil. These data do not in any way indicate the likelihood of a crude-by-rail spill with a fire and explosion, such as the accident that occurred at Lac-Mégantic, Quebec.

The likelihood that a crude-by-rail accident with spillage would result in a fire and/or explosion (including a boiling liquid expanding vapor explosion, or BLEVE) of any kind would depend on a large number of situation-specific factors, including the presence of an ignition source (e.g., an open flame or sparks) and its precise location with respect to the spilled oil and any flammable vapor clouds associated with it. The probability of the presence of ignition sources or for the potential for there to be fires and explosions following crude-by-rail spills is discussed in HROSRA Volume 5.

Likewise, in the analysis of the likelihood of hazardous material tank cars releasing material during an accident, the fire/explosion category does not in any way refer to fires and explosions that may occur *after* there is spillage of oil or other flammable materials. The data merely show that for accidents caused by fire and/or explosion, there may be a hazardous material tank car(s) involved and these may have a release of hazardous material.

Probability of CBR Railroad-Related Spillage along Hudson River

While there is relatively little risk of that occurring at present due to the lack of CBR traffic (with the exception of occasional transits), the probability is analyzed in this report so that the results may be applied for potential future or hypothetical CBR transport. The calculations are based on the numbers of CBR trains, which allows for estimates of risk to be developed for different traffic assumptions.

Despite the number of CBR accidents experienced during 2013–2016, as summarized in Table 69, there are several reasons that the sole use of these anecdotal historic data are insufficient for a reliable projection of potential CBR spills:

- There are too few years of data to develop a statistically-robust incident rate;
- US data on CBR transit miles are unreliable, but would be required to calculate rates;
- Canadian data on CBR accidents involve very different regulations and operations standards than in the US, which reduces even further the number of incidents that can be used for rate analysis;

- Canadian data on CBR transit miles are not accurately recorded;[126] and
- There are a significant number of changes that have or will be made to reduce the accident and spill rate for CBR transport that have not been considered.

For these reasons, a model–CBRSpillRisk–was used to estimate the likelihood of CBR accidents and spills along the Hudson River based on various hypothetical future traffic projections. This model was developed for the use in environmental impact statements for proposed CBR-related projects and has been rigorously peer-reviewed.[127] The CBR-SpillRISK methodology is explained in detail in Appendix E.

The spill rate for loaded trains is as shown in Table 70. The high and low estimates of accidents are based on assumptions of implementation of all safety enhancements (to reduce accidents and reduce the likelihood of the release of oil from tank cars) and assumptions of no implementation, respectively.

Table 70: Expected CBR Spill Frequencies per Million Train-Miles (Loaded)

Estimate	**Mean Annual Frequency per Million Train-Miles**					
	Derailment	**Collision**	**Fire/Explosion[128]**	**Hwy-Rail**	**Misc.**	**Total**
Low	0.0052	0.0001	0.0000	0.0003	0.0006	**0.0062**
High	0.0778	0.0151	0.0077	0.0162	0.0301	**0.1468**

The estimated numbers of spills from CBR trains along the Hudson River were calculated based on various assumptions of CBR traffic, as summarized in Table 71.

Table 71: Projected Numbers of CBR Spills along Hudson River[129]

Hypothetical CBR Transport Scenario[130]	**Annual CBR Trains**	**Low Spill Estimate**		**High Spill Estimate**	
		Annual Frequency	**Annual Probability**	**Annual Frequency**	**Annual Probability**
Current (No Diversion Transport)	0	0	n/a	0	n/a
Current (Diversion Transport)	8	0.0000020	1 in 510,000	0.000046	1 in 22,000
Occasional Diversion Transport	32	0.0000078	1 in 128,000	0.00019	1 in 5,400
Frequent Diversion Transport	96	0.000024	1 in 43,000	0.00056	1 in 1,800
Moderate Historical Transport[131]	780	0.00019	1 in 5,200	0.0045	1 in 220
Peak Historical Transport[132]	1,560	0.00038	1 in 2,600	0.0090	1 in 110
Maximum Hypothetical Transport[133]	4,015	0.00098	1 in 1,000	0.023	1 in 43

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[126] Based on ERC communications with Canadian authorities.

[127] Etkin et al., 2015a; Etkin et al. 2015b; Etkin 2016a; Etkin 2016b; Etkin 2017a; Etkin 2017b; Etkin et al. 2017b.

[128] Note that the "fire/explosion" incident cause in Table 71 is the precipitating event and does not relate to the likelihood fire or explosion after the accident occurs (see explanation above).

[129] Assumes 39.6 train-miles along Hudson River (see Figure 39).

[130] "Diversion transport" is defined as the unusual CBR transport that is diverted through the Hudson corridor due to emergency situations in other parts of the country with the Hurricane Harvey situation as an example. It was assumed that this might happen once per year.

[131] Assumes 15 trains per week.

[132] Assumes 30 trains per week.

[133] Assumes the maximum number of trains to fill the capacity of the refineries in the Northeast (Table 67).

Note that these are spills of *any volume*, not necessarily WCDs. These are also not necessarily incidents in which ignition occurs to cause a fire or explosion. *Note also that these estimates are only about spills to the Hudson River emanating from CBR trains transiting along sections of track that are within 500 feet of the river bank. Since the HROSRA study is specifically focused on Hudson River spillage, the potential for spills along other sections of track are not included.*

The frequency of spills is for any location along the 39.6 miles of track along the Hudson River. The spill probability for each mile along those riverside tracks is shown in Table 72. Note that there are specific types of track conditions and other factors that may make certain sections of track more or less prone to derailment and other types of accidents. Analyses of those factors are beyond the scope of this study.

Table 72: Projected Numbers of CBR Spills per Riverside Track Mile on Hudson River[134]

Hypothetical CBR Transport Scenario[135]	Annual CBR Trains	Low Spill Estimate per Track Mile		High Spill Estimate per Track Mile	
		Annual Frequency	Annual Probability	Annual Frequency	Annual Probability
Current (No Diversion Transport)	0	0	n/a	0	n/a
Current (Diversion Transport)	8	0.000000051	1 in 19.8 mil	0.0000010	1 in 860,000
Occasional Diversion Transport	32	0.00000020	1 in 5.08 mil	0.0000048	1 in 210,000
Frequent Diversion Transport	96	0.00000061	1 in 1.65 mil	0.000014	1 in 71,000
Moderate Historical Transport[136]	780	0.0000048	1 in 210,000	0.00011	1 in 8,800
Peak Historical Transport[137]	1,560	0.0000096	1 in 100,000	0.00023	1 in 4,400
Maximum Hypothetical Transport[138]	4,015	0.000025	1 in 40,000	0.00058	1 in 1,700

The spills in Table 71 are spills of *any* volume. The actual volume of spillage depends on the number of tank cars involved and the degree to which the tank cars are breached, releasing oil. In some cases, there are secondary releases due to thermal damage. The calculation of spill volumes in in CBR-SpillRISK-V is described in Appendix E. The probability distribution of spill volumes (Table 73) depends on train length, which can vary from 100 to 120 tank cars.

Table 73: Expected CBR Spill Volume per Incident (Loaded Trains)

Statistical Parameter	120-Car Trains		100-Car Trains	
	Spill Volume (bbl)	Tank Cars	Spill Volume (bbl)	Tank Cars
Mean	11,253	17.3	10,498	16.2
0 percentile	261	0.4	249	0.4
10th percentile	2,860	4.4	2,718	4.2
20th percentile	4,219	6.5	3,984	6.1
30th percentile	5,705	8.8	5,365	8.3

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[134] Assumes 39.6 train-miles along Hudson River (see Figure 39).

[135] "Diversion transport" is defined as the unusual CBR transport that is diverted through the Hudson corridor due to emergency situations in other parts of the country with the Hurricane Harvey situation as an example. It was assumed that this might happen once per year.

[136] Assumes 15 trains per week.

[137] Assumes 30 trains per week.

[138] Assumes the maximum number of trains to fill the capacity of the refineries in the Northeast (Table 67).

Table 73: Expected CBR Spill Volume per Incident (Loaded Trains)

Statistical Parameter	**120-Car Trains**		**100-Car Trains**	
	Spill Volume (bbl)	**Tank Cars**	**Spill Volume (bbl)**	**Tank Cars**
40th percentile	7,375	11.3	6,918	10.6
50th percentile	9,280	14.3	8,686	13.4
60th percentile	11,507	17.7	10,756	16.5
70th percentile	14,186	21.8	13,236	20.4
80th percentile	17,655	27.2	16,452	25.3
90th percentile	22,830	35.1	21,214	32.6
100th percentile	50,201	77.2	44,455	68.4

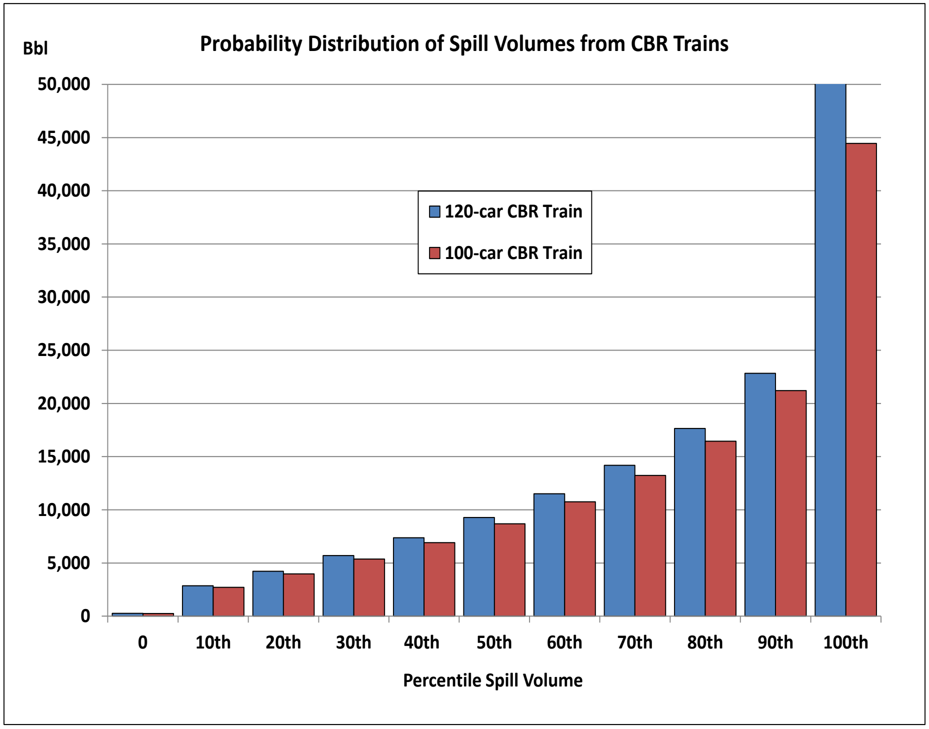

Figure 49: Probability Distribution of Spill Volumes from CBR Trains

The projected annual frequency of CBR spills into the Hudson River is dependent on the expected CBR traffic, as in Table 72. The expected frequencies and annual probabilities were calculated for all of the hypothetical CBR traffic scenarios, as shown in Table 74 and Table 75 as low and high estimates. The same results are shown as the annual probability of a spill in Table 76 and Table 77.[139] There is no probability of a spill when there are no CBR trains operating. Smaller spills related to leaks or errors during transfers are not included herein. The spill volumes assume a mix of trains from 100 to 120 cars in length.

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[139] The annual probability is the inverse of the number of spills/year shown as a 1 in x "chance."

Table 74: Projected Annual Frequency of CBR Spills into Hudson River (Low Estimate)

Spill Volume	Spills/Year (Based on Trains per Year)					
	8 trains Current Diversion	32 trains Occasional Diversion	96 trains Frequent Diversion	780 trains Moderate Historical	1,560 trains Peak Historical	4,015 trains Maximum Hypothetical
<238 bbl	0.000000051	0.0000002	0.00000061	0.0000048	0.0000096	0.000025
2,500 bbl	0.000000046	0.00000018	0.00000055	0.0000044	0.0000087	0.000023
4,000 bbl	0.000000042	0.00000017	0.00000050	0.0000040	0.0000079	0.000021
5,000 bbl	0.000000030	0.00000012	0.00000035	0.0000028	0.0000056	0.000015
8,000 bbl	0.000000027	0.00000011	0.00000033	0.0000026	0.0000051	0.000013
10,000 bbl	0.000000018	0.000000071	0.00000022	0.0000017	0.0000034	0.0000089
15,000 bbl	0.000000014	0.000000054	0.00000017	0.0000013	0.0000026	0.0000068
20,000 bbl	0.0000000051	0.000000020	0.000000061	0.00000048	0.00000096	0.0000025
40,000 bbl	0.00000000051	0.0000000020	0.00000000610	0.000000048	0.000000096	0.00000025
50,000 bbl	0.00000000005	0.00000000020	0.00000000061	0.0000000048	0.0000000096	0.000000025

Table 75: Projected Annual Frequency of CBR Spills into Hudson River (High Estimate)

Spill Volume	Spills/Year (Based on Trains per Year)					
	8 trains Current Diversion	32 trains Occasional Diversion	96 trains Frequent Diversion	780 trains Moderate Historical	1,560 trains Peak Historical	4,015 trains Maximum Hypothetical
<238 bbl	0.000001	0.0000048	0.000014	0.00011	0.00023	0.00058
2,500 bbl	0.00000090	0.0000044	0.000013	0.00010	0.00021	0.00053
4,000 bbl	0.00000083	0.0000040	0.000012	0.000091	0.00019	0.00048
5,000 bbl	0.00000058	0.0000028	0.0000081	0.000064	0.00013	0.00034
8,000 bbl	0.00000054	0.0000026	0.0000075	0.000059	0.00012	0.000311
10,000 bbl	0.00000035	0.0000017	0.0000050	0.000039	0.000082	0.00021
15,000 bbl	0.00000027	0.0000013	0.0000038	0.000030	0.000063	0.00016
20,000 bbl	0.00000010	0.00000048	0.0000014	0.000011	0.000023	0.000058
40,000 bbl	0.000000010	0.000000048	0.00000014	0.0000011	0.0000023	0.0000058
50,000 bbl	0.000000001	0.0000000048	0.000000014	0.00000011	0.00000023	0.00000058

Table 76: Projected Annual Probability of CBR Spills into Hudson River (Low Estimate)

Spill Volume	Spills/Year (Based on Trains per Year)					
	8 trains Current Diversion	32 trains Occasional Diversion	96 trains Frequent Diversion	780 trains Moderate Historical	1,560 trains Peak Historical	4,015 trains Maximum Hypothetical
<238 bbl	1 in 20 million	1 in 5 million	1 in 2 million	1 in 210,000	1 in 100,000	1 in 40,000
2,500 bbl	1 in 22 million	1 in 6 million	1 in 2 million	1 in 230,000	1 in 110,000	1 in 40,000
4,000 bbl	1 in 24 million	1 in 6 million	1 in 2 million	1 in 250,000	1 in 130,000	1 in 70,000
5,000 bbl	1 in 33 million	1 in 8 million	1 in 3 million	1 in 360,000	1 in 180,000	1 in 70,000
8,000 bbl	1 in 37 million	1 in 9 million	1 in 3 million	1 in 380,000	1 in 200,000	1 in 80,000
10,000 bbl	1 in 56 million	1 in 14 million	1 in 5 million	1 in 590,000	1 in 290,000	1 in 110,000
15,000 bbl	1 in 71 million	1 in 19 million	1 in 6 million	1 in 770,000	1 in 380,000	1 in 150,000
20,000 bbl	1 in 200 million	1 in 50 million	1 in 16 million	1 in 2 million	1 in 1 million	1 in 400,000
40,000 bbl	1 in 2 billion	1 in 500 million	1 in 160 million	1 in 21 million	1 in 10 million	1 in 4 million
50,000 bbl	1 in 20 billion	1 in 5 billion	1 in 1.6 billion	1 in 208 million	1 in 100 million	1 in 40 million

Table 77: Projected Annual Probability of CBR Spills into Hudson River (High Estimate)

Spill Volume	Spills/Year (Based on Trains per Year)					
	8 trains Current Diversion	32 trains Occasional Diversion	96 trains Frequent Diversion	780 trains Moderate Historical	1,560 trains Peak Historical	4,015 trains Maximum Hypothetical
<238 bbl	1 in 1 million	1 in 210,000	1 in 70,000	1 in 9,000	1 in 4,000	1 in 2,000
2,500 bbl	1 in 1 million	1 in 230,000	1 in 80,000	1 in 10,000	1 in 5,000	1 in 2,000
4,000 bbl	1 in 1 million	1 in 250,000	1 in 80,000	1 in 11,000	1 in 5,000	1 in 2,000
5,000 bbl	1 in 2 million	1 in 360,000	1 in 120,000	1 in 16,000	1 in 8,000	1 in 3,000
8,000 bbl	1 in 2 million	1 in 380,000	1 in 130,000	1 in 17,000	1 in 8,000	1 in 3,000
10,000 bbl	1 in 3 million	1 in 590,000	1 in 200,000	1 in 26,000	1 in 12,000	1 in 5,000
15,000 bbl	1 in 4 million	1 in 770,000	1 in 260,000	1 in 33,000	1 in 16,000	1 in 6,000
20,000 bbl	1 in 10 million	1 in 2 million	1 in 710,000	1 in 91,000	1 in 43,000	1 in 17,000
40,000 bbl	1 in 100 million	1 in 21 million	1 in 714,000	1 in 910,000	1 in 440,000	1 in 170,000
50,000 bbl	1 in 1 billion	1 in 208 million	1 in 71 million	1 in 9 million	1 in 4 million	1 in 2 million

Any spill of at least 10,000 gallons (238 bbl) would be considered a major inland spill. This volume represents about one-third of a CBR tank car. With an accident that causes spillage from a breached tank car on a CBR train, it is highly likely that the spill would be considered a “major” spill regardless of the exact volume. This would be due to the concerns about the likelihood of fire and explosion with a trainload of Bakken crude or the concern about submerged oil possibilities with a trainload of diluted bitumen product.

Probability of Diesel Locomotive Fuel Spillage along Hudson River

In addition to potential spills of crude oil from loaded CBR trains, there may also be other spills of diesel fuel from locomotives:

- On loaded CBR trains on the western side of the river;

- Empty CBR trains on the western side of the river;
- Other loaded/empty freight trains on either side of the river;
- Long-distance passenger (Amtrak) trains on the eastern side of the river; and
- Commuter trains on the eastern side of the river.

The estimated yearly numbers of trains in these various categories, miles of riverside track, and the estimated total volume of oil carried by the locomotives are shown in Table 78.

Table 78: Train Transits along Hudson River for Potential Locomotive Diesel Spills

Train Type	River Side	Annual Trains	Riverside Track	Train-Miles	Maximum Volume
Loaded CBR–Current Diversion Transport	West	8	39.6 miles	317	525 bbl
Empty CBR–Current Diversion Transport	West	8	39.6 miles	317	525 bbl
Loaded CBR–Occasional Diversion Transport	West	32	39.6 miles	1,267	525 bbl
Empty CBR–Occasional Diversion Transport	West	32	39.6 miles	1,267	525 bbl
Loaded CBR–Frequent Diversion Transport	West	96	39.6 miles	3,802	525 bbl
Empty CBR–Frequent Diversion Transport	West	96	39.6 miles	3,802	525 bbl
Loaded CBR–Moderate Historical Transport	West	780	39.6 miles	30,888	525 bbl
Empty CBR–Moderate Historical Transport	West	780	39.6 miles	30,888	525 bbl
Loaded CBR–Peak Historical Transport	West	1,560	39.6 miles	61,776	525 bbl
Empty CBR–Peak Historical Transport	West	1,560	39.6 miles	61,776	525 bbl
Loaded CBR–Maximum Hypothetical Transport	West	4,015	39.6 miles	158,994	525 bbl
Empty CBR–Maximum Hypothetical Transport	West	4,015	39.6 miles	158,994	525 bbl
Freight Trains (Mixed Manifest)	West	14,300	39.6 miles	566,280	525 bbl
Freight Trains (Mixed Manifest)	East	1,800	133 miles	239,400	262 bbl
Amtrak Passenger Trains	East	10,000	133 miles	1,330,000	124 bbl
Metro-North Commuter Trains	East	21,580	70 miles	1,510,600	67 bbl

The annual frequency and probability of diesel spills for these different types of trains are summarized in Table 79. With the large number of long-distance passenger and commuter trains, 1 in 3 chance of a diesel locomotive spill along the Hudson River tracks each year. The probabilities of locomotive spills by volume based on current traffic are shown in Table 80.

Table 79: Estimated Annual Frequency of Diesel Locomotive Spills along Hudson River

Train Type	River Side	Annual Spills	Annual Probability	Maximum Spill Volume
Loaded CBR–Current Diversion Transport	West	0.000031	1 in 33,000	525 bbl
Empty CBR–Current Diversion Transport	West	0.000031	1 in 33,000	525 bbl
Loaded CBR–Occasional Diversion Transport	West	0.00012	1 in 8,200	525 bbl
Empty CBR–Occasional Diversion Transport	West	0.00012	1 in 8,200	525 bbl
Loaded CBR–Frequent Diversion Transport	West	0.00037	1 in 2,700	525 bbl
Empty CBR–Frequent Diversion Transport	West	0.00037	1 in 2,700	525 bbl
Loaded CBR–Moderate Historical Transport	West	0.0030	1 in 340	525 bbl
Empty CBR–Moderate Historical Transport	West	0.0030	1 in 340	525 bbl
Loaded CBR–Peak Historical Transport	West	0.0060	1 in 170	525 bbl
Empty CBR–Peak Historical Transport	West	0.0060	1 in 170	525 bbl
Loaded CBR–Maximum Hypothetical Transport	West	0.015	1 in 65	525 bbl
Empty CBR–Maximum Hypothetical Transport	West	0.015	1 in 65	525 bbl
Freight Trains (Mixed Manifest)	West	0.055	1 in 18	525 bbl
Freight Trains (Mixed Manifest)	East	0.023	1 in 43	262 bbl
Amtrak Passenger Trains	East	0.13	1 in 8	124 bbl
Metro-North Commuter Trains	East	0.15	1 in 7	67 bbl
Total (Excluding CBR Trains)	**-**	**0.35**	1 in **3**	**525 bbl**

Table 80: Estimated Annual Hudson River Spills from Diesel Locomotives by Volume

Volume	Annual Spills	Annual Probability
5 bbl	0.078	1 in 13
25 bbl	0.069	1 in 15
40 bbl	0.065	1 in 16
50 bbl	0.043	1 in 23
60 bbl	0.041	1 in 25
70 bbl	0.027	1 in 37
100 bbl	0.020	1 in 49
250 bbl	0.0078	1 in 130
300 bbl or more	0.00078	1 in 1,300
Total	**0.35**	**1 in 3**

Potential Oil Spillage along Hudson River: Facilities

The storage of large quantities of oil in tanks at riverside facilities or terminals is another potential source of oil spillage. Spills that occur at facilities will usually be contained with required secondary containment. However, there are circumstances when this containment, which is designed to hold more than the volume of the tanks, may be breached, causing some or all of the spilled oil to enter the river.

Existing Oil Facilities on the Hudson River

There are currently 16 major petroleum storage facilities dotting the Hudson River shorelines storing approximately 144 million gallons (3.5 million barrels, bbl). Individual storage tanks may contain as much as 250,000 to 300,000 bbl of oil. There are 16 facilities that are noted by the US Energy Information Administration as holding *at least* 50,000 bbl, as in Table 81, and Figure 50 to Figure 52.

Table 81: Major Oil Storage Facilities (50,000 bbl+) along Hudson River

Facility Owner	Town
Meenan Oil LP	Cortlandt Manor, NY
Global Co LLC	Newburgh, NY
Global Co LLC	Newburgh, NY
Global Co LLC	Newburgh, NY
Global Co LLC	Newburgh, NY
Buckeye Terminals LLC	Roseton, NY
Meenan Oil LP	Poughkeepsie, NY
Heritage Energy Inc	Kingston, NY
Citgo Holding Terminals LLC	Albany, NY
Buckeye Terminals LLC	Rensselaer, NY
Buckeye Terminals LLC	Albany, NY
Global Co LLC	Albany, NY
Sprague Operating Resources LLC	Rensselaer, NY
Petroleum Fuel and Terminal Co	Rensselaer, NY
IPT LLC	Rensselaer, NY
Global Co LLC	Albany, NY

Assuming that each facility holds approximately the same volume of oil, each facility has about 220,000 bbl. A worst-case discharge (WCD) for a facility would be the largest volume storage tank releasing its entire capacity. For the purposes of this study, the WCD is assumed to be 300,000 bbl. However, this type of a release is highly improbable except in extreme storm events (such as Hurricanes Katrina and Rita in Louisiana). These types of storms and the flooding that caused the destruction of storage tanks during these hurricanes in Louisiana are highly unlikely in the Hudson Valley. Much more likely are the smaller types of spill events that might cause a 200-bbl or smaller spill.

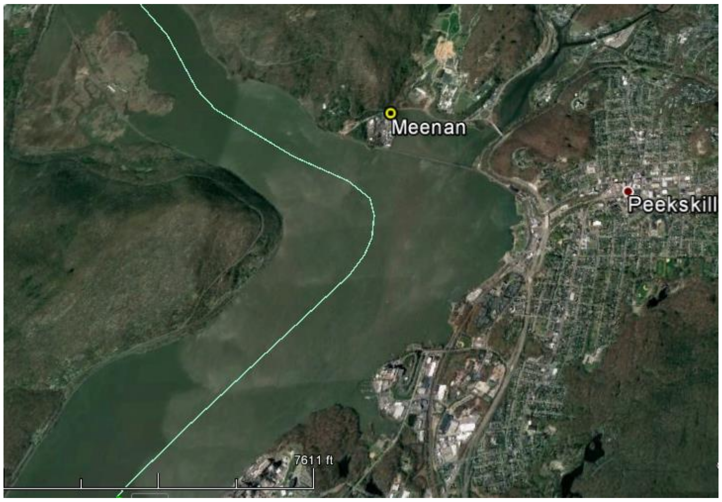

Figure 50: Oil Terminal in Cortlandt Manor, NY

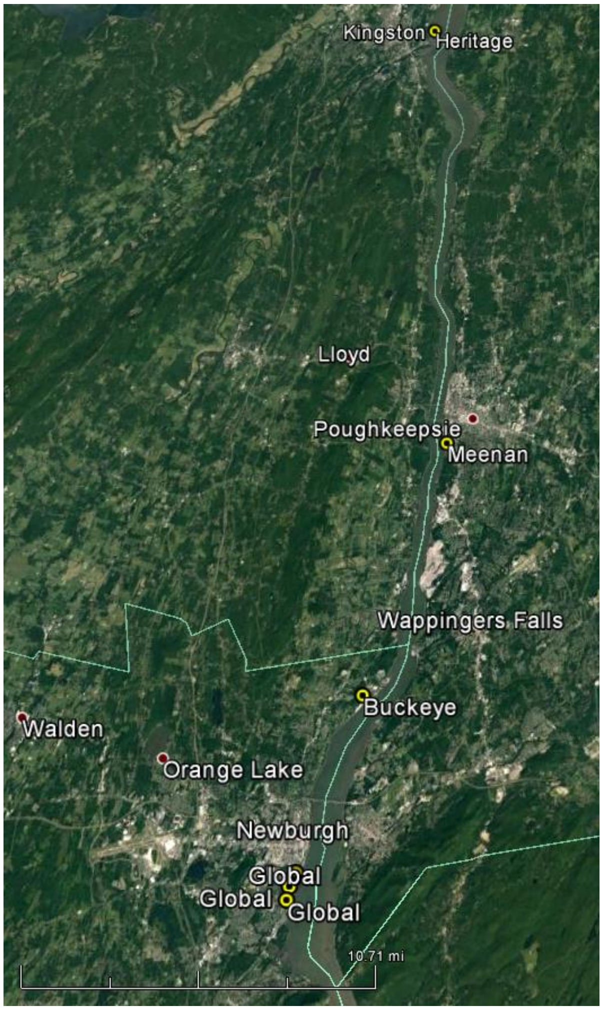

Figure 51: Oil Terminals between Newburgh and Kingston, NY

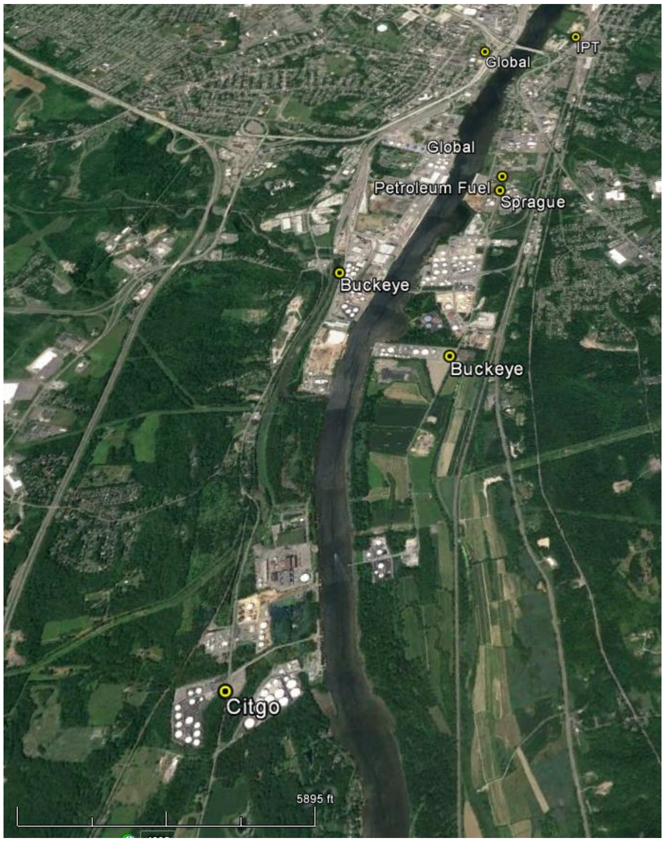

Figure 52: Oil Terminals in Albany-Rensselaer Region

In addition to the larger terminals, there are many smaller facilities that store smaller quantities of oil, such as marinas that store gasoline and diesel fuel, including those listed in Table 82 and shown in Figure 53. Each of the tanks at the marinas generally contains no more than about 30 bbl.

Table 82: Hudson River Boating Fuel Docks[140]

Facility Name	Location	Fuel Stored
JM Englewood Marina	Englewood Cliffs, NJ	Gasoline; Diesel
Alpine Boat Basin	Alpine, NJ	Gasoline
Tarrytown Marina	Tarrytown, NY	Gasoline; Diesel
Westerly Marina	Ossining, NY	Gasoline; Diesel
Haverstraw Marina	Haverstraw, NY	Gasoline; Diesel
Newburgh Yacht Club	Newburgh, NY	Gasoline; Diesel
Whites Hudson River Marina	New Hamburg, NY	Gasoline; Diesel
West Shore Marine	Marlboro, NY	Gasoline; Diesel
Hyde Park Marina	Hyde Park, NY	Gasoline
Roger’s Point Boating Assoc.	Hyde Park, NY	Gasoline; Diesel
Rondout Yacht Basin	Connelly, NY	Gasoline; Diesel

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[140] Source: *Boating on the Hudson & Beyond* http://www.boatingonthehudson.com/flippingbook/2016/jun/Articles/Fueling_Feeding.pdf

Table 82: Hudson River Boating Fuel Docks[140]

Facility Name	Location	Fuel Stored
Certified Marine Service	Connelly, NY	Gasoline; Diesel
Saugerties Marina	Saugerties, NY	Gasoline; Diesel
Riverview Marine Services	Catskill, NY	Gasoline; Diesel
Catskill Yacht Club	Catskill, NY	Gasoline; Diesel
Hudson Powerboat Assoc.	Hudson, NY	Gasoline; Diesel
Coxsackie Yacht Club	Coxsackie, NY	Gasoline
Donovan's Shady Harbor Marina	New Baltimore, NY	Gasoline; Diesel
Coeymans Landing	Coeymans, NY	Gasoline; Diesel
Castelton Boat Club	Castleton, NY	Gasoline; Diesel
Albany Yacht Club	Rensselaer, NY	Gasoline; Diesel

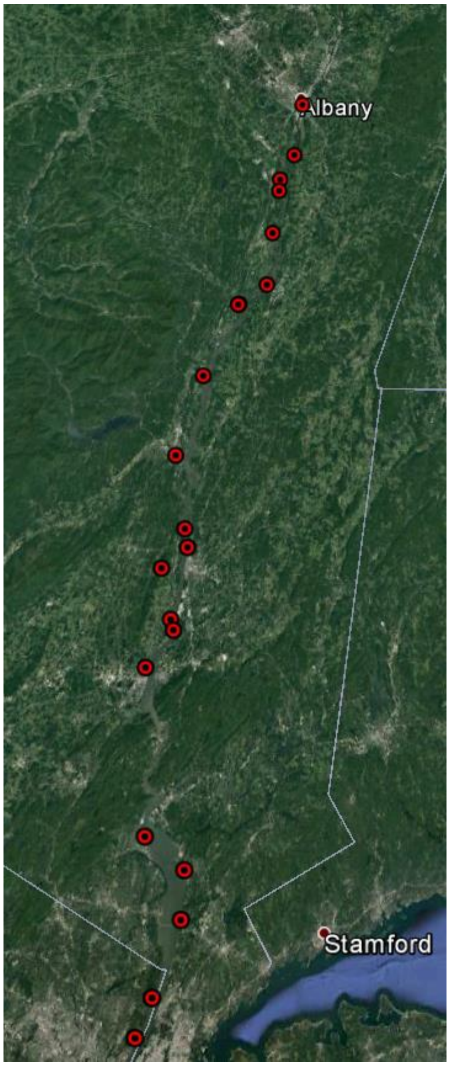

Figure 53: Locations of Fueling Docks along Hudson River

Potential Global Partners Terminal Expansion

There is the possibility of expansion of existing terminals. For example, Global Partners LP originally purchased its 63-acre terminal in Albany from ExxonMobil in 2007. In June 2013, the company applied to expand its terminal to include a rail-loading facility (Figure 54). The permit involved an expansion of crude oil storage capabilities to include heated products (crude, residual fuel, and bio-fuel). The main concerns about the project were related to air emissions. In November 2013, the NYSDEC issued a Negative Declaration asserting that “the emissions from the heated petroleum products are lower than the emissions from the crude oil that is currently permitted for storage at the facility; therefore the facility’s potential to emit (PTE) will not change with this modification.”

In 2015, due mainly to market forces, Global withdrew its permit application for the expansion. As previously discussed, shipments of crude oil stopped in August 2016 and have not resumed since that time. The likelihood that this terminal will be expanded in the future is dependent on oil market forces. If the terminal were to be expanded, which would require a new permit application, an increase in CBR traffic and tank barge traffic would be expected as well.

Figure 54: Global Albany Terminal[141]

Probability Analysis of Oil Spillage from Facilities

Oil spillage can occur at facilities in a number of ways:

- Errors or equipment malfunction during oil transfer operations (from/to vessels, vehicles, or rail tank cars);[142]
- Corrosion or structural failure of storage tanks;
- Unintentional damage during maintenance or repairs;
- Errors or equipment malfunctions within the facility;
- Breakage of tanks due to outside force damage from natural events (seismic events, storms); and

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[141] http://globalalbany.com/about/about-the-albany-terminal/

[142] These spills are treated as vessel- and rail-related incidents as opposed to facility incidents.

- Intentional damage (vandalism, terrorism)

The incidence of facility spills has decreased significantly in the last decades due to stricter regulations at the state and federal level. The US EPA Spill, Prevention, Control, and Countermeasures (SPCC) rule, and its counterparts at the state level, NYSDEC Bulk Storage regulations, help to prevent spills in the first place and to prepare for spills that do occur. One part of these rules is the requirement for adequate secondary containment that prevents the spread of oil beyond the facility grounds in the event of a spill.

A cost-benefit study conducted for the EPA[143] showed a significant reduction in spills with the implementation of SPCC and related state regulations. Between the early 1970s and the 2010s, there was a 98% reduction in the average annual volume of spillage from coastal marine facilities that store large quantities of oil.[144] Currently, about 1,500 bbl spills from these facilities annually throughout the US. Inland facilities that are regulated by EPA spill an average of 19,000 bbl per year throughout the US, which is a 91% decrease from the 1990s. This is less than 40% of the minimum volume of the 16 facilities listed in Table 81.

The frequencies of spill events for inland EPA-regulated facilities are shown in Table 83. These probabilities were applied to the 16 facilities in the Hudson River study area. Note that these are probabilities of any type of spill–not necessarily a WCD. The spill volume distribution for facility spills is shown in Figure 56, and Table 84. The expected frequency of spills of different volumes into the Hudson River from existing oil facilities is summarized in Table 85.

Table 83: Estimated Spill Frequency for Hudson River Oil Facilities

Spill Cause[145]	**Annual Frequency per Facility[146]**		**Hudson River Facilities**	
	Spills/Year	**Annual Probability**	**Spills/Year**	**Annual Probability**
Damage during Maintenance	0.000056	1 in 18,000	0.00090	1 in 1,100
Structural Failure	0.00020	1 in 5,000	0.0032	1 in 310
Mechanical or Equipment Failure	0.00022	1 in 4,600	0.0035	1 in 280
Operational Error (Human Error)	0.00021	1 in 4,800	0.0034	1 in 300
Vandalism[147]	0.000024	1 in 41,000	0.00038	1 in 2,600
Total	**0.00071**	**1 in 1,400**	**0.011**	**1 in 88**

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[143] Etkin 2003a.

[144] Etkin 2003a; Etkin 2003b; Etkin 2004; Etkin 2010a; Etkin 2010b.

[145] All probabilities based on analyses conducted for the US EPA as in Etkin 2003a; Etkin 2004.

[146] Based on an analysis of 41,068 facility spills (Etkin 2003a; Etkin 2003b; Etkin 2004; Etkin 2010a; Etkin 2010b).

[147] Calculating the likelihood of a terrorist attack is beyond the scope of this study. In the event that a terrorist attack were to occur at one or more of the oil terminals along the Hudson River, there would be significant concerns about public safety that may overtake concerns about potential environmental impacts, much as occurred during the 1991 Gulf War spillage. The likelihood of a specific facility being a target for vandalism would depend on the location, accessibility, and motivation of the vandals in each case.

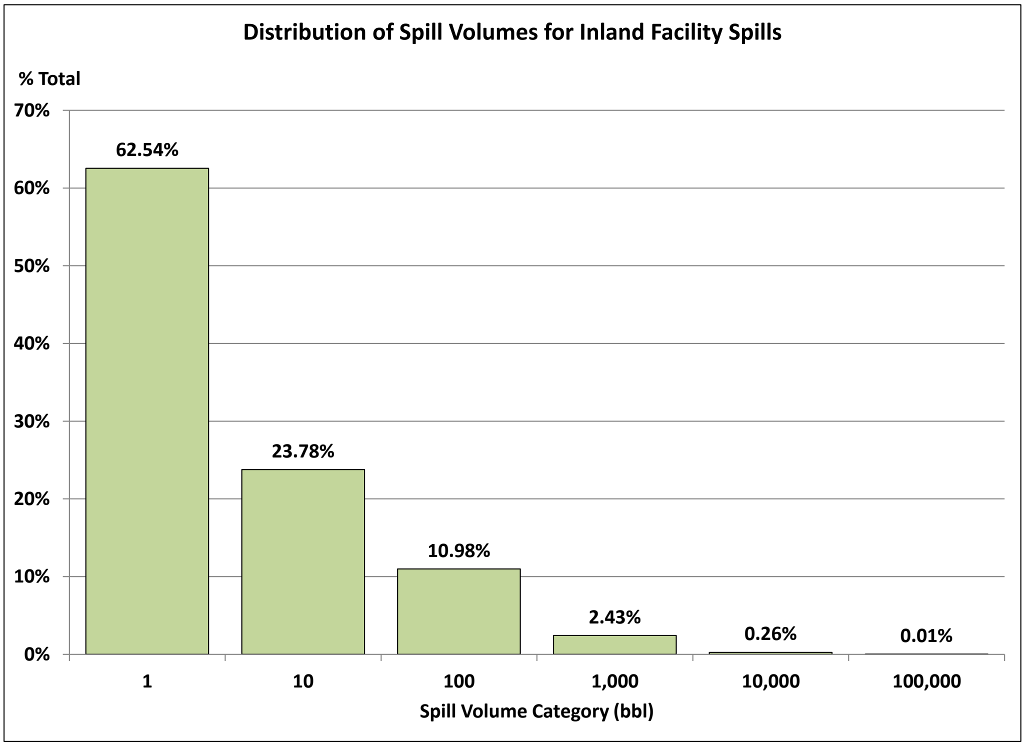

Figure 55: Distribution of Spill Volumes for Inland Facility Spills

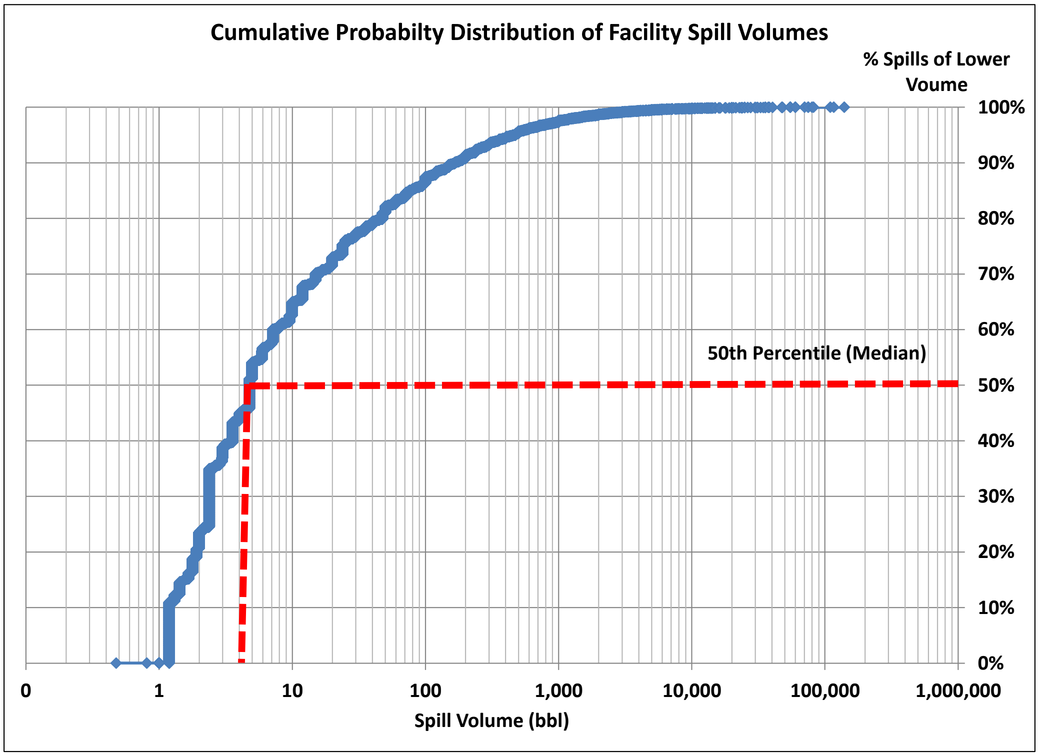

Figure 56: Cumulative Probability Distribution of Inland Facility Spill Volumes

Table 84: Percentile Spill Volumes for US Inland Facilities (1980-2007)[148]	
Percentile[149]	**Volume**
50th (median)	5 bbl
90th	170 bbl
95th	475 bbl
99th	2,900 bbl
Average	178 bbl

Table 85: Projected Annual Oil Facility Spills into Hudson River		
Spill Volume	**Spills/Year**	**Annual Probability**
Any Volume	0.011	1 in 88
≥10 bbl	0.0041	1 in 240
≥238 bbl (Major)	0.00090	1 in 1,100
1–9 bbl	0.0069	1 in 150
10–99 bbl	0.0026	1 in 380
100–999 bbl	0.0012	1 in 830
1,000–9,999 bbl	0.00027	1 in 3,700
10,000–99,999 bbl	0.000028	1 in 36,000
≥100,000 bbl	0.00000080	1 in 1.2 million

Facility Spills due to Damage from Natural Events

These probabilities and spill frequencies were calculated based on national (US) data. There are circumstances that would make some facilities more prone to very large spills due to outside force damage from natural events, such as seismic activity (earthquakes) and significant storms or hurricanes. In seismically-active areas, this is generally considered during environmental impact assessments for new oil terminals or other facilities handling or storing hazardous materials.[150] Storage tanks and oil facilities are generally constructed to withstand damage from seismic activity, though there is a possibility of damage in the event of an earthquake that exceeds 5.0 on the Richter scale.[151]

In the Hudson Valley, there have been no earthquakes exceeding 4.0 in over 100 years. The geological seismic hazard map for New York State is shown in Figure 57. The calculated return period for a seismic event (reference ground motion) that might present a sufficient hazard to cause damage to a facility (or to

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[148] Based on an analysis of 41,068 facility spills (Etkin 2003a; Etkin 2003b; Etkin 2004; Etkin 2010a; Etkin 2010b).

[149] The nth percentile represents the value at which only 100-n % are larger.

[150] For example: AECOM 2017.

[151] Earthquakes are measured based on Richter magnitude, with potential damage generally described by the US Geological Survey as follows:

- Less than 3.5: generally not felt, but recorded.
- 3.5-5.4: often felt, but rarely causes damage.
- 5.5 to 6.0: at most slight damage to well-designed buildings, can cause major damage to poorly constructed buildings over small regions.
- 6.1-6.9: can be destructive in areas up to about 100 kilometers across where people live;
- 7.0-7.9: major earthquake, can cause serious damage over larger areas.
- 8 or greater: great earthquake, can cause serious damage in areas several hundred kilometers across.

a pipeline) in the Hudson Valley area would be about 480 years–or a 1 in 480 chance per year. Earthquakes are not a significant threat for causing spillage from an oil terminal in this area.

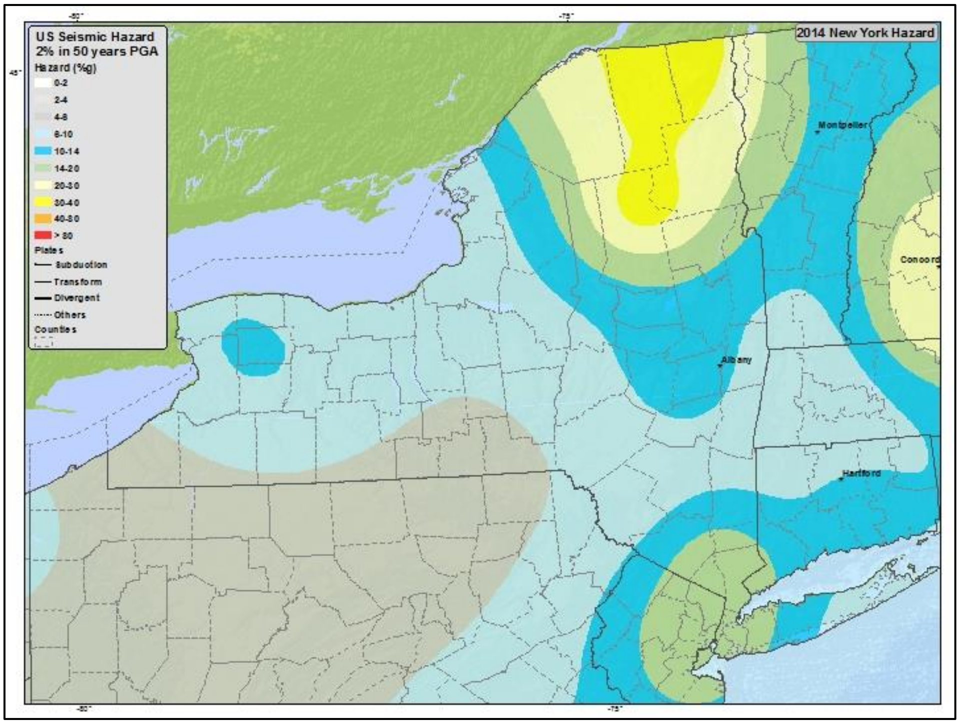

Figure 57: US Geological Seismic Hazard Map for New York[152]

Hurricanes of Category 4 or 5, and their accompanying storm surges and flooding, might potentially cause damage to storage tanks at a facility. This type of damage was experienced in Louisiana during Hurricanes Rita and Katrina.[153] The facilities that experienced this type of damage were near marine waters where the effects of the hurricanes and storm surges were felt more acutely. The damage to storage tanks from Hurricane Katrina was shown to be due flooding, while the damage from Hurricane Rita was attributed more towards direct wind action that caused localized buckling of the shells of the tanks.

The damage potential for hurricanes is described in Table 86. According to NOAA National Hurricane Center data, the return period for a hurricane of at least Category 1 (like Sandy) with winds of 64 kts or 74 mph is 17–24 years for the New York coastal communities. This is an annual probability of 0.04 to 0.06, or a 1 in 24 to 1 in 17 chance each year. For the HROSRA study area, this potentially includes Bronx, Westchester, and Bergen counties. The probability for a major hurricane (Category 3 or higher) with winds of at least 96 kts or 110 mph is 1 in 120 to 1 in 53 each year, or an annual probability of 0.0083 to 0.019. There is evidence that there are increases in the frequency of Category 5 hurricanes in the past decades due to climate change.[154] It is possible that there may be more frequent stronger storms in the Atlantic.

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[152] https://earthquake.usgs.gov/earthquakes/byregion/newyork-haz.php

[153] Godoy 2007.

[154] Mei et al. 2015.

Table 86: Damage Potential from Hurricanes with Land-Fall[155]

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

The potential for damage to riverside oil terminals from a storm surge or flooding is possible in the Hudson River study area. The storm surge and damages from Hurricane Sandy (2012) are shown in Figure 58 and Figure 59. This storm was technically a Category 1 hurricane (based on winds), however, there was significant damage. This damage included at least one release from a ruptured storage tank at the Motiva Enterprises oil tank facility in Woodbridge, New Jersey, in the Arthur Kill (the narrow

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[155] NOAA National Hurricane Center.

waterway separating New Jersey and Staten Island). The release involved 8,300 bbl of diesel fuel. Secondary containment captured most of the oil.

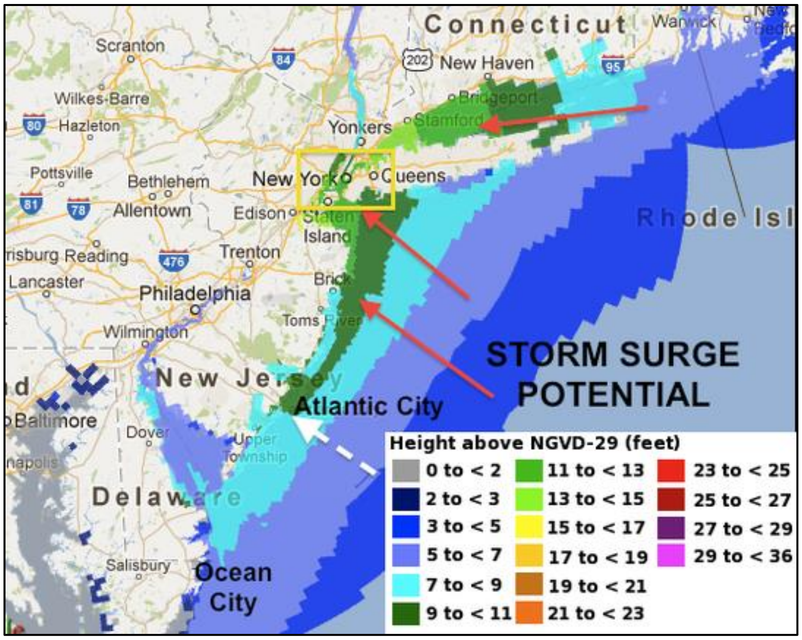
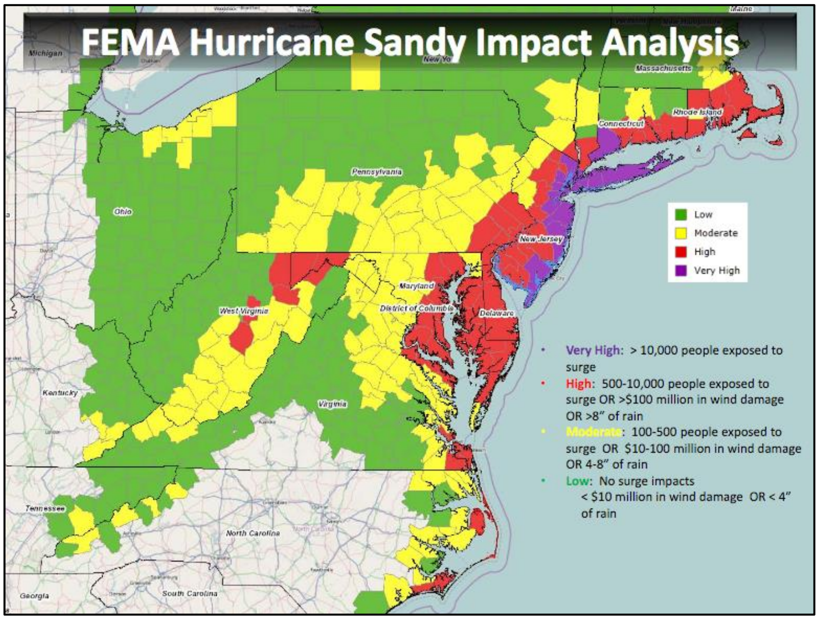


Figure 58: Hurricane Sandy Storm Surge Potential[156]



- Very High: > 10,000 people exposed to surge
- High: 500-10,000 people exposed to surge OR >$100 million in wind damage OR >8" of rain
- Moderate: 100-500 people exposed to surge OR $10-100 million in wind damage OR 4-8" of rain
- Low: No surge impacts < $10 million in wind damage OR < 4" of rain

Figure 59: FEMA Hurricane Sandy Impact Analysis

The storm surges and storm tides elevations produced by Hurricane Sandy were analyzed by the Federal Emergency Management Agency (FEMA) and the US Geological Survey.[157] The calculated FEMA flood

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[156] NOAA National Hurricane Center.

elevations and annual exceedance probabilities for selected locations along the Hudson River are show in Table 87. Hurricane Sandy exceeded the 100-year flood in Dutchess and Greene Counties, and the 500-year flood in Ulster County. These data show that there is a possibility that storm surges may affect locations that have oil terminals along the Hudson River. Even if there is storm surge, this does not mean that there would necessarily be a spill. Secondary containment may hold much or all of spilled oil under most circumstances. However, flooding would likely cause oil to enter the Hudson River.

Table 87: Peak Sandy Storm-Tide Elevations and Corresponding FEMA Flood Data[158]

Location (County)	Latitude	Longitude	FEMA Flood Elevations (Feet above NAVD 88)				Sandy Peak Storm Tide (ft)
			10% (10 year)	2% (50 year)	1% (100 year)	0.2% (500 year)	
Albany	42.64611	-73.74750	10.2	13.8	15.6	19.6	10.57
Dutchess	41.65093	-73.94458	5.9	7.1	8.0	9.7	8.66
Greene	42.22417	-73.88089	6.3	8.0	8.6	10.9	9.80
Ulster	41.91814	-73.98172	6.0	7.5	8.9	10.4	13.5
Westchester	40.94300	-73.72090	8.7	11.3	12.5	16.8	10.5

Structural Failure in Storage Tank: Ashland Oil Spill

An example of a catastrophic structural failure of a storage tank is the January 1988 incident involving the collapse of an Ashland Oil Company storage tank in Floreffe, Pennsylvania.[159] The tank released its entire 90,000 bbl of diesel fuel into the environment, of which 18,000 bbl entered the Monongahela River, 24 miles upstream of Pittsburgh. When the tank split vertically (Figure 60), the contents overwhelmed the standard earthen containment dikes. The storage tank was being filled to capacity for the first time after re-installation on the site. It had been previously constructed 48 years earlier but reconstructed at the site two years before the spill.

Figure 60: Artist Rendering of Ashland Oil Tank Rupture[160]

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[157] Schubert et al. 2015.
[158] Schubert et al. 2015.
[159] Saseen 1988; Clark et al. 1990.
[160] Source: EPA

The cause of the tank rupture was eventually identified as brittle fracture, which had been found in older structures made of weaker forms of steel. The weather (-12°F), in addition to welding defects, exacerbated the fracturing process. In response to this event, federal and state regulations on above-ground storage tanks were changed as part of the existing SPCC program to form SPCC Proposed Rules in 1991, 1993, and 1997. The final Revised SPCC Rule was enacted in 2002. These safety regulations include requirements for structural specifications, inspections, and spill preparedness. The effectiveness of these regulations has been documented.[161]

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[161] For example: Etkin 2003a.

Potential Oil Spillage in Hudson River: Pipelines

Oil pipelines present unique spill risks in that the traverse through high-consequence areas, including highly-populated zones. In their course, they also frequently run under waterways, where a release could cause effects much like a vessel spill.

Note that this analysis specifically does not address natural gas (methane) pipelines, which present very different risks from oil pipelines.[162]

Pipelines that Could Affect Hudson River

Currently, pipelines are not a very likely source of spillage into the Hudson River study area. There is no crude oil or refined product pipeline crossing the Hudson River study area at this time. There is one hazardous liquid pipeline just south of the study area that comes close to the river edge in Edgewater, New Jersey (in red in Figure 61). It appears to be an abandoned pipeline that formerly transported fuel to a shoreside oil terminal that has since been removed.

As an abandoned pipeline, there is a slight possibility that there is residual oil contained within the pipeline that could potentially leak into the Hudson River at the facility site. However, such a spill would be very small and unlikely to enter the river.

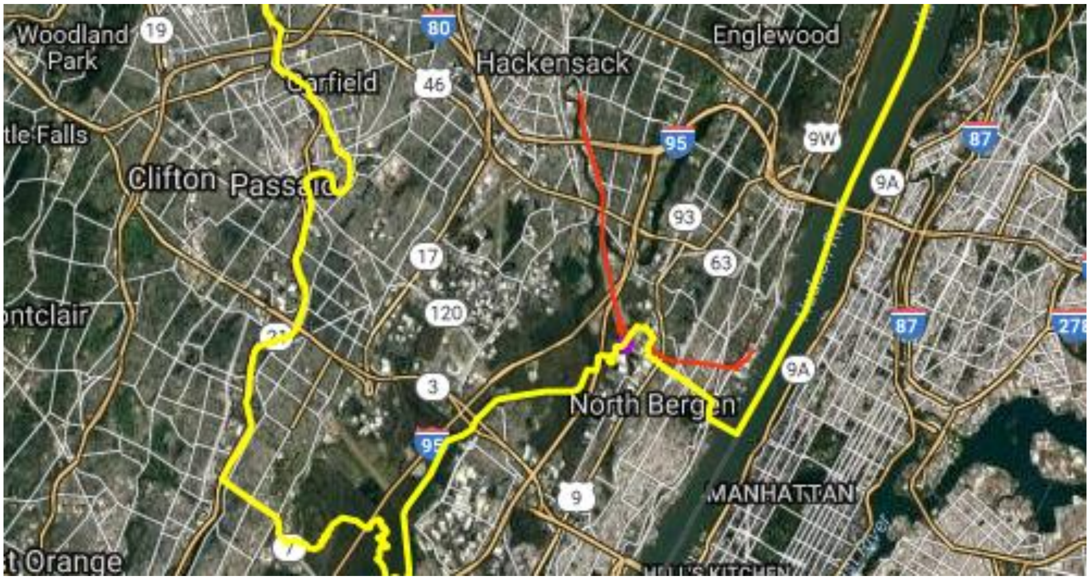

Figure 61: Hazardous Liquid Pipeline in New Jersey[163]

There are 24.8 miles of hazardous liquid pipeline in Albany County (Figure 62) that runs to a facility in Selkirk, New York, that was previously operated by General Electric and was transferred to Sabic Innovative Plastics in May 2007. The pipeline does not run close to the Hudson River. The facility is six miles from the river, thus a spill from this pipeline would not directly affect the river.

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[162] Typically, natural gas releases underwater would result in some impacts to oxygen levels, but most of the components would not dissolve in water (Wimalaratne et al. 2015; Premathilake et al. 2016).

[163] Pipeline in red. Source: Pipeline and Hazardous Material Safety Administration (https://pvnpms.phmsa.dot.gov/PublicViewer/#)

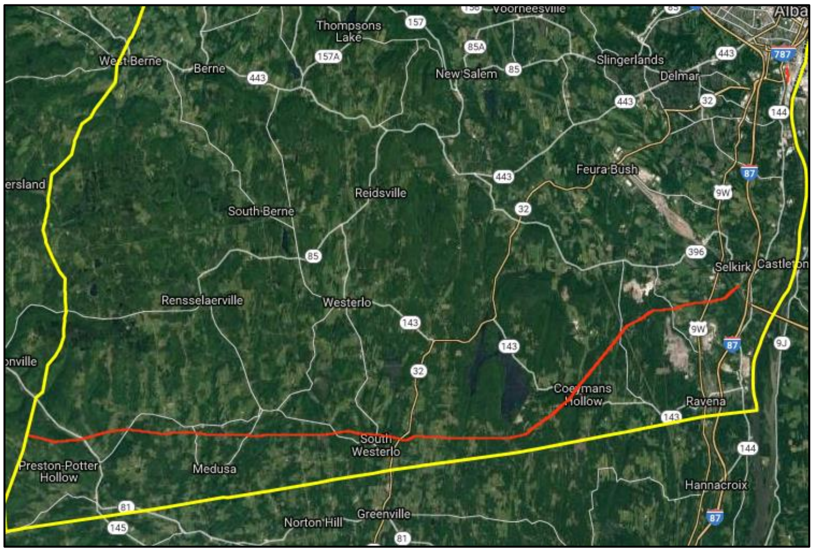

Figure 62: Hazardous Liquid Pipeline in Albany County[164]

Potential Future Changes with Proposed Pilgrim Pipeline

Another factor that could potentially change the nature of crude oil transport in the Northeast and in and along the Hudson River is the construction of the Pilgrim Pipeline. In August 2015, Pilgrim Transportation of New York submitted an application for the construction of two 170-mile parallel interstate pipelines that would run mainly along the New York State Thruway right of way west of the Hudson River (Figure 63). One pipeline would transport crude oil from the Port of Albany south to refineries in Linden, New Jersey. The second pipeline would transport refined petroleum products (gasoline, home heating oil, diesel, and kerosene) north to Albany and points in between. There would be two crossings of the Hudson River at Albany and south of Albany in Glenmont (Figure 64).

The two main pipelines would each be capable of transporting the equivalent of 200,000 bbl of oil per day. This would be the equivalent of two to three CBR trains or one-and-a-half to two tank barges full in each direction. Were the pipeline to be built, and if crude oil transport were still occurring in the Hudson River by tank barge and/or by rail, the pipeline would potentially replace some tank barge traffic.

With its permit application, Pilgrim submitted a preliminary Draft Environmental Impact Statement (DEIS). In September 2016, the New York State Department of Environmental Conservation (NYSDEC) and the New York State Thruway Authority published a positive declaration of impact, which requires the preparation of a DEIS for the project.

There has been no status change in the project since that time. According to some news reports, the two terminals in the Port of Albany, Global Partners and Buckeye Partners, notified NYSDEC that they had no plans to partner with Pilgrim Pipeline. [165] This, along with the overall change in the patterns of oil

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[164] Pipeline in red. Source: Pipeline and Hazardous Material Safety Administration (https://pvnpms.phmsa.dot.gov/PublicViewer/#)

[165] http://www.nj.com/bergen/index.ssf/2017/02/plan_to_pipe_400k_barrels_of_oil_through_nj_highlands_hits_big_setback.html

transport in the region, would appear to make the project unlikely to proceed. If, however, there is a change and the pipeline construction moves forward, this could also cause a shift in the way in which crude oil and/or refined petroleum products are again transported in the region.

The construction of the Pilgrim Pipeline would change the risk of spillage from tank vessels (and possibly trains, if those were to run again) and introduce the risk of a pipeline spill.

Figure 63: Proposed Route of Pilgrim Pipeline[166]

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[166] Source: *Application of Pilgrim Transportation of New York Inc. for a Use & Occupancy Permit*, 7 August 2015.

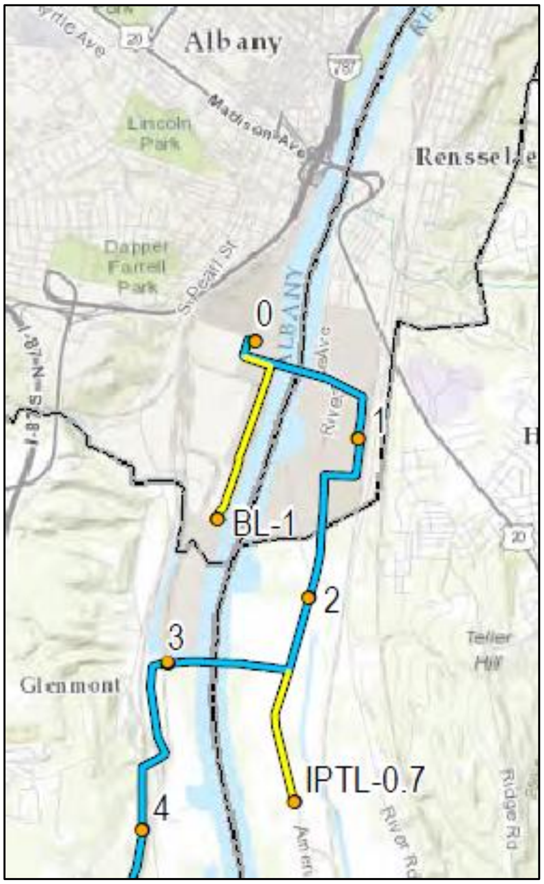

Figure 64: Hudson River Crossings for Proposed Route of Pilgrim Pipeline[167]

Probability Analysis of Oil Spillage from Pipelines

If the Pilgrim Pipeline is built, it would create a possible risk of a pipeline spill that could affect the Hudson River. The probability of a pipeline spill from the Pilgrim Pipeline was calculated so that it could be considered in the future, if necessary.

Comprehensive analyses[168] of pipeline spills in the US covering the years 1968 through 2015 have shown that there has been a significant reduction in the total volume of oil spilled annually from this source (Figure 65). In addition, the numbers of major spills[169] have decreased significantly over this time frame (Figure 66). There was a significant increase in the reporting of smaller spills (of 1–10 bbl) that began in 2001 due to changes in regulations about spill reporting and in changes in record-keeping by federal authorities (Pipeline and Hazardous Material Safety Administration, PHMSA). However, this is not indicative of an increase in pipeline spills.

For spills that have occurred in the last decade (based on data from 2006–2015), 68.3% involved less than 10 bbl, and 87% involved less than 100 bbl. Only 1% of the spill incidents involved more than 2,500 bbl.

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[167] Source: *Application of Pilgrim Transportation of New York Inc. for a Use & Occupancy Permit*, 7 August 2015.

[168] Etkin 2014; Etkin 2017.

[169] Defined for inland areas as those spills of 10,000 gallons (238 bbl) or more, as per the National Contingency Plan (40 CFR§ 300.5).

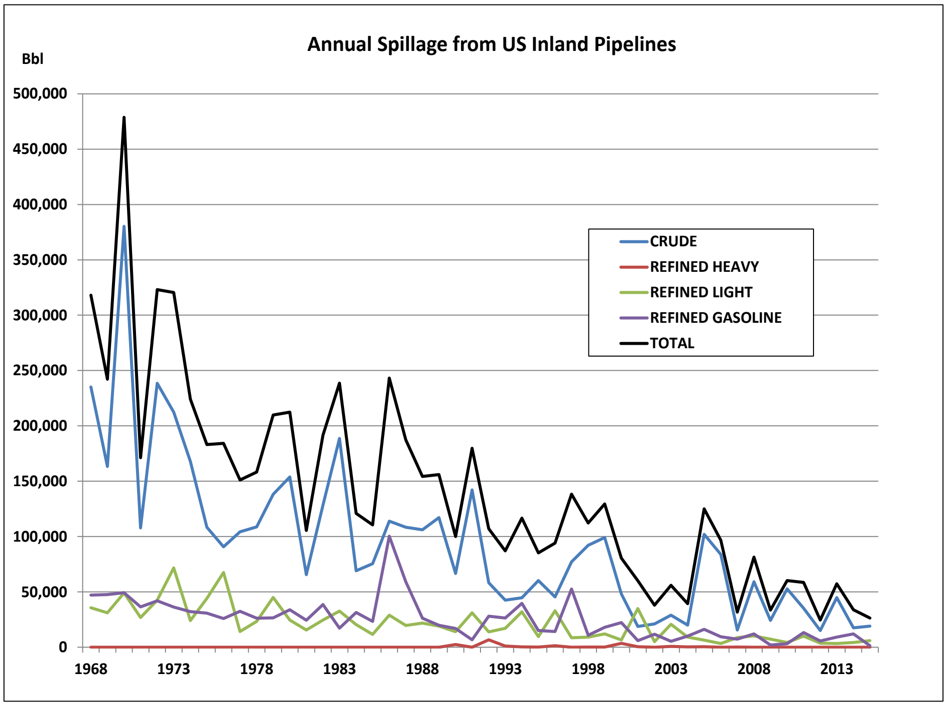

Figure 65: Annual Volume of Spillage from US Inland Pipelines (1968-2015)[170]

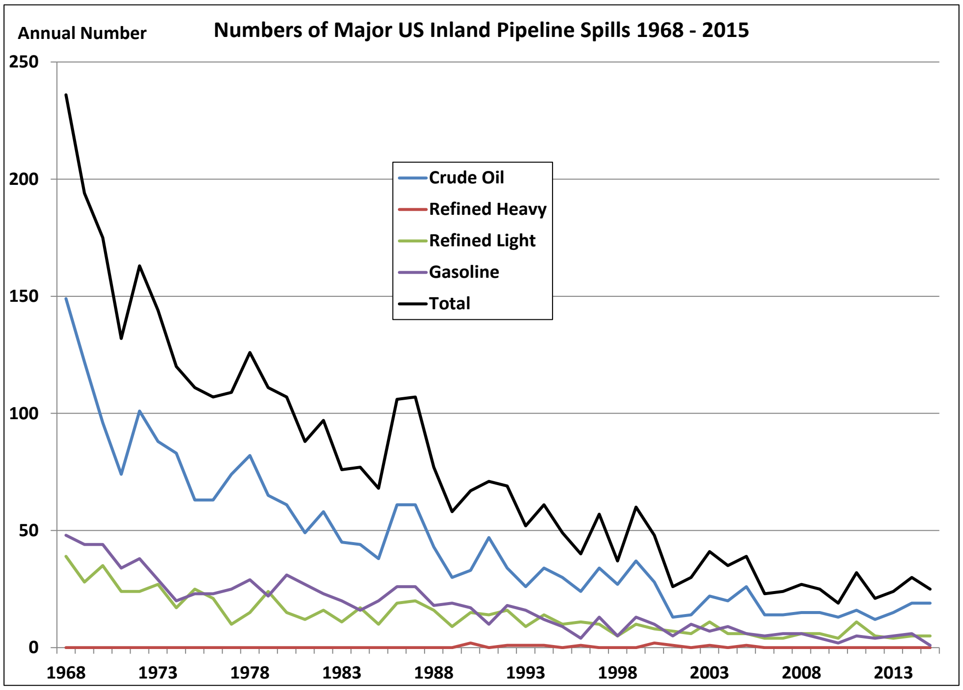

Figure 66: Annual Numbers of Major US Inland Pipeline Spills (1968-2015)[171]

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[170] Etkin 2017 (based on PHMSA data).

[171] Etkin 2017 (based on PHMSA data).

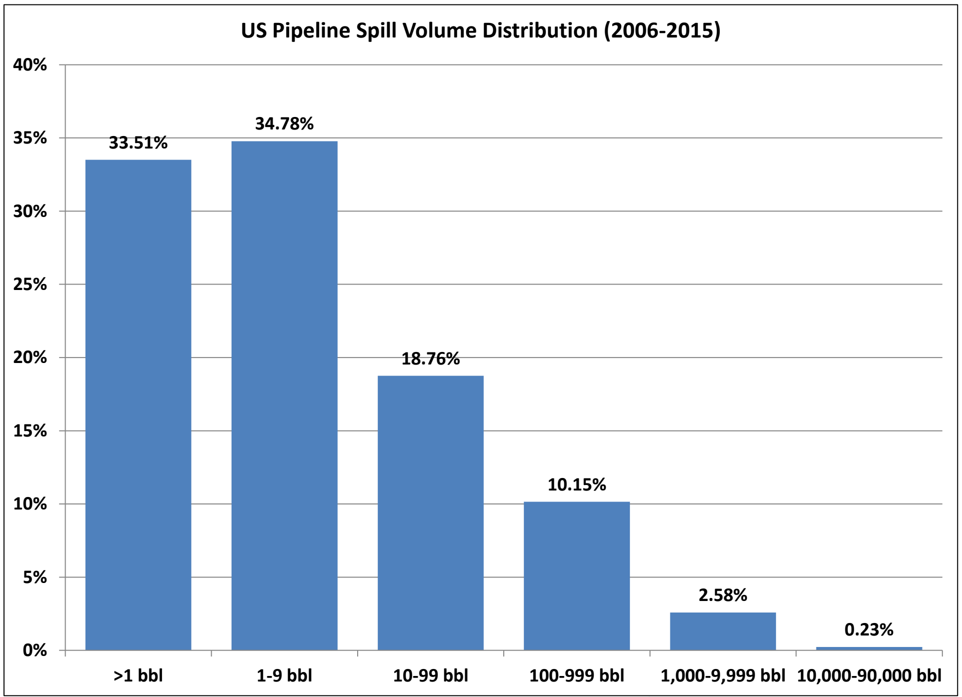

Figure 67: Pipeline Spill Volume Distribution for 2006-2015[172]

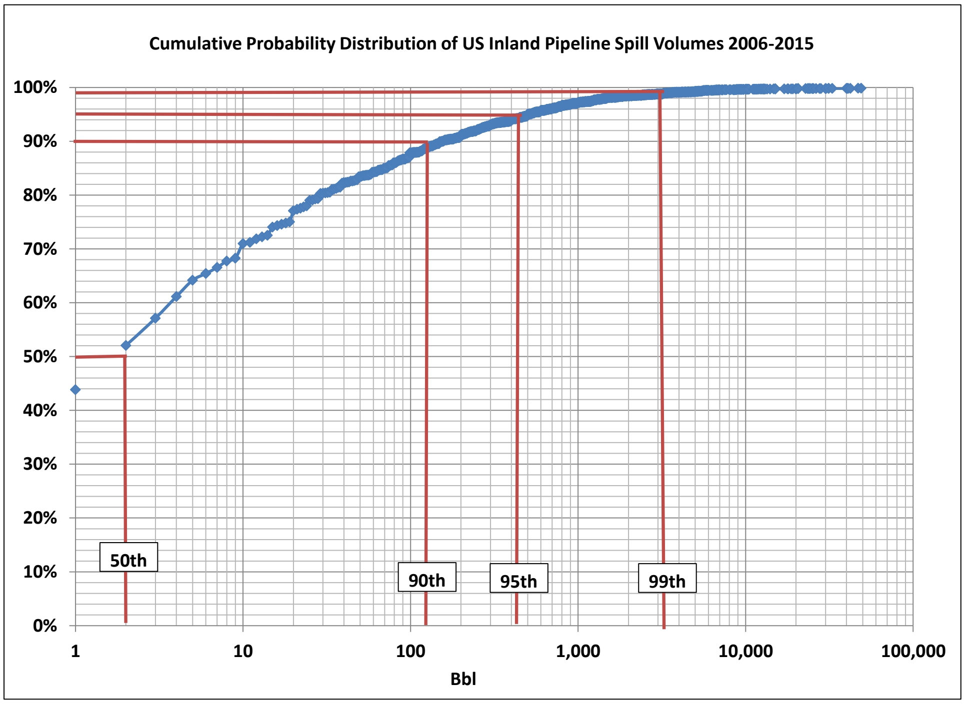

Figure 68: Cumulative Probability Distribution of US Inland Spill Volumes (2006-2015)[173]

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[172] Etkin 2017 (based on PHMSA data).

[173] Etkin 2017 (based on PHMSA data).

Table 88: Percentile Spill Volumes for US Inland Pipelines (2006–2015)[174]

Percentile[175]	Volume
50th (median)	1 bbl
90th	100 bbl
95th	400 bbl
99th	2,500 bbl

The likelihood of a pipeline spill in a particular location is based on the very specific configuration of the pipeline at that location as well as the environmental factors that could affect releases. This type of analysis is beyond the scope of this study. A more generic approach was applied by taking the rate of pipeline spillage per pipeline mile.

For crude pipelines, there are, on average, 0.00115 spills of 10 bbl or more, and 0.00030 major spills of 238 bbl or more per pipeline mile each year. For refined product pipelines, there are, on average, 0.00054 spills of 10 bbl or more, and 0.00015 major spills of 238 bbl or more each year.[176]

For the proposed Hudson River Pilgrim Pipeline crossings, there are approximately 0.30 miles of pipeline directly under the river (two crossings covering 0.15 miles each) for each of the crude and refined product lines. In addition, there are approximately 1.8 miles of pipeline on either side of the river that would run within about 1,000 feet of the river. To be conservatively cautious, the pipeline mileage was assumed to be 2.0 miles for each of the crude and refined product lines. Based on this assumption, the potential for pipeline spills by volume was calculated as shown in Table 89.

Table 89: Projected Annual Pipeline Spills into Hudson River with Pilgrim Pipeline

Pipeline Volume	Crude Pipeline		Refined Product Pipeline		Total	
	Spills/Year	Annual Probability	Spills/Year	Annual Probability	Spills/Year	Annual Probability
≥10 bbl	0.0023	1 in 440	0.0011	1 in 930	0.0031	1 in 320
≥238 bbl (Major)	0.00060	1 in 1,700	0.00030	1 in 3,300	0.00044	1 in 2,300
<1 bbl	0.0025	1 in 400	0.0012	1 in 840	0.0034	1 in 300
1–9 bbl	0.0025	1 in 400	0.0012	1 in 840	0.0034	1 in 300
10–99 bbl	0.0014	1 in 740	0.00067	1 in 1,500	0.0019	1 in 530
100–999 bbl	0.00074	1 in 1,400	0.00035	1 in 2,800	0.0010	1 in 1,000
1,000–9,999 bbl	0.00019	1 in 5,300	0.000091	1 in 11,000	0.00026	1 in 3,900
≥10,000 bbl	0.000017	1 in 56,000	0.0000081	1 in 120,000	0.000023	1 in 44,000

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[174] Etkin 2017 (based on PHMSA data).
[175] The nth percentile represents the value at which only 100-n % are larger.
[176] Etkin 2017 (based on 2001-2015 data).

Other Oil Inputs into the Hudson River

In addition to occasional spills, there are other chronic inputs of oil into the Hudson River. There are no known natural seeps of oil in the river.[177] However, there are other significant chronic inputs of oil from non-point sources[178] through runoff and dumping of oil. These chronic inputs cannot be effectively removed. The only risk mitigation measures involve the prevention or reduction of these discharges.

Non-Point Sources/Runoff

Oil in runoff comes mainly from vehicles that leak or drip oil onto pavements. This oil then is washed away by rainwater into storm sewers and directly into the river. This type of oil can often be seen as rainbow or silvery sheen in puddles in parking lots. The estimated input of oil and grease from land-based sources along the Hudson River is shown in Table 90.[179] In addition to inputs related to the residents of the Hudson Valley counties, there are also inputs from visitors to the area and those transiting the region, including on bridges. An estimated 60,000 bbl of oil enters the Hudson River annually via non-point sources on land. There are also inputs from areas further inland through runoff that goes into small streams and tributaries to the Hudson River that are not fully captured in this estimate. In addition, the dumping of used motor oil into storm sewers, a practice that is illegal, may contribute to oil pollution.[180]

Table 90: Estimated Oil Inputs to Hudson River from Land-Based Non-Point Sources

County	Riverside Community Population[181]	Vehicles per Capita[182]	Number of Vehicles	Annual Oil Input (bbl)[183]
Bergen (New Jersey)	7,275	0.539	3,921	431
Bronx (New York)	47,850	0.539	25,791	2,837
Westchester (New York)	360,766	0.539	194,453	21,390
Putnam (New York)	9,662	0.539	5,208	573
Rockland (New York)	103,123	0.539	55,583	6,114
Dutchess (New York)	113,211	0.539	61,021	6,712
Orange (New York)	83,429	0.539	44,968	4,947
Ulster (New York)	77,708	0.539	41,885	4,607
Greene (New York)	27,508	0.539	14,827	1,631
Albany (New York)	140,809	0.539	75,896	8,349
Columbia (New York)	18,323	0.539	9,876	1,086
Rensselaer (New York)	22,491	0.539	12,123	1,333
Total	**1,012,155**	**0.539**	**545,552**	**60,011**

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[177] The term "oil seeps" is used here to mean crude oil that naturally discharges from fractures in the earth's crust. About 1.12 million bbl of crude oil naturally seeps into North American waters annually (NRC 2003). This is the equivalent of half of the oil that enters marine waters. In addition, methane also seeps out naturally in many locations. The term "oil seep" has also been used colloquially in some news media and other sources to denote oil leakage from facilities, pipelines, or vessels, but it is not used in that context in this study.

[178] Widely-spread or diffuse sources.

[179] The methodology applied is derived from NRC 2003.

[180] http://www.dec.ny.gov/chemical/8468.html

[181] See Table 19 in HROSRA Volume 1.

[182] State Motor Vehicle Registration 2015, US Department of Transportation Office of Highway Policy Information.

[183] Based on estimated 0.11 bbl/vehicle (NRC 2003).

Two-Stroke Engines

The researchers that conducted the 2003 National Research Council (NRC) "Oil in the Sea" study[184] found that the recreational use of older two-stroke engines in many outboard motors and personal watercraft (e.g., jet skis) contributes an estimated 39,200 bbl of hydrocarbons to North American waters each year. This comprises 2% of the average annual total input (including spills) into marine waters.

The bulk of this input is non-combusted gasoline, which is believed to rapidly evaporate and volatilize from the water surface. However, very little is known about the fate of the discharge, though there are indications that there could be toxic effects on fish.[185] There have been some changes to engines required by EPA regulations to reduce air emissions (mostly particulates and the gasoline additive methyl tert-butyl ether, or MBTE) by 2006 that may have affected the amount of inputs to the water to some degree.

The estimated number of two-stroke engines in personal watercraft and outboard motors in coastal communities along the Hudson River is shown in Table 91. The actual inputs to the Hudson River from the two-stroke engine population were calculated to be **8,200 gallons (194 bbl) per year** based on the methodology developed by the NRC.[186]

Table 91: Estimated Two-Stroke Engines in Hudson River Watercraft[187]

County	Estimated Number of Personal Watercraft/Outboard Motors in Hudson River	Estimated Annual Inputs of Hydrocarbons to the Hudson River (bbl)
Albany	7,173	34.2
Bronx	76	0.4
Columbia	2,244	10.7
Dutchess	4,780	22.8
Greene	1,771	8.4
Orange	5,530	26.3
Putnam	2,465	11.7
Rensselaer	4,505	21.5
Rockland	2,639	12.6
Ulster	3,841	18.3
Westchester	5,686	27.1
Total	**40,710**	**193.9**

Operational Spillage from Vessels

Another type of chronic oil input into the river comes from legal operational discharges and leakages of lubricants and hydraulic oils from vessels. These discharges come from on-deck machinery and submerged (in-water) machinery, including stern tubes.

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[184] NRC 2003.

[185] Rice 2004.

[186] NRC 2003. A similar methodology was developed for GESAMP 2007.

[187] Data from New York State boat registrations.

Stern tube leakage is a significant source of lubricant oil inputs to the marine environment. A 2001 study[188] reported on the extent of ship-based oil pollution in the Mediterranean Sea. The study revealed that routine unauthorized operational discharges of oil created more pollution than accidental spills. Stern tube leakage was identified as a major component of these discharges.

The stern tube of a ship is the connection between the engine and the propeller. Inside the stern tube is the propeller shaft, which is driven by the ship's engine and rotates to turn the propeller round. The stern tube is one of the parts of a ship below the waterline that contains a significant amount of lubricant oil.

Generally, stern tube shaft seals are the only barrier between the oil in the stern tube and the marine environment. A propeller shaft sealing system is designed to prevent the entry of water into the stern tube where it could damage the bearings. The seal is also designed to prevent the leakage of lubricating oil into marine waters. Ideally, in this closed system there should be no leakage to the water.

According to the US Environmental Protection Agency,[189] "oil lubricated stern tube seals cannot release oil to the environment under normal ship operations". Some common system design features to prevent releases include :

- Use of multiple sealing rings at both the inboard and outboard stern tube ends;
- Methods to maintain pressure in the stern tube cavity below that of the sea water pressure outside to ensure that in the event of leakage, water will leak in rather than any lubricant leaking out; and
- Positive methods for determining stern tube seal leakage.

Because these seals can become worn over time or damaged by marine debris, particularly rope and fishing lines, oil leakage can occur. Anecdotal and empirical evidence from stern tube lubricant consumption supports this contention. The issue of oil leakage from stern tubes, once considered a part of normal "operational consumption" of oil, has become an issue of concern as it is now being treated as "oil pollution" with the same legal consequences as spills in many jurisdictions (e.g., under the US EPA 2008 National Pollution Discharge Elimination System or NPDES regulations implemented in 2009).

In addition to spills and stern tube leakage, there are "operational inputs" of lubricant oils that occur due to continuous low-level discharges and leakages that occur during normal vessel operations while underway and in port. The sources of operational discharges include deck machinery and in-water (submerged) machinery.

In a study conducted for the International Maritime Organization,[190] the estimated inputs of lubricants and other machinery oils were calculated. Worldwide, an estimated 233,000 to 384,000 bbl of lubricants are discharged into marine waters annually. [This is the equivalent of about one to one and half Exxon Valdez spills of oil.] In the US, the estimate annual operational input is 17,400 bbl annually.

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[188] Pavlakis et al. 2001.

[189] EPA 1999.

[190] Etkin 2010c.

As part of this study the inputs on a per-vessel basis by type of machinery were estimated (Table 92 through Table 94).[191]

Table 92: Estimated Stern Tube Usage (Leakage) per Port Visit

Vessel Type(s)[192]	Stern Tube Usage (bbl/day or bbl/port visit)
Barge Carrier	0.126
Inland Waterway Oil Tanker	0.069
Navy Ships	0.063
General Cargo Ship	0.044
Bulk Carrier; Passenger/Ro-Ro Cargo Ship	0.038
Container Ship; Tender; Live Stock Carrier	0.031
Heavy Load Carrier; Research Vessel; Crude Oil Tanker; Refrigerated Cargo Ship; Chemical Tanker; Container Ro-Ro Cargo Ship; Trawler	0.025
Pusher Tug; Hopper Dredger; Palletized Cargo Ship; Oil Products Tanker; Wood Chips Tanker; Chemical/Oil Products Tanker; Vehicles Carrier; LPG Tanker	0.019
Offshore Supply Ship; Passenger Ferry; Self-Discharging Bulk Carrier; Offshore Tug/Supply Ship; Fish Carrier; Fishing Vessel; Sail Training Ship; Passenger Cruise Ship; Standby Safety Vessel; Cement Carrier; Asphalt/Bitumen Tanker	0.013
Offshore Support Vessel; Bulk/Oil Carrier; LNG Tanker	0.006
Buoy/Lighthouse Vessel; Cable Layer; Crane Ship; Dredger; Fishery Support Vessel; Live Fish Carrier; Motor Hopper; Offshore Processing Ship; Ore Carrier; Passenger/General Cargo Ship; Patrol Vessel; Pipe Layer; Platform; Pollution Control Vessel; Pontoon; Stone Carrier; Work/Repair Vessel	0.000

Table 93: Average Input of Lubricants from Deck-Based Machinery in Port[193]

Deck Machinery Type	Average Input per Port Visit (bbl)
Deck Crane Gears	0.00046
Dredge Pump Shaft Bearings	0.00021
Gear-Driven Mooring Winches	0.00064
Gear-Driven Windlasses	0.00015
Hose-Handling Cranes	0.00004
Hydraulic System Prov Cranes	0.00014
Hydraulic Deck Machinery	0.00124
Hydraulic Windlass Mooring Winches	0.00012
Hydraulic Capstans	0.00019
Hydraulic Cranes	0.00060
Hydraulic Hatch Systems	0.00079
Hydraulic Mooring Winches	0.00069

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[191] Estimates were based on data from 4,708 ports on oil replaced during port maintenance over a five-year period; there were also data on the presence of this machinery on each of the vessel types.

[192] Note that vessels such as barge carriers and inland waterway oil tankers may be consuming larger amounts of stern tube lubricants due to the degree to which the vessels are submerged.

[193] Assumes 10% oil on deck washes into water through deck sweeping, rinsing, or rain runoff.

Table 93: Average Input of Lubricants from Deck-Based Machinery in Port[193]

Deck Machinery Type	Average Input per Port Visit (bbl)
Hydraulic Split Systems	0.00004
Hydraulic System Stern Ramps	0.00017
Miscellaneous Hydraulic Systems	0.00132
Ro-Ro Hydraulic Systems	0.00004
Hydraulic Water-Tight Doors	0.00003
Hydraulic Windlasses	0.00060
Towing Winches	0.00003
Towing Winch Gears	0.00002
Hydraulic Trim Tabs	0.00016
Tugger Winches	0.00006
Total	**0.00775**

Table 94: Average Port Visit Input of Lubricants from Submerged Machinery

Submerged Machinery Type	Average Input per Port Visit (bbl)
Aquamaster–Gears	0.00075
Bow Thruster	0.00692
Bow Thruster Gears	0.00535
CPP System Gears	0.00421
Fin Stabilizer Gear	0.00082
Gears - Azimuth Thrusters	0.00440
Hydraulic Fin Stabilizer	0.00151
Hydraulic Thrusters/ Cpp	0.00717
Hydraulics - Azimuth Thrusters	0.00082
Steering Thrusters	0.00025
Stern Thruster	0.01503
Stern Thruster Gears	0.00132
Thruster Gears	0.00484
Under Water Pump Shaft Bearing	0.00019
Waterjet–Hydraulic	0.00019
Waterjet Gears	0.00019
Total	**0.05397**

This allowed for calculating an estimate of inputs from Hudson River vessel traffic (Table 95). Overall, **at least 1,400 bbl** of lubricants are discharged into the Hudson River annually. There are also inputs from passenger ferries and smaller vessels that are not accounted for in this estimate.

Table 95: Estimated Annual Vessel Operational Oil Inputs into Hudson River

Vessel Type[194]	Annual Port Visits[195]	Per Port-Visit Discharge (bbl)				Annual Input (bbl)
		Stern Tube	Deck Machinery	In-Water Machinery	Total Discharge	
Dry Cargo Ship	3,988	0.113	0.033	0.128	0.274	**1,091**
Dry Cargo Barge	1,443	0.038	0.013	0.065	0.116	**167**
Tanker	32	0.038	0.013	0.065	0.116	**4**
Tank Barge	1,230	0.038	0.013	0.065	0.116	**142**
Total	6,692					**1,404**

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[194] Inputs for barges were calculated to include tow/tugs associated with each barge.

[195] Port visit to the Hudson River is considered one round-trip up and/or down the river.

Summary of Oil Spill Probability for Hudson River

The probabilities of oil spills based on *current conditions* are summarized in Table 96 and Figure 69 by volume. The annual probability of a spill of each volume category is shown in Table 97.

Table 96: Annual Frequency of Oil Spills in Hudson River based on Current Conditions[196]

Spill Volume (bbl)	Vessels			Rail		Facilities	Total
	Tank Vessel	Bunkers	Transfers	CBR	Diesel Fuel		
<1	0.48	3.18	0.86	0	0	0	**4.5**
1–9	0.081	0.39	0.22	0	0.078	0.0069	**0.77**
10–99	0.093	0.17	0.108	0	0.25	0.0026	**0.62**
100–999	0.041	0.18	0.011	0.000001	0.029	0.0012	**0.26**
1,000–9,999	0.024	0.12	0.0011	0.0000029	0	0.00027	**0.14**
10,000– 99,999	0.012	0.031	0.00012	0.00000073	0	0.000028	**0.043**
100,000+	0.0000015	0	0	0	0	0.00000080	**0.000002**
Total	**0.73**	**4.1**	**1.2**	**0.0000046**	**0.35**	**0.011**	**6.36**

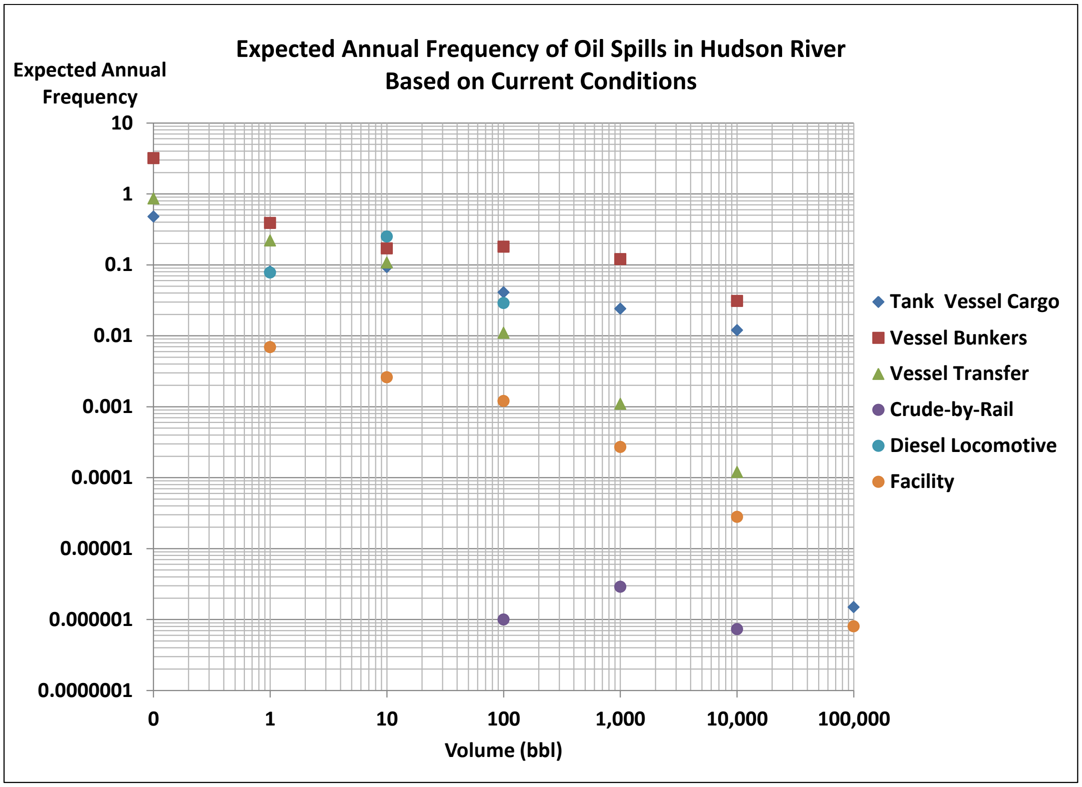

Figure 69: Expected Annual Oil Spill Frequency in Hudson River (Current Conditions)[197]

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[196] Specific probabilities for spills of less than one bbl were not calculated for each category. Minor spills of this volume are possible. For CBR spills, an accident would likely cause at least 100 bbl to spill. There may be minor spills during loading not captured here as loading would not occur on tracks along the river but rather at facilities.

[197] Note logarithmic scales.

Table 97: Annual Probability of Oil Spills in Hudson River based on Current Conditions

Spill Volume (bbl)	Expected Annual Number of Spills by Volume	Annual Probability
<1	4.5	4–5 spills per year
1–9	0.77	1 in 1.3
10–99	0.62	1 in 1.6
100–999	0.26	1 in 4
1,000–9,999	0.14	1 in 7
10,000– 99,999	0.043	1 in 23
100,000+	0.000002	1 in 500,000
Total	**6.36**	**6 spills per year**

The highest probability for spills is attributable to vessels. Increases in vessel traffic and the transport of oil would increase the likelihood of spills. Decreased traffic would decrease the expected frequency (Table 98).

Table 98: Predicted Annual Spill Frequencies based on Vessel Traffic Changes

Vessel Traffic Assumption	Estimated Annual Number of Spills by Volume Category (bbl)							
	<1	1	10	100	1,000	10,000	100,000	Total
Current Traffic	3.66	0.47	0.27	0.22	0.14	0.044	0.0000015	**4.81**
50% Overall Decrease	1.83	0.24	0.13	0.11	0.07	0.022	0.0000007	**2.40**
10% Overall Decrease	3.29	0.43	0.24	0.20	0.13	0.039	0.0000013	**4.32**
50% Decrease Tank Vessels	3.16	0.40	0.20	0.19	0.12	0.035	0.0000007	**4.11**
20% Decrease Tank Vessels	3.46	0.44	0.24	0.21	0.13	0.040	0.0000012	**4.53**
10% Decrease Tank Vessels	3.56	0.46	0.25	0.22	0.14	0.042	0.0000013	**4.67**
10% Increase Tank Vessels	3.75	0.49	0.28	0.23	0.15	0.045	0.0000016	**4.94**
20% Increase Tank Vessels	3.85	0.50	0.29	0.24	0.15	0.047	0.0000018	**5.08**
50% Increase Tank Vessels	4.15	0.55	0.33	0.26	0.17	0.053	0.0000022	**5.50**
10% Overall Increase	4.02	0.52	0.29	0.25	0.16	0.048	0.0000016	**5.29**
100% Increase Tank Vessels	4.64	0.62	0.39	0.29	0.19	0.061	0.0000030	**6.19**
20% Overall Increase	4.39	0.57	0.32	0.27	0.17	0.052	0.0000018	**5.77**
200% Increase Tank Vessels	6.62	0.91	0.63	0.44	0.28	0.097	0.0000059	**8.97**
50% Overall Increase	5.49	0.71	0.40	0.34	0.22	0.066	0.0000022	**7.22**
100% Overall Increase	7.27	0.89	0.51	0.42	0.26	0.085	0.0000080	**9.44**

Mitigation measures to decrease the rate of accidents and spills are presented in the HROSRA Volume 6.

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Appendix A: Synopsis of Vessel Casualty Rate Studies

General Probabilities of Vessel Accidents

As some general background and to provide perspective on vessel accidents, additional data are presented herein for reference. Some studies evaluate the frequencies of accidents without specifically indicating the cause, including events that result in the loss of life or major injury, loss of a ship, material damage to a ship, stranding or collision of a ship, or major environmental damage. A synopsis of findings from these types of studies is shown in Table 99.

Table 99: Review of Study Results on General Vessel Accident Rates

Incident Type	Results	Reference
Severe port Accidents Cherbourg, France Tokai, Japan	Casualty rate per port call: 5×10^{-3} to 7×10^{-3} per ship movement	Yamamoto et al. 1998
Overall UK Port Accidents	Overall in-port accident rate: 1×10^{-3} Commercial vessels: 4×10^{-3} Passenger vessels: 3.3×10^{-4} Fishing vessels: 1.8×10^{-4} Pleasure craft: 1.3×10^{-4} Workboats: 3.2×10^{-4} (only 1% of incidents are "serious") 45% incidents occurred in berthing area 15.7% incidents occurred in harbor approaches 0.5% incidents occurred in anchoring areas	UK Dept. Transport 2010
Overall Accidents for Containerships	Total accidents for containerships: 5.16×10^{-2} per ship year	SAFEDOR 2007
Overall Serious Accidents for Vessels[198]	LNG carrier: 7.8×10^{-3} per year Tanker (double-hull): 8.3×10^{-3} per year Reefer: 1.1×10^{-2} per year Ro-ro/cargo: 1.3×10^{-2} per year Tanker (single-hull): 1.4×10^{-2} per year Offshore supply ship: 1.4×10^{-2} per year Chemical tanker: 1.5×10^{-2} per year Ro-ro passenger: 1.6×10^{-2} per year Bulk carrier: 1.6×10^{-2} per year Container vessel: 1.7×10^{-2} per year LPG carrier: 1.7×10^{-2} per year General cargo vessel: 1.7×10^{-2} per year Car carrier: 2.0×10^{-2} per year Cruise vessel: 4.2×10^{-2} per year Chemical/Oil tanker: 4.4×10^{-2} per year	Nilsen et al. 2005 (Based on Det Norske Veritas 2003)

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[198] A serious accident is defined in this study as: "A breakdown resulting in the ship being towed or requiring assistance from ashore; flooding of any compartment; or structural, mechanical or electrical damage requiring repairs before the ship can continue trading. In this context, serious casualty does not include total loss."

Table 99: Review of Study Results on General Vessel Accident Rates

Incident Type	Results	Reference
Overall Total Loss Accidents for Vessels[199]	LNG carrier: 6.7×10^{-4} per year Tanker (double-hull): 2.7×10^{-4} per year Reefer: 3.2×10^{-3} per year Ro-ro/cargo: 2.0×10^{-3} per year Tanker (single-hull): 5.0×10^{-4} per year Offshore supply ship: 1.4×10^{-3} per year Chemical tanker: 1.8×10^{-3} per year Ro-ro passenger: 1.4×10^{-3} per year Bulk carrier: 3.4×10^{-3} per year Container vessel: 1.2×10^{-3} per year LPG carrier: 2.0×10^{-3} per year General cargo vessel: 5.9×10^{-3} per year Car carrier: 1.8×10^{-3} per year Cruise vessel: 5.3×10^{-3} per year Chemical/Oil tanker: 3.0×10^{-3} per year	Nilsen et al. 2005 (Based on Det Norske Veritas 2003)
Prince Rupert, BC, Canada	Overall accident: 1.09×10^{-2} per year Oil spillage: 1.28×10^{-3} per year Bulk carrier accident: 3.57×10^{-2} per year Containership accident: 3.85×10^{-2} per year Cruise ship accident: 1.56×10^{-2} per year LNG carrier accident: 5.46×10^{-3} per year (without tug escort) Tanker accident: 5.78×10^{-3} per year (without tug escort) LNG carrier accident: 2.81×10^{-3} per year (with tug escort) Tanker accident: 2.97×10^{-3} per year (with tug escort) Tanker accident with spill: 1.28×10^{-3} per year	Det Norske Veritas 2012b
Worldwide	Ship losses in 1995: 3×10^{-3} per ship in world fleet Ship losses in 2000: 1.9×10^{-3} per ship in world fleet	Akten 2006
Strait of Bosporus	Overall accidents: 1.91×10^{-4} per transit	Akten 2006
Tankers in Fraser River, BC, Canada	Overall tanker accidents: 0.17 per year	Det Norske Veritas 2012a
Hong Kong Harbor	Overall accidents: 3.35×10^{-3} per port visit Accidents in channels: 1.01×10^{-4} per port visit Accidents in fairways: 2.01×10^{-4} per port visit Accidents in anchorages: 4.02×10^{-4} per port visit Accidents in other port facilities: 3.35×10^{-4} per port visit Accidents in open water spaces: 1.98×10^{-3} per port visit	Yip 2008
Cook Inlet, Alaska, USA	Tanker incidents: 6.2×10^{-3} per transit-day Tank barge incidents: 4.7×10^{-3} per transit-day Non-tank vessel incidents: 3.4×10^{-3} per transit-day Workboat incidents: 5.0×10^{-4} per transit-day	Etkin 2012; Kirkley and Etkin 2012
West Coast US - Canada	Casualty rate for cargo/freight ships: 5.4×10^{-4} per transit	West Coast Offshore Vessel Traffic Risk Management Project 2002.

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[199] A total-loss accident is defined in this study as: “A total loss is where the ship ceases to exist after a casualty, either due to it being irrecoverable (actual total loss) or due to it being subsequently broken up (constructive total loss). The latter occurs when the cost of repair would exceed the insured value of the ship.”

Table 99: Review of Study Results on General Vessel Accident Rates

Incident Type	Results	Reference
Puget Sound, Washington, USA	All accidents–tankers: 2.26 x 10^{-3} per transit day All accidents–tank barges: 7.68 x 10^{-4} per transit day All accidents–bulk carrier: 5.6 x 10^{-4} per transit day All accidents–cargo ships: 2.171 x 10^{-3} per transit day All accidents–tugs: 9.33 x 10^{-4} per transit day All accidents–passenger and fishing vessels: 1.154 x 10^{-3} per transit day	The Glosten Associates et al. 2013

Rates of encounter-related vessel incidents (vessel-vessel allisions[200] and collisions) have been studied by a number of researchers both on a theoretical basis and with analyses of empirical data for specific port locations or regions. Findings of a number of studies are summarized in Table 100.

Table 100: Review of Study Results on Encounter Incidents

Incident Type	Results	Reference
Collisions in Gulf of Finland	*Any Ship Type* Head-on:0.029 ±0.002 per yr Crossing: 0.180 ±0.014 per yr Overtaking:1.086 ± 0.087 per yr Total: 1.294 ± 0.103 per yr *Tanker Involved* Head-on:0.017 ±0.001 per yr Crossing: 0.101 ± 0.008 per yr Overtaking: 0.919 ± 0.073 per yr Total: 1.037 ± 0.083 per yr *Passenger Vessel Involved* Head-on: 0.011 ±0.001 per yr Crossing: 0.097 ± 0.008 per yr Overtaking: 0.121 ±0.010 per yr Total: 0.228 ± 0.018 per yr *Cargo Vessel Involved* Head-on: 0.015 ± 0.001 per yr Crossing: 0.119 ± 0.009 per yr Overtaking:0.830 ± 0.066 per yr Total: 0.963 ± 0.077 per yr *High-Speed Light Craft Involved* Head-on: 0.001 ± 0.0001 per yr Crossing: 0.005 ± 0.0004 per yr Overtaking: 0.006 ± 0.001 per yr Total: 0.012 ± 0.001 per yr *Other Vessel Involved* Head-on: 0.0002 ± 0.00002 per yr Crossing: 0.006 ± 0.0005 per yr Overtaking:0.025 ± 0.002 per yr Total: 0.031 ± 0.003 per yr Total number of transits = 29, 155	Goerlandt and Kujula 2011
Collisions in UK waters	*Clear Weather Encounters* Head-on: 12 x 10^{-6}/transit Crossing: 6.6 x 10^{-6}/transit Overtaking: 5.7 x 10^{-6}/transit	Lewison 1980

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[200] Allision between vessels when one vessel is stationary at dock or mooring.

Table 100: Review of Study Results on Encounter Incidents

Incident Type	Results	Reference
	Total: 6.9 x 10^{-6}/transit *Mist/Fog Encounters* Head-on: 50 x 10^{-6}/transit Crossing: 20 x 10^{-6}/transit Overtaking: 70 x 10^{-6}/transit Total: 20 x 10^{-6}/transit *Thick/Dense Fog Encounters* Head-on: 290 x 10^{-6}/transit Crossing: 630 x 10^{-6}/transit Overtaking: 350 x 10^{-6}/transit Total: 410 x 10^{-6}/transit	
Collisions	$N_{coll} = N_A P_C$ N_{coll} = number of collisions N_A = number of pairwise encounters during time period P_C = probability of failing to avoid collision course due to technical failure or human error.	Fujii and Shiobara 1971 MacDuff 1974 Motewka et al. 2010
Collision Avoidance Failure Rates (P_C)	*Tanker* Crossing: 5.6 x 10^{-4} Head-on/overtaking: 5.6 x 10^{-4} *Passenger/good visibility* Crossing: 6.83 x 10^{-4} Head-on/overtaking: 4.9 x 10^{-4} *Passenger/poor visibility* Crossing: 4.64 x 10^{-4} Head-on/overtaking: 4.9 x 10^{-4} *Tanker +passenger/good visibility* Crossing: 3.14 x 10^{-4} Head-on/overtaking: 3.05 x 10^{-4} *Tanker +passenger/ poor visibility* Crossing: 5.12 x 10^{-4} Head-on/overtaking: 3.05 x 10^{-4} *All other ships* Crossing: 1.3 x 10^{-4} Head-on/overtaking: 4.9x 10^{-5}	MacDuff 1974 Fowler and Sørgård 2000 Otto et al. 2002 Rosqvist et al. 2002 Reviewed in: Przywarty 2009
Allisions Worldwide	*Oil Tankers* Non-serious incident: 3.5 x 10^{-4}/ship year Serous incident: 6.0 x 10^{-4}/ship year Total loss: 4.0 x 10^{-5}/ship year	Det Norske Veritas 2011b
Collisions Worldwide	*Oil tankers* Non-serious collision: 1.3 x 10^{-3}/ship year Serous collision: 3.0 x 10^{-3}/ship year Total loss: 9.4 x 10^{-5}/ship year *Chemical tankers* Non-serious collision: 1.4 x 10^{-3}/ship year Serous collision: 3.4 x 10^{-3}/ship year Total loss: 1.6 x 10^{-4}/ship year *Bulk carriers* Non-serious collision: 1.6 x 10^{-3}/ship year Serous collision: 4.3 x 10^{-3}/ship year Total loss: 2.0 x 10^{-4}/ship year *General cargo ships* Non-serious collision: 1.4 x 10^{-3}/ship year	Det Norske Veritas 2011b

Table 100: Review of Study Results on Encounter Incidents

Incident Type	Results	Reference
	Serous collision: 4.7×10^{-3}/ship year Total loss: 6.3×10^{-4}/ship year *Containerships* Non-serious collision: 2.1×10^{-3}/ship year Serous collision: 7.1×10^{-3}/ship year Total loss: 5.1×10^{-5}/ship year *Fishing vessels* Non-serious collision: 1.4×10^{-4}/ship year Serous collision: 3.7×10^{-4}/ship year Total loss: 1.0×10^{-4}/ship year *Other ships* Non-serious collision: 4.8×10^{-4}/ship year Serous collision: 1.4×10^{-3}/ship year Total loss: 7.6×10^{-5}/ship year *All ships* Non-serious collision: 7.9×10^{-4}/ship year Serous collision: 2.3×10^{-3}/ship year Total loss: 1.9×10^{-4}/ship year	
Modification Factors for Collision Frequency	Collision frequency/hr = average collision frequency per hour x MF_{traf} MF_{traf} = traffic density (per million km^2)/270 MF_{traf} = port visits per year/430 Modification Factors *Approach type:* $M_{width} = 4.2$ for narrow rivers (<0.5 km) $M_{width} = 1.0$ for wide rivers (0.5–2.5 km) $M_{width} = 0.3$ for wide estuaries (>2.5 km) $M_{width} = 4.2$ for open sea ports *Visibility:* Frequency collision (bad visibility) = 6.9 x frequency collision (good visibility) If bad visibility applies for 2% of time, modification factor is: Collision frequency/ hour = Average collision frequency per hour x MF_{vis} MF_{vis} = 5.3 x Probability of bad visibility + 0.9 *Risk Reduction Measures:* Vessel traffic services: $MF_{VTS} = 0.16$ Traffic separation scheme: $MF_{STS} = 0.40$ Compulsory pilotage: $MF_{pilot} = 0.51$ Non-compulsory pilotage: $MF_{pilot} = 2.0$	Lewison 1980 Det Norske Veritas 2011b Det Norske Veritas 1999
Collisions in Australia	Frequency of *spills* from collisions = 0.224/year Frequency of *spills* from allisions = 0.054/year	Det Norske Veritas 2011a
Collisions (Model)	Probability of head-on collision = 4.9×10^{-5}/transit Probability of bend collision = 1.3×10^{-4}/transit Probability of crossing collision = 1.3×10^{-4}/transit	Fujii et al. 1984 Friis-Hansen et al. 2008.
Collisions in Dover Strait (UK)	Probability head-on collision = 5.18×10^{-4} per transit w/o traffic separation Probability head-on collision = 3.15×10^{-4} per transit w/traffic separation Probability crossing collision = 1.11×10^{-4} per transit w/o traffic separation Probability crossing collision = 0.95×10^{-4} per transit w/traffic separation	MacDuff 1974 Reviewed in: Przywarty 2009
Collisions in Japanese	Probability of head-on collision = 0.49×10^{-4} per transit Probability of crossing collision = 1.23×10^{-4} per transit	Fujii and Mizuki 1998

Table 100: Review of Study Results on Encounter Incidents

Incident Type	Results	Reference
Straits	Probability of overtaking collision = 1.10 x 10^{-4} per transit	
Collisions in Strait of Gibraltar	Probability of collision = 1.2 x 10^{-4} per transit	Friis-Hansen et al. 2008
Collisions in Øresund, Denmark	Probability of head-on collision = 0.27 x 10^{-4} per transit	Karlson et al. 1998
Collisions in Great Belt, Denmark	Probability of bend collision = 1.3 x 10^{-4}/transit	Pedersen et al. 1995
Collisions Model (GRISK)	Probability of head-on collision = 0.5 x 10^{-4} per transit Probability of overtaking collision = 1.1 x 10^{-4} per transit Probability of crossing collision = 1.3 x 10^{-4} per transit Probability of merging collision = 1.3 x 10^{-4} per transit	Friis-Hansen et al. 2008
Cabrillo Port, California Model	*Merchant vessels in coastal traffic lanes:* Probability powered collision = 8.1 x 10^{-6} per year Probability drifting collision = 3.0 x 10^{-3} per year Probability total collision = 3.6 x 10^{-3} per year *Commercial vessels calling at Port Hueneme:* Probability powered collision = 8.2 x 10^{-9} per year Probability drifting collision = 1.8 x 10^{-4} per year Probability total collision = 1.8 x 10^{-4} per year *Crude tankers in Point Mugu Sea Range:* Probability powered collision = 8.0 x 10^{-9} per year Probability drifting collision = 1.4 x 10^{-4} per year Probability total collision = 1.4 x 10^{-4} per year *Navy vessels operating in Point Mugu Sea Range:* Probability powered collision = 0 per year Probability drifting collision = 1.5 x 10^{-4} per year Probability total collision = 1.5 x 10^{-4} per year *LNG carriers calling at Cabrillo Port:* Probability powered collision = 0 per year Probability drifting collision = 2.0 x 10^{-5} per year Probability total collision = 2.0 x 10^{-5} per year *Supply vessels operating near Cabrillo Port:* Probability powered collision = 0 per year Probability drifting collision = 2.0 x 10^{-5} per year Probability total collision = 2.0 x 10^{-5} per year *Fishing vessels:* Probability powered collision = 0 per year Probability drifting collision = 3.0 x 10^{-1} per year Probability total collision = 3.0 x 10^{-1} per year	Risknology 2006
Overall Collisions for Containerships	Collisions for containerships: 1.61 x 10^{-2} per ship year Allision (contact) incidents: 3.65 x 10^{-3} per ship year	SAFEDOR 2007
Collisions Strait of Istanbul	Collisions due to human error: 2.94 x 10^{-4} per transit Collisions due to steering failure: 8.72 x 10^{-6} per transit	Ulusçu et al. 2008
Allisions Strait of Istanbul	Allisions due to human error: 1.53 x 10^{-4} per transit Allisions due to steering failure: 2.62 x 10^{-5} per transit Allisions due to propulsion failure: 2.38 x 10^{-5} per transit	Ulusçu et al. 2008

Table 100: Review of Study Results on Encounter Incidents

Incident Type	Results	Reference
Collisions Strait of Bosporus	Collisions: 8.68 x 10^{-5} per transit	Akten 2006
Tankers in Fraser River, BC, Canada	Tanker collisions: 6.6 x 10^{-3} per year	Det Norske Veritas 2012a
Hong Kong Harbor	Collisions in channels: 5.43 x 10^{-5} per port visit Collisions in fairways: 1.81 x 10^{-4} per port visit Collisions in anchorages: 3.62 x 10^{-4} per port visit Collisions in typhoon shelters: 1.63 x 10^{-4} per port visit Collisions in other port facilities: 1.81 x 10^{-4} per port visit Collisions in open water spaces: 8.69 x 10^{-4} per port visit	Yip 2008
Collisions and Allisions in Nantucket Sound, Massachusetts, USA	Modeled accident rates for proposed offshore wind energy farm: Allisions by cargo ships: 5.07 x 10^{-3} per transit Allisions by tankers: 4.3 x 10^{-4} per transit Allisions by tow/tug boats: 7.6 x 10^{-4} per transit Allisions by ferries: 3.8 x 10^{-4} per transit Allisions by dry cargo barges: 1.28 x 10^{-3} per transit Collisions by all vessel types: 4.3 x 10^{-4} per year	Etkin 2006, 2008
Worldwide	Sea-going merchant ships total-loss collisions: 3.6 x 10^{-4} per ship year	OGP 2010
Baltic Sea	Collisions: 1.03 x 10^{-4} per transit (for years 2004–2011)	Helsinki Commission 2012
Puget Sound, Washington, USA	Collisions underway–tankers: 1.01 x 10^{-4} per transit day Collisions underway–tank barges: 1.71 x 10^{-4} per transit day Collisions maneuvering–tank barges: 9.12 x 10^{-4} per transit day Collisions underway–bulk carriers: 4.14 x 10^{-5} per transit day Collisions underway–passenger/fishing: 5.34 x 10^{-5} per transit day Allisions maneuvering–tank barges: 4.56 x 10^{-4} per transit day Allisions underway–bulk carriers: 4.14 x 10^{-5} per transit day Allisions maneuvering–cargo ships: 2.04 x 10^{-2} per transit day Allisions underway–tugs: 2.70 x 10^{-5} per transit day Allisions maneuvering–tugs: 1.48 x 10^{-3} per transit day Allisions underway–passenger/fishing: 5.34 x 10^{-5} per transit day Allisions maneuvering–passenger/fishing: 1.40 x 10^{-3} per transit day	The Glosten Associates et al. 2013

Probabilities of Grounding Incidents

Rates of groundings have been studied by a number of researchers both on a theoretical basis and with analyses of empirical data for specific port locations or regions. Findings of a number of studies are summarized in Table 101.

Table 101: Review of Study Results on Grounding Incidents

Incident Type	Results	Reference
Groundings Worldwide	*Oil tankers* Non-serious Grounding: 8.2 x 10^{-4}/ship year Serous Grounding: 2.6 x 10^{-3}/ship year Total loss: 3.6 x 10^{-4}/ship year *Chemical tankers* Non-serious Grounding: 1.0 x 10^{-3}/ship year Serous Grounding: 2.9 x 10^{-3}/ship year	Det Norske Veritas 2011b

Table 101: Review of Study Results on Grounding Incidents

Incident Type	Results	Reference
	Total loss: 8.0×10^{-5}/ship year *Bulk carriers* Non-serious Grounding: 1.6×10^{-3}/ship year Serous Grounding: 4.3×10^{-3}/ship year Total loss: 2.0×10^{-4}/ship year *General cargo ships* Non-serious Grounding: 1.0×10^{-3}/ship year Serous Grounding: 5.4×10^{-3}/ship year Total loss: 4.2×10^{-4}/ship year *Containerships* Non-serious Grounding: 4.8×10^{-4}/ship year Serous Grounding: 4.5×10^{-3}/ship year Total loss: 2.0×10^{-4}/ship year *Fishing vessels* Non-serious Grounding: 6.3×10^{-5}/ship year Serous Grounding: 6.9×10^{-4}/ship year Total loss: 2.1×10^{-4}/ship year *Other ships* Non-serious Grounding: 2.4×10^{-4}/ship year Serous Grounding: 1.5×10^{-3}/ship year Total loss: 1.8×10^{-4}/ship year *All ships* Non-serious Grounding: 4.2×10^{-4}/ship year Serous Grounding: 2.5×10^{-3}/ship year Total loss: 3.4×10^{-4}/ship year	
Drift Grounding	Frequency of drift grounding (F_{ground}) Frequency of engine/steering breakdown ($F_{breakdown}$) = 2×10^{-4}/ship hour Probability drift direction towards shore (P_{shore})–based on wind Probability failure to self-repair (P_{repair}) Probability failure to halt drifting using anchors (P_{anchor}) Probability failure emergency towing (P_{tow}) $F_{ground} = F_{breakdown} \cdot P_{onshore} \left(1 - PS_{repair}\right) \cdot \left(1 - PS_{anchor}\right) \cdot \left(1 - PS_{tow}\right)$ The available time to stop the drift before grounding (T_{ground}) depends on the distance offshore (D_{zone}), the component of wind velocity in shore direction (V_{wind}) if positive, and ship drift velocity as fraction of wind velocity (RV_{drift}) so that: $T_{ground} = \dfrac{D_{zone}}{V_{wind} \cdot RV_{drift}}$ D_{zone} = 6 nm (nearshore) D_{zone} = 30 nm (intermediate) D_{zone} = 120 nm (deep sea) $PS_{repair} = 1 - 10^{-01 T_{ground}}$ for T_{ground} in hours *Effects of Risk Reduction Measures (Powered Grounding)* Vessel traffic services $MF_{VTS} = 0.80$ Traffic separation scheme $MF_{STS} = 1.00$ (i.e. no effect)	Det Norske Veritas 1996, 1999, 2011.

Table 101: Review of Study Results on Grounding Incidents

Incident Type	Results	Reference
	Compulsory pilotage MF_{pilot} = 0.51 *Effect of Approach Type* Narrow rivers (under 0.5 km mean width) MF_{width} = 6.3 Wide rivers (0.5 to 2.5 km mean width) MF_{width} = 1.0 Wide estuaries (over 2.5 km mean width) MF_{width} = 0.5 Open sea ports (lock/breakwater approach) MF_{width} = 4.1 *Effect of Distance Offshore* Near-shore (up to 12 nm offshore) MF_{zone} = 3 for trading ships MF_{zone} = 1.1 for smaller vessels Intermediate waters (12-50 nm offshore) MF_{zone} = 0 Deep sea (50-200nm offshore) MF_{zone} = 0	
Groundings in Australia	Frequency of powered groundings that result in spill: 0.369/year Frequency of drift groundings that result in spill: 0.416/year	Det Norske Veritas 2011a
Groundings in Japanese Straits	Probability of grounding = 1.58 x 10^{-4} per transit	Fujii and Mizuki 1998
Groundings in Dover Strait (UK)	Probability of grounding = 1.55 x 10^{-4} per transit without traffic separation Probability of grounding = 1.41 x 10^{-4} per transit with traffic separation	MacDuff 1974
Groundings in Strait of Gibraltar	Probability of grounding = 2.2 x 10^{-4} per transit	Friis-Hansen et al. 2008
Groundings in Øresund, Denmark	Probability of grounding = 2.0 x 10^{-4} per transit	Karlson et al. 1998
Grounding Model (GRISK)	Probability of grounding = 1.6 x 10^{-4} per transit	Friis-Hansen et al. 2008
Containership Groundings	Groundings for containerships: 6.84 x 10^{-3} per ship year	SAFEDOR 2007
Groundings Strait of Istanbul	Groundings due to human error: 1.67 x 10^{-4} per transit Groundings due to steering failure: 3.84 x 10^{-5} per transit Groundings due to propulsion failure: 1.92 x 10^{-5} per transit	Ulusçu et al. 2008
Groundings Strait of Bosporus	Groundings/strandings: 8.92 x 10^{-5} per transit	Akten 2006
Tankers in Fraser River, BC, Canada	Tanker powered groundings: 3.4 x 10^{-2} per year Tanker drift groundings: 1.6 x 10^{-2} per year	Det Norske Veritas 2012a
Worldwide	Sea-going merchant ships total-loss groundings: 5.4 x 10^{-4} per ship year	OGP 2010
Baltic Sea	Groundings: 1.19 x 10^{-4} per transit (for years 2004–2011)	Helsinki Commission 2012
Puget Sound, Washington, USA	Groundings underway–tankers: 2.02 x 10^{-4} per transit day Groundings underway–tugs: 5.41 x 10^{-5} per transit day Groundings underway–passenger/fishing: 5.88 x 10^{-4} per transit day	The Glosten Associates et al. 2013

Probabilities of Other Incidents

Rates of other vessel incidents with spillage potential have been studied by a number of researchers both on a theoretical basis and with analyses of empirical data for specific port locations or regions. Findings of a number of studies are summarized in Table 102.

Table 102: Review of Study Results on Other Incidents

Incident Type	Results	Reference
Fire/Explosion	*Oil tankers* Non-serious fire/exp: 2.8 x 10^{-4}/ship year Serous fire/exp: 1.2 x 10^{-3}/ship year Total loss: 3.2 x 10^{-4}/ship year *Chemical tankers* Non-serious fire/exp: 1.6 x 10^{-4}/ship year Serous fire/exp: 1.1 x 10^{-3}/ship year Total loss: 1.6 x 10^{-4}/ship year *Bulk carriers* Non-serious fire/exp: 2.4 x 10^{-4}/ship year Serous fire/exp: 1.2 x 10^{-3}/ship year Total loss: 1.3 x 10^{-4}/ship year *General cargo ships* Non-serious fire/exp: 1.9 x 10^{-4}/ship year Serous fire/exp: 1.5 x 10^{-3}/ship year Total loss: 3.3 x 10^{-4}/ship year *Containerships* Non-serious fire/exp: 2.5 x 10^{-4}/ship year Serous fire/exp: 2.0 x 10^{-3}/ship year Total loss: 1.4 x 10^{-4}/ship year *Fishing vessels* Non-serious fire/exp: 4.1 x 10^{-5}/ship year Serous fire/exp: 6.9 x 10^{-4}/ship year Total loss: 3.2 x 10^{-4}/ship year *Other ships* Non-serious fire/exp: 1.5 x 10^{-4}/ship year Serous fire/exp: 1.1 x 10^{-3}/ship year Total loss: 2.2 x 10^{-4}/ship year *All ships* Non-serious fire/exp: 1.5 x 10^{-4}/ship year Serous fire/exp: 1.1 x 10^{-3}/ship year Total loss: 2.6 x 10^{-4}/ship year	Det Norske Veritas 2011b
Transfer Errors	*Spills per cargo transfer* Crude oil: 1.9 x 10^{-4} Other petroleum: 1.8 x 10^{-4} Chemicals (low flash): 1.5 x 10^{-4} Liquefied gas: 7.6 x 10^{-5}	Det Norske Veritas 2011b
Other Incidents Australia	Frequency of fire/explosions that result in spill: 0.137/year Frequency of hull damage incidents that result in spill: 0.236/year Frequency of transfer errors that result in spill: 0.384/year Frequency of unauthorized discharges: 0.111/year	Det Norske Veritas 2011a
Fire/Explosion	Fire/explosions: 3.1 x 10^{-4} /ship year (Lloyds data) Fire/explosions: 1.4 x 10^{-2}/ship year (UK MAIB data) Fire/explosions: 11 x 10^{-4}/ship year (Bureau Veritas data on general cargo, container, and ro-ro/passenger ships)	Schneider et al. 1999
Fire/Explosion on Nord Pas-de-Calais, France	Fire/explosions: 2.9 x 10^{-4} /ship year (Lloyds data) Severe fire/explosions: 7 x 10^{-3} /ship year (Lloyds data)	Selway et al. 1999
Fire/Explosion	Fire/explosions: 9.6 x 10^{-8} /nautical mile sailed (Lloyds data) Fire/explosions: 5.4 x 10^{-5} /port call (Lloyds data)	Ammerman et al. 1988

Table 102: Review of Study Results on Other Incidents

Incident Type	Results	Reference
Other Incidents Containerships	Fire/explosions for containerships: 3.55 x 10^{-3} per ship year Machinery damage for containerships: 1.29 x 10^{-2} per ship year Hull damage for containerships: 1.27 x 10^{-3} per ship year Foundering for containerships: 6.52 x 10^{-5} per ship year Other incidents for containerships:7.24 x 10^{-3} per ship year	SAFEDOR 2007
Fire/Explosion Strait of Istanbul	Fire/explosions due to human error: 6.38 x 10^{-5} per transit Fire/explosions due to mechanical/electrical: 7.98 x 10^{-5} per transit	Ulusçu et al. 2008
Tankers in Fraser River, BC, Canada	Tanker structural failures/founderings: 2.0 x 10^{-5} per year Tanker fire/explosions: 5.0 x 10^{-5} per year	Det Norske Veritas 2012a
Containership Container Incidents in Felixstowe, UK	*Cargo damaging accident rates during handling of containers in port:* Cargo accidents per lift (transfer): 1.3 x 10^{-6} per year Probability of breach of containment: 1 x 10^{-2} per year Chance of hazardous cargo release: 3.21 x 10^{-5} per year Cargo-damaging fire at berth: 9.5 x 10^{-6} per year	Clark 2003
Transfer Errors in California and Washington	Washington state: 4.0 x 10^{-4} transfer error spills/transfer (pre-regulation) Washington state: 2.6 x 10^{-4} transfer error spills/transfer (post-regulation) California: 4.6 x 10^{-3} transfer error spills/transfer (post-regulation)	Etkin 2006
Worldwide Tanker Fire/Explosion	Oil tanker fire/explosion total losses: 7.2 x 10^{-4} per ship year Oil tanker fire/explosion serious casualties: 2.6 x 10^{-3} per ship year	OGP 2010
Worldwide	Probability of human error in vessel transit: 2.0 x 10^{-4} per transit (Duration of error: 20 minutes) Probability of steering failure: 6.3 X 10^{-5} per hour Probability of propulsion failure: 1.5 X 10^{-4} per hour (Anchoring probability: 0.7)	Christensen et al. 2001; Fujii 1983; Macduff 1974; Pedersen 1995; Karlsson 1995.
United States	Probability of steering failure: 2.9 X 10^{-5} per hour Probability of propulsion failure: 5.5 X 10^{-5} per hour	The Glosten Associates et al. 2004
Puget Sound, Washington, USA	Other non-impact underway–tankers: 2.82 x 10^{-3} per transit day Other non-impact maneuvering–tankers: 5.06 x 10^{-3} per transit day Other non-impact anchored–tankers: 1.79 x 10^{-4} per transit day Other non-impact docked–tankers: 1.70 x 10^{-3} per transit day Other non-impact underway–tank barges: 4.26 x 10^{-4} per transit day Other non-impact maneuvering–tank barges: 4.56 x 10^{-4} per transit day Other non-impact anchored–tank barges: 1.24 x 10^{-4} per transit day Other non-impact docked–tank barges: 1.70 x 10^{-3} per transit day Other non-impact underway–bulk carriers: 1.24 x 10^{-4} per transit day Other non-impact anchored–bulk carriers: 1.62 x 10^{-3} per transit day Other non-impact docked–bulk carriers: 2.09 x 10^{-3} per transit day Other non-impact underway–cargo ships: 1.68 x 10^{-3} per transit day Other non-impact maneuvering–cargo ships: 1.02 x 10^{-1} per transit day Other non-impact anchored–cargo ships: 5.06 x 10^{-3} per transit day Other non-impact docked–cargo ships: 3.08 x 10^{-3} per transit day Other non-impact underway–tugs: 1.38 x 10^{-3} per transit day Other non-impact maneuvering–tugs: 2.23 x 10^{-3} per transit day Other non-impact anchored–tugs: 9.70 x 10^{-5} per transit day Other non-impact docked–tugs: 4.56 x 10^{-4} per transit day	The Glosten Associates et al. 2013

Table 102: Review of Study Results on Other Incidents

Incident Type	Results	Reference
	Other non-impact underway–pass/fishing: 2.83×10^{-3} per transit day Other non-impact maneuvering–pass/fishing: 1.60×10^{-1} per transit day Other non-impact docked–pass/fishing: 4.56×10^{-4} per transit day Bunker error docked–tankers: 8.49×10^{-5} per transit day Bunker error docked–tank barges: 1.78×10^{-4} per transit day Bunker error docked–bulk carriers: 1.04×10^{-3} per transit day Bunker error anchored–cargo ships: 2.53×10^{-3} per transit day Bunker error docked–cargo ships: 1.03×10^{-3} per transit day Bunker error anchored–tugs: 9.70×10^{-5} per transit day Bunker error docked–tugs: 4.27×10^{-4} per transit day Bunker error docked–pass/fishing: 2.27×10^{-4} per transit day Transfer error anchored–tankers: 1.79×10^{-4} per transit day Transfer error docked–tankers: 1.95×10^{-3} per transit day Transfer error docked–tank barges: 5.33×10^{-4} per transit day	

Vessel Density Approach to Collision Probability

Another approach to collision probability is based on the concept that vessel density (the number of vessels in a given area) is the driving factor, since vessel density affects the potential encounter rate. This approach is useful for determining the increase in likelihood of collisions with increases in overall vessel traffic.

Based on an analysis conducted on vessel collisions and vessel density in the Puget Sound, the following relationship between vessel density and expected collisions was developed:

$$CR_d = 0.00003d^{1.19}$$

Where: d = vessel density (number of vessels per square mile)
CR_d = collision rate (expected collisions per vessel transit) at vessel density, d.

The increase in vessel collisions with the future increase in vessel transits (and thus vessel density) can be calculated by changing the d value in the equation and comparing the baseline year with the future year. If the expected increase in vessel traffic is known or estimated to be a certain percentage (e.g., 10% increase per year or a 65% increase over 10 years), the increase can be applied as in:

$$CR_{yr_0} = 0.00003d_{yr_0}^{1.19}$$

$$d_{yr_n} = d_{yr_0} + T_{increase}n$$

$$CR_{yr_n} = 0.00003 \cdot (d_{yr_0} + T_{increase}n)^{1.19}$$

$$\Delta CR_n = CR_{yr_n} - CR_{yr_0}$$

Where: CR_{yr0} = collision rate at year 0 (base year)
CR_{yrn} = collision rate at year n
d_{yr0} = vessel density at base year
yr = year

n = number of years from base year

$T_{increase}$ = annual increase in vessel transits per year

The relationship between vessel density and collision rate can be seen in Figure 70.

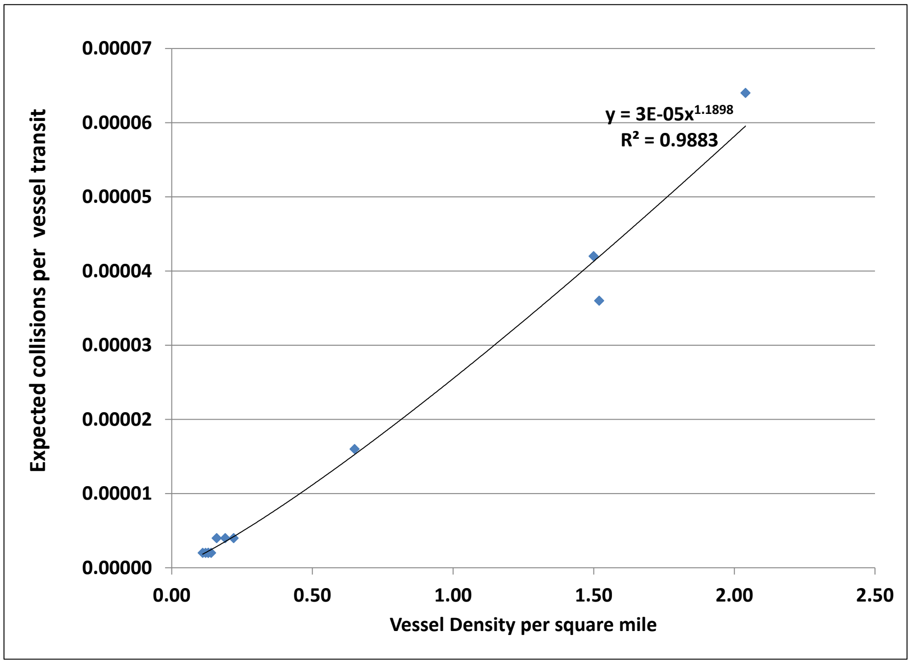

Figure 70: Expected Collisions by Vessel Density[201]

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[201] Equation developed from data on vessel density and collision rates extrapolated from Judson 1992.

Appendix B: Hudson River Navigational Issues Associated with Ice

Regulations on Ice Operations

The regulations with regard to operations under ice conditions on the Hudson River fall under 33 CFR Part 165. These regulations include:

- Vessels less than 3,000 horsepower while engaged in towing operations are not authorized to transit that portion of the Hudson River south of the Troy Locks when ice thickness on average is eight inches or greater.[202]
- Restrictions may be imposed on Hudson River transits during heavy ice conditions requiring an assist tug whenever the sum total length in feet of the tug and barge multiplied by six (6) is greater than the shaft horsepower of the tug pushing the barge.[203]

Under ice conditions, vessels that are northbound from the New York Harbor must use VTS and report all planned destinations, cargo and quantity to the Sector New York Command Center. Likewise, any southbound vessels departing Albany or any northern port must report the same.

The COTP New York will notify mariners of the location and thickness of the ice as well as any restrictions via marine broadcast, Local Notices to Mariners, and VTS New York. For the purpose of this rule, the definition of horsepower in 46 CFR 10.107 applies. When the ice thickness reaches an average of eight inches or greater on the Hudson River along reported routes, vessels of less than 3,000 HP engaged in towing operations would not be authorized to transit unless in conjunction with scheduled Coast Guard icebreaking operations in the area, or operating with an assist tug or as part of a convoy, or specifically authorized by the COTP New York.

Operators of vessels that do not meet the criteria of the operating restrictions, but who believe that they have the capability to operate in ice safely, may seek a waiver from the COTP New York to continue operating. Waivers may be requested by calling telephone number (718) 354–4356 or on VHF channel 13 or 16.

Ice Passing Zones

To provide safer meeting and passing conditions during periods of heavy ice which requires a "track" the Hudson River Pilots, in coordination with the USCG and tug/barge companies, have developed new navigation and vessel communication strategies for the Upper Hudson River. Foremost among these strategies is the creation of 6 areas (meeting zones) where the USCG has committed to breaking ice within each zone to the full width of the channel limits. The ice passing zones are shown in Figure 71 through Figure 78. Use of these meeting/passing zones is strictly voluntary and subject to the judgement of the vessel operators.

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[202] https://homeport.uscg.mil/cgi-bin/st/portal/uscg_docs/MyCG/Editorial/20140204/Ice%20Season%20RNA.pdf?id=8f4f22eeff76bfef9228b62ea0c5b89fd7279a4b&user_id=c8dca2ec360fd10a0f793a98556f886a

[203] *Coast Guard Sector New York Ice Season Fact Sheet*.

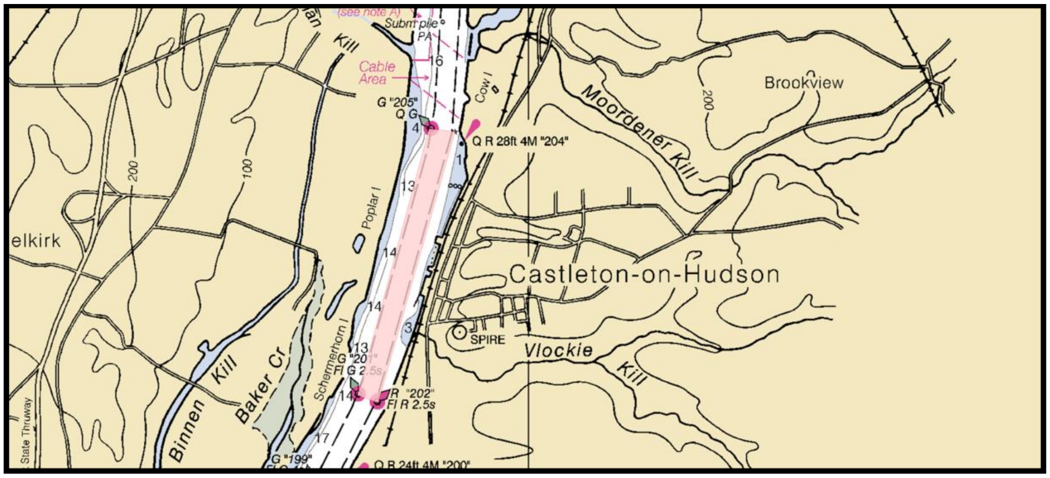

Figure 71: Castleton Ice Passing Zone

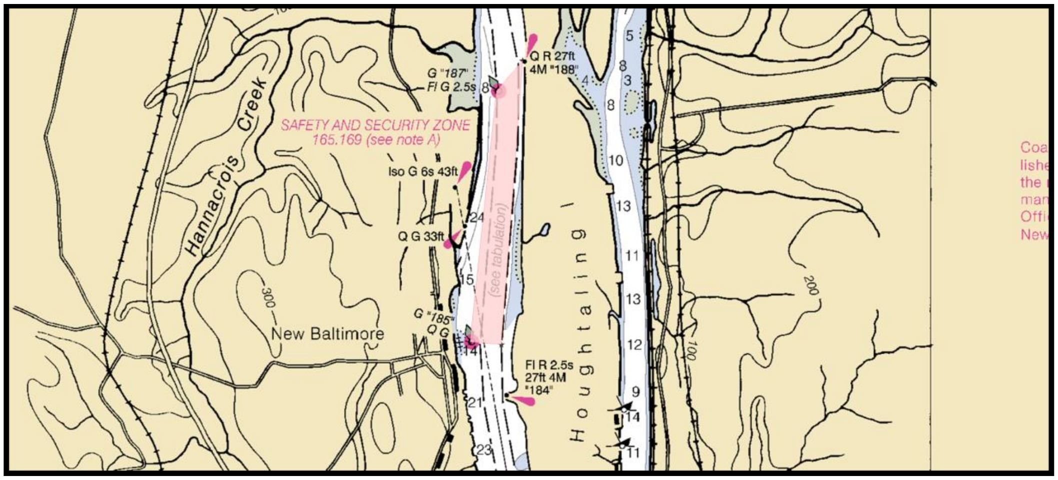

Figure 72: New Baltimore Ice Passing Zone

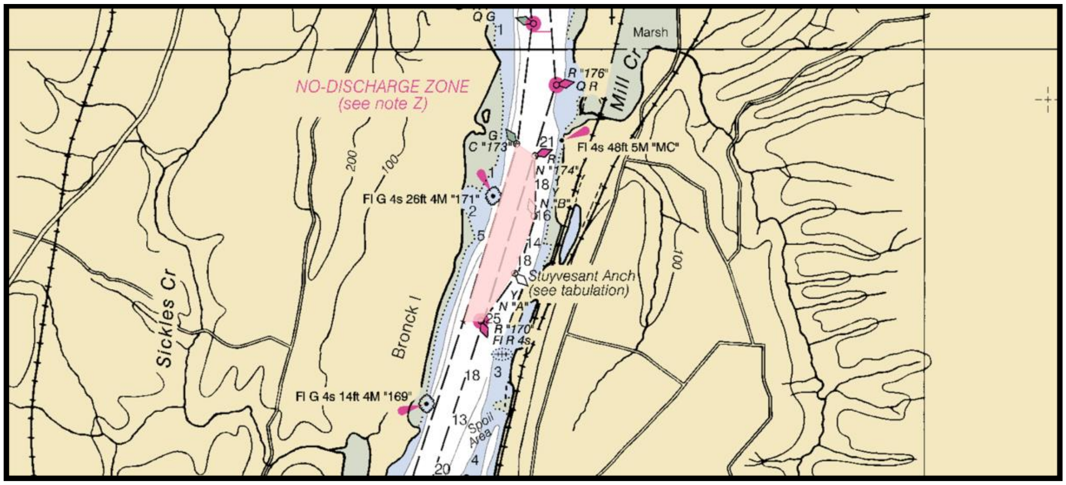

Figure 73: Stuyvesant Anchorage Ice Passing Zone

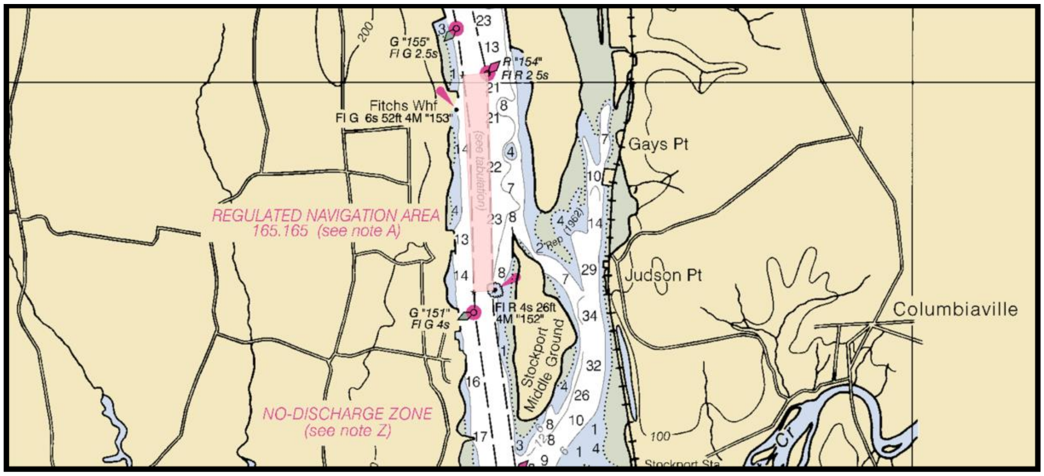

Figure 74: Middle Ground Ice Passing Zone

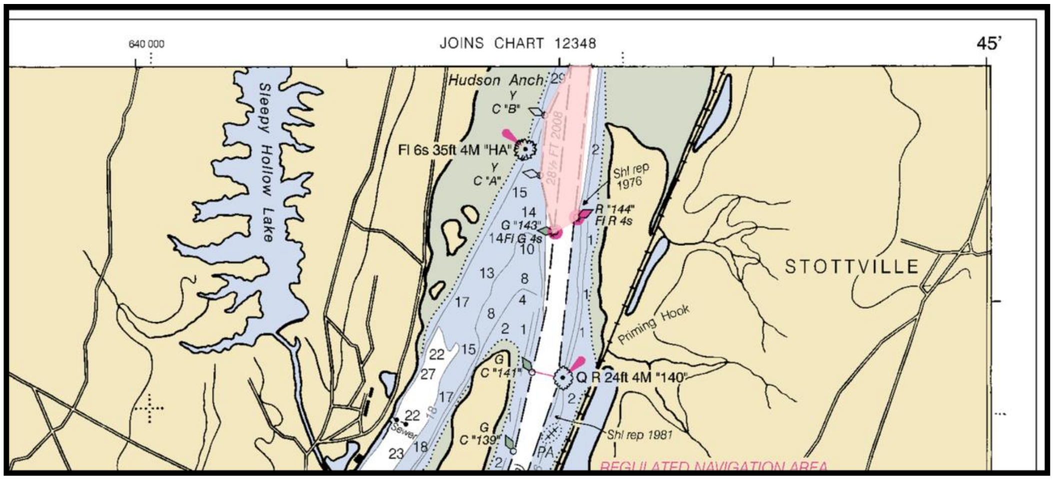

Figure 75: Hudson Anchorage Ice Passing Zone

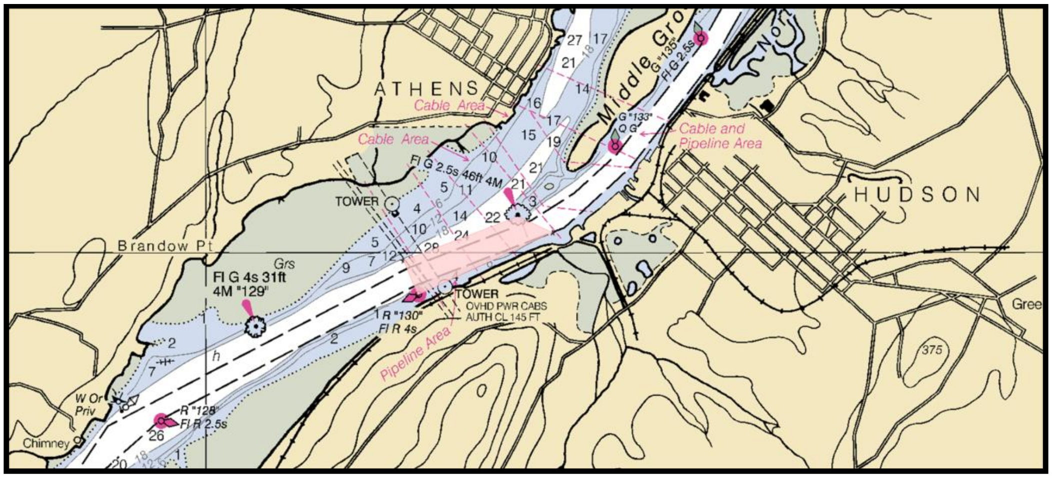

Figure 76: Hudson Light Ice Passing Zone

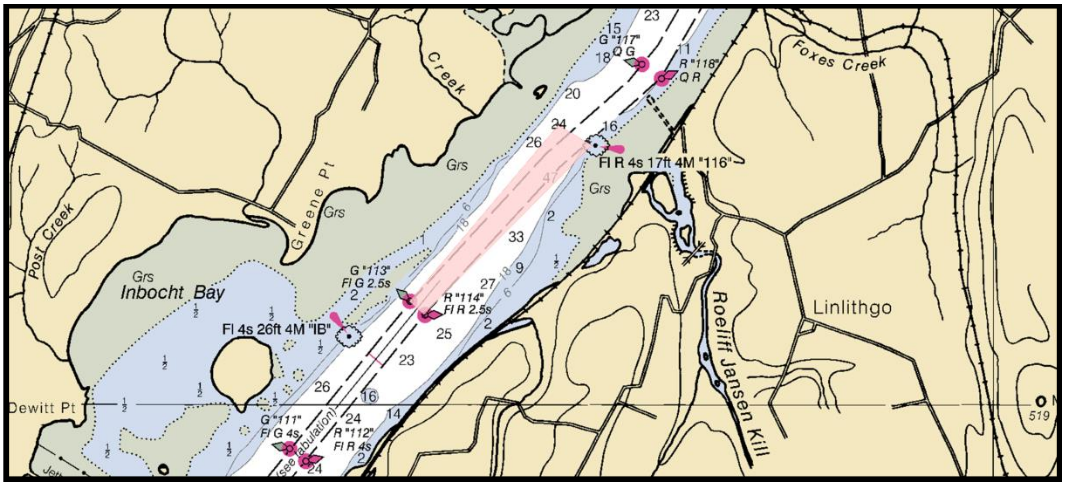

Figure 77: Germantown Ice Passing Zone

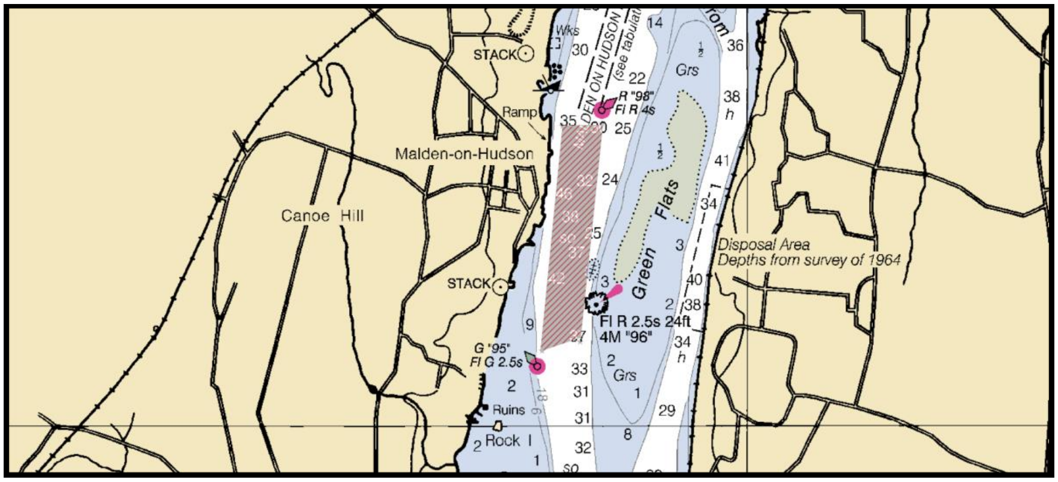

Figure 78: Malden-on-Hudson Ice Passing Zone

USCG Icebreaking Operations

The USCG will conduct icebreaking operations for a variety of prioritized reasons:

- **Ports, Waterways, and Coastal Security (PWCS):** Icebreaking operations may be required to facilitate security operations;
- **Search and Rescue (SAR):** When loss of life on the water or ashore is a possible outcome, the USCG will conduct icebreaking required for SAR response;
- **Urgent Response to Vessels:** The USCG will respond to vessels in urgent situations which, if left unassisted, have a high probability of deteriorating into a hazardous situation (e.g., assistance to an ice-bound vessel in danger of drifting, grounding or becoming trapped in an ice field under pressure and at risk of suffering a hull breach);
- **Exigent Community Services:** The USCG will provide icebreaking assistance to prevent floods

- hazardous water stages caused by ice obstructions and assist remote communities, especially ice-bound communities that have need for fuel, food, and medical supplies;[204]
- **Facilitation of Navigation:** The USCG will conduct ice-breaking operations in ice-covered waterways as resources permit to extricate vessels from danger, mitigate hazardous situations, assist shipping, and other reasons determined by the District Commanders; and
- **Research and Development and Science Missions.**

USCG District 1 has specified the following expectations and goals for icebreaking:[205]

- Facilitate deliveries to energy terminals within 24 hours of scheduled delivery (goal: 100%);
- Passenger and cargo ferry service stoppages to isolated communities should not exceed two days per event where that population is totally dependent on the ferry for services to the community (goal: 100%);
- Respond to all requests from vessels beset in ice to arrive on scene to assist within six hours of notification or at first light (goal: 95%); and
- Commence relief of ice jams within 24 hours of notification by the Army Corps of Engineers (goal: 100%).

During the 2015-2017 ice seasons, the USCG District 1 reported 16 auxiliary overflights related to ice monitoring and 1,327 hours (over 55 continuous days) of USCG Cutter icebreaking. There were no reported SAR assists, ship or facility breakouts, or ship escorts required. The USCG District 1 maintains the icebreaking vessels shown in Table 103.

Table 103: USCG District 1 Icebreaking Assets

Vessel Type	Vessel Name	Homeport	Maximum Speed	Draft	Icebreaking Capability
65’ WYTL Small Harbor Tugs	Line	Bayonne, NJ	10 kts	6.6 ft	12 inches; Thicker ice requires backing and ramming
	Hawser	Bayonne, NJ			
	Wire	Saugerties, NY			
140’ WTGB Icebreaker Tugs	Sturgeon Bay	Bayonne, NJ	14 kts	12 ft	27 inches; Using bubble system, effective loosening brash and opening large tracks
	Penobscot Bay	Bayonne, NJ			
	Thunder Bay	Rockland, ME			
225’ WLB Juniper Class Buoy Tender	Juniper	Newport, RI	16 kts	13 ft	14 inches at 3 kts; 36 inches when ramming
	Willow	Newport, RI			

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[204] This is generally coordinated by the Army Corps of Engineers, which is mandated to do this.

[205] *USCG Sector New York 2016-2017 Icebreaking Season* (from: http://homeport.uscg.mil/newyork)

Appendix C: Pilotage Regulations

Jurisdictional Issues

A distinctive feature of pilotage regulation in the United States is that there are two jurisdictional spheres of government regulation, state and federal. Pilotage of international trade vessels in US waters is governed by the twenty-four coastal states through comprehensive pilotage systems aimed at ensuring well-trained independent pilots are always available, without discrimination, to any vessel required to use a state pilot. Federal pilotage regulations, administered by the US Coast Guard, require certain vessels to be piloted by an individual with a Coast Guard-issued federal pilot license and establish the rules and procedures for the issuance of a federal pilot license and for the oversight of federal pilots' professional conduct.

State regulation has been preempted by Congress in only two limited areas:

(1) States may not regulate pilotage on US-flagged vessels operating in the coastwise or domestic trade; and
(2) States may not regulate pilotage on the Great Lakes.

All acts and laws governing pilotage, with the exception of the Great Lakes Pilotage Act, are placed in chapter Subtitle II of Title 46.71, Chapter 85. As a result, the enabling statutory authority for all state and federal pilotage law in the US, with the limited exception of the Great Lakes, can now be found in the three sections of Chapter 85. The chapter confirms the traditional boundaries between the state and federal pilotage regulation.

States are to have the preeminent role in regulating pilotage in the United States and to have the exclusive role in regulating pilotage of vessels other than coastwise vessels and those in the Great Lakes and contains the prohibition on state laws requiring the use of a state-licensed pilot on a US-flag, coastwise vessel that is either self-propelled or a tank barge inspected under chapter 37 of title 46. This also sets out the requirement to take a federally-licensed pilot for coastwise vessels that are exempt from state pilotage requirements under 8501(d).

Experience Required

Depending on the area for which an individual wants the First Class pilot's license, he/she must have between 12 and 36 months aboard a ship of more than 1,600 gross register tonnage, of which at least 12 are spent in the deck department, standing watch and steering the ship. The individual must have between 12 and 20 round trips through the area for which he/she seeks the pilot endorsement, and 25 percent of those trips must be made at night. The last trip must have been made within six months of the examination date.

Board of Commissioners of Pilots of the State of New York: The Board of Commissioners of Pilots (the "Board") is a public agency, created by the New York State Legislature, Chapter 467, Laws of 1853, as amended to provide for the competitive selection, training, licensing and regulation of State pilots who navigate oceangoing vessels which operate on New York State waters and waters of concurrent jurisdiction in Connecticut and New Jersey. The States, under authority granted by the Congress, have exercised authority to control the piloting of vessels along their waterways, including coastal waterways within the territorial limits of the States, since before the federal constitution was adopted. Federal Law and Regulation (46USC 8501(A)), provides that *"pilots in the bays, rivers, Harbors, and ports of the United States shall be regulated only in conformity with the laws of the States," and that "the States have authority over the Pilotage of all American vessels sailing under register, that is, engaged in foreign trade, and all foreign flag vessels."*

Ship registration is the process of documenting a ship's given nationality. The nationality of a ship allows it to travel internationally wherever citizens of that nation are authorized to travel. The registration is almost like the passport for the ship, itself. Per international agreements, every merchant ship must be registered to a particular country. The country to which a ship is registered is called its “flag state.” A ship is bound by the laws of its flag state.

The Board of Commissioners of Pilots of the State of New York holds weekly public meetings (every Tuesday morning at 10:30am.) for the purpose of maintaining close oversight of the State pilotage system and operations. Each New York State pilot license is renewed annually, following a personal performance interview, at which the pilot's vision, medical records, training and work performance are reviewed in detail. Board members attend additional meetings, hearings, seminars, and conferences on pilotage and navigational safety related subjects with maritime industry, state and federal agency representatives. The Board continuously emphasizes professional development and promotes the highest standards of care and safety in the conduct of marine operations.

To carry out the Board's responsibilities under the New York Navigation Law, the Board provides for educational grants to State pilot associations and participates in funding for advanced State pilot training and technology, including carry-aboard laptop computers equipped with electronic charting and GPS positioning equipment, software development and training, participation in authorizing funds for the construction of new pilot boats and other capital items, including the acquisition of cell phones for use aboard ships on the Hudson River and Azipod propulsion system and tractor tug training. Note that an Azipod is a marine propulsion unit consisting of a fixed pitch propeller mounted on a steerable gondola ("pod") which also contains the electric motor driving the propeller.

The Board currently issues three types of legislatively authorized State pilot licenses, each covering a separate portion of New York State navigable waters. Jurisdiction, originally as to Sandy Hook Pilots at the Port of New York in 1853, was extended to Hell Gate Pilots by Chapter 283, Laws of 1928; extended to Hudson River pilots by Chapter 676, Laws of 1959; and extended to Long Island Sound-Block Island Sound pilots by Chapter 942, Laws of 1971.

The New York State Pilotage Districts under the responsibility of this Board are:

- The Port of New York
- New Jersey District
- The Hudson River District (Port facilities from Yonkers to Albany-Rensselaer)
- Long Island and Block Island Sound District

The Board regards the matter of safety of navigation, protection of the environment, security of our ports and waterways, and thorough training, licensing, professional accountability, and oversight of competitively selected State pilots among its highest priorities.

Board of Commissioners of Pilots of the State of New York

The Board of Commissioners of Pilots of the State of New York Policy and Procedure 012-15 states:

> *"Every foreign vessel and every American vessel under register, except vessels proceeding otherwise then by sea and of three hundred or less gross registered tons and having a fully loaded draft of seven feet or less, entering or departing from the Hudson River north of a line running from the foot of Main Street, Yonkers, New York, west to Alpine, New Jersey, or navigating any of the waters of the Hudson River north of that line, and south of the dam at Troy, New York, shall take a Hudson River Pilot licensed under the authority of the laws of the State of New York (Navigation Law, Article 6, Section 89-a as amended).*
>
> *The Hudson River Pilot is the Compulsory State Pilot for the waters of the Hudson River and has control of the vessel's navigation. It shall be unlawful for any person, other than a licensed Hudson River Pilot to pilot, or offer to pilot such vessels entering or departing the Hudson River.*
>
> *The Master has the right to intervene or displace the State Pilot only in circumstances where the State Pilot is manifestly incompetent. Incapacitated, intoxicated or the vessel is in immediate danger ("in extremis") due to the State Pilot's actions."*

In the event a vessel transiting the Hudson River requires a continuous pilotage of more than ten hours, two pilots are assigned at the beginning of such transit. A second pilot shall not be required when the vessel anchors for a minimum of eight hours such that the transit does not require a continuous pilotage of more than ten hours by one pilot.

Pilot Training

The duties of the Board of Commissioners of Pilots of the State of New York, as provided by the New York Navigation Law, include establishing rules and regulations regarding pilot apprenticeships, approval of applications of apprenticeship, and examination of Sandy Hook, Hudson River, and Long Island Sound Pilots for original licenses and any extensions of route. The qualifications for entrance are rigorous.

An Advanced Pilot Training Program ensures that New York State pilots are the best trained, equipped and informed professionals in the nation. The training program, which is regularly reviewed and upgraded, provides continuing education seminars, including for example:

- Bridge Resource Management for Pilots at the Maritime Institute of Technology and Graduate Studies (MITAGS);
- Manned Model Training at Port Revel, France, the Maritime Pilots Institute in Covington, Louisiana, Marine Safety, Inc. at Newport, Rhode Island, and the Massachusetts Maritime Academy Ship Simulator School;

- Radar Systems Theory and Use, Electronic Chart Display and Information System (ECDIS), Satellite Navigation (SATNAV), Global Positioning System (GPS), Automatic Identification System (AlS), electronic information and auto pilot systems;
- Selected case histories and studies of maritime accidents and casualties;
- Master-Pilot Exchange (MPX) system and protocols;
- Change of the Conn Policies and Procedures;
- Role of the Compulsory State Pilot;
- Human Factors in Marine Operations;
- Fatigue, Sleep and Medications Program at MITAGS;
- Root-Cause Analysis in Marine Casualties;
- Tractor tug, azimuth propulsion, podded propulsion and dynamic positioning training at MITAGS and the Maritime Pilots Institute.

The advanced pilot training program ensures that State licensed pilots maintain their high professional standards in the rapidly changing maritime industry. The courses focus on efficient use of personnel, communications, equipment, organizational development and human, as well as technical, resources available on the bridge of a modern ship. The advanced pilot training program is responsive to, and addresses the recommendations and/or rules of other recognized safety agencies, such as the National Transportation Safety Board, The National Safety Council, Standards for the Training and Certification of Watch Officers and the United States Coast Guard. The goal of the advanced pilot training program is to heighten communication levels and awareness of the various human and operational factors which affect their work, and their lives, in a State pilotage system, which operates twenty four hours a day in all weather conditions.

Regulations for Tugs and Barges

46 CFR §15.605 requires every towing vessel of at least eight meters (26 feet) to be under the direction and control of a person licensed as a master or mate of towing vessels, i.e. the person in command in the wheelhouse. “Licensed” is defined as the fact that the master or mate must have the proper license for a tug of its class, size and service, and for the waters in which it is operating.

There are more specifics in the context of the regulations, but essentially a “deckhand” or even a “senior deckhand” is not qualified as any of the required officers to control a tug. Since many tugs have only one licensed master, and will conceivably operate on more than 12 hours duration, another licensed officer meeting the requirements of 46 CFR §15.610 will be required, unless the operator intends to moor the vessel after 12 hours of operation, to allow at least 12 hours for the master to rest.

An articulated tug-barge (ATB) is classified as a towing vessel. Thus, those that operate them must have the proper credentials that include an “endorsement” for towing vessels similar to the usual tug/push/towing vessels that are the power source used to move non-propelled barges.

There are several paths established in federal regulations for advancement to Mate (Pilot) of Towing, and from there to Master of Towing vessels.

A Merchant Mariner Credential (MMC) officer endorsement as Master or Mate of Towing Vessels is required to be the first or second captain on towing vessels greater than 26 feet in length. The Apprentice Mate (Steersman) is a training position for advancement to Mate of Towing.

The Apprentice Mate requires 540 days that includes 360 days on towing vessels, and 90 days on the desired route.

The Apprentice Mate may advance to Mate of Towing after gaining 360 days experience on Towing Vessels while holding an endorsement as Apprentice Mate, completing a TOAR for the route, and an approved Radar Observer Class.

Mate of Towing may advance to Master of Towing after gaining 540 days as Mate on Towing Vessels while holding an endorsement as Mate of Towing.

Every mariner who stands watch on a towing vessel must have a completed Towing Officers' Assessment Record (TOAR) for that route. There are four TOAR assessment sheets:

- Limited TOAR for a specific company route
- Western Rivers TOAR for the Mississippi River
- Inland and Great Lakes TOAR
- Near Coastal
- Ocean TOAR

The current 46 CFR Part 15.610(b) specifies that the towing vessel be under the control of an officer meeting that section’s requirements for a towing vessel of 26 feet or more in length and that that officer hold ‘‘a first class pilot’s endorsement for that route or MMC officer endorsement for the Western Rivers, or’’ that the officer meets the requirements for a towing vessel of 26 feet or more in length and the requirements based on the type of barge being towed.

46 CFR Section 15.610 Master and Mate (Pilot) of Towing Vessels states:

> (a) Except as provided in this paragraph, every towing vessel of at least 8 meters (at least 26 feet) in length, measured from end to end over the deck (excluding sheer), must be under the direction and control of a person licensed as master or mate (pilot) of towing vessels or as master or mate of vessels of greater than 200 gross register tons holding either an endorsement on his or her license for towing vessels or a completed Towing Officer's Assessment Record (TOAR) signed by a designated examiner indicating that the officer is proficient in the operation of towing vessels. This does not apply to any vessel engaged in assistance towing, or to any towing vessel of less than 200 gross register tons engaged in exploiting offshore minerals or oil if the vessel has sites or equipment so engaged as its place of departure or ultimate destination.
>
> (b) An officer may continue to operate towing vessels within any restrictions of his or her license from May 21, 2001, until the first renewal or upgrade of that license, but not later than May 21, 2006. Every towing vessel covered by paragraph (a) of this section must carry at least the following personnel:

(1) An officer designated Master and holding a license as:

  - (i) Master of towing vessels;
  - (ii) Master of towing vessels (Limited) when operating solely within a limited local area;
  - (iii) Operator of uninspected towing vessels;
  - (iv) Master of inspected, self-propelled vessels within any restrictions on the license; or
  - (v) Mate or first-class pilot of inspected, self-propelled vessels with a license for service in vessels of greater than 200 gross register tons (Domestic service only).

(2) Another officer, if the vessel is operating more than 12 hours in any 24-hour period, holding a license:

  - (i) Listed in 46 CFR §15.610(b)(1);
  - (ii) As mate (pilot) of towing vessels;
  - (iii) As second-class OUTV; or
  - (iv) As mate of inspected, self-propelled vessels within any restrictions on the license.

(c) Any towing vessel operating in the pilotage waters of the Lower Mississippi River must be under the control of an officer who holds a first-class pilot's license or endorsement for that route, or meets the requirements of either paragraph (c) (1) or paragraph (c) (2) of this section as applicable:

(1) To operate a towing vessel with tank barges, or a tow of barges carrying hazardous materials regulated under part N or O of this subchapter, an officer in charge of the towing vessel must have completed 12 round trips over this route as an observer, with at least 3 of those trips during hours of darkness, and at least 1 round trip of the 12 within the last 5 years.

(2) To operate a towing vessel without barges, or a tow of uninspected barges, an officer in charge of the towing vessel must have completed at least four round trips over this route as an observer, with at least one of those trips during hours of darkness, and at least one round trip of the 12 within the last 5 years.

Appendix D: Crew Fatigue/Endurance

Tugboats, towboats, and push boats, all considered towing vessels, are usually navigated underway by a single operator who navigates, steers, and acts as lookout. With two officers on board, the pilot house watch standing period is usually six hours on watch and six hours off watch, any deck crew usually has the same watch standing routine. This is permitted regardless of the length of the voyage. The result has been that officers and crew are working at least 12 hours a day which amounts to an 86-hour work week. Typically two watch crews work 30 days onboard the boat and 15 days ashore, other on and off time schedules are also used.

Many of the tank vessels that move clean products and crude oil on the Hudson River are tank barges being pushed by tugs. In recent years, an increasing number of tug and barges transporting petroleum are Articulated or Integrated. Articulated Tug Barges (ATBs) and Integrated Tug Barges (ITBs) are large barges with ship shaped bows. They have notches on their sterns in which tugs specially designed and built for each barge fit into and are locked in place with hydraulic rams. Effectively, they are a unit, but the tugs can be disconnected relatively easily for dry-docking and repairs. With ITBs, the tug is locked rigidly to the barge. With ATBs, the connection is hinged to allow flexing in larger waves. Articulated ATBs and ITBs are used rather than small tankships primarily because Coast Guard crew requirements for tugs involve fewer crewmembers than tankships. Ships usually have three watches, with crewmembers working 4 hours on duty and 8 hours off duty. Tugs usually have two crews, working 6 hours on, 6 off.

The two-watch schedule used on towing vessels and shorter voyages allows a reduced number of deck officers but does not allow any more than six hours off duty. If no layover occurs in port and the watch schedule continues, the two-watch or six on and six off system does not usually permit readjustment of the crews' circadian-rhythms. Circadian-rhythms are a cyclic variation in physiological state, mental, and physical activity, roughly 24 hours in duration. Portions of the cycle have been identified with drowsiness and low performance.

US Coast Guard Guidance on Crew Endurance

The USCG has a page online for Crew Endurance issues, https://www.uscg.mil/hq/cg5/cg5211/cems.asp. [Additional information concerning this matter can be accessed there.]

In December 2005, the USCG developed a report entitled, *"Implementing the Crew Endurance Management System (CEMS) on Towing Vessels"*, which responded to a requirement in Section 409 of the Coast Guard Authorization Act of 2004 (P.L. 108-293), in which Congress directed the Coast Guard to report on the results of a demonstration project involving the implementation of the Crew Endurance Management System (CEMS) on towing vessels.

In this 2005 report that was distributed to Congress in March 2006, the USCG acknowledged and stated:

> *"Numerous studies indicate that human factors contribute to the vast majority of marine casualties. Most of these human factors relate to cognitive abilities such as situational awareness and situational assessment. Research further indicates that fatigue and poor endurance greatly influence cognitive ability. As with any 24-hour-day, 7-day-week operation, we know that the risk*

> *factors for fatigue and endurance exist throughout the maritime transportation industry. Therefore, addressing fatigue and endurance is a critical part of the Coast Guard's strategy to reduce the risks of marine casualties."*
>
> *"Traditionally, regulators in the transportation sector have addressed fatigue through hours of service or manning requirements. These regulations form an important part of our overall strategy to address fatigue. However, fatigue-related accidents have continued to occur because prescriptive regulations alone do not address the interrelated human factors that contribute to fatigue. Marine operators are exposed to a variety of operational risk factors, such as irregular work hours, extreme temperatures, heavy workloads, and extended separation from family members. In response to this situation, the Coast Guard has developed the CEMS, a set of tools and practices maritime operators can use to manage productivity and safety levels in their operations."*
>
> *"The purpose of the demonstration project was to show that CEMS is feasible, effective, and sustainable. Previous clinical and scientific analysis by the Coast Guard Research & Development Center has already proven that CEMS is effective in improving crewmembers' endurance. This demonstration project focused on how well companies and crewmembers were able to implement CEMS, and the real-world impact CEMS had upon the crew's energy, alertness, and ability to cope with endurance-related risk factors."*
>
> *"The results of the demonstration project show that, when properly practiced, CEMS is effective in reducing fatigue-related risks. The demonstration project results indicate that companies and vessels that followed CEMS practices achieved measurable reductions in all fatigue-related risk factors."*

On March 21, 2008, USCG issued Navigation and Vessel Inspection Circular (NVIC) #02-08, *"Criteria for Evaluating the Effectiveness of Crew Endurance Management System (CEMS) Implementation."* Compliance with this NVIC at the moment is voluntary. The American Waterways Operators website states:

> *"Since 1999, the US Coast Guard and AWO* [America Waterways Operators] *have worked together to promote crew alertness in the 24-hour-a-day environment of the tugboat, towboat, and barge industry. Since that time, the Coast Guard and AWO have collaborated in the development and roll-out of the Crew Alertness Campaign and Stay Alert for Safety brochure, conducted research into CEMS application, and worked together to educate AWO member companies on CEMS principles. More than 130 organizations now have trained CEMS coaches on staff and over 1600 coaches have been certified throughout the United States and internationally. AWO is also sponsoring groundbreaking research aimed at better understanding the sleep habits of towing vessel crew members and promoting best practices to prevent crew fatigue and promote crew endurance."*[206]

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[206] http://www.americanwaterways.com/initiatives/safety-environmental-sustainability/crew-endurance

Final Rule on Inspection of Towing Vessels

On July 20, 2016, the final rule on Inspection of Towing Vessels became effective. Included in the final rule preamble is a discussion on Crew Endurance Management Systems (CEMS) and addresses the numerous public comments concerning that issue and commences on page 40076 of the *Federal Register* Vol. 81, No. 118/ Monday, June 20, 2016 and continues for most of page 40078. In the preamble discussion, USCG states:

> "*We are considering developing a separate rulemaking for Hours of Service (HOS) and Crew Endurance Management (CEM) based on our authority under 46 USC. 8904(c). If we do so, we will publish a separate document in the Federal Register*, *therefore, we have limited our responses because we are not proposing HOS or CEM requirements in this document.*"

Appendix E: CBR-SpillRISK

For determining probabilities of CBR spills, a series of probabilities are at stake, as summarized in Figure 79. There is a probability of a accident (primarily a derailment, but also including collisions and other types of rail accidents), the probability that the accident involves freight (tank) cars rather than just locomotives, the probability distribution of tank cars involved in the accident, the probability that there is release from the tank cars, and the resulting probability distribution of spill volumes.

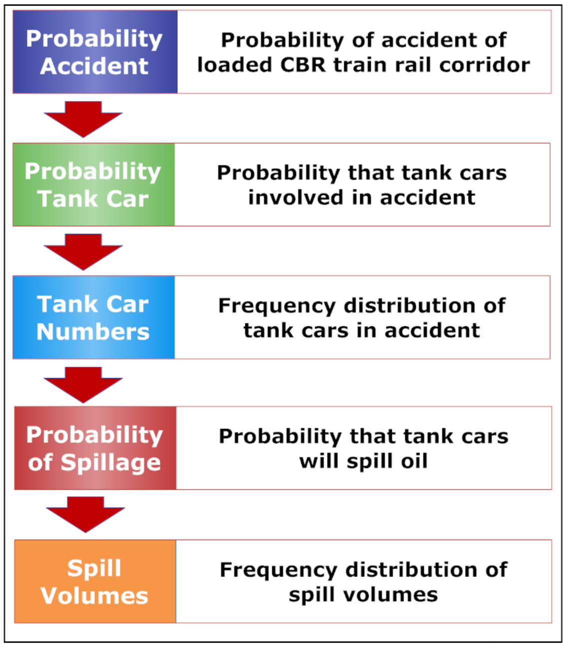

Figure 79: Steps in Determining Probabilities for CBR Spills[207]

This approach was selected for determining CBR spill probabilities and spill volumes because there is a lack of anecdotal data on these types of accidents given that CBR transport with key and unit trains (i.e., trains that include 20 to 120 tank cars containing only crude oil) has only been in existence since about midway through 2011. Prior to that oil transport was generally limited to small numbers of tank cars carrying refined petroleum products and occasional crude oil in manifest freight trains. Therefore, freight trains were used as a proxy for CBR unit trains. The basic approach of analyzing accidents and probabilities of cargo release has been applied in several other studies (e.g., Figure 80).

Forty-five years of FRA freight train accident data were used to determine frequency of rail accidents, numbers of cars derailed per accident, and probability of spillage from tank cars in an accident.[208]

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[207] Based on: Etkin *et al.* 2015b.

[208] The FRA accident data included numbers of rail cars derailed in accidents regardless of cause. “Derailment” is the primary classification of most accidents. However, even accidents that have a different primary classification, such as collision or highway-rail crossing accident, may have cars that derail. Since derailment of cars, regardless of the cause of the derailment, can cause damage to tank cars so that their contents are released, numbers of derailed cars were considered in the analysis.

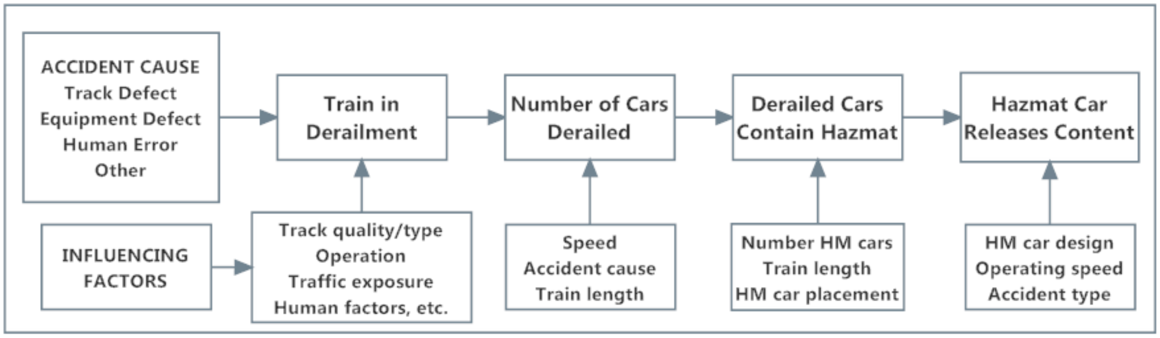

Figure 80: Rail Hazardous Material Spill Risk Analysis Approach of Rail TEC[209]

Both loaded and unloaded CBR unit trains may have spills. For a loaded train, there may be spillage of cargo oil, which may be Bakken crude or some form of diluted bitumen) or from the diesel locomotives. For empty trains, the spills would be only from the locomotives. For an unloaded train, the content of cargo is negligible (*i.e.*, only trace amounts that cling to the insides of the tank car). In this analysis, only crude spills from loaded CBR trains are considered. Diesel spills from locomotives are not included.

Five basic types of accidents were included in the analyses–derailments, collisions, fire-explosion events, highway-rail accidents, and miscellaneous events.[210] A total of 59,379 accidents occurring on main line track[211] during the years 1975 through 2015 were analyzed.

This analysis uses the term rail “accidents” in keeping with industry terminology. This term is used by the Federal Railroad Administration (FRA) in describing train accidents or occurrences that result in a minimum of $10,500 in damages and/or personal injury. Minor “incidents” below this damage threshold are not included in the analysis. Accidents analyzed include derailments, collisions, highway-rail crossing accidents, and other events that resulted in damages to trains, rails, systems, or personnel. In this vain, the term “accident” is used to denote an event that is unplanned, but results in consequences of concern. Applying the term “accident” to a rail event does not imply that the event was unavoidable or could not have been prevented in some manner. The accident could be caused by human error, faulty equipment, and other factors.

The probability analyses were conducted as Monte Carlo-based fault-tree analyses to incorporate uncertainties and probability distributions within each category. In the final probability analysis, factors

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[209] Etkin *et al.* 2015a, 2015b; Saat *et al.* 2014; Saat and Barkan 2006.

[210] Four collision types combined: broken train (moving train breaks into parts and impact occurs between parts, or portion of broken train collides with another consist); raking (between parts or consist on adjacent track, or with structure, *e.g.*, bridge; “side-swiping collision”); rear-end; and side. Fire/explosion accidents include fires, violent ruptures, or detonations occurring as primary events; does not include accidents in which spills ignite or explode secondarily. Highway rail crossing accidents involve other vehicles impacting trains at crossings. Miscellaneous includes obstruction accidents that occurs when trains hits object on train right-of-way, various other kinds of impacts, and other accidents that cannot be captured under the other categories.

[211] Main line track means a track of a principal line of a railroad, including extensions through yards, upon which trains are operated by timetable or train order or both, or the use of which is governed by block signals or by centralized traffic control (23CFR §646 Subpart B).

that could affect accident and spillage probability (such as the use of safer tank cars and implementation of various regulations) were considered.[212]

The historical data that were used to establish baseline probabilities for rail accidents involve equipment and practices that do not necessarily include the most up-to-date regulatory changes and safety measures that may reduce the incidence of accidents to mitigate risk. Risk mitigation measures that may affect the likelihood of future CBR unit train spills include: speed restrictions; enhanced braking; positive train control (PTC); wayside detectors; thermal protection; and tank car design.

The first four measures reduce the likelihood of accidents; the last two measures, tank car design and thermal protection, reduce the probability of spillage due to breaches and thermal damage in the event of an accident. Another risk mitigation measure that has been implemented is the pre-conditioning of Bakken crude oil to reduce volatility. This measure does not reduce the likelihood of spillage, but does reduce the probability of fires and explosions in the event of spills. In addition to factors that could reduce the risks of accidents and spillage, a factor that could increase the risk of accidents were also considered, i.e., train length. Other factors, including later stability, sloshing, and two-person crews were also considered, but ultimately did not factor into any changes in accident or spill probability.

Accident Rates per Train-Mile

Accident rates were re-calculated on a per-train-mile[213] basis for the various data (Table 104).

Table 104: Freight Train Main Line Accident Rate per Train-mile by Period and Type

Accident Type	Average Accidents per Million Train-miles[214]				
	1975–1984	1985–1994	1995–2004	2005–2015	1975–2015
Derailment	5.2701	1.6323	1.0318	0.6475	**2.1089**
Collision	0.3609	0.1387	0.0900	0.0575	**0.1592**
Fire/Explosion	0.1193	0.0198	0.0081	0.0171	**0.0405**
Highway-Rail Crossing	0.3226	0.2211	0.1895	0.1968	**0.2316**
Miscellaneous	0.1913	0.1052	0.0939	0.0799	**0.1167**
Total	**6.2642**	**2.1170**	**1.4134**	**0.9988**	**2.6569**

A brief analysis of accident rates from loaded and unloaded freight trains was conducted to determine if there was a significant difference. The results are shown in Table 105. Assuming that there are roughly an equal number of loaded and empty trains, the probability of an accident is about twice as likely with a loaded train versus an unloaded train. There is a higher probability of an accident with a loaded train for all accident types except for highway-rail crossing accidents. The probabilities of accidents for each of the individual accident types are used in apportioning probabilities of accidents with loaded and empty trains.

The overall probability data for accidents by jurisdiction and accident type are shown in Table 106. These probabilities were then apportioned by loaded and empty trains as per Table 105, with the results shown in Table 107 for loaded trains that would be carrying crude oil cargo.

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[212] The overall approach is described in Etkin 2016 and Horn et al. 2017.

[213] A train-mile is a single train traveling one mile.

[214] National train mile data from FRA.

Table 105: US National Accident Rates with Loaded and Empty Trains (1975–2015)[215]

Accident Type	Loaded #	Loaded %	Empty #	Empty %	Total #	Total %
Collision	281	57.8%	205	42.2%	**486**	**100.0%**
Derailment	5,858	70.4%	2,462	29.6%	**8,320**	**100.0%**
Fire/Explosion	41	71.9%	16	28.1%	**57**	**100.0%**
Hwy-Rail	194	38.5%	310	61.5%	**504**	**100.0%**
Miscellaneous	218	64.1%	122	35.9%	**340**	**100.0%**
Total	**6,592**	**67.9%**	**3,115**	**32.1%**	**9,707**	**100.0%**

Table 106: National Accident Rates Applied in CBR Probability Analysis: All Freight

Accident Primary Classification	Accident Rates on Main Lines Per Million Train-miles[216]		
	High	Low	Average
Collision	0.3609	0.0575	0.1592
Derailment	5.2701	0.6475	2.1089
Fire/Explosion	0.1193	0.0081	0.0405
Hwy-Rail Crossing	0.3226	0.1895	0.2316
Miscellaneous	0.1913	0.0799	0.1167

Table 107: Accident Probabilities for CBR Probability Analysis: Loaded Trains Only

Accident Primary Classification	Accident Rates on Main Lines Per Million Train-miles		
	High	Low	Average
Collision	0.2086	0.0332	0.0920
Derailment	3.7102	0.4558	1.4847
Fire/Explosion	0.0858	0.0058	0.0291
Hwy-Rail Crossing	0.1242	0.0730	0.0892
Miscellaneous	0.1226	0.0512	0.0748

CBR Accident Probability Adjustments

The calculated probabilities of rail accidents were based on historical data that may not be completely relevant for *future* CBR operations for a number of reasons:

- CBR unit trains are operated differently from other freight trains with respect to maximum speed and other factors;
- CBR unit trains act differently from other freight trains with respect to lateral stability;
- Operators plan to make capital improvements on rail lines; and
- A number of safety improvements have been, or will be, in place due to federal and state regulations.

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[215] Includes only FRA data that includes information about whether train was loaded/empty at the time of accident.

[216] High value based on highest time period; low value based on lowest time period; average based on average in all years (as in Table 104).

The safety measures, especially PTC, track upgrades, and wayside detectors, would work together in the prevention of rail accidents, as some have been for some time already to reduce accidents from the historical rates. The reduction factors of PTC, track upgrades, and wayside detectors, therefore, are not truly independent from one another. For this reason the reduction rates cannot be simply added together to calculate an additive reduction factor. The adjustments to accident probability for CBR transport that were considered in this analysis are summarized in Table 108.

Table 108: Considered Adjustments to Rail Accident Probability

Accident Factor for CBR Unit Trains	Assumptions	Potential Adjustments from Baseline Rate
Enhanced ECP Braking[217, 218]	ECP brakes used; effective in reducing accidents	0.007–3.7% reduction[219]
Positive Train Control (PTC)[220, 221]	PTC fully implemented	2–80% reduction
Wayside Detectors[222, 223]	Wayside detectors operational and effective	20% reduction
Two-Person Crews[224]	No adjustment needed as two-person crews already in effect; benefit or detriment unclear	0%
Track Upgrades[225]	Track upgrades completed; effective in reducing accident rates	37.5–75% reduction
Reduced Operating Speed[226]	Operating speeds of 40 mph	0%
Lateral Stability[227]	No adjustment needed for lateral stability (unrelated to sloshing)	0%
Sloshing[228]	Sloshing does not increase accident rate on >90%-full cars	0%

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[217] Electronically-controlled brakes.

[218] Booz Allen Hamilton 2006; Renze 2015; Brousseau 2014; AAR 2014.

[219] In December 2017, the US Department of Transportation rescinded its rule that tank trains carrying flammable commodities be equipped with ECP braking. A year-long study by the Transportation Research Board of the National Academies of Science reported that a comparison between ECP and conventional brakes was "inconclusive." (http://trn.trains.com/news/news-wire/2017/12/05-ecp-brake-rule)

[220] PTC is defined in federal law as: "a system designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zone limits, and the movement of a train through a switch left open in the wrong position" (49 CFR §236). The US federal government had originally mandated PTC for all railroads by the end of 2015, but in October 2015, the statutory deadline was extended to 2018. There are also provisions for case-by-case extensions possible up to the end of 2020 to allow time for railroads to adequately test their systems. This extension was based on the findings of an August 2015 report from FRA on delays in implementation of PTC. 49 CFR §236

[221] FRA 2015; Kawprasert and Barkan 2010; AAR 2015; Peters and Fritteli 2012; Roskind 2009

[222] A key prevention component in minimizing derailments is the extent to which the subject railroad employs monitoring equipment to detect anomalies with a train's operation, its equipment, or other factors that could affect the safe passage of a train. The nationwide wayside detector system is a technology that allows railroads to prevent damage and accidents before they happen. Positioned along 140,000 miles of railroad in the nation, seven kinds of wayside detectors monitor the wheels of passing trains and alert rail car operators to potential defects enabling them to schedule appropriate maintenance in a safe, timely, and cost-effective manner.

[223] McWilliams 2015; http://freightrailworks.org/wp-content/uploads/safety2.pdf.

[224] ICF Incorporated 2015.

[225] Liu *et al.* 2010, 2013a, 2013b; 2014.

[226] Anderson and Barkan 2004 and Liu *et al.* 2011a.

[227] TÜV Rheinland Mobility Rail Sciences Division 2014; Etkin *et al.* 2015a.

[228] Ashtiani *et al.* 2015; Celebi and Akyildiz 2002; Jimin et al. 2009; Tang et al. 2008a; Tang et al. 2008b; Barkan et al. 2000; Wang et al. 2014; Gialleonardo et al. 2013; Abramson 1966

Table 108: Considered Adjustments to Rail Accident Probability

Accident Factor for CBR Unit Trains	Assumptions	Potential Adjustments from Baseline Rate
Train Length[229]	Train length increases accident rate for 100 or 102-car trains.	12.4% increase
	Train length increases accident rate for 120-car trains.	24.7% increase

The factor that has been attributed with the greatest potential reduction in accidents is PTC, which is estimated to prevent anywhere from two to 80% of accidents. Wayside detectors work together with PTC to prevent accidents. The wayside detectors provide information to the PTC system so that trains can be stopped or controlled to prevent an accident when irregularities are detected. For this reason, wayside detectors have not been separately added in to the adjustment factor. Their benefit is assumed to be largely related to the way in which they interact with the PTC system. Likewise, track upgrades include, to some extent, the installation of wayside detectors and other components of PTC. There are also some aspects of track upgrades from FRA Class 3 to FRA Class 4 that involve replacing, repositioning, shoring up, and repairing track to allow for safe operation of trains at greater speeds. If one assumes that track upgrades, which are largely already in place in many locations, is the baseline of adjustment factors (a 75% reduction factor to be applied to historical accident rates), the additional benefits of PTC may increase that somewhat. Any accidents not already prevented by the track upgrades per se may be prevented by the full implementation of PTC (incorporating wayside detectors). And, if one assumes that track upgrades even without fully-implemented PTC is indeed at least half effective, a minimum effectiveness of 37.5% can be assumed.

The factor that can reasonably be considered independent is enhanced braking, which may have a minimal (0.007%) to 3.7% reduction in accidents. This is an aspect of the train rather track infrastructure and operating system overall. ECP braking can be considered an additive factor in this analysis.

However, the greater lengths of the CBR trains (from 100 to 120 cars) have been shown to *increase* the likelihood of an accident over more typical 80-car freight trains. For the 100-car train, the probability of accidents is estimated to increase by 12.4%; for the 120-car trains, the probability is estimated to increase by 24.7%. These increases in accidents somewhat counteract the reductions realized by the various safety measures. The increase in accident rates due to longer trains is taken into account in the calculations.

The adjustment factors for rail accidents are summarized in Table 109 . Since a range of values was considered in the modeling, both the highest and lowest reduction factors were included as per Table 108.

Table 109: Applied Adjustment Factors for CBR Accident Rates

Train Length	Adjustments to Baseline Accident Rate	
	Minimum	Maximum
100 cars	25.1% decrease	71.3% decrease
120 cars	12.8% decrease	59.0% decrease

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[229] Schafer and Barkan 2008

Release Probability with Hazmat Tank Cars

Rail accidents involving hazmat tank cars, such as those used to transport crude oil, do not necessarily result in the release or spillage of any hazardous materials. The next phase of the probability analysis involved determining the release probability in the event of an accident involving CBR tank cars.

To determine the probability of a release from tank cars, an analysis of 3,589 rail accidents involving loaded tank cars was conducted with the results shown in Table 110. In the 3,589 accidents, there were a total of 11,352 hazmat cars damaged or derailed with 2,418 releasing material. In nearly two-thirds (66.2%) of accidents involving hazmat cars, there is no release from damaged or derailed cars. The spillage probability depends on the type of accident and the time period. The cumulative distribution of percentage of hazmat cars with releases in each accident is summarized in Table 111.

Table 110: Percent Damaged/Derailed Loaded Hazmat Car with Release

Accident Type	Percent Hazmat Cars with Release				
	1975–1984	1985–1994	1995–2004	2005–2015	1975–2015
Collision	27.9%	32.1%	12.1%	13.1%	**19.5%**
Derailment	26.5%	22.3%	14.9%	19.4%	**21.5%**
Fire/Explosion	50.0%	100.0%	-	-	**60.0%**
Highway-Rail Crossing	27.7%	24.4%	5.9%	6.8%	**17.0%**
Miscellaneous	8.8%	22.9%	14.0%	47.1%	**19.1%**
Total	**26.4%**	**22.6%**	**14.6%**	**19.0%**	**21.3%**

Table 111: Cumulative Probability of Release Percent from Hazmat Cars (1975–2015)

Percentile (% Accidents)	% Cars with Release					
	Collision	Derailment	Hwy-Rail	Fire/Explosion	Misc.	All Accidents
60th	0%	0%	0%	0%	0%	0%
65th	0%	0%	0%	0%	0%	0%
70th	31%	19%	0%	0%	0%	23%
75th	49%	32%	20%	0%	0%	33%
80th	59%	49%	36%	0%	75%	49%
90th	100%	100%	100%	100%	100%	100%
95th	100%	100%	100%	100%	100%	100%
99th	100%	100%	100%	100%	100%	100%

Adjustments to Spill Probability for CBR

The probability that there would be spillage in the event of a rail accident needs to be adjusted for the particular circumstances of current and future CBR transport since release tank car release probabilities are based on historical data with older tank car designs.

Hazardous material release accidents decreased significantly between 1980 and 1993, and then remained relatively steady until another drop in 2008.[230] Overall there has been a 90% decrease in spillage with improvements in tank car safety design, as well a substantial reduction in accidents. Much of this

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[230] Barkan 2008a; Barkan *et al.* 2013.

reduction in spillage may be attributable to the reduction in accidents. The reduction depends on the specific time period analyzed. An analysis[231] on data from 1985 –2004 showed an 85% reduction in the release rate and a 44% decrease in the accident rate.

A significant emphasis has been placed on reducing the likelihood of spillage from CBR trains with the implementation of safer tank car designs, emphasizing an increase in wall thickness.[232] The effectiveness of the new tank car designs were estimated and modeled by PHMSA, as shown in Table 112.

Table 112: Effectiveness of Newly Constructed Tank Car Options Relative to DOT-111[233]

Tank Car	Total	Head Puncture	Shell Puncture	Thermal Damage	Top Fittings	Bottom Outlet Valve
PHSMA/FRA (DOT-117)	55%	21%	17%	12%	4%	<1%
AAR 2014 Design	51.3%	21%	17%	12%	1.3%	<1%
Enhanced CPC-1232	41.3%	19%	9%	12%	1.3%	0%

In another analysis conducted by AAR in conjunction with the Railway Supply Institute (RSI) as part of the RSI-AAR Railroad Tank Car Safety Research and Test Project, the conditional probability of release for various types of tank cars were found to be as shown in Table 113.

Table 113: Conditional Probability of Release by Tank Car Type[234]

Car Category	Additional Features[235]					Conditional Probability of Release	
	Shell	Jacket	HHS	FHHS	TFP	Any Volume	>2.4 bbl
DOT-111 (Legacy)	7/16”					26.6%	19.6%
	7/16”	✓				12.8%	8.5%
CPC-1232	1/2”		✓		✓	13.2%	10.3%
	7/16”	✓		✓	✓	6.4%	4.6%
	1/2”	✓		✓	✓	5.2%	3.7%
DOT-117	9/16”	✓		✓	✓	4.2%	2.9%

Taking the data in Table 113, the calculated reductions in probabilities of release (spillage) from the newer design tank cars are shown in Table 114. Note that the two values highlighted in pink are actually *increases in release probability*. This means that the jacketed ½”-CPC-1232 is actually *more* likely to release oil than the jacketed DOT-111 car.

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[231] Barkan 2008a.

[232] Wall (tank) thickness is inversely related to the probability of release (Barkan 2008a; Hughes *et al.* 1998).

[233] *Federal Register* Vol. 79, No. 108 (August 1, 2014), Part III Department of Transportation, Pipeline and Hazardous Materials Safety Administration (49 CFR § 171, 172, 173, 174, 179) pp. 45,016–45,079.

[234] API/AAR 2014; Treichel 2014; Barkan et al. 2015. Probability that there will be a release or spill from a tank car given an accident.

[235] HHS = half-height head shield; FHHS = full-height head shield; TFP = top-fittings protection.

Table 114: Estimated Reductions in Release Probability with Newer Tank Cars

Car Category	Additional Features[236]					Estimated Reduction in Release Probability Compared with DOT-111			
						DOT-111 Non-Jacketed		DOT-111 Jacketed	
	Shell	Jacket	HHS	FHHS	TFP	Any Volume	>2.4 bbl	Any Volume	>2.4 bbl
CPC-1232	1/2”		✓		✓	50.4%	47.4%	-3.1%	-21.2%
	7/16”	✓		✓	✓	75.9%	76.5%	50.0%	45.9%
	1/2”	✓		✓	✓	80.5%	81.1%	59.4%	56.5%
DOT-117	9/16”	✓		✓	✓	84.2%	85.2%	67.2%	65.9%

Another study estimated the reduction in the average probability of release from tank cars that meet the specifications of the DOT-117 car to be 85% compared with the probability of release from the current non-jacketed DOT-111 car.[237] In addition, the enhanced design is expected to considerably reduce the likelihood of secondary failures caused by fire. Thermal protection systems on tank cars limit the heat flux to the tank car containers when exposed to fire, reducing the likelihood of product release.[238]

Train speed also affects the probability that a derailment will result in spillage from tank cars.[239] At a slower speed, fewer cars would be expected to release material. The probability of a multi-car release reduces by 22% to a probability of 0.32, and the mean number of tank cars releasing reduces by 25% to 1.38 cars. The study assumes that there are 10 tank cars on an 82-car train.

Table 115 summarizes the adjustments to spill probability applied in the final CBR spill probability analysis.

Table 115: Considered and Applied Adjustments to Tank Car Release Probability

Factor	Assumptions	Adjustments to Baseline Tank Car Release Rate	
		Minimum	Maximum
Tank Car Design	DOT-117 and DOT-117R tank car release rate applied[240]	43% reduction	72.2% reduction
Operating Speed	Release rate reduced due to lower operating speeds[241, 242]	35% reduction	35% reduction
Thermal Protection	Thermal protection reduces releases due to fire/explosion[243]	12% reduction	12% reduction
Adjustment Applied to Impact Accident Rate		**43% reduction**	**72.2% reduction**
Adjustment Applied to Fire/Explosion Accident Rate		**12% reduction**	**12% reduction**

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[236] HHS = half-height head shield; FHHS = full-height head shield; TFP = top-fittings protection.
[237] Barkan *et al.* 2015.
[238] http://www.ntsb.gov/safety/safety-recs/recletters/R-15-014-017.pdf.
[239] Kawprasert and Barkan 2010; Liu *et al.* 2014.
[240] For impact-related accidents (derailments, collisions, highway-rail crossing accidents, miscellaneous).
[241] Kawprasert and Barkan 2010.
[242] For impact-related accidents (derailments, collisions, highway-rail crossing accidents, miscellaneous).
[243] Reduction applied only to accidents caused by fire/explosion.

Numbers of Cars Involved in Transit Accidents

When a rail accident occurs in transit, there are varying numbers of freight cars that may be involved. An analysis of the numbers of freight cars involved in derailments and other accidents was conducted. Based on the national FRA accident data,[244] the probability distributions of number of cars and percentage of total cars were developed, as shown in Table 116. For each type of accident there are many factors that determine the number of cars involved.

Speed is an important factor in determining the number of cars that derail in an accident. One study[245] examined the average numbers of cars that derail based on track class and speed, as in Figure 81.[246]

Table 116: Damaged/Derailed Freight Cars Involved in Transit Accidents by Type/Time[247]

Time Frame	Statistic	Number of Freight Cars Involved per Transit Accident					
		Collision	**Derailment**	**Hway-Rail**	**Fire/Explosion**	**Misc.**	**All**
2005–2015	**% 0 cars**	50.5%	3.6%	94.1%	97.5%	88.3%	31.7%
	Average	2.8	8,2	0.5	0.3	0.7	5.7
	Maximum	41	122	46	27	39	122
	Accidents	390	4,390	1,257	118	529	6,684
All Years 1975–2015	**% 0 cars**	50.1%	2.5%	85.6%	97.2%	82.9%	17.1%
	Average	2.9	7.8	1.3	0.3	1.0	6.6
	Maximum	58	122	80	43	66	122
	Accidents	3,106	43,656	4,456	872	2,390	54,480

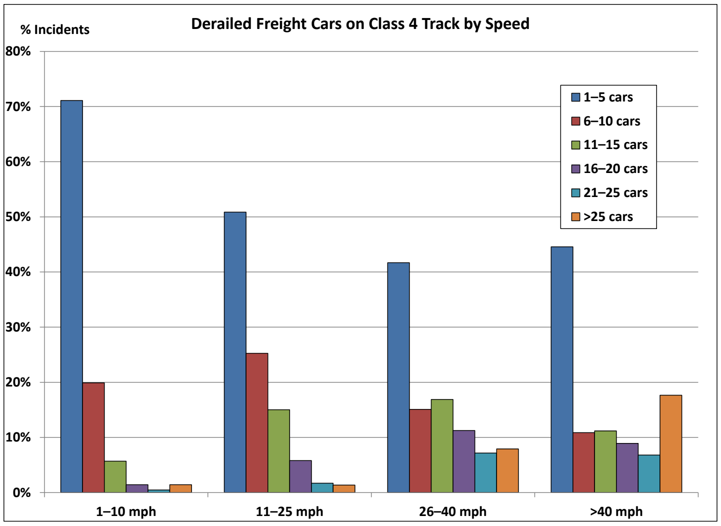

Figure 81: Frequency Distributions of Derailed Cars on FRA Class 4 Track by Speed[248]

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[244] This follows the methodology in Etkin *et al.* 2015b.

[245] Anderson and Barkan 2005.

[246] Track classified by FRA with respect to maximum speed for track condition as 60 mph for freight, 80 mph for passenger. This is the dominant class for main-line track used in passenger and long-haul freight service.

[247] FRA accident data on freight trains of at least 20 freight cars on main line track (54,480 accidents).

[248] Based on Anderson and Barkan 2005.

When a tank car is breached, the entire contents may not necessarily be released to the environment. The amount released depends specifically on the size of the puncture or tear in the tank, its location, the orientation of the car (upright, at an angle or on its side or end), the volume of fluid in the tank, as well as the characteristics of the fluid (*e.g.*, its viscosity and pour point) at the prevailing environmental conditions (primarily air temperature).

A literature review revealed four studies that mention the distribution of release percentages. One study mentioned that in one-third of cases, only 5% of the tank car contents is released, and that in one-third of cases, 80 to 100% is released. Presumably, the remaining one-third releases between 5 and 80%.[249] A second study evaluated the release rates of tank cars with the results shown in Figure 82.[250, 251]

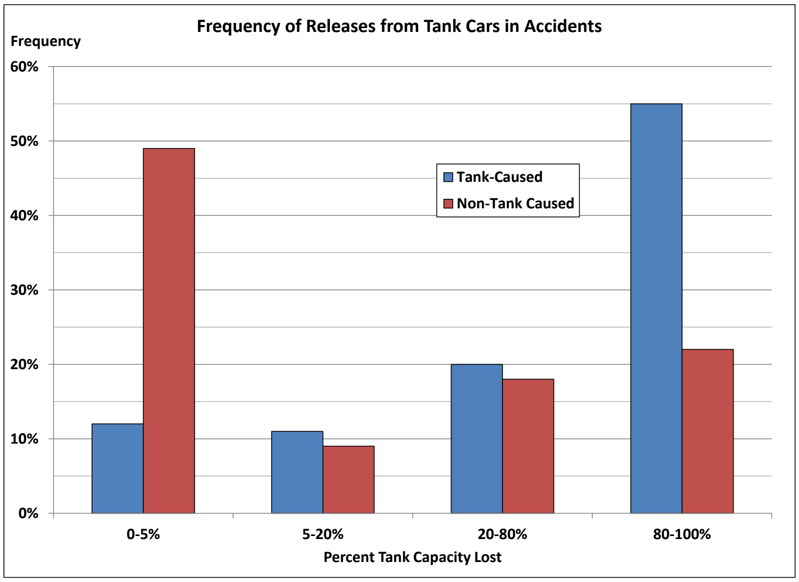

Figure 82: Frequency of Releases of Different Volumes[252]

A third study combined conditional probability of release with percentage release. The analyses indicated that the conditional probability of release (*i.e.*, a spill in the event of a derailment) was 0.117 for tank-related causes and 0.207 for non-tank-related causes for DOT-111 tank cars, and that 62% and 32.1% of the tank capacity would be lost, respectively. Multiplying these values together netted a 7.25% average tank capacity release risk for tank-caused accidents and 6.65% for non-tank-caused accidents. With an average tank capacity for DOT-111 cars of 717.7 bbl, this would mean an average release risk per derailment of 52 bbl and 48 bbl, respectively, depending on whether the release occurred due to tank- or non-tank-related causes.

The fourth study assumed a Poisson binomial probability distribution of the number of tank cars that would release material assuming there were 10 tank cars (Figure 83).[253]

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[249] Treichel *et al.* 2006.

[250] Saat and Barkan 2005.

[251] Tank-caused accidents involve damage to the head and shell; non-tank-caused accidents involve damage to other tank car components, principally the top and bottom fittings.

[252] Based on Anderson and Barkan 2004.

The percentage of release from individual tank cars and the numbers of tank cars involved, in combination with the amount of oil contained in each tank car, will determine the total amount of oil released to the environment.

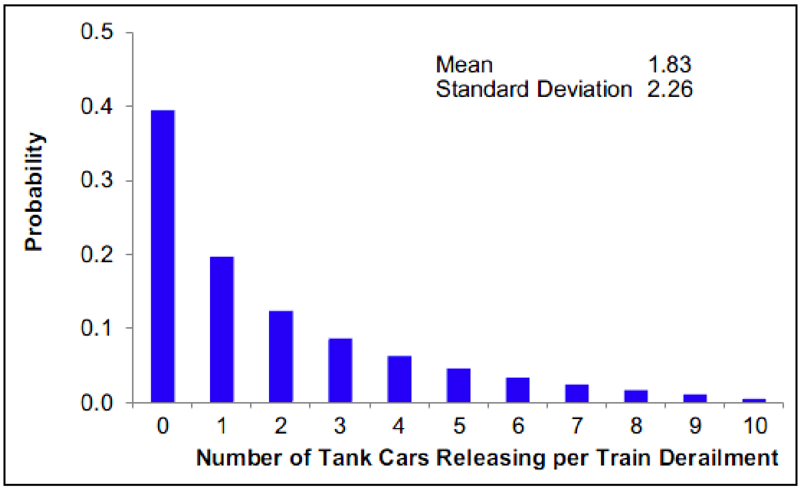

Figure 83: Estimated Probability Distribution of Derailed Tank Car Numbers[254]

The actual volume of crude oil in each tank car may vary depending on:

- The type of oil and its density (specific gravity or °API);
- The capacity of the tank car based on its model design;
- The degree to which each tank car is filled (to allow for air space); and
- The total weight limit allowed per tank car (gross rail load).

Capacities of various tank car designs are shown in Table 117. The tank capacity is not necessarily the amount of Bakken crude that would be contained in an individual car, because there is a maximum total gross weight (the empty tank car plus its cargo) that is allowed. This weight, called the gross rail load (GRL) is set by regulations. The GRL for North American free interchange is set at 263,000 pounds (131.5 short tons). The GRL for heavy axle load weight for North American Class I railroads is currently set at 286,000 pounds. (143 short tons), which puts a load of 36 tons per axle for a typical four-axle freight car. This weight limit exists regardless of the commodity being carried.

Typically, the nominal capacity (also called "light weight" or "tare weight") of a tank car is about 66,000 pounds (33 tons), which allows for 220,000 pounds (110 tons) of cargo. The volume depends on the density of the commodity. In the case of Bakken crude, with a density of 0.808 (°API of 43.67) at 60°F, 110 tons is the equivalent of 776.8 bbl. However, this exceeds the tank capacity of the tank cars, as shown in Table 117. (The reason for the discrepancy is that Bakken crude oil is particularly light.) A fully-loaded

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[253] Liu *et al.* 2014.

[254] Liu *et al.* 2014; assumes 10 DOT-111 tank cars in an 82-car train.

DOT-117 or CPC-1232 tank car filled to a 675.5-barrel capacity weighs 70.6 tons. Regardless of the tank capacity, tank cars of crude oil are generally loaded to allow for air space so the oil can expand due to temperature differences during transport. Older tank cars (unjacketed DOT-111) generally are loaded with 690 barrels of Bakken crude oil.[255] For the newer DOT-117 tank cars, the expected loading volume is 650 barrels. This takes into account a 4% expansion space.

Table 117: Capacity of Tank Car Designs[256]

Tank Car Type	Typical Tank Full Capacity (bbl)[257]	Maximum Total Gross Rail Load (lbs)[258]
DOT-111 (Non-Jacketed)	717.7	263,000
DOT-111 (Jacketed)	607.1	263,000
CPC-1232 (Jacketed)	675.5	286,000
DOT-117	675.5	286,000

CBR Accident/Release Probability Modeling (CBR-SpillRISK)

The analyses of rail accidents and spills, as well as the various adjustments based on specific CBR factors all inform the inputs for the final spill probability modeling–one for loaded CBR unit trains and one for empty trains. The basic fault-tree models are solved with a Monte Carlo simulation approach. This allows for distributions of values and uncertainties to be incorporated into the analysis rather than solely static values. The calculations are made in accident and spill frequencies per train-mile. The train-miles vary based on the numbers of trains expected. The adjustments to accident probability and to release probability were applied to accident rates, and the adjustments for the release rate from tank cars take into account safety enhancements are summarized in Figure 84 .

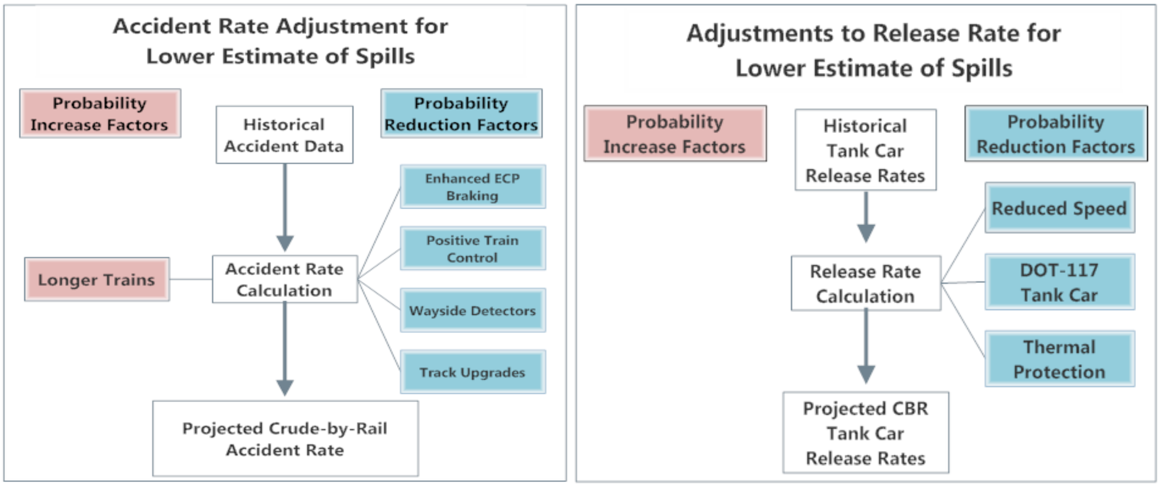

Figure 84: Adjustments to Historical Rail Accident and Release Probabilities

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[255] The unjacketed DOT-111 cars involved in the Lac-Mégantic accident contained about 672.22 bbl each.

[256] Based on data provided by Railway Supply Institute.

[257] Actual capacity will depend on the specific design features.

[258] The change in regulatory gross rail load (GRL) from 263,000 to 286,000 was made in 2003 and is not unique to tank cars but applies to all rail cars (Barkan 2008a, 2008b; AAR 2003; Barkan *et al.* 2015).

The rail accident-related inputs into CBR-SpillRISK model are in Table 118. Pre-adjustment accident rates are the highest and lowest rates in Table 104 for 1995–2015. The accident numbers per million train-miles apportioned into accidents with loaded and empty trains based on data in Table 105. Only loaded trains were considered in the accident and spill analysis.

Table 118: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Loaded Trains)

Accident Type	Accident Probability Per Million Train-Miles						
	Pre-Adjustment		Adjustment			Adjusted	
	Low	High	Train Length (cars)	Multipliers		Low	High
				Min.	Max.		
Derailment	0.4403	0.7016	100	0.749	0.287	0.1264	0.5255
			120	0.872	0.410	0.1805	0.6118
Collision	0.0123	0.0946	100	0.749	0.287	0.0035	0.0709
			120	0.872	0.410	0.0050	0.0825
Fire/Explosion	0.0000	0.0116	100	0.749	0.287	0.0000	0.0087
			120	0.872	0.410	0.0000	0.0101
Hway-Rail Cross	0.0541	0.1338	100	0.749	0.287	0.0155	0.1002
			120	0.872	0.410	0.0222	0.1167
Miscellaneous	0.0543	0.1284	100	0.749	0.287	0.0156	0.0962
			120	0.872	0.410	0.0223	0.1120

Since the accident rates are on a per train-mile basis, the accident numbers for CBR trains need to be calculated from estimated CBR train-miles. There are no definitive data on CBR train-miles nationwide. It was assumed that of the approximately 600 million annual freight train-miles,[259] 3% could be apportioned to CBR traffic (based on the percentage of CBR as part of overall freight). Therefore, with an estimated 18 million train-miles for CBR traffic, the "low" and "high" estimates of accidents in Table 119 are based on the low and high adjusted accident probabilities in Table 118.

Table 119: Estimated Accident Rate for National CBR Transport

Accident Primary Classification	Adjusted Accident Probability Per Million Train-Miles		Estimated Annual Accidents		Estimated Accident Return Years	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Derailment	0.1264	0.6118	2.2752	11.0124	0.4	0.1
Collision	0.0035	0.0825	0.0630	1.4850	15.9	0.7
Fire/Explosion	0.0000	0.0087	0.0000	0.1566	0.0	6.4
Hway-Rail Cross	0.0155	0.1167	0.2790	2.1006	3.6	0.5
Miscellaneous	0.0156	0.112	0.2808	2.0160	3.6	0.5
Total	**0.1610**	**0.9317**	**2.8980**	**16.7706**	**0.3**	**0.1**

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[259] FRA data.

Based on this analysis, it is estimated that there might be 2.9 to 16.8 *accidents* per year with loaded CBR trains. This is the equivalent of a loaded CBR accident once every one to four months. *Note that these accidents would not necessarily result in spillage.*

The tank car release (spill) probability inputs into the CBR-SpillRISK model are in Table 120. Release probabilities are based on the data in Table 110 for 1985–2015, with adjustments based on Table 115.

Table 120: CBR-SpillRISK Release Probability Inputs with Adjustments (Loaded Trains)

Accident Type	Pre-Adjustment Release Probability per Accident		Adjustment Multiplier		Adjusted Release Probability per Accident	
	Low	High	Min.	Max.	Low	High
Derailment	0.1490	0.2230	0.570	0.278	**0.0414**	**0.1271**
Collision	0.1210	0.3210	0.570	0.278	**0.0336**	**0.1830**
Fire/Explosion	0.5000	1.0000	0.880	0.880	**0.4400**	**0.8800**
Hway-Rail Cross	0.0590	0.2440	0.570	0.278	**0.0164**	**0.1391**
Miscellaneous	0.1400	0.4710	0.570	0.278	**0.0389**	**0.2685**

The expected frequencies of spills (*of any volume*) are in Table 121. The end result is that there would be expected to be 0.1 to 2.6 crude spills–or one spill every three months to nine years–from loaded CBR trains annually on a national basis. The higher estimate of spill frequency is based on more "pessimistic" assumptions about the effectiveness or installation of the various safety measures designed to reduce accidents and releases from CBR trains. The vast majority of accident reduction measures is already in place, or will be in place in the next year or two, though the universal availability of the safest tank cars is in question, however.

Table 121: Annual Frequency of Crude Spills of Any Volume (Loaded CBR Trains)

Accident Type	Mean Spills/Year		Return Years	
	Low Estimate	High Estimate	Low Estimate	High Estimate
Derailment	0.094	1.400	10.6	0.7
Collision	0.002	0.272	472.4	3.7
Fire/Explosion	0.000	0.138	-	7.3
Hwy-Rail	0.005	0.292	218.6	3.4
Miscellaneous	0.011	0.541	91.5	1.8
Total	**0.112**	**2.643**	**8.9**	**0.4**

The frequencies of spills in Table 121 are based on an assumption of 18 million train-miles for CBR traffic nationally, as is currently the case. If CBR traffic were to further decrease or to increase again, based on economic factors that drive this traffic, the spill frequencies would change. To project spill rates for future traffic, the spill frequencies per million train-miles are provided in Table 122.

Table 122: Expected CBR Spill Frequencies per Million Train-Miles (Loaded)

Estimate	Mean Annual Frequency per Million Train-Miles					
	Derailment	Collision	Fire/Explosion	Hwy-Rail	Misc.	Total
Low	0.0052	0.0001	0.0000	0.0003	0.0006	**0.0062**
High	0.0778	0.0151	0.0077	0.0162	0.0301	**0.1468**

CBR Spill Volume Model (CBR-SpillRISK-V)

The second part of the modeling involved deriving the probability distribution of potential spill volumes. Assuming that a spill occurs, the volume can range from very small up to a much larger, or potentially worst-case, discharge. For a loaded CBR unit train, the maximum spillage is based on the number of tank cars and the volume to which each tank car is loaded. A tank car volume of 690 bbl was assumed (DOT-111 car), a tank car volume of 650 bbl was assumed (DOT-117 car).

The model, CBR-SpillRISK-V, was based on:

$$Volume_{spill} = N_{total} \cdot P_{involvement} \cdot Volume_{car} \cdot \%Outflow$$

Where, N_{total} = total number of tank cars; $P_{involvment}$ =% tank cars involved in accident (derailed or otherwise damaged); $Volume_{car}$ = volume content of tank car; and *%Outflow* = percentage of release of tank car contents.

Each of the variables has a distribution of values associated with it, as in Table 123 for loaded trains. A total of 500,000 simulations of CBR-SpillRISK-V were run for each of the accident types based on the criteria in Table 123. The estimate for the expected CBR spill volume probability distribution for loaded trains is described in Table 124 and Figure 85.

Table 123: CBR-SpillRISK-V Inputs: Loaded Trains

Variable	Accident Type	Low Value		High Value	
Total Car Number	-	100		120	
Volume/Car (bbl)	-	650		675.5	
% Cars Involved / % Outflow/Car	**Derailment**	0%	5%	100%	100%
% Cars Involved / % Outflow/Car	**Collision**	0%	5%	50%	100%
% Cars Involved / % Outflow/Car	**Fire/Explosion**	0%	1%	20%	100%
% Cars Involved / % Outflow/Car	**Highway-Rail**	0%	5%	10%	100%
% Cars Involved / % Outflow/Car	**Miscellaneous**	0%	5%	50%	100%

Table 124: Expected CBR Spill Volume per Incident (Loaded Trains)

Statistical Parameter	120-Car Trains		100-Car Trains	
	Spill Volume (bbl)	Tank Cars	Spill Volume (bbl)	Tank Cars
Mean	11,253	17.3	10,498	16.2
0 percentile	261	0.4	249	0.4
10th percentile	2,860	4.4	2,718	4.2

Table 124: Expected CBR Spill Volume per Incident (Loaded Trains)

Statistical Parameter	120-Car Trains		100-Car Trains	
	Spill Volume (bbl)	Tank Cars	Spill Volume (bbl)	Tank Cars
20th percentile	4,219	6.5	3,984	6.1
30th percentile	5,705	8.8	5,365	8.3
40th percentile	7,375	11.3	6,918	10.6
50th percentile	9,280	14.3	8,686	13.4
60th percentile	11,507	17.7	10,756	16.5
70th percentile	14,186	21.8	13,236	20.4
80th percentile	17,655	27.2	16,452	25.3
90th percentile	22,830	35.1	21,214	32.6
100th percentile	50,201	77.2	44,455	68.4

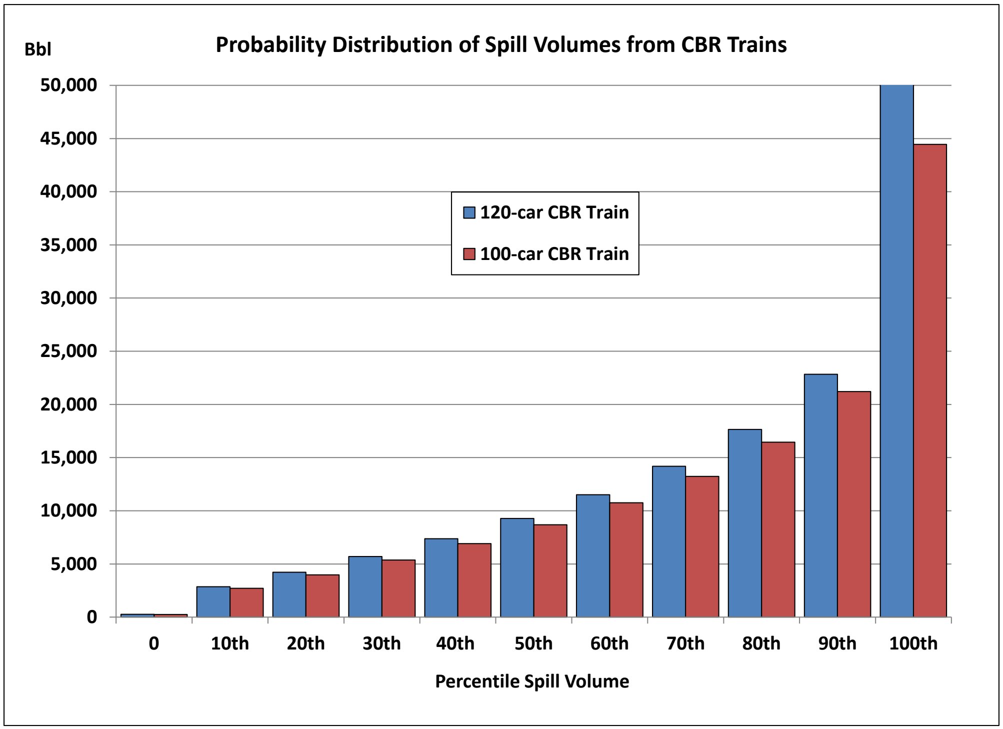

Figure 85: Probability Distribution of Crude Spill Volumes from CBR Trains

Combining Spill Probability and Volume Analyses

Each spill frequency value needed to be apportioned to the distribution of spill volumes. The average annual spill frequency of 0.11 to 2.6 for loaded CBR trains nationally, there is a 10% chance that the spill would be a volume of 20,000 bbl or more. This means that annually, there is a 0.01 to 0.26 probability of a 20,000 bbl or larger crude oil spill from a loaded CBR train. The expected recurrence interval or return period of such a spill volume scenario would be 4 to 89 years. The estimate of annual probabilities and return periods for spills of different volumes for loaded CBR trains are in Table 125.

Note that the largest CBR spill in the US to date is roughly half the size of the 90th percentile spill volume. The volume of the Lac-Mégantic spill in Quebec approached the 95th to 99th percentile spill volume, but there are a large number of reasons that this type of incident is much less likely in the US than in Canada. In addition, the actual volume of spillage in the Lac-Mégantic incident can technically be divided into two releases.

Table 125: Estimated Expected Average Frequency of CBR Oil Spills by Volume[260]

Spill Volume	Frequency per Year		Return Years	
	Low Estimate	High Estimate	Low Estimate	High Estimate
250 bbl or less	0.11	2.6	8.9	0.38
2,500 bbl	0.10	2.4	9.9	0.42
4,000 bbl	0.091	2.1	11	0.47
5,000 bbl (30PD)	0.064	1.5	16	0.66
8,000 bbl	0.059	1.4	17	0.72
10,000 bbl	0.039	0.92	26	1.1
15,000 bbl	0.0299	0.69	34	1.4
20,000 bbl (90PD)	0.011	0.26	89	3.8
40,000 bbl	0.0011	0.026	890	38
50,000 bbl	0.00011	0.0026	8,900	380

Any spill of 10,000 gallons (238 bbl) or larger would be considered a major inland spill. This volume represents about one-third of a CBR tank car. With an accident that causes spillage from a breached tank car on a CBR train, it is highly likely that the spill would be considered a "major" spill regardless of the exact volume. This would be due to the concerns about the likelihood of fire and explosion with a trainload of Bakken crude, especially in the proximity of a populated area, or the concern about submerged oil possibilities with a trainload of diluted bitumen product.

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[260] Results have been rounded to two significant digits.