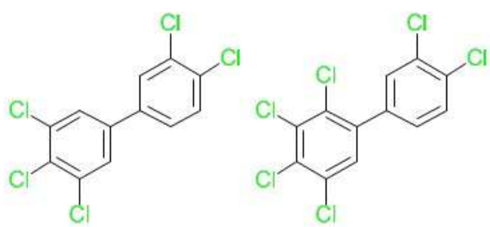
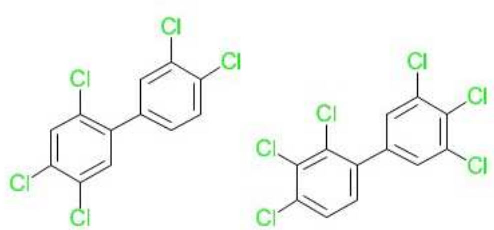
Potential Natural Resource Damages Related to Polychlorinated Biphenyl (PCB) Discharges into the Hudson River





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Cover Photograph Credit

The photograph of the great blue heron was taken by Dagmar Schmidt Etkin.

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Research Team

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 led development of natural resource damage assessment (NRDA) models established in the 1996 U.S. Federal regulations under CERCLA and the Oil Pollution Act, which also evaluate restoration strategies and bioeconomic valuations in marine and freshwater environments. 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 and chemical spills. Dr. French-McCay has worked (for the trustees) on many NRDAs over the past three decades, involving both oil and chemical discharges. In support of the government's NRDA for the Deepwater Horizon oil spill of April-July 2010 in the Gulf of Mexico, she modeled oil transport, fate and exposure using SIMAP to evaluate injuries for water column organisms. Dr. French McCay, representing NOAA, was the lead of the Offshore Water Column, Plankton and Fish Technical Working Group of scientists who evaluated data needs and developed over 40 work plans for cruises each involving one or more vessels in the Gulf of Mexico that collected physical, chemical, and biological data for use in the NRDA. 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.

Gretchen Greene, PhD (Greene Economics, LLC)

Dr. Gretchen Greene has over 25 years of diverse economics experience in natural resource, energy, and community economics. Dr. Greene has expertise in ecosystem service valuation, natural resource damage assessment (NRDA), recreation, water demand and management, and public infrastructure investment. She also brings expertise in endangered species economics; land conservation and sustainable economic development; cost-benefit analysis; demographics, socioeconomics, and environmental justice; decision analysis with uncertainty; and survey design and data analysis. An experienced facilitator, Dr. Greene has developed focus groups and surveys covering a variety of environmental topics. She has worked in dozens of different cultural environments, from southern Africa to Mongolia to Native American communities. She has worked with numerous federal, state, tribal, and municipal agencies as well as private industrial clients and law firms. Dr. Greene has a BA in Religious Studies from Wellesley College, a MS in Food and Resource Economics from University of Florida, and a PhD in Food and Resource Economics from University of Florida.

Dagmar Schmidt Etkin, PhD (Environmental Research Consulting)

Dr. Etkin has 45 years of experience in environmental analysis–14 years investigating issues in population biology and ecological systems, and 31 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 received a BA in Biology from University of Rochester, and MA and PhD degrees from Harvard University in Organismic/Evolutionary Biology, specializing in ecological modeling and statistics.

Acronyms

- **µg/g:** micrograms per gram
- **µg/L:** micrograms per liter
- **bbl:** barrels (42 gallons)
- **ATSDR:** Agency for Toxic Substances and Disease Registry
- **BAF:** Bioaccumulation Factor
- **BEHP:** bis 2-ethylhexyl phthalate
- **CAG:** Community Advisory Group
- **CERCLA:** Comprehensive Environmental Response, Compensation, and Liability Act of 1980
- **CFR:** Code of Federal Regulations
- **Class GA:** fresh groundwater classification[1]
- **COC:** Certificate of Completion
- **CWA:** Clean Water Act
- **DDT:** dichlorodiphenyltrichloroethane
- **DOI:** Department of Interior
- **DWH:** Deepwater Horizon
- **EPA:** Environmental Protection Agency
- **ERC:** Environmental Research Consulting
- **FDA:** US Food and Drug Administration
- **FWS:** US Fish and Wildlife Service
- **GE:** General Electric
- **HEA:** Habitat Equivalency Analysis
- **HUDTOX:** Hudson River Toxic Chemical Model
- **km^2:** square kilometers
- **LHR:** Lower Hudson River
- **mg/L:** milligrams per liter
- **MNA:** Monitored Natural Attenuation
- **NOAA:** National Oceanic and Atmospheric Administration
- **NPS:** National Park Service
- **NRD:** Natural Resource Damages
- **NRDA:** Natural Resource Damage Assessment
- **NWI:** National Wetland Inventory
- **NYCRR:** New York Codes, Rules, and Regulations
- **NYSCC:** New York State Canal Corporation
- **NYSDEC:** New York State Department of Environmental Conservation
- **NYSDOH:** New York State Department of Health
- **PAH:** polycyclic aromatic hydrocarbons
- **PCB:** Polychlorinated biphenyls
- **PCDD:** polychlorinated dibenzo-p-dioxins

[1] All fresh groundwater in New York State is Class GA.

- **PCDF:** p*olychlorinated* dibenzofurans
- **PEC:** Probable Effects Concentration
- **ppb:** parts per billion
- **ppm:** parts per million
- **ppt:** parts per trillion
- **PRP:** potentially responsible party
- **REA:** Resource Equivalency Analysis
- **RM:** River Mile
- **ROD:** Record of Decision
- **RS:** River Section
- **SDWA:** Safe Drinking Water Act
- **TCDD:** tetrachlorodibenzo-*p*-dioxin
- **UHR:** Upper Hudson River
- **VOC:** volatile organic compounds
- **WTP:** willingness to pay
- **WQS:** Water Quality Standard

Executive Summary

The research team evaluated available data, studied existing Hudson River Natural Resource Trustee reports and factsheets, and conducted a literature review to gain an understanding of the overall state of the Hudson River Polychlorinated Biphenyl (PCB) natural resource damage assessment (NRDA) case. Generally established injury and damage quantification methodologies were applied to estimate the potential magnitude of natural resource damages (NRD). Other PCB case studies were also reviewed to provide a means to benchmark a potential NRD settlement for the Hudson River.

The adverse effects of PCB contamination on wildlife and other organisms are well studied and documented in peer-reviewed literature. For this report, 77 reports and cited papers from the Hudson River Natural Resource Trustees were reviewed. An additional 61 PCB studies conducted specifically on the Hudson River, and 206 other studies on PCB effects and toxicology were also identified.

PCBs are persistent in the environment, highly toxic, and biomagnify (i.e., increase in concentrations in organisms higher in the food web). Approximately 85% of the over 10,000 water samples that have been taken from 200 miles of the Hudson River since the mid-1970s have contained PCBs, often at concentrations an order of magnitude or more above relevant state and federal regulatory criteria. Contamination in the Hudson River is over a larger geographic area than in other PCB-contaminated sites that have been or are being evaluated for NRDA claims. Environmental exposures to Hudson River PCB contamination known to cause injuries to the ecosystem and human services (e.g., drinking water, fisheries) began decades ago and will continue for decades into the future. Thus, quantification of the extensive injuries from PCBs in the Hudson should be summed over many years, and the injuries from past years should be compounded forward to adjust to present-day equivalent values.

Therefore, the NRDA claim for the Hudson River PCB contamination would be expected to be relatively large compared to other NRDA cases, including the largest oil spill settlement to date, that for the 2010 Deepwater Horizon (DWH) spill in the Gulf of Mexico. In contrast to PCBs, hydrocarbons from oil spills that adversely affect biota degrade much more readily, are less toxic, and are metabolized by organisms, mitigating to some extent the effects of large oil spills, such the DWH oil spill.

The preliminary estimates of damages for some of the injuries to Hudson River natural resources due to PCB contamination are summarized in Table 1. Additional damages could be claimed for other resource service losses not quantified here, such as interim service losses related to fish and invertebrates, ecological communities in the river and floodplain, surface water quality, groundwater, navigation, recreational hunting, subsistence fishing and hunting, contact recreation (swimming, wading, picnicking and beach use), and recreational boating.

In addition to the compensatory damages for past and ongoing injuries to wildlife, drinking water, navigation and recreational fishing, the estimated damages include the cost of additional dredging in the Upper Hudson River (UHR), as primary restoration to prevent additional injuries from accruing in future decades to centuries in the Upper and Lower Hudson River. Additional dredging is needed to reduce UHR sediment PCB concentrations such that Hudson River fish meet USEPA's (2002) fish consumption advisory-based remediation goal. Future ecological services would also be restored by the additional dredging, as the thresholds to restore recreational fishing services are below those for protecting wildlife and aquatic biota. Dredging would also restore surface drinking water services in future years. However,

lost ecological and human services in the past decades and in the future up until this dredging is completed would still be compensable as part of an NRD claim.

Table 1: Potential Damage Estimates due to Hudson River PCB Contamination	
Resource Category	**Estimated Damages**
Wetland-Dependent Wildlife: Upper Hudson[2]	$5.73 billion
Wetland-Dependent Wildlife: Lower Hudson[3]	$1.65 billion
Drinking Water	$1.4 billion
Navigation (Primary Restoration Only)	> $225 million
Recreational Fishing: Lost Value due to Consumption Restrictions	$1.9 billion
Recreational Fishing: Lost Value due to Closures	$523 million
Dredging of Upper Hudson River to meet Remediation Goal	$10.7 billion
Total	**$22.1 billion**

The settled NRD claim for the DWH was $9.2 billion, which is about half of the preliminary damage estimate of the estimated $22.1 billion for the Hudson River PCB contamination as in Table 1. For context, a comparison of the two cases is shown in Table 2.

Table 2: Deepwater Horizon NRDA Settlement and Hudson River PCB Comparison		
Factor	**Hudson River PCBs**	**Deepwater Horizon Oil Spill**[4]
Natural Resource Damages	$22.1 billion (estimated)	$9.2 billion (settled)
Duration of Release	Decades	Three months
Persistence in Environment	Highly persistent (decades)	Degradation in months to years
Toxicity	Highly toxic	PAHs less toxic than PCBs
Biomagnification[5]	Biomagnification in food web	PAHs metabolized by organisms
Exposure Period	Decades	Months
Fishery Injuries	Fisheries injuries and closures for decades	Fisheries recovered by 8 years
Drinking Water Effects	Extensive drinking water effects	No drinking water effects

The analyses conducted in this report should be considered preliminary. They were developed for the purpose of benchmarking the approximate magnitude of an appropriate damage claim due to the documented and estimated effects of PCBs in the Hudson River. Available data were analyzed using established methodologies typically employed to quantify damages. Due to the preliminary nature of these analyses, additional more in-depth analyses may be advisable when more data are available.

Table 3 shows which elements of a potential damage claim have been included in this report, which have been partially analyzed, and which remain outstanding. For each affected resource type, an assessment is

[2] Includes wildlife injuries in wetlands (assumed up to 40% reduction in densities) along the Hudson channel as well as wetlands within 6 km of the main river.
[3] Federal Dam to Catskill, assuming up to 10% reduction of wildlife densities in wetlands within 6-km of main river.
[4] PAHs are polycyclic aromatic hydrocarbons that occur naturally in oil (also called polynuclear aromatic hydrocarbons).
[5] Biomagnification (also called bioamplification or biological magnification), is the increasing concentration of a substance, such as a toxic chemical, in the tissues of organisms at successively higher levels in a food chain.

shown for whether injuries have been estimated for lost resource services in the past or the future, and whether damages based on valuation methods, primary restoration and/or compensatory restoration have been evaluated. Primary restoration is evaluated as a future dredging activity, so compensatory restoration would still be required in all cases where primary restoration is noted. A resource service is described as partially analyzed if damages (i.e., primary and/or compensatory restoration) for another resource service could potentially compensate for its injuries, but quantification of the injuries/damages has not been performed for that specific resource. Riverine refers to the mainstem of the Upper Hudson River, estuarine refers to the mainstem of the Lower Hudson River, and wetland includes wetlands and tributary streams to the Hudson River (i.e., riparian habitats) within 6 km of the main river.

Table 3: Status of Elements of Potential Injury and Damage Estimates in this Report[6]

Affected Resource	Injuries		Restoration/Damages	
	Past	Future	Primary	Compensatory
ECOLOGICAL SERVICES				
Mink	●	●	○	●
Wetland Dependent Wildlife (Birds, Mammals other than Mink, Reptiles, Amphibians)	○	○	○	◐
Riverine Wildlife (Birds, Mammals, Reptiles, Amphibians)	○	○	◐	○
Estuarine Wildlife (Birds, Mammals, Reptiles)	○	○	○	○
Wetland Dependent Fish and Invertebrates	○	○	○	◐
Riverine Fish and Invertebrates	○	○	●	○
Estuarine Fish and Invertebrates	○	○	◐	○
Sturgeon (Threatened & Endangered Species)	○	○	◐	○
Mussels and Other Benthic Communities	○	○	○	○
Surface Water	○	○	◐	○
HUMAN USE SERVICES				
Recreational Fishing	●	●	◐	●
Commercial Fishing	○	○	○	○
Drinking Water Quality	●	●	◐	●
Navigation	○	○	◐	○
Recreational Boating	○	○	◐	○
Contact Recreation (Swimming)	○	○	◐	○
Subsistence	○	○	◐	○
Wildlife Hunting	○	○	◐	○
Indoor Air Quality (Vapor Intrusion)	○	○	◐	○
Wildlife Viewing/ Passive Use	○	○	◐	○

[6] Solid black circle = analyzed; grey circle = partially analyzed; empty white circle = not analyzed.

Chapter 1: Overview

1.1. Introduction

In the late 1940s through 1977, the General Electric Corporation (GE) discharged millions of pounds of polychlorinated biphenyls (PCBs) into the Hudson River from two electric capacitor manufacturing plants at Fort Edward and Hudson Falls, New York. These facilities are about 40 and 45 miles north of the Troy Federal Lock and Dam, and 200 miles north of New York City.

Figure 1: Site of General Electric Capacitor Plants

As part of the remedial action directed by US Environmental Protection Agency (EPA) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, dredging and capping of contaminated sediments was performed from 2009 to 2015.

1.2. Phase 1 Remedial Dredging

The US EPA recommended that 2.65 million cubic yards of contaminated sediments containing PCBs be dredged from the Upper Hudson River.[7] In 2009, the EPA ordered Phase 1 dredging for the areas shown in Figure 2 through Figure 4. This removed 296,000 cubic yards of PCB-contaminated sediment along a six-mile stretch.

[7] US EPA 2000a.

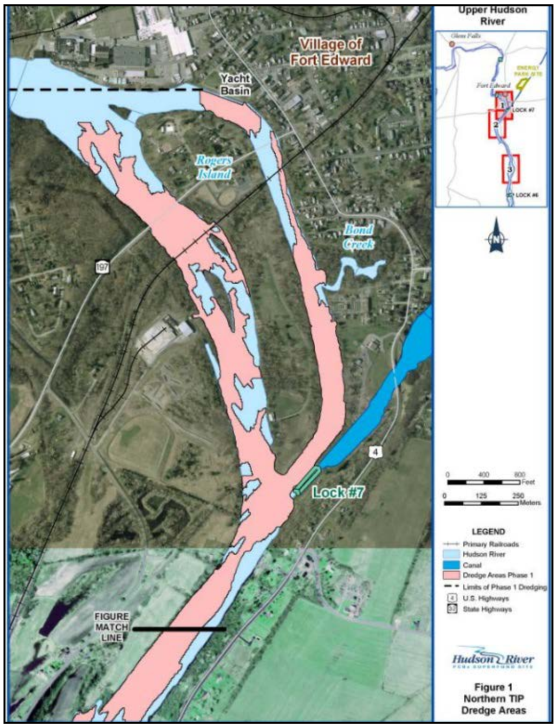

Figure 2: Phase 1 PCB Northern Dredging Areas (Thompson Island Pool-North)[8]

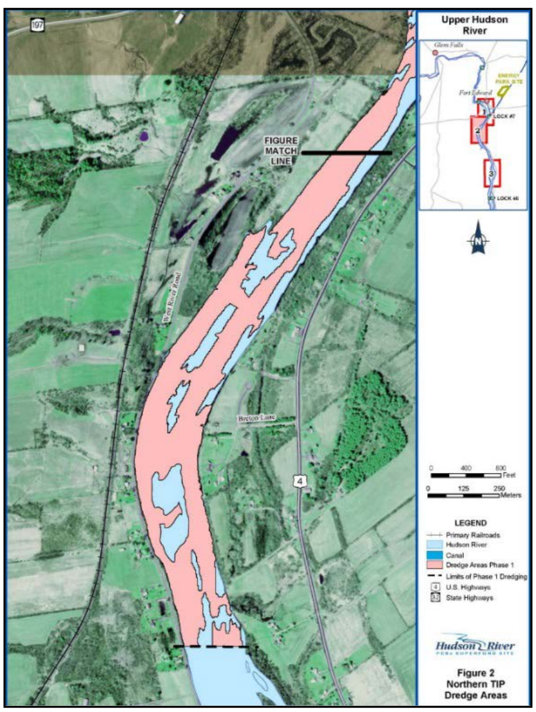

Figure 3: Phase 1 PCB Northern Dredging Areas (Thompson Island Pool-South)[9]

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

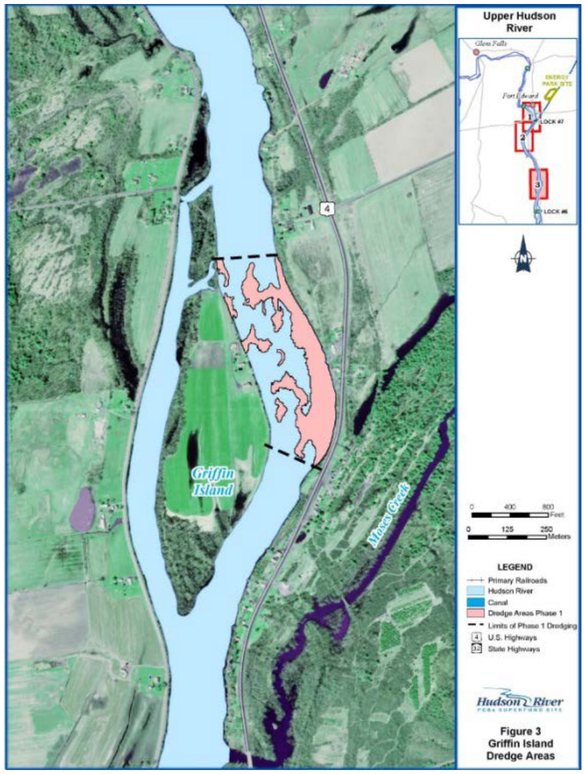

Figure 4: Phase 1 PCB Dredging Areas (Griffin Island)[10]

1.3. Phase 2 Remedial Dredging

Phase 2 dredging during 2011 through 2015 removed 2.75 million cubic yards of contaminated sediment from selected areas between Fort Edward to just above the Troy Federal Lock and Dam (Figure 5). A summary of the 2009–2015 dredging activities is shown in Table 4.

Table 4: Summary of Phase 2 Dredging Operations[11]

Operation	Sediment Removed	River Bottom Area	PCBs removed
Phase 1	286,000 cubic yards	48 acres	18,230 kg
Phase 2-2011	363,332 cubic yards	75 acres	27,020 kg
Phase 2-2012	663,265 cubic yards	118 acres	33,370 kg
Phase 2-2013	628,057 cubic yards	100 acres	32,460 kg
Phase 2-2014	582,917 cubic yards	Not reported	26,570 kg
Phase 2-2015	230,399 cubic yards	Not reported	8,185 kg
Phase 2 Total	**2,467,970 cubic yards**	**433 acres**	127,605 kg
Phase 1 + Phase 2 Total	**2,753, 970 cubic yards**	**481 acres**	**145,835 kg**

[10] https://www3.epa.gov/hudson/pdf/factsheet2005.pdf
[11] Sediment volume and total PCB for all years, and total acres dredged in 2011–2015, from Parsons, 2019. Annual river bottom areas for 2009-2013 from EPA reports to Hudson River PCB Community Advisory Group (http://www.hudsoncag.ene.com/documents.htm)

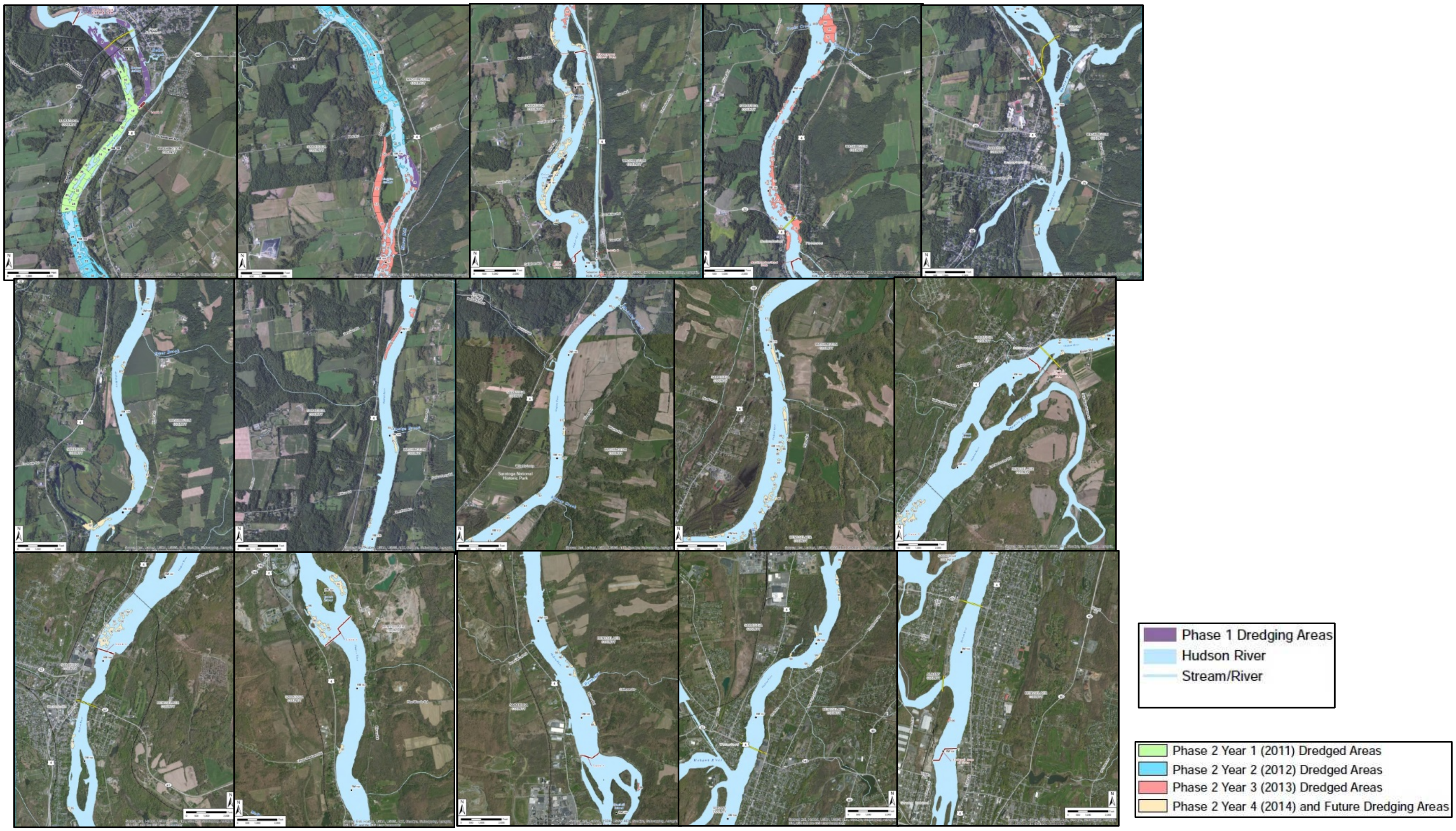

Figure 5: Phase 1 and Phase 2 Dredging Areas in Upper Hudson River

1.4. Post-Dredging Monitoring

Post-dredging monitoring has shown that there continues to be a large amount of contamination remaining that will continue to endanger the health of the river and its dependent species. The monitoring has not shown expected improvement in fish, sediment, and water quality, and it is fully expected that the temporal and fish contamination target criteria in the record of decision (ROD) will not be met for several or more decades.[12]

Prior to the dredging operations, the levels of PCBs in fish in the Upper Hudson River far exceeded those believed to impact health of people who consume fish based on risk-based levels established by credible toxicological methods. In addition, the concentrations of PCBs in fish and wildlife exceed levels believed to cause harm (Table 5 and Table 6).[13]

Table 5: PCB Levels in Upper Hudson River Fish Compared to Other Coastal Waters[14]

Location		Mean PCB Concentration (ppm) (Pre-Dredging)
Hudson River[15]	**Thompson Island Pool**	7–29
	Stillwater Reach	1.6–41
	Waterford Reach	3–19
	Below Troy Federal Dam	1.1–11
Great Lakes[16]		0.4–1.9
Delaware Bay[17]		0.4–0.7
Chesapeake Bay[18]		0.05–1.0

Table 6: Great Lakes Protocol Risk-Based PCB Advisory[19]

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

After the release of the preliminary second five-year report in June 2017,[20] the New York State Department of Environmental Conservation (NYSDEC) rejected the findings of the EPA that the PCB cleanup had been

[12] https://www.epa.gov/sites/production/files/2019-04/documents/seggos_to_lopez_4-5-19.pdf
[13] Baker et al. 2006.
[14] Based on: Baker et al. 2006.
[15] US EPA 2000c.
[16] http://www.epa.gov/grtlakes/glindicators/fish/topfish/topfishb.html
[17] Ashley et al. 2003.
[18] Liebert et al. 2001.
[19] Great Lakes Sport Fish Advisory Task Force 1993.
[20] US EPA 2017.

satisfactory. NYSDEC's research and analysis indicate that there are still unacceptable levels of PCBs in river sediments and fish tissue.[21]

In April 2019, after reviewing NYSDEC and other data, US EPA issued a second (of a total of three) Certificate of Completion (COC) to GE, which confirmed that the dredging, capping, habitat restoration, and deconstruction/decontamination of the sediment processing facility that was conducted between 2009 and 2016 were "properly performed in accordance with the 2006 Consent Decree between EPA and GE."[22] This finding has been disputed by NYSDEC and the federal Trustees. The issuance of a COC could trigger the start of the Natural Resource Damage Assessment (NRDA) for evaluation of injuries to ecological and socioeconomic resources and their uses.

According to EPA, the issuance of the second COC in April 2019 "does not cover, and does not in any way release GE from, any obligation to continue its operation, maintenance, and monitoring responsibilities under the Consent Decree."[23]

Significantly, in its second five-year report,[24] EPA decided to "defer a determination of protectiveness of the remedy in the Upper Hudson River until more years of Hudson River fish tissue data are gathered."

1.5. Natural Resource Damage Assessment (NRDA) under CERCLA

Under CERCLA, NRDA Trustees may claim damages for injuries to natural resources held in trust for the public. These resources include "land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other such resources." The resources for which NRDA claims include those "belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by" the United States, a State, or an Indian Tribe.

The total measure of damages is the cost of restoring injured resources to their baseline condition, compensation for the interim loss of injured resources pending recovery, and the reasonable cost of a damage assessment (the process of calculating the damages).

The Trustees may claim damages to natural resources based on losses of ecological service and human use of natural resource services. Natural resource services are the physical and biological functions performed by the resource including the human uses of those functions. These services are the result of the physical, chemical, or biological quality of the resource. These natural resource services may include:

- Ecological Services, which are services to other natural resources, such as providing food, shelter, or nesting; and
- Human Use Services, which directly benefit humans and the human use of those services, such as drinking water supply, fishing, and other recreational activities. Nonuse value may also be a service loss.

[21] Hudson River Estuary Program 2018.
[22] https://www.epa.gov/sites/production/files/2019-04/documents/hudson_news_release_final_0.pdf
[23] https://www.epa.gov/sites/production/files/2019-04/documents/hudson_news_release_final_0.pdf
[24] US EPA 2019.

For NRDA, **injury** is defined as a measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a release of a hazardous substance. Injury also includes impairment of a natural resource service and impacts caused by remedial actions. The damages, as explained above are the monetary compensation needed to remedy the injuries.

There are two different types of restoration damages. Primary restoration covers the cost of accelerating the injured resource recovery to its original service level. Compensatory restoration is the value of interim service loss prior to recovery. An initial estimate of resource injury is required before determining either of these types of restoration damages.

Primary restoration returns the impacted resources to the condition that would have existed if the incident had not occurred. Compensatory restoration addresses losses from the date of injury until recovery is completed. While the resource is impaired, it is unable to provide either the ecological, or the human use services, on which the ecosystem and the public rely (e.g., fish production or recreational use). The theoretical model of primary and compensatory restoration is illustrated in Figure 6. The vertical axis shows the percent of a resource service that is functioning through time. The horizontal axis shows time, an demonstrates that after a release, the service functionality will rapidly decline and then begin to naturally recover (follow the solid line rightward). The dotted line shows how a restoration action can bring the resource back to the full recovery level sooner than the solid line. The solid line represents that natural recovery rate. The gains from primary restoration are shown as the area above the solid line and below the dotted line. This can be thought of as the improved service functioning of a resource that results from the restoration activity, summed year after year from the beginning of restoration to the point full recovery absent the restoration activity. Note that when primary restoration occurs, the size of the interim losses – the compensatory restoration required – is also reduced.

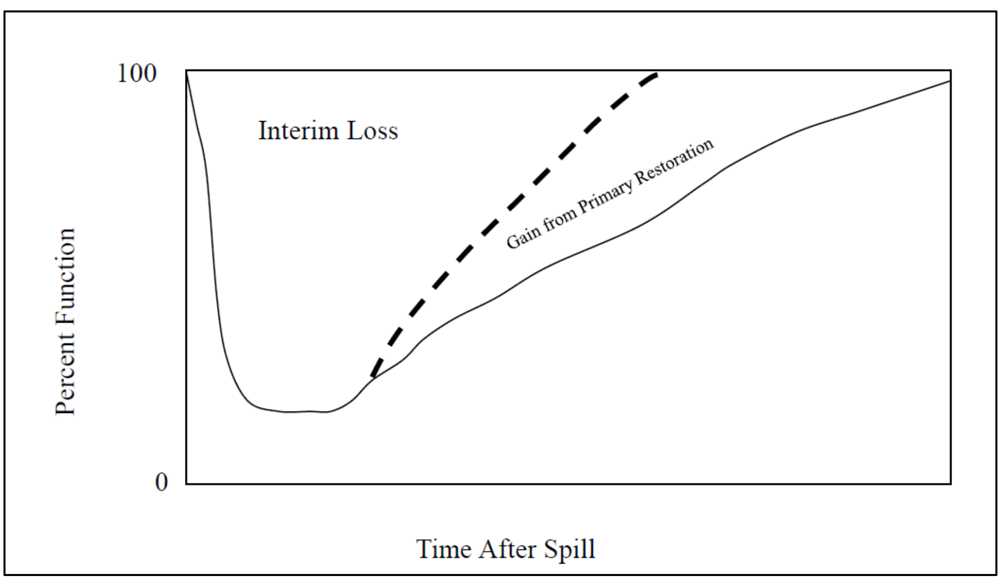

Figure 6: Percent Function of Affected Ecological Services after Spill

The basic approaches to NRDA injury quantification, and required restoration under CERCLA are:

- **Habitat Equivalency Analysis (HEA),** which involves estimating the amount of habitat (such as scrub-shrub or forested wetland, marsh, submerged aquatic vegetation, or oyster reef) restoration needed to compensate for losses of (injuries to) the same or similar kinds of habitats. The scale of the required restoration is based on the additional production needed (e.g., of the injured resource or to the ecosystem supporting the injured resource) to restore the service level and to compensate for the interim losses. HEA is scaled to account for the lag time before restoration begins, development time for the habitat, and the delay in benefits.
- **Resource Equivalency Analysis (REA)**, which involves protection, support or restocking of targeted species (in kind or equivalent), such as projects to increase (e.g., fledgling) productivity of birds or other wildlife. Again, as with HEA, the REA is scaled to account for the lag time before restoration begins, natural growth and mortality of the population, and the delay in benefits.

In addition to ecological service losses, there are also natural resource service losses to humans that may be included in NRDA. Services directly benefiting humans and the human use of those services that may be compensated include:

- Recreational use and nonuse values related to ecological resources and services (e.g., bird watching, recreational fishing and hunting);
- Other recreational activities such as swimming and boating;
- Scenic values (e.g., vistas); and
- Drinking water services (surface and groundwater with prior designated use).

For the NRDA, it is necessary to quantify the value of the loss of services based on:

- "Willingness to pay" (WTP) to avoid the loss;
- Consumer and producer surplus values (e.g., not the cost of the fishing trip, but the value to the person using the service over-and-above the cost of partaking);
- Availability of substitute services; and
- Other economic factors.

The responsible party (RP) must pay interest for prior and future service losses. Future losses and gains of restoration are discounted.

The steps involved in an NRDA include:

- Preliminary Assessment
    - Ephemeral data collection
    - Documentation that injury has likely occurred
- Injury Assessment/Restoration Planning
    - Injury determination
    - Injury quantification
    - Damage determination
- Restoration Implementation

During this process, the NRDA Trustees are required to provide opportunities for public review on:

- Assessment Plan
- Restoration and Compensation Determination Plan
- Restoration Plan
- Significant modifications to the Restoration Plan

1.6 Settlement of NRDA

The US government has the statutory authority to pursue monetary damages from entities that injure natural resources. The monetary damages are used to make the public whole after environmental harm by restoring the injured natural resources to their baseline conditions. These damages are independent of the costs for cleanup. The funds must be spent on restoration.[25]

The damage assessment process is used to determine the nature and extent of injury and the amount of compensation (damages) for the injuries caused by the spill or contamination. Once damages are determined, the US Department of the Interior's (DOI) NRDA Restoration Program attempts to negotiate a settlement with the parties responsible for the release of oil or hazardous substances for the cost of the restoration, the interim loss of use of the natural resource by the public, and the reasonable costs incurred by the NRDA Restoration Program to assess the damages. If the NRDA Restoration Program is unsuccessful in negotiating a settlement, the United States can then take the responsible parties to court.[26]

The physical and scientific evidence of natural resource injury forms the basis for the Department's claim for appropriate compensation through settlements that enable the NRDA Restoration Program to contribute to the DOI's goals of protecting the nation's natural and cultural resources. Information regarding the nature and extent of the injury, and the means by which they are determined, also help establish the goals of the restoration plans and influence the determination of when those goals have been successfully reached.

In practice, the trustees must both demonstrate (determine) that an injury has occurred and quantify the interim losses resulting from the injury. While potentially responsible parties (PRPs) are in some cases 'cooperative" with the trustees, it is not in their interest to proactively support studies that quantify injuries, leaving many studies to be supported by trustees with limited resources. When supporting scientific information and/or data are incomplete, the injury quantification is often questioned rigorously by the PRP's experts. A typical argument is that the losses are not measurable as they are less than the uncertainty in the data or natural variability. This makes it difficult for the trustees to press claims fully, and settlements may be made in the interest of expediting funding for restoration rather than continuing the assessment and negotiations over lengthy periods of time.

When an agreement is reached between the parties, the applicable US district court has to approve a consent decree. A consent decree is an agreement or settlement that resolves a dispute between two parties without admission of guilt or liability. The consent decree specifies the terms of the settlement, including the damages that need to be paid to the Trustees.

[25] Bradshaw 2016.
[26] https://www.doi.gov/restoration/damageassessment

1.7 Hudson River PCB NRDA Status

The NRDA Trustees for the Hudson River, including National Oceanic and Atmospheric Administration (NOAA); US Fish and Wildlife Service (FWS); New York State Department of Environmental Conservation (NYSDEC), and the National Park Service (NPS), have released reports related to early steps for an NRDA. The trustees have documented injuries have occurred but have not provided their plans for injury quantification and damage assessment whereby dollar damages will be estimated and negotiated with the responsible party. It could reasonably be anticipated that the NRDA would involve several additional years of analysis by the trustees, given the extent of the contamination and complexity of the problem.

1.8 Summary Timeline of PCBs in the Hudson River

The following is a brief timeline of significant developments related to contamination of the Hudson River with PCBs:

1929: Monsanto Company begins making PCBs.[27] They are used in capacitors, transformers, plasticizers, surface coatings, inks, adhesives, pesticide extenders, and carbonless duplicating paper.[28]

1947: GE Fort Edward Plant begins to discharge PCB-laden waste into Hudson River.

1952: GE Hudson Falls Plant begins to discharge PCB-laden waste into Hudson River.[29]

1973: Deteriorating Fort Edward dam removed, increasing the amounts of PCBs carried downstream.

1974: US Food and Drug Administration (FDA) sets safety threshold of 5 ppm PCBs in fish for human consumption.

1974: Use of PCBs restricted to production of capacitors and transformers.[30]

1974: EPA study shows high levels of PCBs in Hudson River fish.

1976: US Congress passes the Toxic Substances Control Act banning manufacture of PCBs and prohibiting all uses except in totally enclosed systems.

1976: NYSDEC bans fishing in Upper Hudson River between Fort Edward dam and Federal Dam at Troy, closes commercial fisheries on Hudson River, and warns public of dangers of eating Hudson River fish.

1976: Administrative Hearing finds GE at fault for PCB pollution of Hudson River.

1977: Direct discharges of PCBs halted. Indirect discharges continue. Both GE Plants continue to dispose of PCB-laden waste into nearby landfills and wastewater collection systems (e.g., sewers and municipal

[27] https://www.clearwater.org/news/timeline.html

[28] EPA Fact Sheet 2016-09: Polychlorinated Biphenyls (PCBs) (Arochlors). https://www.epa.gov/sites/production/files/2016-09/documents/polychlorinated-biphenyls.pdf

[29] Discharges between 1956 and 1975 have been estimated at about 30 pounds per day or about 11,000 pounds per year (EPA 2000c). EPA has estimated that the two GE manufacturing facilities located in Fort Edward and Hudson Falls discharged up to 1.3 million pounds of PCBs into the river (EPA 2002), but the actual amount of PCBs discharged into the river, while unknown, could be significantly higher.

[30] ATSDR 1997.

wastewater treatment plants).[31] GE agrees to spend $1 million on PCB research and $3 million to monitor PCB pollution in Hudson River.[32]

1977: Monsanto Company ceases all production of PCBs.

1979: PCBs no longer used in production of capacitors and transformers.

1983: EPA releases updated Superfund National Priority List, which includes the Upper Hudson River.

1984: Record of Decision (ROD) is issued by EPA to stabilize remnant deposits upstream of Fort Edward dam. Field surveys showed PCB contamination in 40 submerged sediment hot spots, five exposed shoreline remnant deposits, dredge spoils on the banks of the Upper Hudson River, and in estuary sediments. In-place containment of remnant shoreline deposits is selected as remediation. The alternative to address submerged PCB hot spots was not selected due to "lack of existing data to establish that existing technology would be effective and reliable."

1984: FDA revises safety threshold for PCBs to 2 ppm for human consumption.

1985: NYSDEC closes commercial striped bass fisheries in New York Harbor and western Long Island.

1987: NYSDEC reopens recreational striped bass fisheries in New York Harbor and western Long Island, although health advisories remain in effect.

1987: NYSDEC designates GE's Hudson Falls Plant as a State Superfund site.

1989: NYSDEC requires GE to conduct further investigations of contamination and to evaluate possible on-site and off-site cleanup alternatives.

1989: NYSDEC asks EPA to reconsider 1984 ROD.

1989: NYSDEC releases Hudson River PCB Action Plan calling for dredging of 250,000 pounds of PCBs from Hudson River.

Mid-1990s: Water quality monitoring indicates continued release of PCBs to Hudson River. Water testing in the Upper Hudson River show unusually high levels of PCBs (4,539 parts per trillion, ppt, or 0.0045 parts per billion, ppb).[33] Residual PCBs are shown to seep into river through fractured bedrock beneath Hudson Falls plant site.[34]

1993: NYSDEC and GE agree to begin cleanup at Hudson Falls and Fort Edward sites.

1995: NYSDEC reopens catch-and-release fishing in Upper Hudson River.

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[31] US EPA 1997.
[32] https://www.clearwater.org/news/timeline.html.
[33] https://www.clearwater.org/news/timeline.html
[34] These seeps combined with other locations are a continuing source of PCB inputs to the Hudson and appear to be contributing approximately 0.2 pounds of PCBs per day (QEA 1999).

1996: After the release of scientific papers on elevated PCB blood levels in Hudson Valley residents through non-consumption exposure, the EPA states that PCB health risk assessment will not include inhalation pathway, endocrine disruption effects, or risks to women and children.[35]

1997: US Fish & Wildlife Service releases study showing high concentrations of PCBs in tree swallow bodies and eggs.

1997: NY Governor announces NY will join federal government in establishing a Hudson River National Resource Trustee Council. The *Preassessment Screen Determination for the Hudson River* is released determining that a Natural Resource Damages claim is warranted and should be pursued.[36]

2000: Phase 3 of EPA PCB Reassessment begins. EPA releases Feasibility Study Scope of Work outlining process of conducting Feasibility Study and remediation plan. EPA recommends that 2.65 million cubic yards of contaminated sediments be dredged from Upper Hudson River.[37]

2002: Hudson River Natural Resource Trustees release the *Hudson River Natural Resource Damage Assessment Plan.*[38]

2003: Hudson River Natural Resource Trustees release the report, *Injury Determination Report: Hudson River Surface Water Resources: Hudson River Natural Resource Damage Assessment.*[39] This report was updated in January 2008 with a public release in December 2008.[40]

2003: EPA's April 2003 Draft Community Involvement Plan for Hudson River PCBs Superfund Site identifies interests for development of Hudson River PCBs Community Advisory Group (CAG).

2004: Hudson River PCBs CAG holds its first official meeting to:

- Promote broad, balanced representation of communities and stakeholders along the entire site, in this case the Hudson River;
- Encourage more routine and consistent communications and coordination between EPA and the community;
- Solicit ongoing recommendations about ways to enhance community involvement;
- Provide an avenue for the community to voice its needs and concerns; and
- Provide for a consistent source of dialogue for EPA to gauge interests and needs.

2004: ROD executed with GE constructing underground well system to intercept and collect remaining PCBs in bedrock to prevent future migration into the river (Tunnel Drain Collection System).

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35 https://www.clearwater.org/news/timeline.html
36 Hudson River Trustee Council 1997 (https://www.dec.ny.gov/lands/32758.html)
37 US EPA 2000a.
38 Hudson River Trustee Council 2002.
39 Hudson River Natural Resource Trustees 2003.
40 Hudson River Natural Resource Trustees 2008.

2006: Hudson River Natural Resource Trustees release the report, *Injuries to Hudson River Surface Water Resources Resulting in the Loss of Navigational Services: Hudson River Natural Resource Damage Assessment.*[41]

2009: EPA orders Phase 1 dredging operations, which removes 283,000 cubic yards of contaminated sediment.

2011–2015: Phase 2 dredging operations conducted removing 2.75 million cubic yards of contaminated sediment.

2011: Hudson River Natural Resource Trustees release the reports:

- *Congener-Specific Analysis of Polychlorinated Biphenyl Residues in Tree Swallow Chicks, Eggs, and Other Biota from the Hudson River*[42]
- *Organochlorine Contaminants in Bald Eagle Eggs.*[43]
- *Organochlorine Contaminants in Biota from the Hudson River, New York.*[44]
- *Organochlorine Contaminants in Tree Swallow Nestlings and in Adipose Tissue from Great Blue Heron Nestlings: Hudson River Natural Resource Damage Assessment.*[45]
- *Polychlorinated Biphenyls and Organochlorine Pesticides in Bald Eagles and Fish from the Hudson River, New York, Sampled 1999-2001.*[46]
- *Polychlorinated Biphenyls and Organochlorine Pesticides in Bald Eagle Blood and Egg Samples from the Hudson River, New York.*[47]
- *Preparation of Individual and Custom PCB Mixture Dosing Solutions for Avian Egg Injection Studies Associated with Injury Determinations under the Hudson River NRDA: Hudson River Natural Resource Damage Assessment.*[48]

2012: Hudson River Natural Resource Trustees release the report, *Study Plan for Mink Injury Determination: Investigation of Mink Abundance and Density Relative to Polychlorinated Biphenyl Contamination within the Hudson River Drainage: Hudson River Natural Resource Damage Assessment.*[49]

2014: Hudson River Natural Resource Trustees release the reports:

- *Population Assessment and Potential Functional Roles of Native Mussels in Select Reaches of the Upper Hudson River: 2013 Remedial Injury Pilot Study*[50].

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[41] Hudson River Natural Resource Trustees 2006.
[42] Hudson River Natural Resource Trustees 2011a.
[43] Hudson River Natural Resource Trustees 2011c.
[44] Hudson River Natural Resource Trustees 2011b,
[45] Hudson River Natural Resource Trustees 2011d.
[46] Hudson River Natural Resource Trustees 2011e.
[47] Hudson River Natural Resource Trustees 2011f.
[48] Hudson River Natural Resource Trustees 2011g.
[49] Hudson River Natural Resource Trustees 2012.
[50] Hudson River Natural Resource Trustees 2014a.

- *Responsiveness Summary for the Hudson River Natural Resource Damage Assessment Plan.*[51]
- *Study Plan for Mussel Injury Investigation for the Hudson River: Hudson River Natural Resource Damage Assessment.*[52]

2015: ROD executed with GE manually recovering PCB oil recovery from bedrock wells, along with routine water sampling and annual groundwater and biota monitoring.

2015: Hudson River Natural Resource Trustees release the reports:

- *Injuries to Hudson River Fishery Resources: Fishery Closures and Consumption Restriction: Hudson River Natural Resource Damage Assessment.*[53]
- *Injury Determination Report: Hudson River Groundwater Resources: Hudson River Natural Resource Damage Assessment.*[54]
- *PCB Contamination of the Hudson River Ecosystem Compilation of Contamination Data Through 2008: Hudson River Natural Resource Damage Assessment.*[55]

2016: Hudson River Natural Resource Trustees release the reports:

- *Pilot Study for the Characterization of Sediment Chemistry, Sediment Toxicity, and Benthic Invertebrate Community Structure for PCB-Contaminated Sediments from the Upper Hudson River, New York: Hudson River Natural Resource Damage Assessment.*[56]
- *Fact Sheet Hudson River: Predicting Future Levels of PCBs in Lower Hudson River Fish.*[57]

2017: Hudson River Natural Resource Trustees release the reports:

- *Data Report for the Collection of Gray Catbird Eggs along the Hudson River from Hudson Falls to Schodack Island, New York, for Exposure to Polychlorinated Biphenyls (PCBs).*[58]
- *Data Report: PCB Concentrations in Mink Prey Items–Fish, Frogs, and Small Mammals–Collected from the Hudson River.*[59]

2017: EPA issues *Proposed Second Five-Year Review Report for Hudson River PCBs Superfund Site,* which concludes that GE's cleanup efforts have been satisfactory.[60]

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[51] Hudson River Natural Resource Trustees 2014b.
[52] Hudson River Natural Resource Trustees 2014c.
[53] Hudson River Natural Resource Trustees 2015e.
[54] Hudson River Natural Resource Trustees 2015f.
[55] Hudson River Natural Resource Trustees 2015g.
[56] Hudson River Natural Resource Trustees 2016b.
[57] Hudson River Natural Resource Trustees 2016a.
[58] Hudson River Natural Resource Trustees 2017a
[59] Hudson River Natural Resource Trustees 2017b.
[60] US EPA 2017.

2017: NYSDEC rejects findings of the EPA report *Proposed Second Five-Year Review Report for Hudson River PCBs Superfund Site* stating that research and analyses by NYSDEC revealed unacceptable levels of PCBs in river sediment and fish tissues.[61]

2017: NOAA, representing the Federal Trustees, expresses concerns about the findings of the EPA report *Proposed Second Five-Year Review Report for Hudson River PCBs Superfund Site* citing:

- Substantial quantities and very high levels of sediment PCB concentration in natural resources and human use of resource, resulting in "ongoing injury and lost uses to the public;"
- Overestimated rates of recovery for PCBs in water, sediment, fish, and PCB load traveling from the Upper to Lower Hudson River;
- The magnitude of contamination remaining, which may limit the type and amount of in-river restoration option available, especially in the Upper Hudson River;
- Need for a robust and data-driven monitoring program due to the extended recovery time; and
- The remedial work in the Upper Hudson River having little or no beneficial impact in the Lower Hudson River.[62]

2018: Hudson River Natural Resource Trustees release the report, *Injury Determination Report: Hudson River Surface Water Resources: Hudson River Natural Resource Damage Assessment.*[63]

2018: EPA reports to CAG (November 2018) that:

- There are ongoing discussions with NYSDEC and GE on habitat monitoring, fish monitoring, and cap monitoring programs;
- Preliminary risk assessments have begun;
- A draft Screening-Level Ecological Risk Assessment report has been submitted to EPA, which identifies representative species that may be impacted by PCBs; and
- A draft Human Health Screening Level Assessment report has been submitted to EPA, which identifies properties needing further evaluation for risk to human health.

2019: EPA announced two actions in April 2019:

- Issuance of the *Final Second Five-Year Review Report for the Hudson River PCBs Superfund Site*,[64] which includes EPA's decision to defer a determination of the protectiveness of the remedy in the Upper Hudson River until more years of Hudson River fish data are gathered.
- Issuance of a Certificate of Completion (COC) to GE for activities it conducted that were components of the remedy selected for the cleanup of the Upper Hudson River. This is the second in a series of three COCs. This first was issued in 2012 and the third is not expected to be available to GE for more than five decades. The third COC is not currently being contemplated.[65]

[61] NYSDEC 2017.
[62] NOAA 2017.
[63] Hudson River Natural Resource Trustees 2018f.
[64] US EPA 2019.
[65] https://www.epa.gov/sites/production/files/2019-04/documents/hudson_news_release_final_0.pdf

2019: Upon receipt of EPA's announcement of issuance of the second COC to GE, New York Governor Andrew Cuomo announced intent to sue to EPA "for failing to hold GE accountable."

1.9 US EPA Final Second Five-Year Review

In April 2019, the EPA released the *Final Second Five-Year Review Report for the Hudson River PCBs Superfund Site*.[66] In the report, EPA stated that it is "deferring a determination about the protectiveness of the remedy in the Upper Hudson River until more years of Hudson River fish tissue data are gathered."

EPA will continue collecting and evaluating water, sediment, fish and habitat data necessary to track the recovery of the Upper Hudson River, as it continues necessary, additional, environmental investigations of the Upper Hudson floodplain and supplemental studies of the Lower Hudson River below the Troy Dam." [*Note that as of the writing of this report, EPA has not yet released the Operation, Maintenance & Monitoring (OM&M) plan.*]

Over the course of 2018, EPA reviewed data collected by NYSDEC from approximately twelve hundred sediment samples taken by the state in 2017 from the Upper Hudson River, along with the results from some 215 sediment samples taken by GE in 2016 under EPA direction. Available fish tissue samples were also analyzed in combination with sediment samples in an effort to review the effectiveness of the selected remedy (which included dredging and monitored natural attenuation) in the Upper Hudson in advancing the River's recovery. Both sediment and fish data were reviewed by river reach (pools in the Upper Hudson separated by dams), as well as by river section, as defined in the 2002 Record of Decision (ROD). The analysis by river reach was preferred by NYSDEC and provided the ability to look at fish populations within each reach to determine if they were showing improvement after dredging, or if populations in certain reaches (pools) were lagging behind what was projected in the remedy. Additionally, the individual sediment data points were plotted and analyzed by reach and river section to determine if areas of higher concentrations ("hot spots") remained in the Upper Hudson after dredging.[67]

Data was analyzed by both total PCB concentration as well as by "Tri Plus" (Tri+) PCB concentration. Tri+ concentrations represent an important subset of total PCBs known to bioaccumulate in fish (and any person or animal eating the fish), thus serving as an important metric for assessing the "protectiveness" of the remedy in promoting recovery of the Upper Hudson.

After analyzing the combined EPA/NYSDEC data, the EPA concluded that post-dredging fish, water, and sediment data results are inconclusive indicators of remedy "protectiveness" at this time. More time and monitoring are needed. EPA will continue to review fish data collected through semi-annual sampling for a number of years before it can make reliable conclusions on the effectiveness of the remedy (the combination of dredging and natural attenuation) in the Upper Hudson.[68]

1.7 Second Certificate of Completion of Remedial Action

In April 2019, concurrent with the release of the second five-year review, but in a separate action, EPA issued second (of three) Certificates of Completion (COC). In issuing the COC to GE after reviewing

[66] US EPA 2019.
[67] US EPA 2019.
[68] US EPA 2019.

NYSDEC and other data, EPA confirmed that the dredging, capping, habitat restoration, and deconstruction/decontamination of the sediment processing facility that was conducted between 2009 and 2016 were "properly performed in accordance with the 2006 Consent Decree between EPA and GE.[69]

In the EPA's press release, the agency stated that the COC was not based on the findings in the five-year review or conclusions about the "protectiveness" of the remedy, but only as an acknowledgment that the required activities were carried out by GE. "Under the terms of the Consent Decree, GE can be compelled to conduct further actions, potentially including additional dredging, should EPA conclude in the future, based on the semi-annual sampling that will occur under the ROD and any other relevant information, that the remedial action carried out in the Upper Hudson is not protective of public health or the environment."

Prior to the public issuance of the second COC, NYSDEC had an opportunity to review and respond to EPA's decision. NYSDEC Commissioner Basil Seggos. The Commissioner issued a letter to EPA[70] stating that the EPA had not addressed NYSDEC's concern that "the remedy for the Upper Hudson River is far from complete."

"As you know, EPA did not modify the scope of the remedial action when significantly more PCBs were identified during the project design, during project implementation, and even after more date became available after remedy implementation. EPA's stubborn refusal to do so has not been adequately explained. Based on recent EPA public statements, DEC now estimates that over 40% extra PCB mass (or more than 15 tons of PCBs) remains in the Upper Hudson, much more than EPA believed would remain after remediation."[71]

NYSDEC also identified concerns about concentrations of PCBs measured in fish after dredging activities. The first Record of Decision (ROD) target for fish PCB concentrations was 0.4 ppm in 2020, five years after the completion of dredging. The most recent measurements (in 2017) show concentrations three times the target, as the rate of decline is slower than expected. The second target, 16 years after dredging (2031), of 0.2 ppm is also unlikely to be met. NYSDC stated that the only remaining controls on human health and ecological risk are the NYS Department of Health fish consumption advisories, which are not completely effective for protecting the public and do not address ecological risk.

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[69] https://www.epa.gov/sites/production/files/2019-04/documents/hudson_news_release_final_0.pdf
[70] https://www.epa.gov/sites/production/files/2019-04/documents/seggos_to_lopez_4-5-19.pdf
[71] https://www.epa.gov/sites/production/files/2019-04/documents/seggos_to_lopez_4-5-19.pdf

Chapter 2: Summary of Biological Injuries from Trustee Studies

2.1. Ecosystem

Ecosystems along the Hudson River are polluted with PCBs from Hudson Falls to the mouth. In an ecosystem, PCBs can seep into the groundwater table, remain in the water column, settle out into riverbed sediments, and reach floodplain soils during flood events. These abiotic components maintain high levels of contamination today, with highest levels occurring immediately downstream of the GE facilities in the Upper Hudson River.[72] Interaction, ingestion, and absorption of these remaining contaminated components by biotic organisms propel PCBs through the trophic levels that make up the Hudson River ecosystem.

In 2013, the Trustees reviewed historic and recent data from the Hudson River ecosystem in order to assess current knowledge and contamination levels. Surface water samples have been taken throughout the Hudson River since the 1970s and although average PCB concentration has slightly decreased, levels remain in exceedance of current critical threshold levels (NYSDEC: 0.000014 ppb for protection of freshwater aquatic life). Surface sediments throughout both the Upper and Lower Hudson River also remain elevated beyond thresholds safe for exposed biota (NYSDEC: 0.042 ppm for wildlife bioaccumulation, 0.58 ppm for chronic benthic effects, and 83 ppm for acute benthic effects).[72]

2.2. Mink (Including Mink Prey) and Otter

Numerous studies have been conducted by the Trustees to determine the potential effect PCBs have on aquatic mammals. In 2001 the Trustees conducted a trapping study on mink, otters, and muskrat in the Upper Hudson River to determine their PCB levels. PCB levels exceeding criteria for reproductive and health impairment were found in mink and otters trapped and collected in contaminated areas along the Hudson River.[73] Animals collected further upstream generally had PCB levels below the no-effect threshold. Of the three mammal species studied, muskrat had the lowest PCB levels, while otters had the highest. The difference in PCB levels between species is likely related to varied foraging and life history patterns. Muskrats are vegetarians, whereas otters and mink are predators, and PCBs bioaccumulate to a greater extent higher in the food web. Otters have the longest life span of the three species and have a strong preference for aquatic over terrestrial prey, which likely contributes to the increased accumulation in these animals.

Mink have been the focus of the subsequent Trustees' studies because of their presence in contaminated areas along the Hudson River, known sensitivity to PCBs, and ability to be utilized in lab experiments. Common mink prey items in the Hudson River, including fish, frogs, and small mammals, were studied to determine if PCB accumulation in mink is due to floodplain- or river-based prey components.[74] All prey items were contaminated with some level of PCBs, indicating mink along the Hudson River are exposed to and can accumulate high levels of PCBs from both aquatic and floodplain-based prey sources. Health effects directly linked to diets that contained PCB contaminated fish from the Hudson River include reduced reproductive performance of adult female mink and offspring survival and growth and severe jaw

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[72] Hudson River Natural Resource Trustees 2015g
[73] Mayack and Loukmas 2001
[74] Hudson River Natural Resource Trustees 2017a

lesions.[75,76] Specifically, kit mortality is expected even if the diets of mink residing and foraging along the Upper Hudson River contain less than 10% fish contaminated with environmentally relevant concentrations of PCBs.[77] Given this high potential for kit mortality with the consumption of even low amounts of contaminated prey, Trustees assessed whether PCB contamination can affect species at the population level. In a survey conducted in 2013 and 2014, mink densities along the polluted Hudson River and relatively clean Mohawk River were compared using genetic samples of mink scat collected in both regions. Hudson River mink densities were 40% lower than those estimated along the Mohawk River, indicating PCB contamination not only causes individual injury but severe declines in regional populations as well.[78]

2.3. Avians

Birds can be exposed to PCBs through ingestion of contaminated water, soil, or sediment, consumption of PCB laden prey, or maternally from adult females to eggs.[79] The sensitivity of wild birds to PCBs has varied widely among species, with critical egg thresholds for reproduction of intermediately sensitive species ranging from 6 ppm to 50 ppm.[80,81] To assess the extent of the PCB contamination in birds using the Hudson River Basin, the Trustees began sampling and testing a variety of bird species for PCB concentrations in various tissues including, eggs, fat and muscle, and liver.[82] In the late 1990s Trustees collected nestlings of tree swallows and great blue herons, two bird species know to utilize various habitats along the Hudson River.[83] PCB concentrations in tree swallow nestlings were significantly lower than those found in great blue heron nestlings, likely reflecting relative positions in the food web, with levels ranging from 0.51 ppm to 8 ppm in swallows and 15 ppm to 220 ppm in herons. In 2002, Trustees conducted an extensive preliminary avian exposure study and collected eggs from the nests of belted kingfisher, American robin, Eastern phoebe, spotted sandpiper, red-winged blackbird, and American woodcock. These species were selected as the focus of the study because they represented different ecological niches, utilize wetland/floodplain habitat for at least a portion of their lifecycle, and consume prey items with documented PCB contamination. In addition, eggs of Eastern screech owl, common grackle, northern rough-winged swallow, barn swallow, and Eastern bluebird were sampled opportunistically. Overall, PCBs were detected in all sampled eggs, with contamination levels typically higher in regions closer to the pollution source; however, this pattern was not realized for all species. Average concentration for each species sampled ranged from 0.096 ppm (American woodcock) to 15.2 ppm (spotted sandpiper). Spotted sandpiper and belted kingfisher, two species highly associated with aquatic foraging behaviors, had the highest concentrations of PCBs in eggs.

Belted kingfisher, spotted sandpiper, and tree swallows were further examined to assess differences in the PCB levels of insectivorous, omnivorous, and piscivorous bird species.[84] PCB levels were on average highest in omnivorous sandpipers (12.6 ppm), followed by piscivorous kingfishers (10.6 ppm) and then

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75 Bursian et al. 2013a
76 Bursian et al. 2013b
77 Bursian et al. 2013a.
78 Sutherland et al. 2018
79 Hudson River Natural Resource Trustees 2015a
80 Harris and Elliott 2011
81 Hudson River Natural Resource Trustees 2015g
82 Hudson River Natural Resource Trustees 2006
83 Hudson River Natural Resource Trustees 2011e
84 Custer et al. 2010a

insectivorous tree swallows (6.8 ppm). Further analysis of injury from PCBs on sandpipers have been inconclusive, however, sampling results observed many birds with PCB contamination levels above estimated thresholds for reduced hatching in other species.[85] Although kingfishers sampled in these studies were similarly found to have elevated PCB levels, no evidence was found of reduced reproductive success in populations nesting along the Hudson River.[86]

2.4. Gray Catbird (Including Eggs)

Gray catbirds were the focus of an extensive Trustees-lead contamination study because they are known to both breed and forage in floodplain habitats along the Hudson River and are classified as having Type I (highest level) sensitivity to PCBs.[87] All catbird eggs sampled from four river sections (section 1-3 located in Upper and section 4 located in Lower Hudson River) had detectable levels of total PCBs. Concentrations in individual eggs ranged from 0.03 to 8.03 ppm, with eggs collected in the Upper Hudson River typically having higher PCB concentrations than the Lower Hudson River. Of the all eggs collected in the study, just under one quarter contained PCB levels exceeding ecologically significant levels, indicating increased potential for embryo mortality in catbirds along the Hudson River.[88] Trustees have not released information on the observed PCB-related injuries to catbirds along the Hudson River.

2.5. Tree Swallows

Tree swallows have been the subject of multiple Trustees-lead contamination and injury studies because they link PCBs from aquatic sediments to terrestrial wildlife through consumption of insect prey that inhabit the river bottom as larvae, have documented high PCB levels, breed and forage in high abundances along the Hudson River, and are willing to utilize nesting boxes, which aids in surveying. Results from these studies have found that tree swallows contain high levels of PCBs across all life stages, with observed concentrations of 77 ppm in eggs,[89] 96 ppm in nestlings,[90] 190 ppm in adults.[91] PCB contamination at these levels has been linked to impaired reproductive success due to high levels of nest abandonment,[89] abnormal nest building behavior,[92] which resulted in lower quality nests, and unusual plumage expression in sub-adult females during the breeding season.[93,94]

More recent research on tree swallow survival in relation to PCBs in the Hudson River found little conclusive evidence of a direct relationship between PCB contamination and survival. However, the researchers observed lower survival rates in females with brown plumage when compared to those with blue plumage.[95] In addition, to assess effects on developing cardiovascular systems, tree swallow eggs from uncontaminated sites were lab dosed with PCBs. These hatchlings were compared to environmentally

[85] Custer et al. 2010b
[86] Bridge and Kelly 2013
[87] Hudson River Natural Resource Trustees 2017a
[88] Hudson River Natural Resource Trustees 2017a
[89] McCarty and Secord 1999a
[90] Echols et al. 2004
[91] Hudson River Natural Resource Trustees 2011a
[92] McCarty and Secord 1999b
[93] Secord and McCarty 1997
[94] McCarty and Secord 2000
[95] Custer et al. 2012

exposed hatchlings on the Hudson River.[96] No adverse effects on embryonic survival were observed in tree swallow nestlings environmentally exposed to or lab dosed with PCBs. Heart deformities were also not observed in environmentally exposed hatchlings, while deformities increased in eggs treated with 0.1 ppm and 1 ppm PCBs (PCB 77). Although multiple injury assessments have been conducted on tree swallows, conclusions have not included quantifiable injury and may indicate less sensitivity to these contaminants than other bird species inhabiting the Hudson River Basin.

2.6. Birds of Prey

Numerous contamination studies have also been conducted on birds of prey, such as bald eagle, peregrine falcon, screech owl. These species are of particular interest because they are at the top of the food web and at a high risk of accumulating PCBs from contaminated prey sources.

In the 1990s Trustees began monitoring bald eagle nests and collecting biological samples from eagles and likely prey items to assess reproductive success in the area.[97,98,99,100,101] Across the studies, bald eagle eggs that failed to hatch had high PCB levels ranging between 4.5 ppm and 62 ppm (wet weight). High PCB levels were also detected in Peregrine falcon, which are listed as Endangered by the State of New York, and screech owl eggs sampled along the Hudson River, with levels ranging from 5.29 ppm to 6.69 ppm in falcon eggs and 0.74 ppm to 7.5 ppm in owl eggs.[102,103]

Trustees have not released data pertaining to the quantification of injury to birds of prey residing along the Hudson River. However, PCBs have been shown to cause a variety of adverse effects on birds and could be hindering the reproductive success of these populations.[97]

2.7. Waterfowl

Previous research indicates waterfowl can rapidly accumulate PCBs in their tissues. Therefore Trustees collected both adult and juvenile mallards from the Hudson River to assess the extent of contamination and potential injury.[104] Mallards are the most numerous duck species in New York and breeding populations utilize the Hudson River Basin for five months, two of which birds are flightless and remain in the water or on the shore.[105] Mallards were collected from above the GE pollution source, the Upper Hudson River below the pollution source, and in the Lower Hudson River estuary. Results indicated that the PCB levels in both juvenile and adult mallards collected in the upstream reference site (above GE pollution source) were significantly lower than those collected in the Upper Hudson River and in the Hudson River estuary.[105] Birds collected in two areas below the GE pollution source in the Upper Hudson River had the highest PCB contamination levels (average: 39.15 ppm and 24.73 ppm), with concentrations in most birds surpassing the 3 ppm (in fat) federal tolerance value for PCBs in poultry. Only one bird from both the upstream and

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[96] Carro et al. 2018
[97] Hudson River Natural Resource Trustees 2015g
[98] Hudson River Natural Resource Trustees 2012
[99] Hudson River Natural Resource Trustees 2011b
[100] Hudson River Natural Resource Trustees 2011c
[101] Hudson River Natural Resource Trustees 2011d
[102] Hudson River Natural Resource Trustees 2004b
[103] Hudson River Natural Resource Trustees 2005a
[104] http://www.dec.ny.gov/lands/50958.html
[105] Hudson River Natural Resource Trustees 2013a

downstream estuary sample areas had concentrations above the federal threshold. Although potential health injury to humans has been assessed and PCB contaminant levels determined for waterfowl, the Trustees have not quantified toxic effect-related injuries directly to waterfowl in the Hudson River.

2.8. Fish

The Hudson River estuary's range of habitats and salinities supports a wide vary of fishes. The 2017 Great Hudson River Fish Count netted 1,325 samples of 48 species of fish, which gives a general sense of the distribution of species.[106] Species found in the Hudson River are shown in Table 7.

Table 7: Great Hudson River Fish Count (August 2017)[107]

Fish	Number of Specimens by Hudson River Mile												
	18	**25**	**28**	**35**	**55**	**59**	**61**	**76**	**84**	**92**	**123**	**133**	**Total**
American Eel	0	0	1	6	0	0	0	0	0	0	0	0	**7**
Alewife	0	0	0	0	7	9	0	0	0	0	0	0	**16**
Blueback Herring	0	0	0	29	16	7	0	0	0	0	0	0	**52**
Herring Species	0	0	0	16	0	0	0	0	0	20	20	31	**87**
Golden Shiner	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Spotfin Shiner	0	0	0	0	0	0	0	0	0	0	5	0	**5**
Spottail Shiner	0	0	0	0	45	6	1	0	0	10	23	10	**95**
Brown Bullhead	0	0	0	11	0	0	0	0	0	0	0	0	**11**
Oyster Toadfish	0	2	0	0	0	0	0	0	0	0	0	0	**2**
Banded Killifish	0	0	2	5	0	0	0	0	0	0	0	2	**9**
Mummichog	0	3	0	0	0	0	0	0	0	0	0	0	**3**
Atlantic Silverside	0	16	2	9	0	0	0	0	0	0	0	0	**27**
Northern Pipefish	0	0	8	1	0	0	0	0	0	0	0	0	**9**
White Perch	1	14	13	50	10	12	0	10	0	2	3	5	**120**
Striped Bass	4	47	5	335	8	6	6	29	0	15	10	0	**465**
Redbreast Sunfish	0	0	0	1	0	0	0	0	5	0	0	0	**6**
Pumpkinseed	0	0	0	0	0	0	0	1	0	0	0	3	**4**
Bluegill	0	0	0	0	0	1	0	0	0	0	0	0	**1**
Sunfish Species	0	0	0	8	0	0	0	0	0	0	0	0	**8**
Smallmouth Bass	0	0	0	0	0	0	0	0	3	0	0	0	**3**
Largemouth Bass	0	0	1	1	0	0	0	0	0	0	0	0	**2**
Tessellated Darter	0	0	0	0	0	0	0	1	0	0	0	4	**5**
Bluefish	0	11	0	12	0	0	0	0	0	0	0	0	**23**
Hogchoker	0	0	0	0	0	0	0	0	0	1	0	0	**1**
Total	**5**	**93**	**32**	**484**	**86**	**41**	**7**	**41**	**8**	**48**	**61**	**56**	**962**

In order to assess PCB related injuries to fish in the Hudson River, the Trustees conducted a multi-phase study, which included screening PCB levels in multiple fish species, reviewing previous research on effects

[106] http://www.dec.ny.gov/docs/remediation_hudson_pdf/hrepfc17rev.pdf
[107] http://www.dec.ny.gov/docs/remediation_hudson_pdf/hrepfc17rev.pdf

of PCBs in fish, and conducting a field study to assess the prevalence of abnormalities in fish in the Hudson River. Based on existing studies and screening levels of Hudson River fish, Trustees concluded that liver PCB concentrations between 0.3-70 ppm could result in reduced gonad growth, egg deposition, and survival.[108,109] The Trustees lead field study examined PCB levels and related injuries in brown bullhead, smallmouth bass, and yellow perch from the polluted Hudson River and less polluted references areas. Results indicated no lesions or changes in gonadal development associated with PCB exposure in bullhead or bass. In yellow perch, re-absorption of immature ovarian follicles was prevalent, but weakly associated with PCBs as it was present in fish from reference sites as well.[110,111]

Given current understanding of the relationship between contamination and injury in fish from PCBs in the Hudson River and elsewhere, quantification of injury at the population level apparently has not been attempted by the trustees or researchers. These studies suggest elevated tissues levels of PCBs in fish, but do not support a claim of direct injury to fish populations. However, measured levels of PCB contamination in fish are high enough to indicate injuries in wildlife predators are occurring on an on-going basis.

2.9. Sturgeon

Two species of endangered sturgeon, the Atlantic and shortnose, reside in the Hudson River. Atlantic sturgeon are anadromous and utilize the Hudson River estuary as adults to spawn and as juvenile for nursey habitat before seaward migrations. Shortnose sturgeon remain in the Hudson River through all life stages. Both sturgeon species are long-lived, benthic foragers, which makes them highly susceptible to PCB toxicity from contaminated Hudson River sediments. Because of the endangered status of these species and their high risk for toxic effects, Trustees conducted a pilot study to determine if early-life stages are sensitive to PCBs. Results from the study indicated that PCB toxicity lead to decreased hatching success and various sublethal effects including shortened body length and smaller head size, reduced quantity of yolk reserves, and delayed eye development.[112] Of the endpoints assessed, reduction of eye function was one of the most sensitive and ecologically important as underdevelopment of the eyes has been found to severely limit foraging success of the early-life stage of multiple species.

Overall, both species of sturgeon exhibit toxic responses to PCBs at concentrations within the range that could be present in the Hudson River estuary. However, population parameters, such as baseline natural mortality by life stage, are poorly understood, so injury quantification due to PCB exposure is a challenge. It does not appear that the trustees have quantified this injury.

2.10. Freshwater Mussels

An estimated 19 different freshwater mussel species reside in the Hudson River; however, characterization and documentation of these mussels is limited. Mussel populations are an important link in the community structure in these habitats as they enable energy flow between lower and higher trophic levels, filter materials from the water, and provide habitat for other organisms. Through filter-feeding activities, mussels can reduce the load of contaminants, such as PCBs, in the water, however, this process in turn increases

[108] Monosson 1999
[109] Hudson River Trustee Council 2002
[110] Hudson River Natural Resource Trustees 2017b
[111] Pinkney et al. 2017
[112] Chambers et al. 2012

chemical concentrations in the sediment (through produced waste) and allows for the trophic transfer of contaminants.[113] Mussel communities and habitat are at the highest risk of destruction during the on-going remedial dredging activities throughout the Hudson River. Since dredging began in 2009, it is likely large areas of native mussel beds have already been destroyed. To characterize mussel communities in unaltered areas in the Hudson River, the Trustees conducted a pilot and Remedial Injury study in 2013 and 2015, respectively.[114,115] Results from these Trustee studies have not yet been published

2.11. Amphibians

The Trustees have conducted multiple studies on a variety of frog species present along the Hudson River. Amphibians become contaminated with PCBs through contact with contaminated water, sediment, soil, and through the consumption of contaminated prey. As a central link in both aquatic and terrestrial food webs, amphibians can transfer contaminants to their high trophic level predators, which include fish, turtles, birds, and mink.[116]

In 2003, Trustees sampled bull frog tadpoles and sediment from sites along the Hudson River and found that PCB concentrations in tadpoles and sediments ranged from 0.4 ppm to 9.3 ppm and 2.6 ppm to 57.6 ppm, respectively, with concentrations decreasing with distance downstream.[117] In addition, PCB concentrations found in the tadpoles mirrored concentrations found in the sediment, indicating that in addition to PCBs transferring from female frogs to eggs and tadpoles, a significant amount of contamination comes directly from the environment. The Trustees also conducted a pilot study on the PCB contaminant levels in the breeding habitats of the wood frog and northern leopard frog. Results from this study suggested that although the small size of these populations does not lend itself to a full injury study, PCB levels in the sediment of these breeding areas are at ecologically significant levels.[118]

The Trustees have not directly quantified the injury to the amphibian populations along the Hudson River, however, the EPA determined the PCB concentrations of 1 ppm can pose significant adverse effects in amphibians, including unbalanced sex ratios, malformities during metamorphosis, and mortality.[119,120]

2.12. Reptiles

Of the few Trustee-lead contamination and injury studies conducted on reptiles, snapping turtles have been the focus, in part, because previous research indicates PCBs are associated with reduced hatching of eggs and behavioral abnormalities and biochemical alterations in adults.[121] In 2002, snapping turtle eggs were collected from sites along both the Upper and Lower Hudson River.[122] Trustees found that PCB concentrations in the snapping turtle eggs ranged from 0.07 ppm to 31.8 ppm with average concentrations decreasing with downstream sampling area. Research conducted on the effect of maternal PCB exposure

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[113] Bruner et al. 1994; Strayer 2012.
[114] Hudson River Natural Resource Trustees 2014a
[115] Hudson River Natural Resource Trustees 2014b
[116] Hudson River Natural Resource Trustees 2004a
[117] Hudson River Natural Resource Trustees 2007a
[118] Hudson River Natural Resource Trustees 2008
[119] Monosson 1999
[120] Hudson River Natural Resource Trustees 2014b
[121] Hudson River Trustee Council 2002
[122] Hudson River Natural Resource Trustees 2005c

on pre- and post-hatch snapping turtles from the Upper Hudson River and reference sites observed overall reduced growth rates and increased mortality of PCB exposed post-hatch juveniles.[123] Specifically, researchers found that turtles that were maternally exposed to PCBs from the Hudson River had mortality rates of 60% after 14 months post-hatch, compared to turtles from the reference sites that experienced only 10% mortality. In addition, mortality rate was positively correlated with total PCB levels and suggested that a roughly 20% reduction in survival for eggs with PCB levels of 3.3 ppm.[124,125]

[123] Eisenreich et al. 2009
[124] Monosson 1999
[125] Hudson River Trustee Council 2002

Chapter 3: Summary of Human-Use Injuries from Trustee Studies

The Trustees have also conducted a number of studies related to human use of natural resources, including groundwater contamination, surface water effects, loss of navigational services, and fisheries.

3.1. Groundwater Contamination

The Trustees have determined that an injury to groundwater occurred in the municipalities of Hudson Falls, Fort Edward, and Stillwater, New York. Groundwater near the Hudson Falls and Fort Edward plant sites has exceeded groundwater standards for over 20 years. The Village of Stillwater well field has exceeded the PCB standard for at least 10 years. Stillwater is approximately 25 miles downstream from Hudson Falls. Groundwater has not been used as a drinking water source in Fort Edward or Hudson Falls since the late 1980s. The Stillwater well field has not been in use since 2011.

Recent sampling has confirmed the general location, movement, and concentrations of contaminated groundwater at the Fort Edward plant site. Twelve sampling wells that had previously not detected PCBs through the late 1990s exceeded the New York State groundwater standard in 2011.[126]

The groundwater standards for PCBs are found in the New York Codes, Rules, and Regulations (6 NYCRR § 703.5). The standards have changed over the last 30 years. For PCBs, the standard for freshwater is 0.09 ppb (0.09 µg/L). The most restrictive standard for volatile organic compounds (VOCs) is 2 ppb for vinyl chloride. For dichlorobenzene, the standard is 3 ppb, and for chloroform the standard is 7 ppb. For all other VOCs, the standard is 5 ppb. Exceedance of these standards constitutes a natural resource injury pursuant to DOI NRDA regulations.

According to DOI NRDA regulations at 43 CFR §11,62 (c) (1), the definition of "groundwater injury" is:

- Concentrations of substances in excess of water quality criteria, established by section 1401(1)(d) of the Safe Drinking Water Act (SDWA), or by other Federal or State laws or regulations that establish such criteria for public water supplies, in groundwater that before the discharge or release met the criteria and is a committed use, as the phrase is used in this part, as a public water supply; or
- Concentrations of substances in excess of applicable water quality criteria, established by section 304(a)(1) of the Clean Water Act (CWA), or by other Federal or State laws or regulations that establish such criteria for domestic water supplies, in groundwater that before the discharge or release met the criteria and is a committed use as that phrase is used in this part, as a domestic water supply.

DOI's NRDA regulations at 43 CFR §11.62 (c) provide that groundwater is injured when the following conditions are met. The Trustees concluded that all four of these conditions had been met.[127]

- The concentrations and duration of hazardous substances measured in the groundwater are in excess of applicable water quality regulatory standards or guidance criteria established by section 1401(1)(d) of the Safe Drinking Water Act (SDWA), section 304 (a)(1) of the CWA, or by other

[126] Hudson River Natural Resource Trustees 2015c; Hudson River Natural Resource Trustees 2015f.
[127] Hudson River Natural Resource Trustees 2015f.

Federal or State laws or regulations that establish such criteria for public or domestic water supplies (43 CFR §11.62 (c)(1)(ii),(iii));

- The groundwater met the regulatory standard or guidance criteria before the discharge or release of the hazardous substance (43 CFR §11.62 (c)(1)(ii),(iii));
- The groundwater has a committed current or planned public use as a public or domestic water supply under applicable Federal or State laws or regulations that establish such criteria (43 CFR §11.62 (c)(1)(ii), (iii)); and
- Concentrations of hazardous substances are measured in (a) two groundwater samples from the same geohydrologic unit, obtained from two properly constructed wells separated by a straight-line distance of not less than 100 feet, (b) a properly constructed well and a natural spring or seep separated by a straight-line distance of not less than 100 feet, or (c) two natural springs or seeps separated by a straight-line distance of not less than 100 feet (43 CFR §11.62 (c)(2) (i)-(iii)).

The results of groundwater sampling for contaminants in Hudson Falls are shown in Table 8.

Table 8: Maximum Concentrations Detected in Groundwater at Hudson Falls[128]

Contaminant	Prior to 1989		1989–1997		1998–2011	
	Class GA Standard[129] (ug/L)	Maximum Concentration Detected	Class GA Standard (ug/L) 7	Maximum Concentration Detected	Class GA Standard (ug/L)	Maximum Concentration Detected
1,2,4-Trichlorobenzene[130]			5	7,700	5	399
1,2-Dichlorobenzene			4.7	31	3	4
1,3-Dichlorobenzene			4.7	36	3	4
1,4-Dichlorobenzene			4.7	110	3	5
Chlorobenzene			5	340	5	56
cis-1,2-Dichloroethene			5	120,000	5	121,000
trans-1,2-Dichloroethene		53	5	11,000	5	993
Toluene		10	5	13	5	241
Trichloroethylene		38	5	130,000	5	25,200
Vinyl chloride	5	75	2	27,000	2	2,590
1,1-Dichloroethane		15	5	8,200	5	3,280
1,1,1-Trichloroethane		2	5	15,000	5	1,520
Tetrachloroethylene			5	97	5	649
Chloroform	100	23	7	45	7	13
PCBs		1,630	0.10	2,100,000	0.09	72,000

Results for Fort Edward are shown in Table 9.[131] For the Village of Stillwater well field, located about 120 to 500 feet from and hydraulically connected to the Hudson River, sampling conducted in 2008

[128] Other contaminants detected at various times in concentrations exceeding water quality standards (WQS) are: 1,2,3-trichlorobenzene, chloroethane, napthalene, methylene chloride, ethyl benzene, benzene, 1,1-dichloroethene, and bis 2-ethylhexyl phthalate (BEHP).
[129] 6 NYCRR § 703
[130] Groundwater was only sporadically analyzed for chlorinated benzenes until the 1990s.
[131] Hudson River Natural Resource Trustees 2015f.

indicated PCB concentrations of 0.082 to 0.164 ppb.[132] Additional sampling indicated concentrations up to 0.196 ppb.

Table 9: Maximum Concentrations Detected in Groundwater at Fort Edward[133]

Contaminant	Prior to 1989		1989–1997		1998–2011	
	Class GA Standard (ug/L)	Max. Conc. Detected	Class GA Standard (ug/L) 7	Max. Conc. Detected	Class GA Standard (ug/L)	Max. Conc. Detected
1,2,4-Trichlorobenzene		1,100	5	240	5	80
1,2-Dichlorobenzene		8	4.7	8,900	3	63
1,3-Dichlorobenzene			4.7	12,000	3	120
1,4-Dichlorobenzene		1,071	4.7	6,900	3	190
Chlorobenzene		68	5	3,800	5	240
cis-1,2-Sichloroethene			5	760	5	3,000
trans-1,2-Dichloroethene		3,400	5	1,300	5	7
Toluene		70	5	39	5	117
Trichloroethylene		50,154	5	18,000	5	13,000
Vinyl chloride	5	4,452	2	136	2	270
1,1-Dichloroethane		233	5	3,600	5	7,000
1,1,1-Trichloroethane		6,238	5	1,100	5	29
Tetrachloroethylene		101	5	29	5	16
Chloroform	100	44	7	70	7	93
PCBs		110,000	0.10	10,000	0.09	38,300

3.2. Surface Water Resources: Human-Use Effects

Approximately 85% of the over 10,000 water samples that have been taken from the Hudson River since the mid-1970s have contained PCBs, often at concentrations an order of magnitude or more above relevant state and federal regulatory criteria. The exceedances have occurred through all parts of the river south of Hudson Falls and for every year sampled from 1975 through 2014.[134] The applicable PCB water quality standards and guidance criteria for human-use of surface waters are shown in Table 10.

These exceedances have occurred throughout all parts of the river and for every year sampled. According to the Hudson River Natural Resource Trustees, these exceedances of water quality standards "demonstrate that Hudson River's surface water has been and continues to be injured as a consequence of PCB exposure. These injuries are expected to continue into the future." The Trustees concluded that the 15% of samples that did not contain detectable concentrations of PCBs, were likely collected or analyzed with methods that were not sufficiently sensitive to detect the PCB concentrations present. In the post-2008 ambient water

[132] Malcolm Pirnie 2009; Palmer 2011.
[133] This table presents data for contaminants detected at the Hudson Falls site in each of the past two decades (1990 through 2012). Other contaminants which were detected at various times in concentrations exceeding WQS are: 1,2,3-trichlorobenzene, chloroethane, napthalene, methylene chloride, ethyl benzene, benzene, 1,1-dichloroethene, and BEHP.
[134] Hudson River Natural Resource Trustees 2018f.

quality data collected as part of the dredging-related baseline monitoring program and remedial action monitoring program, approximately 93% of samples contained detectable concentrations of PCBs.[135]

Table 10: Applicable PCB Water Quality Standards and Guidance Criteria: Human-Use[136]			
Standard (Applicability)	**Threshold[137]**	**Effective Dates**	**Authorities**
Human Health (All Surface Water)	0.000079 µg/l Guidance Criterion	11/28/80–2/4/93	45 FR 79318 (November 28, 1980) US EPA Ambient Water Quality Criteria for Polychlorinated Biphenyls. Office of Water Regulations and Standards. EPA 440/5-80-068. October 1980.
	0.000044 µg/l Guidance Criterion[138]	2/5/93–12/18/98	57 FR 60848 (December 22, 1992) (effective 2/5/93) 63 FR 68354 (December 19, 1998)
	0.00017 µg/l Guidance Criterion	12/19/98–11/02	US EPA National Recommended Water Quality Criteria–Correction. Office of Water. EPA 822-Z-99-001. April 1999.
	0.000064 µg/l Guidance Criterion	11/02–present	US EPA National Recommended Water Quality Criteria: 2002. Office of Water. EPA-822-R-02-047. November 2002.
Human Sources of Drinking Water (Class A, A-S, AA, and AA-S waters)	0.0095µg/l Guidance Criterion	1/23/84–8/1/85	NYSDEC Division of Water, Technical, and Operation Guidance Services (84-W-38) Ambient Water Quality Criteria. Dr. Robert Collin. January 23, 1984.
	0.01 µg/l Regulatory Standard	8/2/85–3/12/98	6 NYCRR § 701, App. 31 (until 8/91); 6 NYCRR § 703.5 (from 8/91 to 3/12/98)
	0.09 µg/l Regulatory Standard	3/12/98 –present	6 NYCRR § 703.5
Human Fish Consumption (All Surface Water)	0.0000006 µg/l Guidance Criterion	11/15/91–3/11/98	New York State Human Health Fact Sheet–Ambient Water Quality Value Based on Human Consumption of Fish and Shellfish. Polychlorinated Biphenyls, PCBs. November 15, 1991 and March 31, 1993. NYSDEC Division of Water. Technical and Operation Guidance Services (1.1.1.) Ambient Water Quality Standards and Guidance Values. John Zambrano. November 15, 1991
	0.000001 µg/l Regulatory Standard	3/12/98 - present	6 NYCRR § 703.5

The Hudson River Natural Resource Trustees offer that their 2018 report fulfills the requirements for surface water injury determination, as set forth in the DOI NRDA regulations (43 CFR §§11.61 and 11.62).

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[135] Hudson River Natural Resource Trustees 2018g.
[136] Hudson River Natural Resource Trustees 2018f.
[137] A PCB concentration of one microgram per liter (1 µg/l) means that there is one microgram (0.000001 gram) of PCBs per liter of water. Because a liter of water weighs 1000 grams, another way to express the concentration 1 µg/l is as 1 ppb, or one part per billion. EPA's 0.001 µg/l criterion can, therefore, also be written as 0.001 ppb.
[138] This criterion applies to measurements of individual Aroclors (e.g., Aroclor 1242) rather than to total PCBs.

Subsequent reports will address other NRDA requirements, such as pathway determination (43 CFR §11.63), injury quantification (43 CFR §11.70 et seq.), and damage determination (43 CFR §11.80 et seq.).

Water sampling has shown that exceedances of state and federal water quality standards have occurred through all parts of the river for every year sampled from 1975 to 2014.

During this time period, over 10,000 surface water samples were collected of which 8,667 contained PCBs at detectable concentrations. Nearly all exhibited concentrations that exceeded one or more regulatory standards –often at levels hundreds of times higher than relevant New York health-protective regulatory criteria for water:

- 0.00012 ppb to protect wildlife that eat fish; and
- 0.000001 ppb to protect human consumers of fish.[139]

The results of surface water PCB large-volume sampling programs are shown in Figure 7.

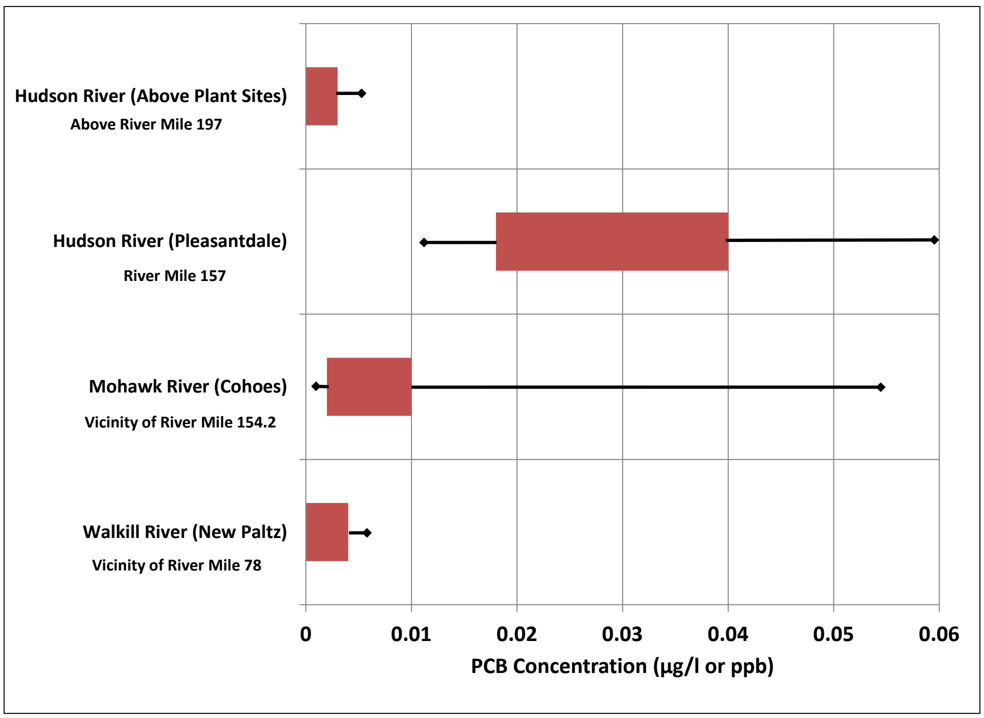

Figure 7: Surface Water PCB Concentrations in Hudson River and Tributaries[140]

The concentration above the plant sites and in the Mohawk River (the largest tributary, which enters the Hudson River south of the plant sites) and the Wallkill River (a tributary 119 miles south of the plant sites),

[139] Hudson River Natural Resource Trustees 2018g.
[140] Hudson River Natural Resource Trustees 2018e. Boxes represent 25th and 75th percentiles; whiskers represent maximum and minimum values. The horizontal line in the box indicates the median. Datasets used in this graph come from Bopp et al. (1985), EPA, and NYSDEC. The Mohawk River is the largest tributary of the Hudson. Its flow is approximately equal to that of the Hudson at their confluence. Other large tributaries below Poughkeepsie are about five percent of the main stem flow.

are all lower than the concentrations at Pleasantdale, 40 miles south of the plants and just above the Mohawk River confluence with the Hudson River.

The summary of exceedances of applicable PCB guidance criteria and regulatory standards for human-use surface water (Table 10) is shown in Table 11. As shown in Figure 8, the samples downstream of the plants exceeded concentrations of 0.001 µg/l and were orders of magnitude above the more stringent standards. Figure 9 shows the results for the most recent decade (2005–2014) by river mile.

Table 11: Exceedance of Human-Use Surface Water Guidance Criteria/Standards

Standard	Threshold	Effective Dates	% Exceedances
Human Health (All Surface Water)	0.000079 µg/l Guidance Criterion	11/28/80–2/4/93	87.4%
	0.000044 µg/l Guidance Criterion	2/5/93–12/18/98	Not calculated
	0.00017 µg/l Guidance Criterion	12/19/98–11/02	65.5%
	0.000064 µg/l Guidance Criterion	11/02–present	90.2%
Human Drinking Water Sources (Class A, A-S, AA, and AA-S waters)	0.0095µg/l Guidance Criterion	1/23/84–8/1/85	92.8%
	0.02 µg/l Regulatory Standard	8/2/85–3/12/98	79.9%
	0.09 µg/l Regulatory Standard	3/12/98 –present	31.5%
Human Fish Consumption (All Surface Water)	0.0000006 µg/l Guidance Criterion	11/15/91–3/11/98	86.4%
	0.000001 µg/l Regulatory Standard	3/12/98 - present	85.3%

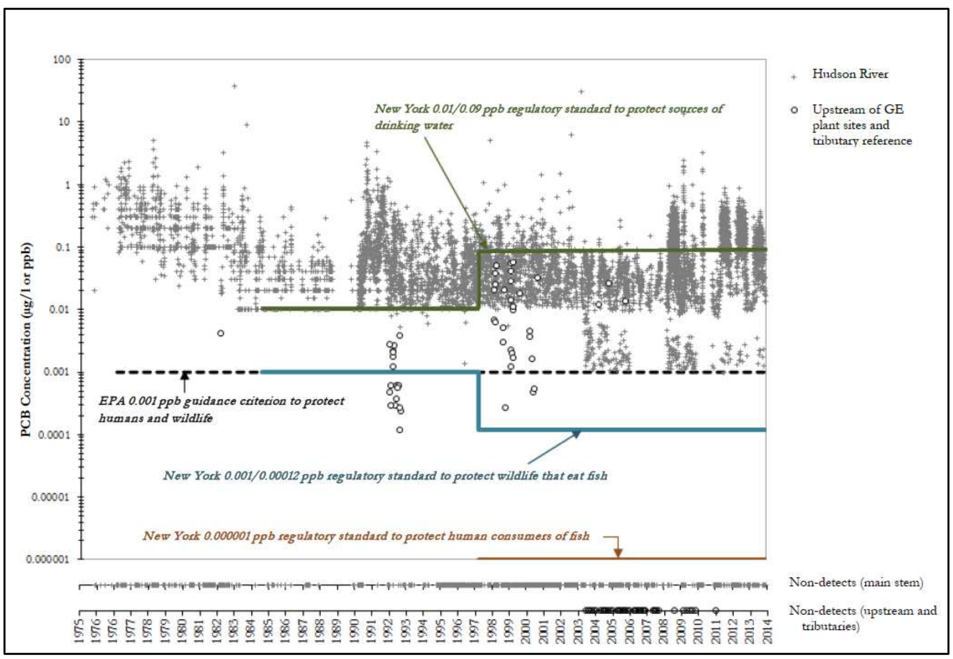

Figure 8: Hudson River Surface Water PCB Concentrations by Year 1975–2014[141]

[141] Hudson River Natural Resource Trustees 2018e.

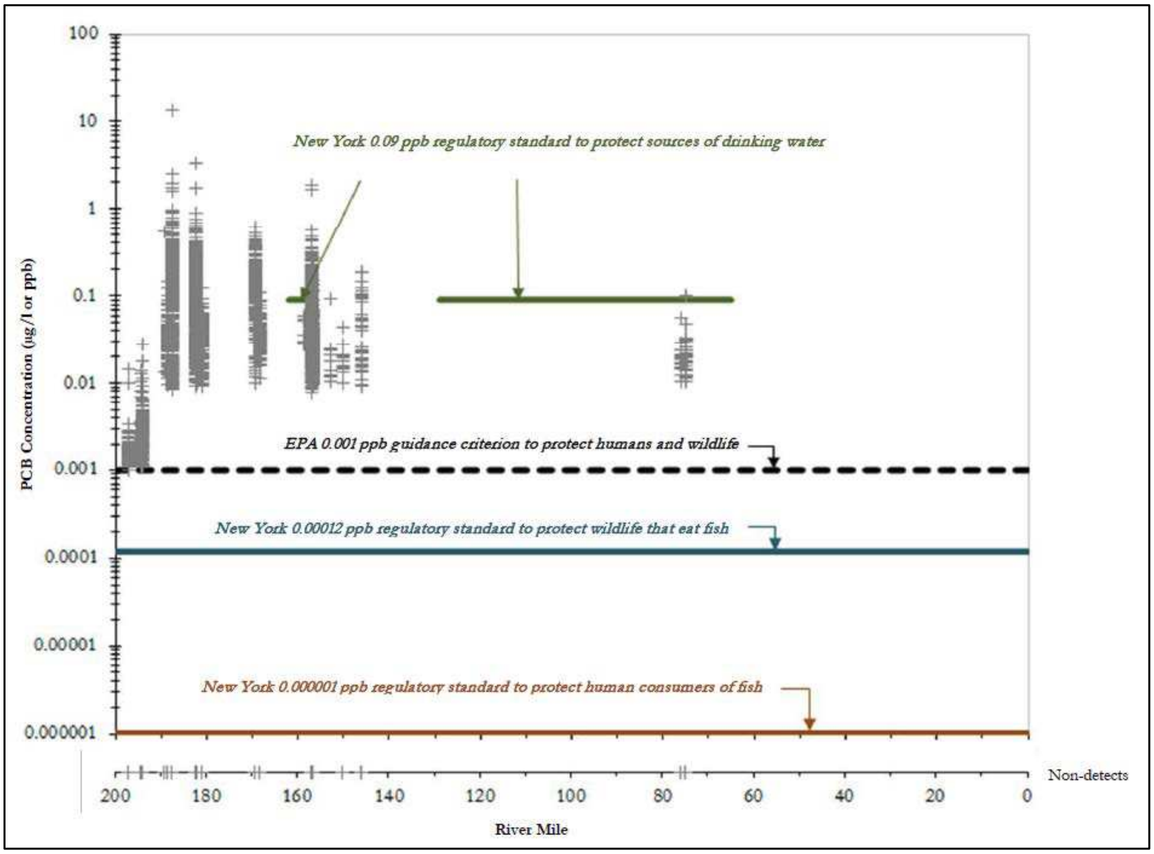

Figure 9: Hudson River Surface Water PCB Concentrations 2005–2014 by River Mile[142]

In establishing the injury to surface water resources, in addition to showing contamination, it must be established that the river water met the applicable regulatory standards prior to the release of the hazardous substance. The Trustees indicated that this element of the injury assessment is satisfied by the fact that median PCB concentrations upstream of the GE plants are 40-fold lower than median concentrations taken near Pleasantdale (as in Figure 7). In addition, NYSDEC had demonstrated that non-GE sources of PCBs in the Hudson River contributed negligible amounts prior to 1975.[143] Although PCB standards were not put in place until 1976, had the applicable standards been in effect at the time of GE's PCB releases, the surface water of the Hudson River between Hudson Falls and the Battery likely would not have complied with those standards.[144]

The third element that needs to be satisfied in the injury determination is that the resource must be a "committed use as a habitat for aquatic life, water supply, or recreation." The State of New York established these committed uses as summarized in Table 12. Note that not all of the communities along the Hudson have drinking water supply as a committed use of the river. The committed use for drinking water applies to communities along River Miles 65 to 129.2 and 156 to 162.

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[142] Hudson River Natural Resource Trustees 2018e.
[143] Interim Opinion and Order, "In the Matter of Alleged Violations of Sections 17-0501, 17-0511, and 11-0503 of the Environmental Conservation Law of the State of New York by General Electric Company," (February 9, 1976).
[144] Hudson River Natural Resource Trustees 2018e.

Table 12: Hudson River Committed Uses[145]

River Mile Range	Location Description	New York State Water Quality Class (Water Type)	Committed Uses[146]
0 to 14.5	Battery to New York/Bronx County border	Class I (Saline Surface Water)	**Secondary contact recreation** **Fishing** Fish propagation and survival (6 NYCRR § 701.13 *et seq.*)
14.5 to 47	New York/Bronx County border to Bear Mountain Bridge	Class SB (Saline Surface Water)	**Primary and secondary contact recreation** **Fishing** Fish propagation and survival (6 NYCRR § 701.11 *et seq.*)
47 to 65	Bear Mountain Bridge to Chelsea Station 4	Class B (Fresh Surface Water)	**Primary and secondary contact recreation** **Fishing** Fish propagation and survival (6 NYCRR § 701.7 *et seq.*)
65 to 129.2	Chelsea Station 4 to Houghtaling Island at light 72	Class A (Fresh Surface Water)	**Water supply for drinking, culinary or food processing** **Primary and secondary contact recreation** **Fishing** Fish propagation and survival (6 NYCRR § 701.6 *et seq.*)
129.2 to 156	Houghtaling Island at light 72 to Mohawk River confluence	Class C (Fresh Surface Water)	**Fishing** Fish propagation and survival Primary and secondary contact recreation[147] (6 NYCRR § 701.8 *et seq.*)
156 to 162	Confluence with Mohawk River to Lock 2 Dam	Class A (Fresh Surface Water)	**Water supply for drinking, culinary or food processing** **Primary and secondary contact recreation** **Fishing** Fish propagation and survival (6 NYCRR § 701.6 *et seq.*)
162 to 165	Lock 2 Dam to Lock 3 Dam	Class C (Fresh Surface Water)	**Fishing** Fish propagation and survival Primary and secondary contact recreation[148] (6 NYCRR § 701.8 *et seq.*)
165 to 182.2	Lock 3 Dam to confluence with Battenkill	Class B (Fresh Surface Water)	**Primary and secondary contact recreation** **Fishing** Fish propagation and survival (6 NYCRR § 701.7 *et seq.*)
182.2 to 197	Confluence with Battenkill to end of National Priorities List site	Class C (Fresh Surface Water)	**Fishing** Fish propagation and survival Primary and secondary contact recreation [149] (6 NYCRR § 701.8 *et seq.*)

[145] Hudson River Natural Resource Trustees 2018e.
[146] The designated "best use(s)" for each water class are indicated in boldface. Waters of a given class must also be suitable for the other listed purposes.
[147] Although factors other than water quality may limit the use for these purposes.
[148] Although factors other than water quality may limit the use for these purposes.
[149] Although factors other than water quality may limit the use for these purposes.

3.3. Surface Water Resources: Loss of Navigational Services

Another type of human-use loss from PCB contamination relates to injuries resulting from the loss of navigational services. This loss is due to the fact that the presence of PCBs has made the cost of dredging to maintain the Champlain Canal and Upper Hudson River from the Fenimore Bridge in Hudson Falls (River Mile 197.3) to the Federal Dam at Troy (River Mile 153.9) prohibitively expensive. This, in turn, has affected recreational and commercial navigation. With the inability to properly remove naturally accumulated sediment, the Canal and Upper Hudson River (Figure 10) have become increasingly more difficult and dangerous for navigation.[150]

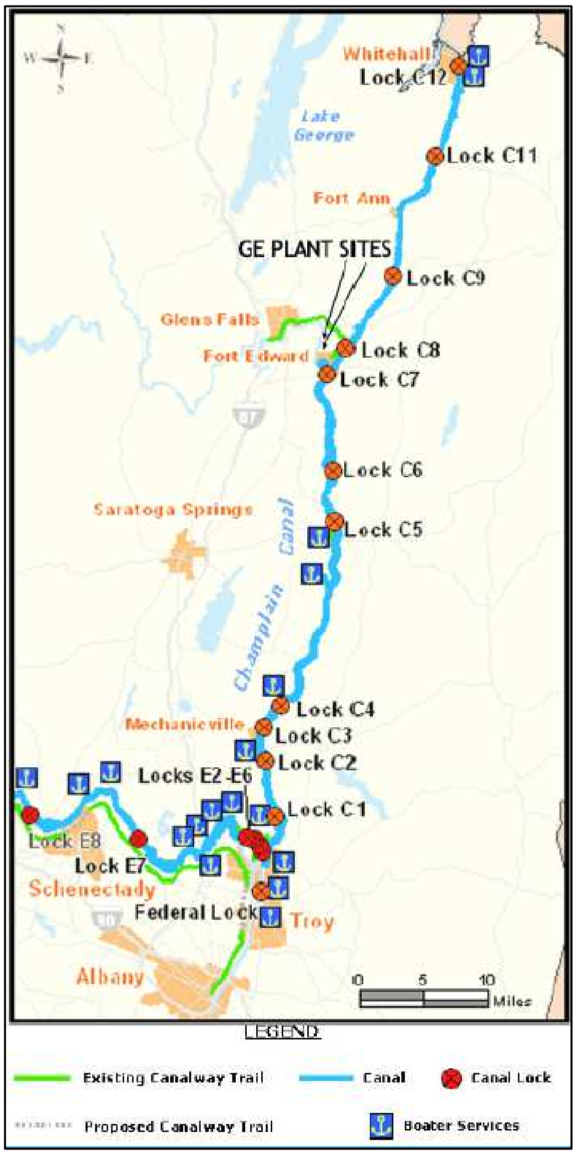

Figure 10: Champlain Canal[151]

[150] Hudson River Natural Resource Trustees 2006.
[151] Hudson River Natural Resource Trustees 2006.

The New York State Canal Corporation (NYSCC)[152] is required to by regulation to maintain a 200-foot wide main channel in the river sections of the Champlain Canal with a water depth of 12 feet.[153] Tug boats require a draft of 10 to 12 feet and barges require at least that much. Dredging was performed regularly on the Champlain Canal until about 1980. At that time, the presence of PCBs in the dredging material and the regulatory requirements for disposal of PCB-contaminated sediments made the cost of maintenance dredging prohibitively expensive. The cost of dredging with on-site disposal of dredged material from uncontaminated waterways is approximately $6 per cubic yard with hydraulic dredging, and $35 per cubic yard with mechanical dredging. The cost of dredging, treating, and disposing of PCB-contaminated sediments is over $300 per cubic yard (mechanical dredging).[154] In 1991, NYSCC reported that the canal channel below Fort Edward contained between 275,000 and 300,000 cubic yards of refill (silting) that could not be dredged. This has restricted vessel traffic.

In its annual Notice to Mariners, NYSCC reports the reduced depth of the canal. In 2005, it reported that in the 57 reaches in the Champlain Canal, over 72% had drafts less than 12 feet, and 12% were less than nine feet. One reach had a draft of only three feet. The latest available data from NYSCC (February 2019) indicate that 66% of depth testing locations (typically at buoys) have depths of less than 12 feet. The shallow sections are distributed throughout the river making navigation by vessels requiring a 12-foot depth impossible.

In 2005, the NYSCC identified reaches containing approximately 500,000 cubic yards of sediment that needed to be dredged from the Upper Hudson portions of the Champlain Canal for navigational purposes in the future. In 2011, NYSCC estimated that there were 628,000 cubic yards of contaminated sediment remaining in the navigation channel.[155] In 2013, NYSCC reported that there were “over 600,000” cubic yards of contaminated sediment remaining.[156]

The presence of PCBs in the sediment has added to dredging costs and to disposal costs. In the dredging process additional monitoring needs to be conducted to control for resuspension of contaminated sediment. The presence of PCBs in excess of specified concentrations (nominally 50 ppm, but in practice as low as 32 ppm) requires special transport and disposal in a landfill that meets the requirements of the Toxic Substances Control Act (TSCA) or incineration.[157]

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[152] The Champlain Canal was opened to traffic in spring 1916. The New York State Department of Public Works was originally charged with responsibility to maintain it. In 1967, that responsibility was transferred to New York State Department of Transportation and, in 1992, to New York State Thruway Authority, and then its subsidiary, the New York State Canal Corporation (Canal Corporation). Canal L. § 6(1). The Canal Corporation runs the New York State Canal System, which includes the Erie, Champlain, Oswego, and Cayuga-Seneca canals. Spanning 524 miles, the waterway links the Hudson River with the Great Lakes, the Finger Lakes and Lake Champlain. (http://www.canals.ny.gov/about/about.html)

[153] 21 NYCRR §155.2.

[154] Hudson River Natural Resource Trustees 2006.

[155] Moloughney 2011.

[156] Moloughney 2013.

[157] 40 CFR. §761.61 & § 761.3 (definition of "PCB remediation waste") and 6 NYCRR §371.4(e).

Another cost related to the inability of the NYSS to maintain the Champlain Canal channel depths and widths is from the fact that commercial traffic must use smaller, lighter loads, which has a direct impact on the cost-effectiveness of water transport.[158]

NYSCC stresses that the remedial dredging conducted under EPA are based on "hot spot" removal to achieve a goal of 1 ppm PCB residuals. This means that the majority of the river below Lock C6 (see Figure 10) will remain unremediated (and not dredged). NYSCC estimated that of the 2.4 million cubic yards in GE's dredging program, only 92,000 cubic yards (less than 4%) will improve navigation (for example, see Figure 11). The remedial dredging program will remove less than 15% of the total navigation dredging needs in the river.[159]

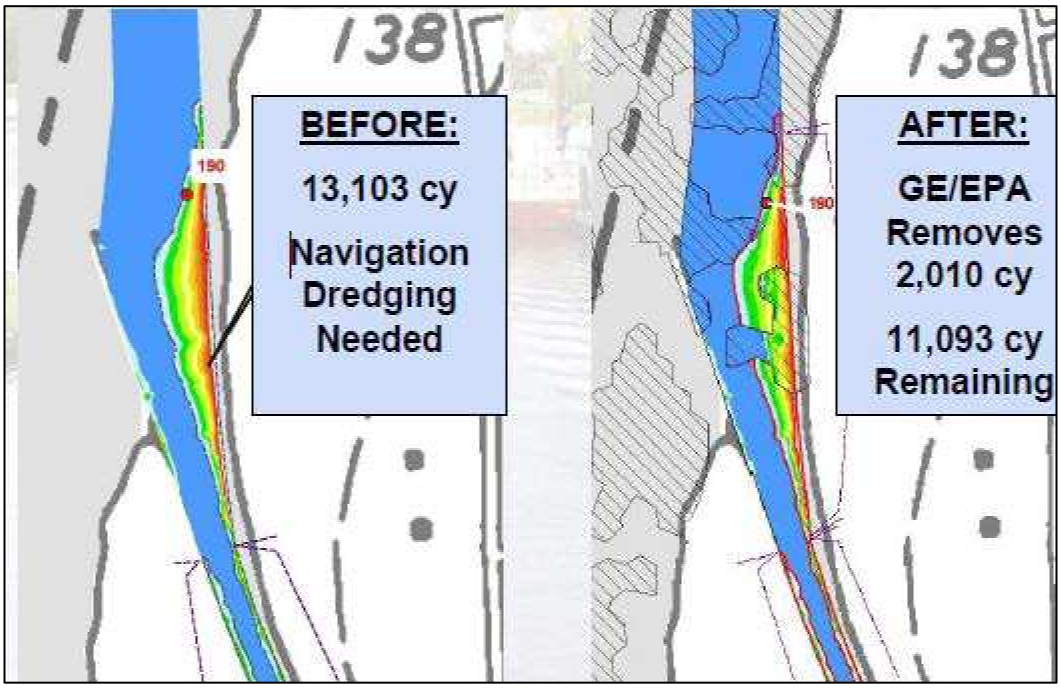

Figure 11: Example of Navigation Dredging Needs after GE/EPA Remedial Dredging[160]

3.4. Fisheries (Closures, Restrictions, and Consumption Issues)

The Trustees have concluded that the Hudson River fishery has been injured as the result of many years of fishery closures and health advisories. Since 1975, the presence of high concentrations of PCBs has led New York State officials to close recreational and commercial fisheries and to issue various types of advisories on the consumption of fish from the river.

Recreational fishing in the 40-mile stretch from Hudson Falls to the Troy Dam was prohibited from 1976 to 1995, after which it was designated as "catch and release" with possession of fish remaining illegal except for anadromous river herring. A number of commercial fisheries south of Troy have been closed for nearly 40 years. The various closures are summarized in Figure 12 and Figure 13. In addition, consumption

158 Moloughney 2011.
159 Moloughney 2011.
160 Moloughney 2011.

advisories have been in effect for the entire 200-mile stretch from Hudson Falls to the Battery (Table 13).[161] Note that all advisories and closures also apply to tributaries and connected waters where there are no dams, falls, or barriers to prevent fish from moving upstream.

The baseline condition that would have existed had the discharge of the hazardous substance under investigation (PCB) not occurred would be the condition of the river absent GE's Fort Edward and Hudson Falls plants. The Trustees determined that absent these releases, few or no PCB-advisories would be in place between South Glens Falls Dam through the Tappan Zee Bridge.

The Trustees maintain that their 2015 report[162] establishes that the "public's use of the Hudson River fishery, whether for livelihood, a source of recreational enjoyment, or for nutrition, has been and continues to be severely curtailed" or, in some cases, completely eliminated as a result of the closures and health advisories related to PCB contamination. In order for these restrictions to be removed, additional reductions in PCB concentrations would be necessary.

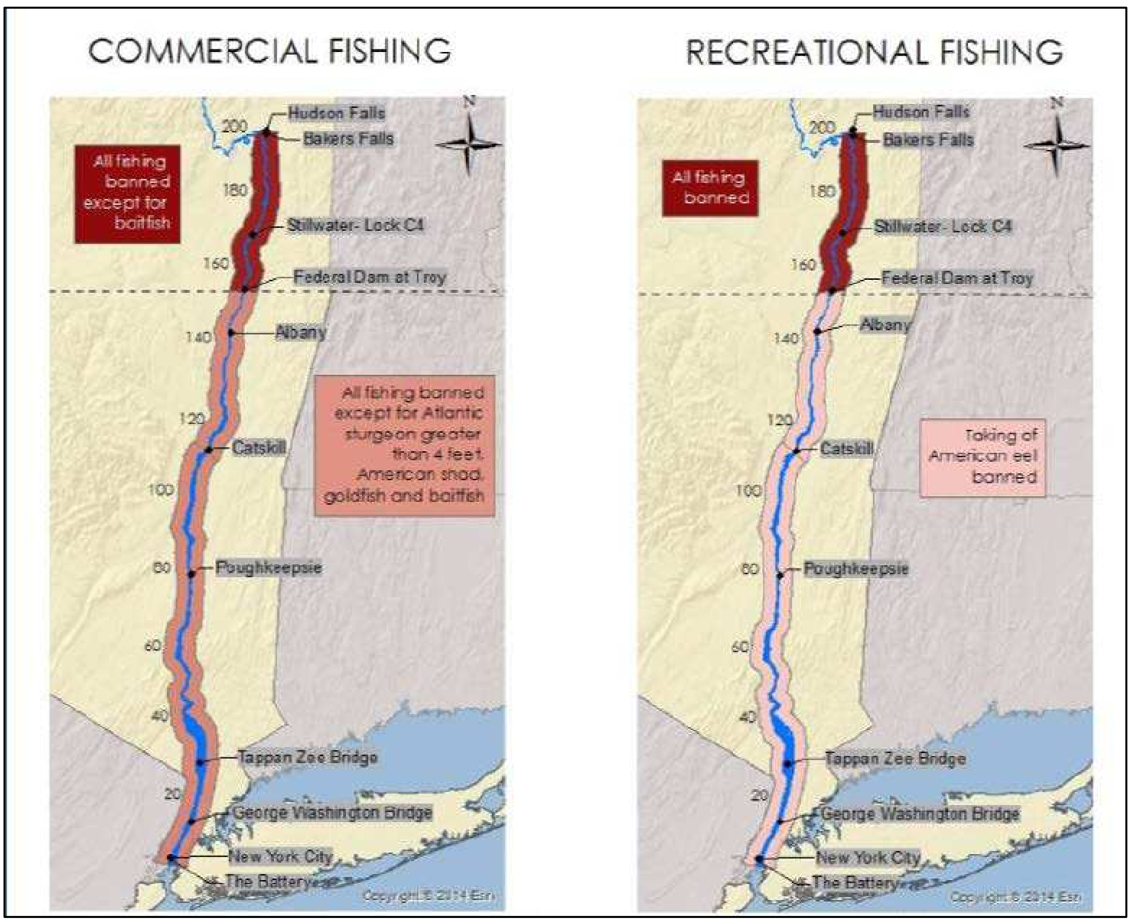

Figure 12: Hudson River Fishery Closures in 1976[163]

[161] Hudson River Natural Resource Trustees 2015e.
[162] Hudson River Natural Resource Trustees 2015e.
[163] Hudson River Natural Resource Trustees 2015e.

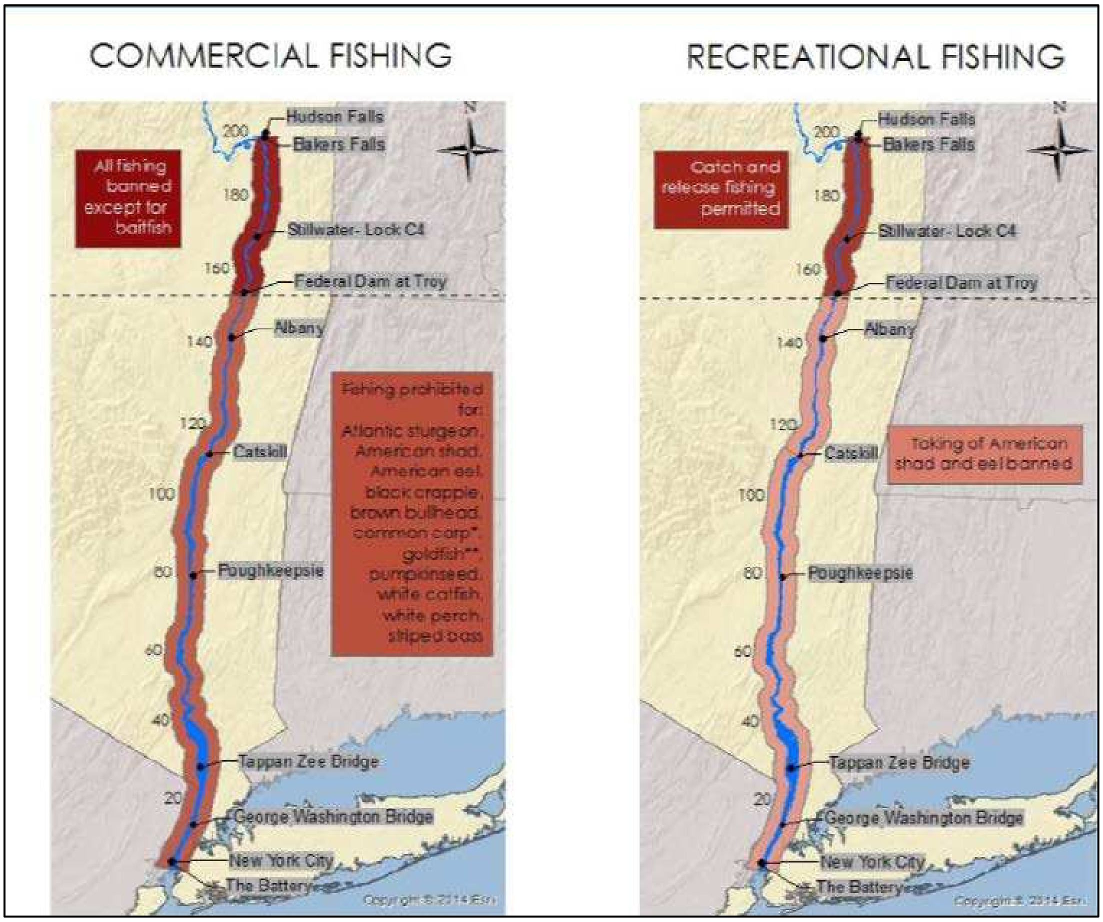

Figure 13: Hudson River Fishery Closures in 2014–2015

Table 13: Hudson River Fish Consumption Advice (NYSDEC)

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

In 2002, the US EPA[164] had estimated a recovery rate for fish contamination in the Lower Hudson River based on an exponential rate of decay in surface sediment. Subsequent NOAA studies have indicated that these projections greatly underestimate the recovery time, which could be several decades longer without remediation. For example, for white perch in the Albany/Troy area, the time to 0.2 ppm and 0.05 ppm thresholds could take two to more than three decades, respectively. [165]

3.5. Human Health Effects from PCBs in the Hudson River

Fish consumption is one of the primary modes of exposure to Hudson River PCBs for humans. Prior to the dredging operations, the levels of PCBs in fish in the Upper Hudson River far exceed those believed to impact health of people who consume fish based on risk-based levels established by credible toxicological methods.[166] In addition, the concentrations of PCBs in fish and wildlife exceed levels believed to cause harm (Table 14 and Table 15).[167]

Table 14: PCB Levels in Upper Hudson River Fish Compared to Other Coastal Waters[168]

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

Table 15: Great Lakes Protocol Risk-Based PCB Advisory[169]

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

Despite concerns about PCB, as well as mercury, dioxin, cadmium, and other contamination, there is still a significant amount of subsistence fishing in the Hudson River. In a survey conducted by Scenic Hudson and the Sierra Club,[170] 32% of anglers were found to consume fish in exceedance of the amounts and portion size recommended in New York State Department of Health Guidelines (Table 13). The 2016 survey found

[164] US EPA 2002.
[165] Field et al. 2015a, 2015b, 2015c, 2016.
[166] Fitzgerald et al. 2007.
[167] Baker et al. 2006.
[168] Based on: Baker et al. 2006; Ashley et al. 2003; Liebert et al. 2001; US EPA 2000c; and http://www.epa.gov/grtlakes/glindicators/fish/topfish/topfishb.html
[169] Great Lakes Sport Fish Advisory Task Force 1993.
[170] Garcia and Stone 2016.

that Latino anglers reported the highest rate of fish consumption (64%), followed by African-Americans (41%) (Figure 14). The socioeconomic groups most affected were those with an annual income between $25,000 and $50,000.

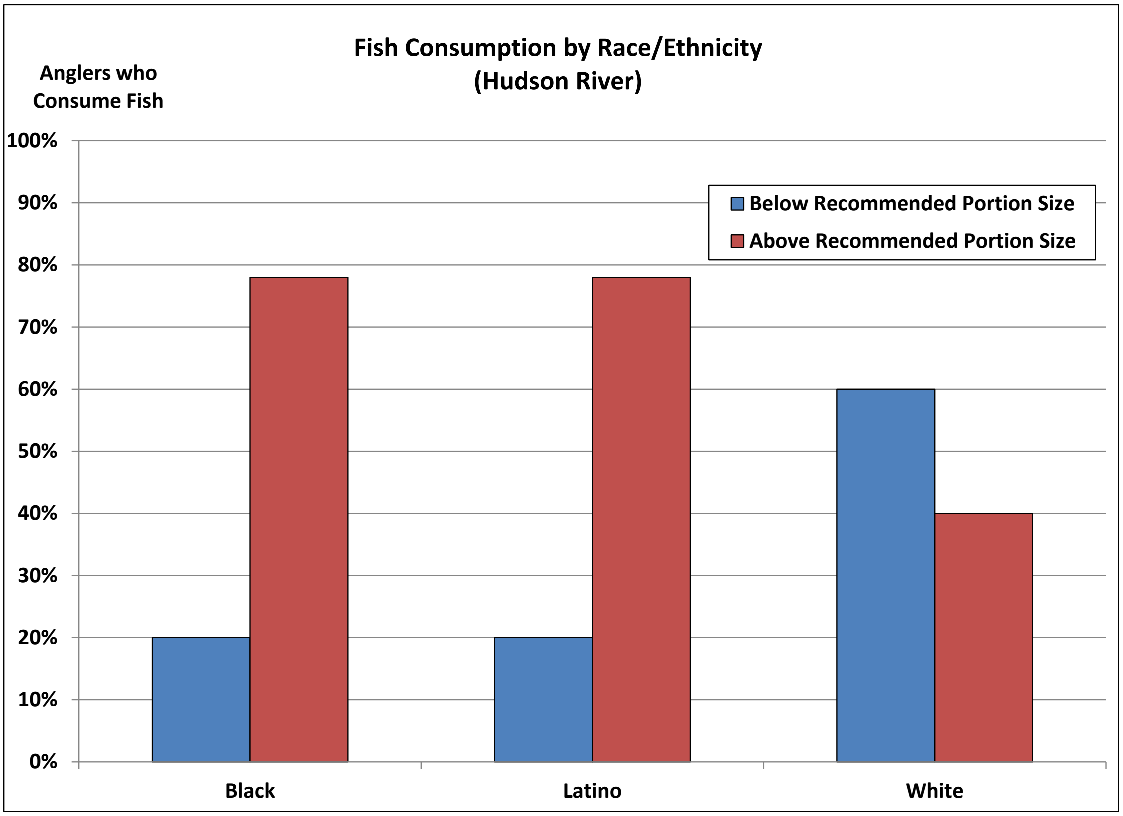

Figure 14: Hudson River Fish Consumption by Race/Ethnicity[171]

In addition to PCB-contaminated fish consumption, PCBs in indoor air has also been shown to be a source of exposure for residents in the Hudson River communities closest to the GE plant sites. This was particularly true for older residents that had lived in the region for 39 or more years.[172]

[171] Based on: Garcia and Stone 2016.
[172] Fitzgerald et al. 2011; Wilson et al. 2011.

Chapter 4: Quantifying Biological Injury and Restoration Scaling

4.1. Restoration of Wetland/Floodplain-Dependent Species

Freshwater wetlands, floodplains, and brackish and freshwater tidal wetlands provide essential habitat and food resources for aquatic mammals such as muskrat, mink and river otter, bald eagles and other raptors, wading birds, rails, waterfowl, insectivorous birds such as catbirds, tree swallows, blackbirds and marsh wrens, turtles, diamondback terrapins, fiddler crabs, killifish, crayfish and dragonflies. Shallows and submerged aquatic plant beds support blue crabs, bait fish, ducks, osprey, striped bass and American shad. Likely many or all of these species have been adversely affected by the PCB contamination in the wetlands and floodplains, either directly or by biomagnification of PCBs in the prey they consume.

Habitat restoration can help to rebuild and sustain fish populations and other life in the river. Since all of the above species, and specifically mink, are dependent on food production from and/or refuge in wetlands and floodplains, wetland habitat restoration would be compensatory for injuries to these species and the entire aquatic food web.

For wetland/floodplain species, restoration scaling was based on needed compensation for injury to mink populations along the Hudson River. Mink were chosen as a representative species because injury at a population level has been quantitatively determined, they consume both aquatic and terrestrial prey from the Hudson River Basin, and restoration of important mink habitat would be beneficial to other species dependent on wetland/floodplain habitat and/or food production, including other mammals, birds, reptiles, and amphibians. The assumption is that the scale of restoration required for the other species is similar to or less than for mink, such that wetland restoration scaled for mink losses would compensate for all wetland-dependent wildlife injuries. Mink, otter, and raptors are high in the food web, and because PCBs biomagnify, these wildlife predators presumably are the most adversely affected. To the extent that injuries to other species are greater than those to mink, the scale of restoration needed to compensate for all wetland/floodplain-dependent species is underestimated.

Wetland restoration was scaled as if new wetland habitat will be created. However, the land used for the wetland project has some prior ecological service value. The service losses of the destroyed habitat would need to be added to the PCB-caused injury, if considered significant. For example, if waste or developed (e.g., industrial) areas were purchased and wetlands created on the sites, the ecological service losses of the land used would not be considered significant. However, remaining highly contaminated flood plains and wetlands along the Hudson River could be dredged and regraded with clean material to create new uncontaminated and fully productive wetlands. Compensation would be needed for the interim lost services due to removal of these reduced-function habitats. Essentially, this rehabilitation of existing PCB-contaminated sites could be accomplished as remediation or under NRDA compensation. In either case, the interim losses should be compensated as part of the damages.

4.2. Mammals

Injury to mink from the GE PCB contamination was estimated to be a 40% reduction in population size, based on research published in 2018 by the Trustees.[173] The Trustees also determined that adverse effects, such as reduced reproduction and growth, and increased mortality, could be expected if mink diets consisted of fish with lipid PCB concentrations of ≥0.11 mg/kg (ppm).[174] In both the Upper and Lower Hudson River, fish regularly have levels of PCBs which exceed the 0.11 ppm threshold safe for fish-consuming wildlife.[175]

In order to quantitatively estimate injury and related restoration costs, the aforementioned reductions in population size were utilized in conjunction with the area of wetland habitat in the estimated linear home range distance of the Hudson River of mink that feed on prey originating in the PCB-contaminated areas. These methods are supported by a recent study which compared various methods for estimating mink home ranges and found that models that incorporate biologically relevant landscape features were more reflective of the observed spatial use by mink than generalized areas.[176] In addition, because mink is one of the few biological receptors for which PCB injury has been determined and they utilize both aquatic and terrestrial habitats, restorative actions for mink are assumed to be encompassing of the needs of other wetland/floodplain-dependent species, such as birds, amphibians, and reptiles.

4.3 Restoration Scaling for Mink Injuries

In the Upper Hudson, in appropriate mink habitat within a home range distance (6 km) of the Hudson River, injury to mink has been documented as a 40% reduction in mink densities.[177] Mink obtain their food from the wetlands in that area. Thus, the area of wetlands (inclusive of wetlands, ponds, and riverine [i.e., stream] habitats within 6 km of the main river channel) from Hudson Falls to the Federal Dam, 16,696 acres (68 km^2), was calculated from US Fish and Wildlife National Wetland Inventory (NWI) data[178]. This is the injured supportive habitat for mink. As mink reproduce annually, the 40% reduction in densities are assumed to be an annual loss.

The acreage of wetland habitat injured may be compensated by creation of habitat that provides the same or similar services. HEA (see Section 1.2) is used to calculate the scale of the required restoration based on the additional wildlife production gained by the restoration activity. The calculations account for the lag time after the injury occurred before restoration begins, development time for the restored habitat, and the delay in benefits. The Responsible Party should pay compounded interest (assumed 3% per annum, based on practice recommended by the US Office of Management and Budget, OMB) for delayed benefits (i.e., injuries that occurred in the past and are compensated in the present). For example, if compensation is paid in 2020, injuries occurring in 2019 are valued at 1.03 times the 2020 value. The injuries in 2018 are 1.03^2 times as valuable today (i.e., compounded) as the injuries of 2020, and so on. Future injuries are also compensated, but future injuries are discounted at 3% per year (compounded annually) to today's values.

[173] Sutherland et al. 2018.
[174] Sloan et al. 2005.
[175] Hudson River Trustee Council 2002.
[176] Halbrook and Petach 2018
[177] Sutherland et al. 2018
[178] https://www.fws.gov/wetlands/data/mapper.html; data from ftp://128.104.224.198/State-Downloads/NY_geodatabase_wetlands.zip

Conceptually, the public is compensated today for future losses that are of less value today the farther into the future they occur.

It is expected that habitat restoration would take some time to plan after a settlement. For example, if a NRDA settlement is made such that compensatory habitat is created in 2024, the payment would be made in 2024 dollars for 2024 values of the injury. The equation for the compound/discount factor, F_{id}, per unit of annual injury, where compensation is paid y years after injury began is as in Equation 1 :

$$F_{id} = \sum_{n=-100}^{y} 1.03^{n}$$

Equation 1

where y = years of past losses prior to the year compensation is paid and n = number index for years prior to compensation where injuries occurred (i.e., negative n values indicate future years). In the calculations made here, wetland injuries were developed in 2024 values, assuming a settlement is made whereby the habitat creation would be performed in 2024. The years of losses before restoration starts are assumed 44 years (y = 44), back to 1980 when CERCLA was passed.[179] Injuries are quantified for the restoration year (n=0) and 100 years into the future. Because of the discounting at 3% compounded annually, injuries > 100 years into the future have essentially no present-day value. Thus, including the restoration year taken as 2024, this covers 145 years of injuries, and F_{id} = 124.3, a unit factor accounting for a 100-year project life for compensatory restoration services, and 45 years of injury prior to and in the year of restoration activities, assuming the typically-used discount factor of 3% per year.

F_{id} is multiplied by the number of acres of injured wetland (16,696 acres in the Upper Hudson), the fractional loss in the wetland (0.40 for lost mink production), the assumed productivity of the created wetland compared to that where injuries occurred (assumed 1, or equivalent), and by a factor accounting for the development time of the restored wetland .

The development of plant and animal production in a restored wetland is assumed to follow a sigmoid function where production increases to the pre-injury level over a specified number of years (based on literature documenting such recovery rates)[180]. This function is described by Equation 2:

$$\frac{dP_R}{dt} = a_r P_R (1 - P_R)$$

Equation 2

where P_R is portion developed (recovered), t is time, and a_r is a constant. The sigmoid function was chosen since, at first, recovery is slow while seeding/settlement and early succession take place. Later recovery speeds up as filled-in vegetation and new settlers grow rapidly, but the final establishment of the mature habitat proceeds at a slower rate. Each year of benefits over this development period is valued based on the

[179] Note that an argument could be made that compensation should be paid for injuries prior to 1980. However, since the contamination levels prior to 1977 when the direct discharges of PCBs were halted varied considerably in time and remain unquantified, estimation of injuries in the years before 1980 would require more research.
[180] French-McCay and Rowe 2003; French-McCay 2009

sigmoid function and future gains (assuming 100 years of project life) are discounted to present-day values. Further detail on HEA methods are available from trustee guidance documents.[181]

Forested and shrub-scrub wetlands provide good habitat for mink and other wetland/floodplain dependent species. It is assumed that restoration for the injuries in the Hudson River system would be compensated by creation of forested and/or shrub-scrub wetlands. Development/recovery time for these habitats is about 20 years.[182] The cost of creating forested and/or shrub-scrub wetlands is $128,533 per acre (or $31.76/m^2) in 2016 dollars.[183]

HEA was used to calculate compensatory wetland needs for the Upper Hudson, using the estimate of 16,696 of wetland acres injured. Contamination is also sufficiently high in the Lower Hudson to adversely affect the productivity of mink and other wildlife. Data documenting reductions in mink or other wildlife in the Hudson River habitats compared to reference areas are not available. However, for demonstration purposes, it is assumed that mink population densities are suppressed by 10% from the Federal Dam at Troy to Catskill, and that mink losses are higher or equal to other wildlife such that restoration of mink would restore other wetland-dependent wildlife. Table 16 summarizes the results. The per-acre restoration cost is estimated to be $162,821 in 2024 dollars.

Note that the estimates of compensatory restoration needs and costs are underestimated to the extent that injuries to mink and other wildlife occurred and continue to accrue down-river of Catskill. Given PCB contamination levels measured in sediments and biota throughout the Hudson River estuary, injuries and damages would be considerably higher.

Table 16: Injured and Compensatory Wetland Areas Scaled to Mink Injury

River Section	Injured Area		Restored Area		Potential Cost in 2024$
	acres	km^2	acres	km^2	
Upper Hudson	16,696	67.6	31,495	127.5	$5.73 billion
Federal Dam to Catskill	19,172[184]	77.6	9,041	36.6	$1.65 billion

4.4 Birds

High contamination levels have been observed in over two dozen species that utilize wetland/floodplain habitats along the Hudson River. However, a quantification of injury on the population level has not been performed. The sensitivity of wild birds to PCBs varies from species to species, with critical egg thresholds for reproduction of intermediately sensitive species ranging from 6 ppm to 50 ppm.[185] These threshold for injury are presumably much lower for bird species defined as highly sensitive or "Type I", such as the gray catbird, which is common in floodplain habitats along the Hudson River.[186] Based on the overlap of habitats

[181] NOAA 1997.
[182] Mancini 1989.
[183] Louis Berger 1997; price indices for translation to 2016 dollars from http://liberalarts.oregonstate.edu/spp/polisci/research/inflation-conversion-factors; converted to 2018 dollars ($33.69/m^2) and 2022 dollars ($37.92/m^2) assuming 3% increase per annum.
[184] Assuming 10% reduction in mink population size in NWI wetlands and riverine habitats within 6 km of the Hudson River Channel
[185] Hudson River Natural Resource Trustees 2015g
[186] Hudson River Natural Resource Trustees 2018a

with mink, it is likely birds in this region will also benefit from the restoration of preferable mink habitat, which includes wetland/floodplain habitats.

4.5 Reptiles and Amphibians

Reptiles and amphibians utilize floodplain and river habitats along the Hudson River. PCB contamination and injury studies on snapping turtles found that there was significantly higher post-hatch mortality in snapping turtle eggs from the Hudson River than from reference sites.[187] Although studies have established evidence indicating elevated levels of PCBs in amphibians from Hudson River habitats, injury has not been determined. Based on the floodplain habitat use of the species in these subgroups, restorative efforts conducted on mink habitat will be inclusively beneficial to reptile and amphibian populations along the Hudson River.

4.6 Fish and Invertebrates

Although there has been extensive trustees-lead field and laboratory studies on fish injury from PCBs in the Hudson River, population-level injury in fish have not been quantified and remains unknown. Conclusions made by the Trustees indicate fish with liver PCB concentrations between 0.3–70 ppm could be experiencing reduced reproductive growth and survival.[188] In order to classify amount of affected environment in the Hudson for fish and invertebrates, biological injury thresholds for sediment and water were used. NYDEC (2014) determined that the Probable Effects Concentration (PEC) of PCBs in surface sediment concentrations is 0.68 ppm, above which sediment-dwelling organisms would likely be negatively affected. For surface waters, the EPA and State of New York protective PCB concentration criteria for freshwater aquatic life is 0.000014 ppb, with lethal effects to for zooplankton, large invertebrates, and fish observed at levels from 1–10 ppb.[189] Sediment samples in the Upper Hudson River consistently contains PCB concentrations well above the NYDEC PEC, ranging from >1–1,650 ppm.[190] Sediment sampling at six sites in the Lower Hudson River (between River Mile 140.5–42) observed PCB concentrations above the PEC, between 0.93–1.89 ppm.[191] Surface waters sampled throughout the Hudson River during 1998–2007 were, on average, between 10–100 ppt (0.00001–0.0001 ppb).[192] Although there is evidence that sediments and surface water PCB concentrations in the Lower Hudson River are orders of magnitude lower than the Upper Hudson River, based on the values presented, it is likely that all aquatic organisms inhabiting sediment or water column habitats in the Hudson River are exposed to values potentially harmful to them.

Restoration that would benefit fish and invertebrates in the Hudson River could include wetland habitat creation or sediment remediation, i.e., dredging and/or capping. To the extent that mink or other wildlife species injuries can be quantified downstream of the Federal Dam to the Tappan Zee Bridge, fish and invertebrate injuries sustained in wetlands could be considered compensated by a wetland restoration program addressing needs for mink or other indicator species of wildlife. However, additional injuries (e.g., for species utilizing main channel and estuarine habitats) sustained in the main river would not necessarily be covered by the wetland compensation.

[187] Eisenreich et al. 2009
[188] Monosson 1999; Hudson River Trustee Council 2002; Hudson River Natural Resource Trustees 2013.
[189] Hudson River Trustee Council 2002; Hudson River Natural Resource Trustees 2013.
[190] Hudson River Natural Resource Trustees 2013b.
[191] NYDEC 2000.
[192] Hudson River Natural Resource Trustees 2013b.

4.7 Sturgeon

Although sturgeon are only present in the lesser polluted, Lower Hudson River, due their threatened and endangered status, restoration effort and cost would likely be assessed using a Resource Equivalency Analysis (REA). Comprehensive stock assessments for Atlantic and shortnose sturgeon have not been conducted since 1992 and 2007, which estimated the Hudson River supported <1,000 and <65,000 adult sturgeon, respectively.[193]

A pilot study conducted by the Trustees found that survivorship to hatch was significantly lower in shortnose sturgeon eggs reared in water with PCB concentrations of 10–1000 ppb.[194] Although these levels are higher than water column PCB concentrations observed in the Hudson River (mentioned above), sturgeon eggs are typically found near the river bottom, where higher exposure can occur through sediments.

4.8 Freshwater Mussels and Other Benthic Communities

As stated in Section 2.10 above, mussel beds support diverse communities and link higher and lower trophic levels. The extent of mussel beds and habitat in the Hudson River is currently unknown; however remedial dredging in the Upper Hudson River puts these habitats at a high risk for destruction. In this assessment, total dredged area conducted between 2009 and 2015, was used to estimate the area where injuries occurred (Table 17 and Table 18).

Table 17: Dredged Area and Volume from 2009–2015 in the Upper Hudson River[195]

Phase	River Section(s)	Total Area/Volume Dredged		Year
		Acres	Cubic Yards	
1	**River Section 1**	50	283,000	2009
2	**River Section 1**	80		2011
2	**River Section 1**	110		2012
2	**River Sections 1, 2, 3**	135	~2,500,000	2013
2	**River Sections 2, 3**	105		2014
2	**River Sections 2, 3**	40		2015
Total		**500[196]**	**~2,750,000**	**Total**

Table 18: Dredged Area by River Section from 2009–2015 in the Upper Hudson River[197]

River Section	Years	Total Area (Acres)
River Section 1	2009–2013	290
River Section 2	2013–2015	90
River Section 3	2013–2015	110

[193] USFWS 2016; NOAA 2018.
[194] Chambers et al. 2012.
[195] US EPA 2015. Phase 2 Overview Factsheet. Hudson River PCBs Superfund Site. Accessed: https://www3.epa.gov/hudson/pdf/Phase2_Overview-2015.pdf or https://www3.epa.gov/hudson/cleanup.html
[196] Total area dredged adds to 520 acres due to some overlap in Certification Units (5 acres each) across years.
[197] US EPA 2015. Phase 2 Overview Factsheet. Hudson River PCBs Superfund Site. Accessed: https://www3.epa.gov/hudson/pdf/Phase2_Overview-2015.pdf or https://www3.epa.gov/hudson/cleanup.html

Injuries would have continued over the recovery period of the mussels and other biota in the benthic community. Data are insufficient at this time to estimate compensatory restoration needs for mussels. It is assumed that the wetland restoration would compensate for most of the benthic production impacted by the dredging, but at least some species of mussels may require specific habitat features other than wetlands.

Chapter 5: Human-Use Injury and Compensatory Damages

In addition to biological injuries, there have been injuries to resources used by humans, including drinking water, navigational services, and recreational fishing.

5.1 Drinking Water Injuries

Many municipal water suppliers use alluvial surface waters as a water source. When such easily accessible water supplies are contaminated or otherwise not available, municipalities spend millions of dollars to transport water tens or even hundreds of miles from distant water sources to the end-user. Alternatively, municipalities might treat contaminated water, making it usable.

Damages for lost drinking water service could be based on a number of methods. However, under the CERCLA regulations, the trustees should consider potential alternatives and choose the most cost-effective option.

One approach would be to calculate the cost to restore the lost water supply services. This includes the costs to remediate the source of contamination (i.e., primary restoration) such that the services are brought back to baseline faster than relying on natural recovery and the costs of the interim lost services as compensatory restoration. The primary restoration would likely involve further dredging of contaminated sediments, as the remediation to date has not demonstratively reduced concentrations of PCBs in the water column (see Section 1.1). If dredging is not performed to remove much of the contamination from the river and flood plains, water column contamination is likely to continue for decades or more into the future. Thus, indications are that the compensatory restoration of interim service losses, for the entire affected portion of the river, would need to continue into the indefinite future, essentially infinitely in terms of compensatory restoration scaling because of the discounting of future service losses (similar to compensatory restoration for biological injuries, as discussed in Section 4.3).

A number of Resource Equivalency Analysis (REA) methods for scaling injuries and damages for water supply have been used in NRDAs, typically based on a service-to-service approach where the lost service is replaced, and the damages are the costs of providing the alternative service less what the costs would be if the injured resource was usable. Thus, one approach for estimating damages is as follows:

1. Estimate the volume of fresh water used annually for water supply that is obtained from sources outside of the PCB-contaminated area in lieu of using the contaminated river water.
2. Quantify the additional annual cost of obtaining and delivering that water over the costs of using Hudson River water.

Another method of estimating damages for lost drinking water services could be the additional costs borne by municipalities that use Hudson River water but need to treat it. For this rehabilitation approach, the damages are based on:

1. Volume of fresh water annually used for water supply that is obtained or planned to be obtained from the PCB-contaminated Hudson River.
2. Annual cost of treating that water such that it meets drinking water standards and can be used.

A third approach is using contingent valuation to quantitatively measure the damages to lost drinking water quality. The method relies on hypothetical questions posed by surveys to ascertain how much respondents would be willing to pay to preserve the natural resource, which in this case is the quality of drinking water. While conducting firsthand surveys are beyond the scope of this project, a benefits transfer method can be used, which involves the application of value estimates and data from existing studies to estimate damages for the case at hand. For this, the damages are based on:

1. The number of households using fresh water annually that is obtained or planned to be obtained from the PCB-contaminated Hudson River.
2. Annual amount each household is willing to pay on top of their water bill for water that meets drinking water standards and can be used.

Following any of these approaches, the annual water supply volume accounted for in any settlements made by municipalities with the responsible party would need to be subtracted from the total volume service.

The Hudson River includes two river-mile stretches that are designated as committed use for drinking water supply, i.e., river miles 65-129.2 and 156-162 (Table 10). However, the river serves as a source of water for industrial and commercial facilities, recreational facilities (e.g. pools, golf courses), agricultural lands, and for drinking water for a number of communities (both within and outside the committed use areas), as summarized in Table 19. Since many of these water intakes are downriver from the highest levels of PCB contamination, there is more concern for the intakes further upriver, north of the Federal Dam at Troy. The communities that currently use Hudson River water as a source of drinking water that are north of the dam are shown Figure 15. Table 18 lists estimated drinking water use by municipality, based on population. According to the US Geological Survey, each person uses about 80 to 100 gallons of tap water per day.[198]

As noted above, compensatory damages for lost services of surface water used as drinking water could be based on the cost of additional treatment required to get drinking water supplies to acceptable levels of PCB (less than 500 parts per trillion, ppt).[199] PCBs can potentially be removed or brought down to acceptable levels through granular activated carbon filtration. The cost of filtration is estimated at $0.31 to $1.04 per 1,000 gallons (in 2020 dollars).[200,201]

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[198] https://water.usgs.gov/edu/qa-home-percapita.html

[199] https://www.epa.gov/gro.und-water-and-drinking-water/national-primary-drinking-water-regulations The zero maximum contaminant level goal or MCLG and the 0.0005 mg/L or 500 ppt maximum contaminant level or MCL for PCBs are considered by EPA to be protective of human health.)

[200] https://safewater.zendesk.com/hc/en-us/articles/211400478-How-much-does-it-cost-to-treat-and-deliver-drinking-water-

[201] Personal communication with Randy Altstadt, Poughkeepsie, New York, Water Treatment Plant Administrator, 20 November 2018.

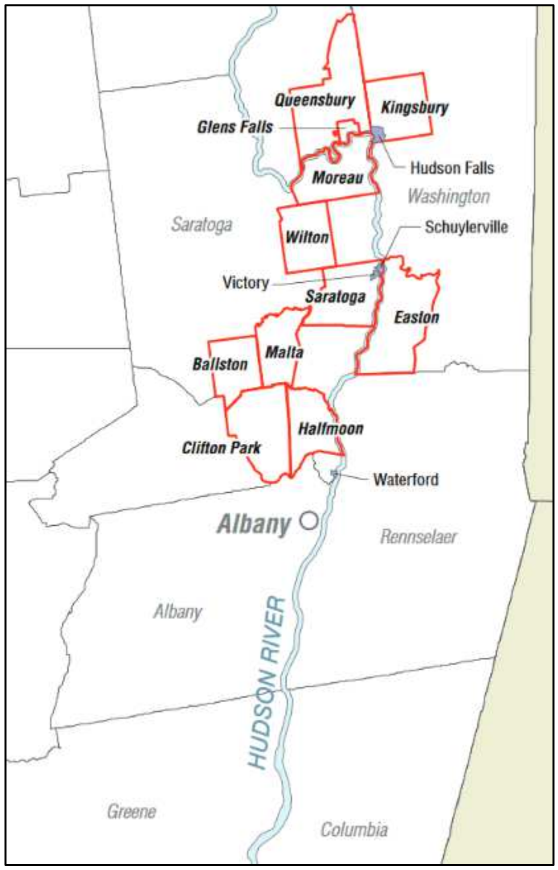

Figure 15: Upper Hudson Communities with Hudson River as Drinking Water Resource[202]

Table 19: Water Intakes in Hudson River[203]					
Facility	**Town**	**Public**	**Agriculture**	**Industrial**	**Recreation**
Domino Sugar Refinery	**Yonkers**			●	
Montefiore Hospital	**Tarrytown**			●	
Tallman Mountain State Park	**Orangetown**				●
Sleepy Hollow Country Club	**Briarcliff**				●
Rockland Lake Golf Course	**Orangetown**				●
Tilcon Stone Quarry	**Haverstraw**			●	
Haverstraw Power Plant	**Haverstraw**			●	
Indian Point Energy Center	**Cortlandt**			●	
Camp Smith Military	**Cortlandt**			●	
Charles Pt. Resource Recovery	**Peekskill**			●	
Town of Fort Montgomery	**Fort Montgomery**	●			
Village of Cold Spring	**Philipstown**	●			

[202] Haverstraw Water Supply Project DEIS. http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B32141E81-BD3E-4A7F-A42D-FD62F0AB83C1%7D (Additional water intakes identified as in Table 19 from ESI maps.)
[203] Etkin et al. 2018.

Table 19: Water Intakes in Hudson River[203]

Facility	Town	Public	Agriculture	Industrial	Recreation
City of Beacon	Beacon	●			
Southern Dutchess Country Club	Beacon				●
Danskammer Power	Newburgh			●	
Roseton Power	Newburgh			●	
Town of Chelsea	Wappinger	●			
VA Hudson Valley Castle Point	Wappinger	●			
Marlboro Quarry	Marlboro			●	
Agricultural Area	Milton		●		
IBM	Poughkeepsie			●	
Dutchess Golf Club	Poughkeepsie				●
Marist College	Poughkeepsie	●			
City of Poughkeepsie	Poughkeepsie	●			
Town of Highland	Highland	●			
Town of Hyde Park	Hyde Park	●			
Town of Rhinebeck	Rhinebeck	●			
Town of Port Ewen/Rondout	Esopus	●			
Town of Catskill	Catskill	●			
Town of Ulster	Ulster	●			
Town of Athens	Athens	●			
Town of Coxsackie	Coxsackie	●			
Town of Castleton-on-Hudson	Schodack	●			
Epcor Utilities	Schodack			●	
PSEG Power New York	Bethlehem			●	
Pfizer/AMRI	Rensselaer			●	
City of Albany	Albany	●			
Agricultural Area	Menands		●		
Office of General Services	Albany				●
Town of Watervliet	Watervliet	●			
Town of Green Island	Green Island	●			
City of Troy	Troy	●			

Estimated costs for treating drinking water in the upper Hudson River are shown in Table 20. For the Upper Hudson River municipalities (Albany to Moreau), annual Hudson River drinking water usage totals about 10.2 billion gallons, which needs to be filtered at a cost of $3 million to $11 million each year (in 2020 dollars). Of that total, treatment for Halfmoon's water supply in the committed use area costs $270 to $907 thousand per year.

Table 20: Municipalities in Upper Hudson Dependent on Hudson River Drinking Water				
Municipality	**Population**	**Estimated Annual Water Usage[204] (gallons)**	**Potential Annual Water Filtration/Treatment Cost**	
			Low Cost Estimate[205]	**High Cost Estimate[206]**
Moreau	15,275	557,537,500	$172,837	$579,839
Wilton	16,785	612,652,500	$189,922	$637,159
Schuylerville	1,355	49,457,500	$15,332	$51,436
Saratoga	5,646	206,079,000	$63,884	$214,322
Easton	2,274	83,001,000	$25,730	$86,321
Malta	15,892	580,058,000	$179,818	$603,260
Halfmoon[207]	23,898	872,277,000	$270,406	$907,168
Clifton Park	36,755	1,341,557,500	$415,883	$1,395,220
Troy	49,702	1,814,123,000	$562,378	$1,886,688
Green Island	2,598	94,827,000	$29,396	$98,620
Watervliet	10,120	369,380,000	$114,508	$384,155
Albany	98,111	3,581,051,500	$1,110,126	$3,724,294
Total	**278,411**	**10,162,001,500**	**$3,150,220**	**$10,568,482**

In addition to the Upper Hudson River municipalities dependent on the river for drinking water, there are also some communities below the Troy dam that have drinking water intakes in the Hudson River, as shown in Table 21. For these communities, the treatment for the water supply costs $1.35 million to $4.51 million per year (in 2020 dollars).

Table 21: Municipalities in Lower Hudson Dependent on Hudson River Drinking Water				
Municipality	**Population**	**Estimated Annual Water Usage (gallons)**	**Potential Annual Water Filtration/Treatment Cost**	
			Low Cost Estimate	**High Cost Estimate**
Stuyvesant	1,921	70,116,500	$21,736	$72,921
Catskill	11,365	414,822,500	$128,595	$431,415
Esopus	8,839	322,623,500	$100,013	$335,528
Saugerties	19,907	726,605,500	$225,248	$755,670
Kingston	23,210	847,165,000	$262,621	$881,052
Poughkeepsie	30,267	1,104,745,500	$342,471	$1,148,935
Peekskill	24,053	877,934,500	$272,160	$913,052
Total	**119,562**	**4,364,013,000**	**$1,352,844**	**$4,538,574**

However, the argument could be made that filtration systems would likely have been used in any case to filter out other contaminants, including bacteria. Therefore, it would be important to determine the additional filtration that would be required to remove contaminants such as PCBs. PCBs are insoluble and

[204] Assuming 100 gallons per person per day.
[205] Assuming $0.31 per 1,000 gallons.
[206] Assuming $1.04 per 1,000 gallons.
[207] Committed use area for water supply for drinking, culinary, or food processing.

hydrophobic, which means that they tend to move out of water by adhering to sand, silt, decaying organic debris. This means that filtration is relatively easy provided one removes sediment and organic debris, which filtration systems are generally designed to accomplish. The highest PCB concentrations in drinking water would most probably have been seen during the active dredging operations.

5.2 Protection of Drinking Water during PCB Dredging Operations

Besides ongoing filtration and treatment, some communities have had to find alternative sources of drinking water.

The town of Halfmoon (population 23,898) settled a 2009 lawsuit with General Electric in 2016 for a cost of $5.6 million. The cost was for the reimbursement for finding an alternate water supply as a result of the PCB dredging operations. The EPA had also spent more than $3 million on a water line to supply the community and nearby Waterford with water from the city of Troy.[208] Halfmoon had opened a $12 million water plant on the Hudson River in 2003. The plant was shut down in 2010 when PCB levels were 2,000 ppt (four times the acceptable level).

Waterford and Stillwater had settled their cases with GE in 2014 for $7.95 million. The water authority claimed that it spent $27 million building a water plant on the Hudson upstream of the PCB contamination.

Since these communities have already settled with GE for part or all of their drinking water injuries, these could not be included in an NRDA settlement. However, Halfmoon only settled for the alternative water supply costs during the PCB dredging operations.

In April 2011, during dredging operations, the New York State Department of Health (Figure 16) had determined that: [209]

- Queensbury was far enough upstream of the GE PCB dredging that it was not affected;
- Halfmoon and Waterford were using an alternate water source (Troy's water supply) via an EPA-installed water line;
- Stillwater was using an EPA-installed and operated PCB treatment system;
- Schuylerville showed little evidence of PCBs in water due to the effectiveness of existing treatment systems;
- Green Island had an alternate water source if needed;
- Bethlehem's water supply was primarily for non-residential use; and
- Water in the lower river (Rhinebeck and south) was unlikely to have higher contaminant levels because of the distance from the dredging and dilution of the water as it traveled downriver.

[208] https://www.timesunion.com/tuplus-local/article/Final-lawsuit-over-GE-s-Hudson-River-PCB-8563072.php
[209] NYS Dept. of Health (https://www.health.ny.gov/environmental/outdoors/hudson_river/docs/mapspread.pdf)

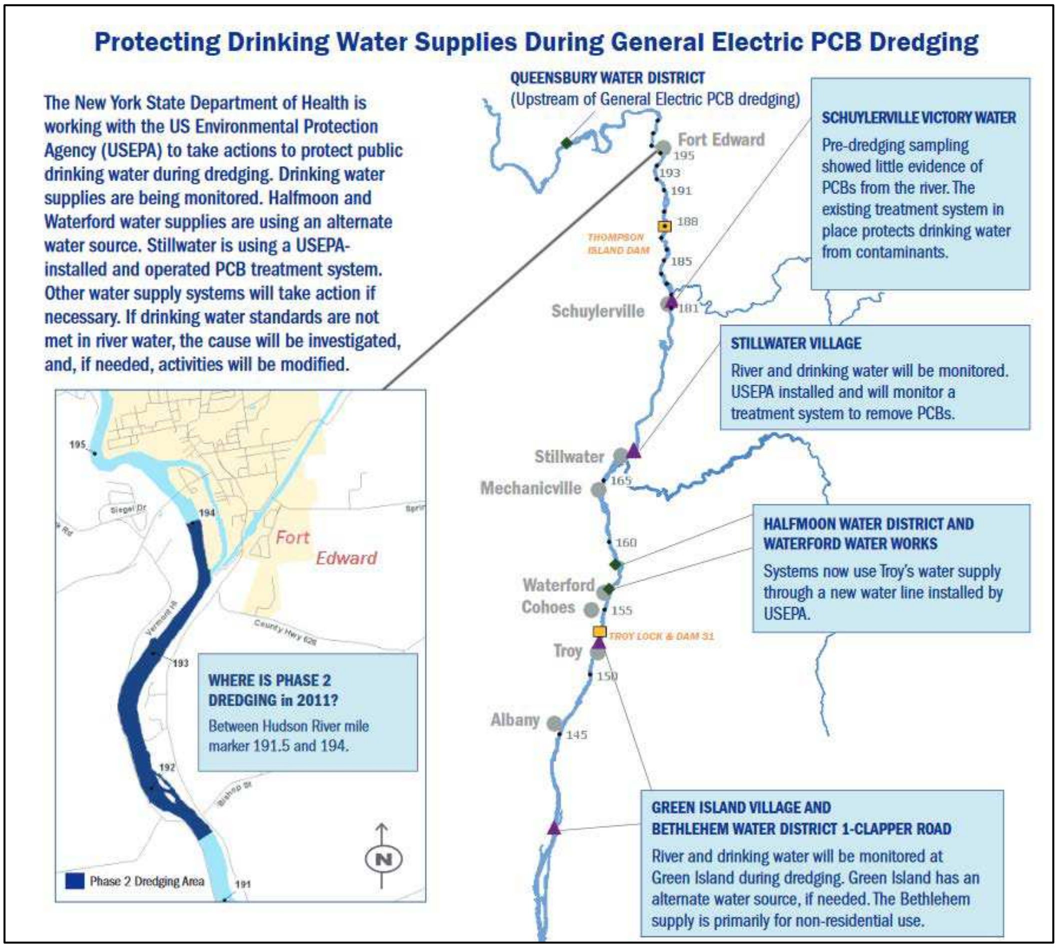

Figure 16: Protection of Drinking Water during Dredging Operations (April 2011)[210]

5.3 Calculation of Drinking Water Injuries and Compensatory Damages

To develop a preliminary estimate of compensatory damages for drinking water services, the water treatment (filtration) approach is assumed first. As noted above, the annual cost of water filtration is estimated at $0.31 to $1.04 per 1,000 gallons.[211,212] This cost range is in 2020 dollars. In earlier years, costs were lower (having been paid at those times in the past), and in future year costs will be higher (payments being made at some future date), than in today's dollars. However, compensation is still owed for the past years' expenses, and compensation is expected at the time of settlement for the future costs of water filtration.

[210] New York State Dept. of Health (https://www.health.ny.gov/environmental/outdoors/hudson_river/docs/mapspread.pdf)
[211] https://safewater.zendesk.com/hc/en-us/articles/211400478-How-much-does-it-cost-to-treat-and-deliver-drinking-water-
[212] Personal communication with Randy Altstadt, Poughkeepsie, New York, Water Treatment Plant Administrator, 20 November 2018.

Including as injuries the costs of water filtration back to 1980 when CERCLA was passed, i.e., 40 years ago, up to 100 years into the future, the 2020 cost is multiplied by the compound/discount factor, F_{id}, as in Equation 3:

$$F_{id} = \sum_{-100}^{40} 1.03^{n} = 110.0$$

Equation 3

where n = number of years where injuries occurred prior to compensation (i.e., negative n values indicate future years). The drinking water filtrations costs from 1980 to 100 years into the future, 2120, valued in 2020 would be $33.08 to $110.26 per annual use of 1,000 gallons (i.e., 110 times the annual cost per 1,000 gallons).

It is not clear if damages can only be claimed for the water usage in committed use areas, or if all demonstrated water supply use can be claimed by the trustees. Multiplying the unit costs per 1,000 gallons by the annual water usage (in thousands of gallons) in the Upper Hudson amounts to $336 million-1.1 billion in 2020 dollars.

If compensation were paid in 2020, the payment would be made in 2020 dollars at 2020 costs. However, if a NRDA settlement is made in 2022, for example, compensatory payments would be translated from 2020 dollars to 2022 dollars at a rate of 3% per year. Paid in 2022, the compensation would cover 1980 to 2122 (i.e., 2 additional years, keeping to the compensation ending 100 years into the future from the date paid), the 2020 costs would be compounded for 2 years (by a factor 1.03^2), and the total would be $357 million to $1.2 billion for the Upper River. For the communities in the Lower Hudson (Table 21), the total compensation costs would be $153 million to $511 million.

The F_{id} where compensation is paid in 2022 is calculated as in Equation 4:

$$F_{id} = \sum_{n=-100}^{y} 1.03^{n}$$

Equation 4

The estimated compensation for water quality based on the water filtration and treatment costs for 1980 through 2122 is as shown in Table 22.

Table 22: Estimated Potential Compensation by Water Filtration/Treatment Costs

Area	Population	Estimated Annual Water Usage (gallons)	Potential Annual Water Filtration/Treatment Cost	
			Low Estimate	High Estimate
Upper Hudson	278,411	10,162,001,500	$3,150,220	$10,568,482
Lower Hudson	119,562	4,364,013,000	$1,352,844	$4,538,574
Compensation for Water Quality (1980-2072)		**$481 Million to $1.6 Billion**		

An alternative approach is applied to complement the analysis and to try to estimate where the true value lies within the range that we found using the water filtration/treatment cost approach presented above. As noted earlier, compensatory damages for lost services of surface water used as drinking water could also be based on the willingness to pay by the consumers to get drinking water supplies to acceptable levels of PCB (less than 500 parts per trillion, ppt).[213] Given that a formal contingent valuation method is beyond the scope of this study, a benefits transfer method is used. A review of literature was conducted in order to look at studies that used contingent valuation approach to estimate willingness to pay for clean drinking water. The selection of literature included studies conducted in the US, as well as globally, and estimated amounts that people were willing to pay per month/billing cycle per household, as a percentage of total household income, or as a percentage of average or median water bill. A 2017 study done for the City of Jacksonville (Florida) was found most relevant to use for this analysis.[214] The study estimated weighted average of willingness to pay for safe drinking water at $6.22 ($6.51 in 2020 dollars) per household per water bill. This amounts to a willingness to pay per household per year of $78.12 in 2020 dollars.

The number of households that use water from the Hudson River is calculated by dividing the populations of municipalities provided in Tables 19 and 20 for Upper Hudson and Lower Hudson, respectively, with the average household size in the State of New York of 2.6 persons per household (2014-2018).[215] Multiplying the number of households by the willingness to pay per household per year in the Upper Hudson amounts to $922 million in the Upper Hudson and $396 million in the Lower Hudson, for a total of approximately $1.3 billion (in 2020 dollars) from 1980 to 100 years into the future, 2120.

If compensation were paid in 2020, the payment would be made in 2020 dollars at 2020 costs. However, if a NRDA settlement is made in 2022, for example, compensatory payments would be translated from 2020 dollars to 2022 dollars at a rate of 3% per year. Paid in 2022, the compensation would cover 1980 to 2122 (i.e., two additional years, keeping to the compensation ending 100 years into the future from the date paid), the 2020 costs would be compounded for two years (by a factor 1.03^2), and the total would be $979 million in the Upper Hudson and $421 million in the Lower Hudson, for a total of approximately $1.4 billion, as shown in Table 23.

Table 23: Estimated Potential Compensation by Households' Willingness to Pay

Area	Population	No. of Households	Estimated WTP[216] per Year
Upper Hudson	278,411	107,081	$10.5 million
Lower Hudson	119,562	45,985	$4.5 million
Compensation for Water Quality (1980-2072)			**$1.4 billion**

5.4 Damages for Lost Navigational Services

Compensation for lost navigational services could include costs of restoring the services by dredging the channel and disposing of the contaminated dredge materials (primary restoration) plus compensatory damages for interim lost services. While the estimation of compensatory damages for lost interim services (e.g., costs of alternate transportation methods) is not attempted here, the costs for dredging are quantified.

[213] https://www.epa.gov/gro.und-water-and-drinking-water/national-primary-drinking-water-regulations The zero maximum contaminant level goal or MCLG and the 0.0005 mg/L or 500 ppt maximum contaminant level or MCL for PCBs are considered by EPA to be protective of human health.)

[214] Chatterjee et al. 2017.

[215] US Census Bureau. 2020. QuickFacts: New York; New York city, New York. Persons per Household 2014-2018. Available at: https://www.census.gov/quickfacts/fact/table/NY,newyorkcitynewyork/PST040218

[216] Willingness to pay.

As noted above, the cost of dredging, treating, and disposing of PCB-contaminated sediments was estimated in 2006 as over $300 per cubic yard (mechanical dredging).[217] In 2018 dollars, this cost is $374.40 per cubic yard. In 2013, NYSCC reported that there were "over 600,000" cubic yards of contaminated sediment remaining.[218] Thus, the total dredging cost in 2018 dollars is at least $225 million.

5.5 Calculation of Recreational Fishery Losses

The Hudson has had a rich history of commercial fishing in the past, particularly of sturgeon, shad, and striped bass.[219] However, the PCB contamination, in addition to over-fishing and other problems have effectively closed those fisheries. There are still recreational, and subsistence fishing activities in the Hudson River, but there are health issues associated with the consumption of fish caught in the river. Current regulations for the tidal Hudson River are shown in Table 24. In addition to finfish, there is also fishing for blue crabs. For blue crabs, there is a daily limit of 50 crabs per person.

Table 24: Fishing Regulations for Tidal Hudson River

Species	Location	Open Season	Minimum Length	Limit/Day
American Eel	Hudson River from NYC Battery to Troy Dam; all tributaries upstream to first barrier impassable by fish	All year	Eels (9-14 inches) for bait only; no processing for food	25
Black Bass (Largemouth or Smallmouth)[220]	Hudson River from Troy Dam downstream and all tributaries to first barrier impassable by fish	3rd Saturday June–30 November	15 inches minimum	5
Striped Bass	Hudson River and tributaries north of George Washington Bridge	1 April–30 November	One fish 18–28 inches total or one fish >40 inches	1
American Shad	Fishing for or possessing American Shad is prohibited in the Hudson River			
Hickory Shad	Hudson River and tributaries north of Tappan Zee	1 August–30 November	Any size	5
Anadromous River Herring[221]	Hudson River Waterford Lock south to George Washington Bridge	15 March–15 June	Any size	10/angler; 50/boat[222]

To a large extent, the enjoyment of recreational fishing (and subsistence fishing) has been affected by the severe restrictions on consumption of fish that are caught (as in Table 13).

An adaptation of a frequently used approach used to calculate the injury to recreational fishing could be applied to the Hudson River PCB case in the following manner:

- Gather data on angler-days and/or trips per river mile or area;
- Document the spatial extent and time of the recreational fishery closures and/or restrictions on catch consumption for the river;

[217] Hudson River Natural Resource Trustees 2006.
[218] Moloughney 2013.
[219] http://www.dec.ny.gov/lands/74069.html [These are just the fish that were caught and released, not the total number of fish in the river, which would be a much higher number.]
[220] It is illegal to fish (including catch & release) for largemouth bass and smallmouth bass during closed season.
[221] Includes: alewife and blueback herring; only angling or personal nets allowed.
[222] Whichever is lower.

- Estimate angler-days and/or trips in areas where consumption of fish is restricted;
- Determine the value for the lost enjoyment of being able to consume the fish that are caught per angler-day or per angler-trip in the restricted areas; and
- Calculate the total value lost for all angler-days and/or trips taken in restricted areas and times, adjusting for past years through compounding, and discounting losses in future years.

To the angler-days or trips taken, but where consumption was restricted, an accepted value for the added enjoyment of being able to consume the fish that are caught by anglers can be applied. This would provide an estimate of the value of the lost use for recreational fishing where consumption of fish was/is/will be restricted.

In order to evaluate lost use due to recreational fishing closures, the following procedure could be applied:

- Estimate fishing trips that would have been taken to the Hudson River if there were no closures;
- Estimate fishing trips in the area to other water bodies during and because of the closures, which served as substitutes for the lost Hudson River trips;
- Calculate the lost trips as the difference in annual recreational fishing trips, accounting for substitute trips, because of the Hudson River closures;
- Multiply lost trips by the value of each trip, compounding forward for past years;
- Calculate for the substitute trips, the difference in value to the angler per trip;
- Multiply the number of substitute trips by the difference in value of each trip (because they fished elsewhere but would have preferred fishing in the Hudson River), compounding the lost value for past years; and
- Sum value of lost trips with the decreased in value for substitute trips to calculate total losses due to closures.

The most recent data on angler-days in New York are shown in Table 25. Only the data for the counties adjacent to the Hudson River are included. These data include fishing activities and trips in those counties, including those for people who traveled to those counties to fish.[223]

Not all fishing would be expected to have occurred in the Hudson River itself. There are many lakes and streams in which other fishing might occur. The data were adjusted to include only species that would typically be found in the river as exclude those that would typically be found in streams and lakes (mainly trout species). The sections of the Hudson River that could be used for fishing are broken out in Table 26.

[223] NYSDEC 2014.

Table 25: Annual Recreational Fishing Data for Counties Adjacent to Hudson River[224]						
County	**Total Angler Days**	**At-Location Expenditures (2020 dollars)**	**% Non-Trout Fishing[225]**	**Estimated Hudson Angler Days**	**Estimated Hudson At-Location Expenditures (2020 dollars)**	**Mean Distance Traveled**
Warren	470,306	$12,306,340	73%	343,323	$8,983,628	86.5 miles
Saratoga	497,200	$3,187,263	94%	467,368	$2,996,028	24.9 miles
Washington	250,048	$942,339	56%	140,027	$527,710	33 miles
Albany	173,208	$705,411	88%	152,423	$620,762	19.4 miles
Rensselaer	351,410	$1,020,791	79%	277,614	$806,425	18.3 miles
Greene	76,190	$1,185,435	71%	54,095	$841,659	50.4 miles
Columbia	115,363	$593,298	79%	91,137	$468,706	28.5 miles
Ulster	334,890	$3,264,184	62%	207,632	$2,023,794	44.4 miles
Dutchess	183,836	$992,500	50%	91,918	$496,250	22.1 miles
Orange	349,190	$1,691,520	78%	272,368	$1,319,385	29.1 miles
Putnam	266,602	$1,295,041	63%	167,959	$815,876	23.4 miles
Rockland	178,689	$784,897	92%	164,394	$722,105	18.4 miles
Westchester	415,041	$1,475,508	64%	265,626	$944,325	22.2 miles
Total	**3,661,973**	**$29,444,528**	**-**	**2,695,884**	**$21,566,653**	

Table 26: Recreational Fishing Areas in Hudson River by County			
County	**Shore Miles**	**Average River Width (Miles)**	**River Area[226] (Sq. Mi.)**
Warren	61.2	0.1	6.1
Saratoga	73.1	0.1	3.7
Washington	27.7	0.1	1.4
Albany	16.1	0.2	1.6
Rensselaer	12.9	0.2	1.3
Greene	29.6	0.5	7.4
Columbia	27.4	0.5	6.9
Ulster	43.4	0.7	15.2
Dutchess	40.6	0.7	14.2
Orange	24.4	1.1	13.4
Putnam	13.1	0.9	5.9
Rockland	22.9	2.5	28.6
Westchester	35.2	2.5	44.0
Total	**427.6**	**-**	**149.7**

[224] Based on data in NYSDEC 2014.
[225] Based on data on fish species found typically in streams and lakes rather than in Hudson River (e.g., trout) in NYSDEC 2014.
[226] Based on shore miles and estimate of river width at that part of river, assuming half of river is part of counties on opposite sides of river.

Based on the information in the fishery closure maps in Figure 12 and Figure 13, the estimated closure areas of the Hudson River (by county) were derived as in Table 27.

Table 27: Estimated Recreational Fishing Angler-Days & Trips Taken in Hudson River				
County	**Annual Angler-Days**[227]	**Estimated Annual Angler Trips**	**Years Closed to All Fishing**[228]	**Years Fish Consumption Restricted Through 2018**[229]
Warren	343,323	303,290	1976–1995	1996–2020
Saratoga	467,368	412,870	1976–1995	1996–2020
Washington	140,027	123,699	1976–1995	1996–2020
Albany	152,423	134,650	1976–1995	1996–2020
Rensselaer	277,614	245,243	1976–1995	1996–2020
Greene	54,095	47,787	-	1976–2020
Columbia	91,137	80,510	-	1976–2020
Ulster	207,632	183,421	-	1976–2020
Dutchess	91,918	81,200	-	1976–2020
Orange	272,368	240,609	-	1976–2020
Putnam	167,959	148,374	-	1976–2020
Rockland	164,394	145,225	-	1976–2020
Westchester	265,626	234,653	-	1976–2020
Total	**2,695,884**	**2,381,529**	**-**	**-**

The additional value, is measured as the willingness to pay (WTP) for the additional enjoyment of being able to consume fish that were caught,. Based on the angler-day and fishing trip data from US Fish & Wildlife Service for New York for 2011 and for the United States for 2016, fishing generally involves 1.1 angler-days per trip, or 0.88 trips per angler-day. The annual angler-days were then converted to trips taken in Table 27.

The additional value of being able to consume the fish that are caught is estimated to be $7.48 per trip,[230] based on a review of literature in other areas of the country, where fish consumption advisories were either removed or installed for PCBs. The benefits estimated in the other locations (Tennessee, and Wisconsin) are transferred to the Hudson. The value of fishing overall is $67.71 per trip.[231] Both of these value estimates are assumed to be in 2020 dollars.

Compensation is owed for the lost value of recreational fishing trips in consumption-restricted fishing areas going back 24 years (Upper Hudson) or 44 years (Lower Hudson), as well as into the future, assumed here to be 100 years after the payment is made. Note that in the Upper Hudson between 1976 and 1995, recreational fishing was closed, and so compensation would be due for the closure losses, i.e., lost trips and

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[227] Based on Table 25 for estimated Hudson River-specific angler-days.
[228] Illegal to do any fishing.
[229] Consumption would have theoretically been restricted in the Upper Hudson River during 1976–1995 because the more restrictive ban on any fishing (even catch-and-release) was in effect.
[230] Jakus et al. 1998; Morey and Breffle 2006 (updated to 2020 dollars).
[231] Based on the economic value of a day of trout fishing in New York from USF&WS 2016 (updated to 2020 dollars).

lost marginal value of substitute trips. Thus, consumption-restricted fishing losses do not accrue for 1976-1995.

In 2020, the marginal value of being able to consume the fish that are caught was $7.48 per trip. However, the marginal value in 2019 is 3% higher, if paid in 2020, and so on going back 24–44 years (analogous to the calculations for drinking water). If compensation were paid in 2020, the payment would be made in 2020 dollars at 2020 values.

However, if a NRDA settlement is made in 2022, for example, compensatory payments would be translated from 2020 dollars to 2022 dollars at a rate of 3% per year. Paid in 2022, the compensation would cover 1976–2072 or 1996–2072, and the 2020 values would be compounded forward for two years (by a factor 1.03^2). The calculation for the compound/discount factor, F_{id}, where compensation is paid in 2022 is as in Equation 5:

$$F_{id} = \sum_{n=-100}^{y} 1.03^n = 1.03^2$$

Equation 5

where y = years of past closures prior to 2022 (assumed date that compensation paid) and n = number of years where injuries occurred prior to compensation (i.e., negative n values indicate future years). This value of F_{id} is multiplied by the number of trips each year and by the marginal value of a fishing trip ($7.48 in 2020) to calculate the total damages. The total damages, in 2022 dollars, are $700 million for the Upper Hudson plus $1.21 billion for the Lower Hudson, totaling $1.9 billion overall.

Data are not presently available for estimating the number of fishing trips per year in the Upper Hudson River that would have occurred if it weren't for the PCB contamination and fishing closures, or for the number of substitute trips per year to other water bodies because of the fishing closures. These data might be developed after additional research into fishing statistics for the 1976–1995 period. As a demonstration of this potential loss, we assume the number of trips per annum was the same in 1976–1995 as they are today in the Upper Hudson, i.e., 1.22 million trips per year. If we assume that, for example, 10% of the desired trips were not taken to other locations, and that substitute trips were of equal value to trips in the Hudson River, then 122 thousand trips were lost per year in 1976–1995. Each trip is valued at $67.71 in 2020 dollars. For fishery closures, the equation for the compound/discount factor, F_{id}, where compensation is paid in 2022 is as in Equation 6:

$$F_{id} = \sum_{n=27}^{46} 1.03^n$$

Equation 6

where n = number of years where injuries occurred prior to compensation. The resulting damages are $121{,}975 \times 67.71 \times F_{id}$, which amounts to $523 million in 2022 dollars.

The grand total value of damages, summing both the angler trips foregone (assuming 10%) and the value of trips restricted, is $2.439 billion (Table 28).

Table 28: Potential Recreational Fishing Lost-Use Values from 2017 Angler Survey[232]				
River Portion	**Angler Trips Closed**	**Angler Trips Restricted**	**Value of Angler Trips Closed**	**Value of Angler Trips Restricted**
Upper Hudson	24.4 million	29.3 million	$523 million	$700 million
Lower Hudson	0.0	51.1 million	$0	$1.216 billion
Total	**24.4 million**	**80.4** million	**$523 million**	**$1.916 billion**
Grand Total Lost and Restricted Trip Value				**$2.439 billion**

[232] Responsive Management 2019a, 2019b, 2019c.

Chapter 6: Dredging as Primary Restoration

6.1 Reasons Additional Dredging Should be Considered

The above analysis includes quantification of injuries and compensatory restoration scaling or damages for some but not all the injuries caused by the GE PCB contamination in the Hudson River ecosystem. Below is a summary outline of the quantifiable injuries and compensatory damages developed in the preceding chapters of this report, as well as other injury categories that have not been quantified. Those included in the preceding chapters are emphasized in **bold.**

Ecological Services

- Wetland/Floodplain-Dependent Species
    - Injuries have occurred and are on-going for mammals, birds, reptiles, and amphibians in these riparian habitats.
    - Measured levels of PCB contamination in fish are high enough to indicate injuries in wildlife predators are occurring on an on-going basis.
    - **Mink injuries were quantified for the UHR, and approximated for the LHR north of Catskill, based on reductions in populations due to bioaccumulation of PCBs.**
    - The scale of restorative actions for mink are assumed to be encompassing of the needs of other wetland/floodplain-dependent species, including mammals, birds, reptiles, amphibians, fish, and invertebrates.
- Hudson River (UHR and LHR)
    - Injuries to fish and invertebrates in the Hudson River itself, both UHR (riverine) and LHR (estuarine) have not been quantified for any species.
    - Several species are threatened or endangered (2 species of sturgeon, potentially several freshwater mussel species)
    - Terrestrial, freshwater/riverine, and estuarine fish and wildlife consumers of the biota inhabiting the river are bioaccumulating the remaining PCBs to varying degrees causing injuries that remain unquantified.

Human Services

- Commercial fishing losses have not been quantified.
- Recreational and subsistence fishing
    - **Fish consumption advisories based on PCB levels in fish have led to human service losses due to lost fishing trips and the value of trips taken, that are compensable under CERCLA.**

    - Foregone subsistence fishing has not been evaluated.

- Wildlife Hunting
    - Lost recreational hunting services have not been quantified. Duck and geese hunting activities have likely been reduced in the Hudson River. However, these and other hunted wildlife move in and out of the Hudson area, and so the contamination is more widespread than the locally present individual animals. Like the fishing service losses, this would include lost hunting trips and the value of trips taken.
    - Foregone subsistence hunting has not been evaluated.
- Recreation
    - Lost recreational boating services have not been quantified. How the number of trips or value of the trips have been affected by the PCB contamination has not been evaluated.
    - Contact recreation service losses, i.e., foregone swimming, wading, picnicking and beach use, have not been evaluated.
- Fish and Wildlife Viewing and Nonuse Values
    - Lost wildlife viewing and passive, or nonuse, values as the result of PCB contamination in the Hudson River have not been quantified.
- Navigation
    - **Dredging can restore demonstrated losses of navigational services. The needed scale of this primary restoration has been quantified.** However, this dredging has not been performed because of the expense of treating the contaminated sediments. Compensatory damages for the years of lost services has not been quantified.
- Surface and Groundwater
    - **Drinking water service losses for surface waters have been quantified based on costs of developing alternatives and using willingness to pay measures.**
    - Groundwater standards have been demonstrated as exceeded, but related service losses have not been quantified.
- Indoor Air Quality (Vapor Intrusion) service losses have not been evaluated.

Dredging in the riparian habitat adjacent to the Hudson River could potentially off-set some of the scale of wetland restoration needs to compensate for lost wetland-dependent wildlife production and other injuries to wetland-dependent biota. However, dredging in riparian habitats would cause additional injuries as well, which would need to be considered and quantified.

Additional dredging in the upper Hudson River itself could restore future ecological and human use service losses related to sediment PCB contamination in the UHR and potentially in the LHR. Dredging would benefit fish and invertebrates and their consumers, recreational and subsistence fishing, and hunting services, contact recreation and boating, navigation, surface water and groundwater services after the completion of the work and a service recovery period. However, lost ecological and human services in the past decades and in the future up until this restoration is completed would still be compensable as part of an NRD claim. Compensation for past injuries will be much larger than future gains because the Responsible Party needs to compensate the public for the delay in benefits from the compensation, i.e., due to compounding of losses suffered in the past that remain uncompensated. Future gains are discounted (in practice by 3% annually), so >50 years into future, the damages only contribute a small fraction to the total summed over past to future time. Yet the injuries suffered by the public in the future will still be occurring without mitigating the PCB contamination. Hence, the scale of needed dredging to remove the GE-contributed PCB contamination in the LHR and UHR is evaluated below.

6.2 Overview of Approach to Quantify Dredging Needs

If additional dredging were to bring sediment PCB concentrations below those causing fish consumption advisories, the ecological services would also be restored, as the thresholds to protect human consumption are below those for protecting wildlife and aquatic biota (USEPA 2002). Dredging would also restore surface drinking water services in future years.

Thus, the overall approach is to calculate how much dredging is needed to reduce PCB concentrations in fish below the human consumption-advisory levels. Both the LHR and the UHR are considered. The scaling is performed by quantifying the PCB reduction resulting if more dredging is performed to reduce the sediment concentrations to below various thresholds in each reach of the UHR. “Potential dredging areas” (PDAs) were selected, in order from those with highest contamination, to determine the area of dredging required to reduce the overall average sediment PCB contamination in each reach by the needed amount (i.e., by averaging all PDAs with the dredged areas now below the dredging threshold with other areas in the reach at their respective sediment concentrations at the time of the hypothesized dredging program).

Two models were used to estimate fish tissue reductions resulting from reduction in the mean sediment PCB concentrations in each reach:

1. The “Emulated Model” developed by Field et al. (2016), which uses USEPA’s mechanistic numerical models of PCB transport, fate and fish bioaccumulation for the Hudson River to estimate fish tissue PCB concentrations in the LHR as a function of UHR sediment concentrations and upstream loading of PCBs.

2. An empirically based bioaccumulation model relating fish PCB concentrations in the UHR to local sediment PCB contamination.

Both these models utilize sediment PCB concentration data for 2017 (after the USEPA 2002 selected remedy was performed) and a bioaccumulation model for estimating fish tissue concentrations. Bioaccumulation in the Emulated Model is modeled from sediment to water to fish. The empirically based bioaccumulation model does not explicitly consider water concentrations, modeling fish concentrations based on the local sediment concentrations. The Emulated Model also uses as input estimates of the upstream water PCB concentrations entering the UHR at Fort Edward Dam. The models and results of the calculations are described in the next two sub-chapters of this report.

6.3 Dredging Scaling Based on NOAA's Emulated EPA Model

6.3.1 Emulated Model

The implications and benefits of additional dredging were evaluated using the Emulated Model, which is essentially a statistical regression model developed by NOAA[233] that best fits and predicts (i.e., emulates) the results of the US EPA's mechanistic numerical models Hudson River Toxic Chemical Model (HUDTOX), the "Farley Model"[234]; and FISHRAND.[235] GE sponsored similar mechanistic models for the Hudson River,[236] which were judged as generally consistent with those developed by USEPA.[237]

Simulating HUDTOX, the Emulated Model calculates sediment concentrations and resulting water concentrations of Tri+ PCB in each River Section (RS) of the Upper Hudson River (UHR) in each year in the future, given:

- Starting mean sediment concentrations in each of the eight Reaches that combine to make up the three RSs and subsections of RS3 (Table 29);
- An annual "recovery rate" (natural attenuation rate); and
- A concentration in the upstream river water entering RS1 at the Fort Edward Dam.

Table 29: River Sections (RS) and Reaches for the Upper Hudson River (UHR)

River Section	River Section Name	Reach #	Reach Name	Reach Definition
RS1	Thompson Island Pool	8	Thompson Island Pool	Fort Edward Dam/Rogers Island to Thompson Island Dam
RS2	Schuylerville	7	Fort Miller Pool or Landlocked Pool	Thompson Island Dam to Fort Miller Dam (Lock 6)
RS2	Schuylerville	6	Northumberland Pool	Fort Miller Dam (Lock 6) to Northumberland Dam (=N end Lock 5)
RS3A	Stillwater	5	Stillwater Pool	Northumberland Dam to South end of Lock 5
RS3A	Stillwater	5	Stillwater Pool	South end Lock 5 to Lock 4 (Stillwater)
RS3B	Waterford	4	Upper Mechanicville Pool	Lock 4 (next to Stillwater Dam) to Lock 3 (Mechanicville, NY)
RS3B	Waterford	3	Lower Mechanicville Pool	Lock 3 to Lock 2 (Mechanicville, NY)
RS3C	Troy	2	Lock 1 Pool	Lock 2 to Lock 1 (Halfmoon, NY)
RS3C	Troy	1	Waterford (or Troy) Pool	Lock 1 at Waterford Dam to Federal Lock and Dam at Troy

233 Field et al. 2016.
234 Farley et al. 1999,
235 USEPA 1999, 2000a, 2000b, 2002.
236 QEA, 1999a,b; Connolly et al. 2000.
237 Field et al. 2016.

The sediment concentrations in the UHR decline exponentially at a constant "recovery rate" input to the Emulated Model. The USEPA[238] used the projections of PCB load from the UHR (at Waterford, River Section 3B, RS3B) to the Lower Hudson River (LHR) produced by HUDTOX as input to the Farley model[239] to calculate sediment and water concentrations in the LHR. The Emulated Model simulates this loading to the LHR and then calculates Tri+ PCB concentration in fish in the Lower Hudson River (LHR) from the mean Tri+ PCB concentrations in water at Waterford (RS3B). Specifically, it emulates the FISHRAND model (a mechanistic food web model) to predict Tri+ PCB concentrations in tissues of four species of fish (white perch, brown bullhead, largemouth bass, and yellow perch) at four LHR locations identified by River Mile (RM): Federal Dam at Troy (RM152), Catskill (RM113), Kingston (RM90), and Highland Falls/West Point (RM50).

Use of the Emulated Model is based on several assumptions, which derive from the US EPA models HUDTOX, the Farley model, and FISHRAND. It assumes:

- The EPA mechanistic numerical models are still valid after the extensive dredging in the Upper Hudson River in 2009–2015;
- Tri+ PCB concentrations in water at Waterford (River Section 3B, RS3B) control the concentrations in the LHR;[240] and
- Tri+ PCB concentrations in fish in LHR (emulating FISHRAND) are result of water concentrations.

Note that HUDTOX was calibrated to historical (pre-2009) conditions when PCB concentrations were orders of magnitude higher. Thus, the Emulated Model does not consider changes in the UHR system resulting from the extensive dredging that occurred during 2009–2015 or local sediment PCB contamination and other complexities in the LHR that may be contributing to the fish contamination.[241] Importantly, the Emulated Model does not address UHR fish contamination at all.

Based on FISHRAND, the most bioaccumulating fish species of the four considered by the Emulated Model was largemouth bass. Thus, water concentrations that would reduce concentrations in largemouth bass to below US EPA fish tissue threshold levels protective of human health would be protective for all four species. The Emulated Model was used to calculate water concentrations at Waterford (RS3B) that would reduce largemouth bass tissue concentrations to below US EPA fish fillet consumption thresholds at the Federal Dam at Troy, and therefore be predicted to reduce concentrations in all four fish species below the thresholds at all locations of the LHR. The US EPA fish tissue thresholds and estimates of safe concentrations at Waterford are in Table 30. The fish thresholds are used by the New York State Department of Health (NYSDOH) for fish advisory considerations.

[238] USEPA 1999.
[239] Farley et al. 1999.
[240] Based on the Farley model, Farley et al. 1999.
[241] Connolly et al. 2000; Farley et al 2017.

Table 30: Fish Consumption Thresholds and Water Concentrations at Waterford (RS3B) Predicted to Reduce Fish Tissue Concentrations in LHR to Below Threshold.[242]			
Fish Tissue Threshold	**Human Consumption Considered Safe**	**Fish Tissue Concentration (mg/kg)**	**Needed Water Concentration (ng/L) at Waterford (RS3B)**
Tri+ PCB Remediation Goal	1 meal per week	0.05	0.81
Interim Target (Monthly)	1 meal per month	0.2	3.13
Interim Target (Bimonthly)	1 meal per two months	0.4	6.23

The Emulated Model was used to calculate water concentrations in each RS, and the number of years required to reach the target concentrations at Waterford (RS3B) that would reduce fish concentrations to below each of the thresholds, based on the following input data:

- Mean Tri+ PCB sediment concentrations in 2017 in each of the Reaches that combine to make up RS1, RS2, RS3A, and RS3B;
- Annual recovery rate (percent decrease per year), and
- Tri+ PCB concentration in the upstream river water entering RS1 at the Fort Edward Dam.

Aroclor[243] measurements of sediment concentrations were translated to Tri+ PCB using the GE regression to mGBM equivalent in Equation 7[244]. This conversion corresponds to the EPA models underlying the Emulated Model. The ratio of Total PCB by method 1668c is about 2.6 times Tri+ PCB by mGBM as in Equation 7:[245]

$$\text{Tri} + \text{PCB}_{est} = (0.13 \times \text{A1221}) + 0.89 \times (\text{A1242} + \text{A1254})$$

Equation 7

Where: A1221, A1242 and A1254 refer to the concentrations of Aroclor 1221, Aroclor 1242 and Aroclor 1254, respectively and Tri+ PCB_{est} is the estimated Tri+ PCB concentration present in the sample.

The Emulated Model, as shown in Equation 8, was set up with areas for each RS, distances between the dams at the ends of each RS, and transfer coefficients following the model in Field et al. (2016).[246] Table 31 defines the coefficients and assumed values.

$$c_{wi} = c_{wi-1} \times (1 - g_i \times \delta i) + \{\gamma_i \times (c_{si} \times A_i) x (1 - g_i \times D_i) + \beta_i \times (R_i \times c_{si} \times A_i)\}$$

Equation 8

[242] US EPA 2002.
[243] Aroclor a trade name for a PCB mixture produced during 1930–1979. There are many types of Aroclors and each has a distinguishing suffix number that indicates the degree of chlorination
[244] Equation 7 from Attachment A, Section A.3.1 of Louis Berger and Kern 2019.
[245] Louis Berger and Kern 2019.
[246] Field et al. 2016.

Table 31: Emulated Model Inputs, Coefficients, and Dimensions for Each RS

Symbol	Definition	Units	RS1	RS2	RS3A	RS3B
i	Segment number	#	1	2	3	4
δ_i	Distance between dams ($\delta i = di - di$-1)	km	10.1	8.2	24.50	7.60
d_i	Locations of the four dams	km	303.4	295.2	270.7	263.1
D_i	Distance from the downstream dam in subsection	km	5.05	4.1	12.25	3.80
A_i	Area of cohesive sediments (Ai)	ha	42	54	93	52
γ_i	Transfer coefficient from water to sediment	fraction	0	0.035	0.0157	0.0641
g_i	Transfer coefficient from sediment to water	fraction	0.016	0.0095	0.0078	0.0451
β_i	Sediment to water net transfer coefficient for dredged residuals	fraction	0.0251	0.0143	0.0283	0.0357
C_{si}	Sediment Tri+ PCB concentration in 2017	mg/kg	0.950	1.303	0.790	0.561
R_i	Decay rate of post-dredge residual concentrations[247]	percent	2-10	2-10	2-10	2-10

The mean sediment Tri+ PCB concentrations in each RS in 2017 were set at the area-weighted averages calculated by Louis Berger & Kern,[248] based on the NYSDEC 2017[249] and sediment samples taken in 2016 by GE. Measured PCB concentrations in the NYSDEC sediment samples are tabulated in EA (2018). The GE samples taken in the fall of 2016 were from non-dredged areas. The NYSDEC samples in 2017 were taken by EA in other areas (dredged and non-dredged) where EA could obtain samples. The measured PCB concentrations in the GE 2016 sediment samples are available from the Hudson River Watershed.[250] All the samples were randomly placed within equal-area polygons laid over the Hudson River bottom. Thus, simple averaging of the samples can be used.

However, Louis Berger and Kern[251] accounted for unsampled areas in their calculations of the area-weighted mean in each Reach and RS. Unsampled locations were either non-recoverable (bedrock), assigned the median detection limit 0.03 mg/kg, or assigned the mean of sampled locations (non-dredged or dredged, depending on location's treatment).[252]

The initial Tri+ PCB concentration in water entering from upstream of RS1 (at Fort Edward Dam) was about 1–2 ng/l Tri+ PCBs before 2002[253] and the 2009–2015 dredging program. In 2016, the year following the dredging activity, 2–10 ng/l Tri+ PCBs was measured at the Fort Edward Dam station.[254] However, ~0.5 ng/l Total PCBs was measured in 2017–2018 at RM 197, Fort Edwards,[255] equivalent to ~0.2 ng/L Tri+ PCB. Because the dredging was just completed in 2015, and restoration activities occurred in the UHR during 2016 (presumably disturbing sediments), it is assumed that the 2017 – 2018 data are representative of the upstream source water concentration (C_{wi-1}, where i=1, in Equation 8) in the years after 2017.

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247 Varied in model runs.
248 Louis Berger & Kern 2019.
249 EA 2018.
250 https://www.diver.orr.noaa.gov/web/guest/diver-explorer?siteid=608&subtitle=Hudson%20River%20Watershed
251 Louis Berger & Kern 2019.
252 See Louis Berger & Kern (2019) for details.
253 EPA 2002.
254 Field et al. 2016; Farley et al. 2017.
255 Based on GE monthly reports to NYSDEC; Farrar, 2019b.

However, sensitivity to this assumed input was examined, running the range of 0–10 ng/l Tri+ PCBs.

The natural recovery (i.e., attenuation) rate of the UHR sediments is highly uncertain. At the time of the US EPA 2002 ROD, recovery rates were predicted to be on the order of eight percent (8%) per year. Recent estimates range from 1–10% annual decrease in RS-mean sediment PCB concentrations.[256] However, these estimates are of necessity based on fits (regressions) to pre-dredging data (i.e., prior to 2011). Field et al. (2016) estimated a mean of 1.3% and 95% upper confidence limit of ~ 3%.

Louis Berger and Kern (2019) analyzed the pre-2011 data in detail and concluded that the median was 6% per year, with an uncertainty range of 2 – 10%. Papadopulos & Associates (2019) analyzed recent and historical fish tissue concentration data, finding the rate of decline in fish tissues has varied from 1–7% when including data collected after 2015.

The Emulated Model was run assuming Monitored Natural Attenuation (MNA) after 2017 and for various assumed dredging scenarios. Under MNA, the sediment Tri+ PCB concentrations decline over future years according to the assumed annual recovery (attenuation) rate. Several assumed recovery rates were run, and the year in which the USEPA fish tissue concentration thresholds would be met at Troy was calculated. In running the scenarios assuming additional dredging would be performed, that dredging is assumed to occur in 2025.

In the year 2025, the sediment concentrations of the assumed-dredged locations were set at various targets and recovery followed thereafter. For these assumed dredging scenarios, the NYSDEC 2017 and GE 2016 sediment samples were sorted into the appropriate Reaches, based on Appendix 2 of USEPA (2019) and notes in EA (2018). The weighted-mean sediment Tri+ PCB concentration in each RS, assuming the dredged areas met target concentrations (and including unsampled areas at the concentrations used by Louis Berger and Kern (2019) in their calculations), was calculated annually into the future. The year in which the USEPA fish tissue concentration thresholds would be met in the LHR below Troy, under the assumed dredging plan, was then calculated using the Emulated Model.

6.3.2 Emulated Model Results Assuming No Further Dredging

The results of the Emulated Model calculations assuming MNA after 2017 showed that the 0.05 mg/kg remediation goal could not be met if the upstream source water concentration exceeded 2 ng/l Tri+ PCBs. The years required to meet the remediation goal is highly sensitive to the assumed recovery rate and to varying upstream source water concentrations that exceed ~1.5 ng/L (Figure 17).

[256] Field et al. 2016; Louis Berger and Kern 2019.

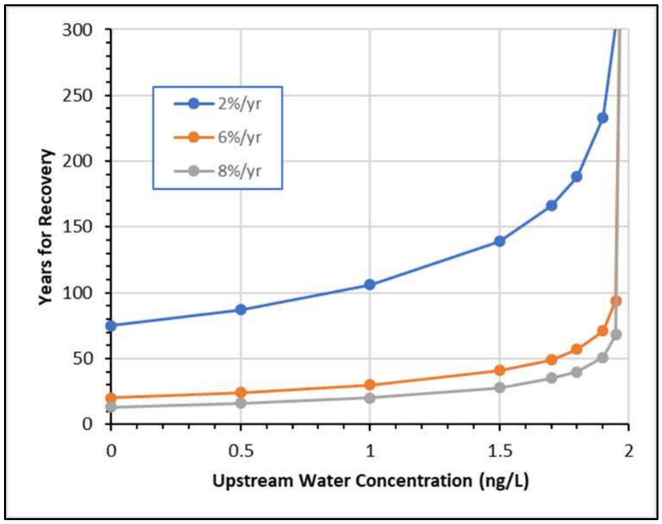

Figure 17: Years Required to Meet Remediation Goal (0.05 mg/kg) in LHR Fish as Function of Assumed Recovery (Attenuation) Rate and Upstream Source Water Tri+ PCB Concentration

Thus, the Emulated Model indicates the remediation goal cannot be met if the upstream source is not controlled. Recent water samples from the Fort Edward Dam monitoring station suggest the upstream source is presently under control, but this should and will be monitored over time. However, the time to reach the interim target of 0.2 mg/kg in LHR fish was not as sensitive to the assumed upstream source water concentration within the range considered (Figure 18).

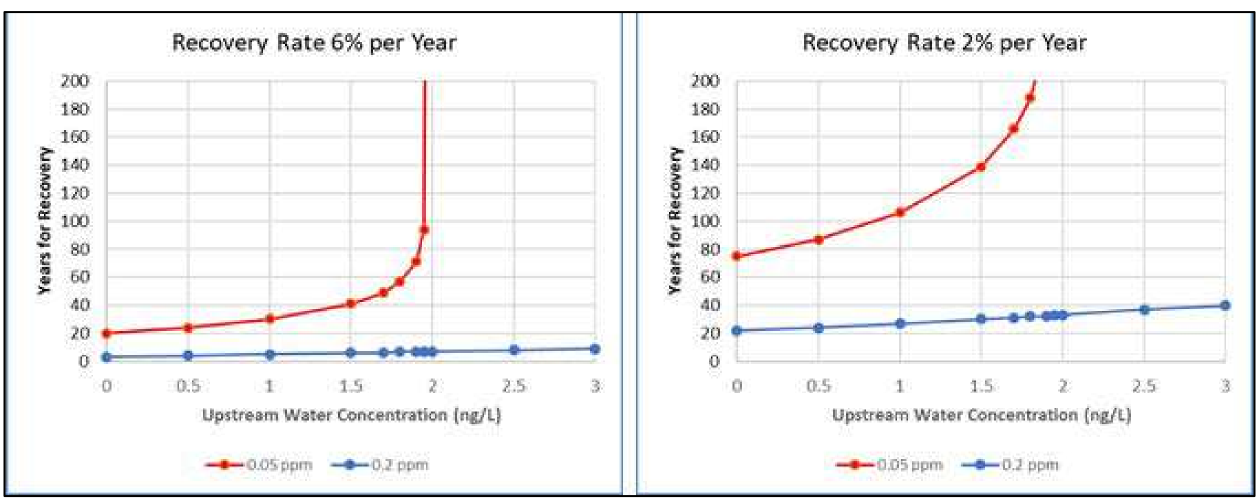

Figure 18: Years Required to Meet Remediation Goal (0.05 mg/kg) and Interim Target (0.2 ppm) in LHR fish as Function of Assumed Recovery (Attenuation) Rate and Upstream Source Water Tri+ PCB Concentration

If the upstream source water concentration remains ~0.2 ng/L, the 0.2 mg/kg interim target in fish could be met after 2 years assuming 10% per year, 7 years assuming 6% per year, 13 years assuming 4% per year, and 32 years assuming 2% per year for recovery rates. Meeting the remediation goal (assuming 0.2 ng/L in upstream water) would take 13 years assuming 10% per year, 27 years assuming 6% per year, 44 years assuming 4% per year, and 96 years assuming 2% per year for recovery rates (Figure 19). As the recovery rate appears to be less than 6% annually post 2015, this essentially means the remediation goal will not be met in the foreseeable future, i.e., not over the next 3 decades or so where NRDA compensation would be claimed if the claim were calculated today. Note that discounting makes injuries more than 30 years into the future essentially negligible in the damage claim, given the decades of historical injuries and damages owed the public in compensation.

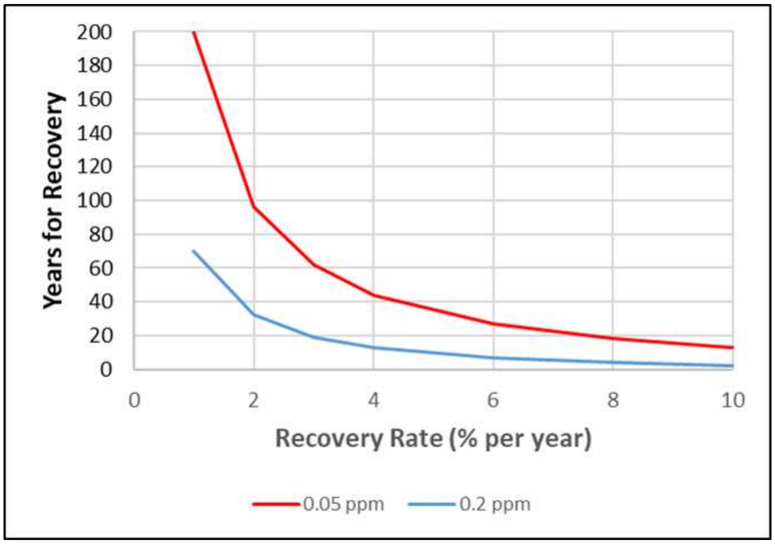

Figure 19: Years Required to Meet Remediation Goal (0.05 mg/kg) and Interim Target (0.2 ppm) in LHR fish as Function of Assumed Recovery (Attenuation) Rate Assuming Upstream Source Water Tri+ PCB Concentration of 0.2 ng/L for All Years

6.3.3 Emulated Model Results Assuming Dredging

Given that the remediation goal for fish contamination in the LHR will not be met in the foreseeable future, and the UHR contamination is not sufficiently remediated to bring UHR fish below human consumption thresholds, various potential alternatives for additional dredging were evaluated using the Emulated Model. If the remediation phase under CERCLA does not address this contamination, the dredging could be considered as primary restoration for preventing further on-going injuries as part of the NRDA.

Louis Berger and Kern[257] identified 11 hot spots, amounting to 18.5 acres.[258] If these 11 hot spots were assumed dredged in 2025, and the recovery rate is 6% annually, the interim target of 0.2 mg/kg in fish would be met in the LHR in 2029 and it would take until 2049 to meet the remediation goal of 0.05 mg/kg in LHR fish (Table 32). This small change from MNA is because there are large areas of "warm" sediments in the rest of the RS, such that the mean sediment concentrations in each RS would not change significantly. This would not be expected to be measurable in LHR fish tissues, even after the many years required to reach the thresholds.

Alternative dredging plans were explored where all locations within a RS, as represented by the 2016–2017 sediment samples, were assumed to be identified as above specific sediment concentration thresholds and

[257] Louis Berger and Kern 2019.
[258] In Table 5.1-1 of their report.

so dredged beginning in 2025. The post-dredging mean sediment Tri+ PCB concentration for the RS where dredging is assumed to occur was calculated using the 2016–2017 sediment data for areas assumed not to be dredged (because they were below the target concentration) and assuming a target concentration was met in locations dredged. Two target sediment concentrations were explored: 0.25 mg/kg (ppm, which was USEPA expectation in the 2002 ROD) and 0.10 ppm. Table 32 and Table 33 summarize the results for various assumed recovery rates and assuming 0.2 ng/L Tri+ PCB in the water at the upstream source.

Table 32: Recovery Time to Below Fish Concentration Thresholds and Areas Dredged for Alternative Dredging Projects Assumed to Begin in 2025

Scenario	Dredge River Segment				Recovery Rate per Year	Year to Meet Goal in Fish[259]		Acres to Dredge
	RS1	RS2	RS3A	RS3B		0.2 mg/kg	0.05 mg/kg	
MNA, No More Dredging	(none)	(none)	(none)	(none)	6%	2032	2052	0
Dredge 11 Hot Spots Identified[260]	3 locations	2 locations	1 location	4 locations	6%	2029	2049	18.5
Dredge RS1	***>0.25 ppm***	(none)	(none)	(none)	6%	2031	2052	103
Dredge RS2	(none)	***>0.25 ppm***	(none)	(none)	6%	2029	2047	279
Dredge RS3A	(none)	(none)	***>0.25 ppm***	(none)	6%	2032	2052	278
Dredge RS2 & RS3A	(none)	***>0.25 ppm***	***>0.25 ppm***	(none)	6%	2025	2044	557
Dredge RS2, RS3A, RS3B	(none)	***>0.25 ppm***	***>0.25 ppm***	***>0.25 ppm***	6%	2025	2041	577
Dredge RS1, RS2, RS3A, RS3B	***>0.25 ppm***	***>0.25 ppm***	***>0.25 ppm***	***>0.25 ppm***	6%	2025	2041	680
Dredge RS1, RS2, RS3A, RS3B	(none)	***>0.1 ppm***	***>0.1 ppm***	***>0.1 ppm***	6%	2025	**2032**	**1,405**

[259] Interim Target 0.2 mg/kg and Remediation Goal 0.05 mg/kg.
[260] In Louis Berger & Kern (2019) Table 5.1-1.

Table 33: Recovery Time to Below Fish Concentration Thresholds and Areas Dredged for Alternative Dredging Projects Assumed to Begin In 2025 and Where Interim Target (0.2 mg/kg) Could be Met the Year of Dredging (2025)

Scenario	Dredge River Segment				Recovery Rate per Year	Year to Meet Goal in Fish		Acres to Dredge
	RS1	RS2	RS3A	RS3B		0.2 mg/kg	0.05 mg/kg	
Dredge RS1, RS2, RS3A, RS3B	***>0.1 ppm***	***>0.1 ppm***	***>0.1 ppm***	***>0.1 ppm***	2%	2025	**2032**	1,743
Dredge RS1, RS2, RS3A, RS3B	(none)	***>0.1 ppm***	***>0.1 ppm***	***>0.1 ppm***	2%	2025	2049	1,559
Dredge RS1, RS2, RS3A, RS3B	(none)	***>0.1 ppm***	***>0.1 ppm***	***>0.1 ppm***	4%	2025	2036	1,494
Dredge RS1, RS2, RS3A, RS3B	(none)	***>0.1 ppm***	***>0.1 ppm***	***>0.1 ppm***	6%	2025	**2032**	1,405

The results show that, assuming a 6% recovery rate, the interim target of 0.2 mg/kg in LHR fish could be met essentially immediately by dredging remaining sediments >0.25 ppm in RS2 and RS3A (557 acres). This is 7 years earlier than under MNA, but the remediation goal would still not be met for decades (not until 2044). In order to meet the remediation goal of 0.05 mg/kg in fish by 2032 (which would be the soonest it could feasibly met, given the extent of the sediment areas still contaminated), and assuming 6% recovery rate, dredging to 0.1 ppm would be necessary in remaining contaminated areas of RS2, RS3A and RS3B. Dredging remaining sediments >0.25 ppm in RS1 would not change down river contamination significantly. If the recovery rate is lower than 6%, remaining sediment contamination >0.1ppm in RS1 would also need to be dredged in order to meet the remediation goal for LHR fish be 2032. Thus, the needed dredging program would cover 1,405–1,743 acres. The 2011–2015 dredging covered 443 acres in 5 years (i.e., most of the dredging was done in 2011–2015; another 58 acres were dredged in 2009). Thus, this much additional dredging would be about 4 times the area as the 2009-2015 program and would likely take at least 7 years (i.e., until 2032) to accomplish.

6.4 Dredging as Primary Restoration of Both UHR and LHR

The calculations using the Emulated Model only addresses fish contamination in the LHR. In order to evaluate dredging needed to reduce fish PCB contamination in the UHR to the remediation goal, a simpler modeling approach is used, which is based measurements of UHR sediment and fish samples. Assuming fish contamination is the result of local PCB sediment contamination, the ratio of fish concentration to sediment PCB concentration yields an empirical site-specific Bioaccumulation Factor (BAF) for fish. Mean fish tissue Total PCB concentrations by RS for samples taken from the UHR in 2015, 2016 and 2017 are available,[261] and listed in Table 34 along with the mean Tri+ PCB concentration in each RS. Their ratio is the estimated BAF for fish Total PCB / Sediment Tri+ PCB. Dividing the remediation goal for fish tissue 0.05 mg/kg by the RS-specific BAF gives a RS-specific remediation goal for the sediments, as Tri+ PCB. Similarly, dividing the interim target for fish tissue 0.2 mg/kg by the RS-specific BAF gives a RS-specific

[261] In Farrar 2019a,b.

interim target for the sediments, as Tri+ PCB. Table 34 lists these sediment interim targets and remediation goals.

Table 34: Empirical Bioaccumulation Factors for PCB and Sediment Thresholds to Meet Interim Target and Remediation Goals in the Upper Hudson River

Metric	RS1	RS2	RS3A	Mean	Note
Mean 2017 Tri+ PCB in Sediments (mg/kg)	0.95	1.30	0.79	(na)	Area-weighted averages in 2017 based on NYSDEC 2017 and GE 2016 samples (Louis Berger & Kern 2019)
Mean 2016-2017 Total PCB in Fish (mg/kg)	1.22	1.55	1.16	(na)	Based on data in Farrar 2019a,b
BAF Fish Total PCB / Sediment Tri+ PCB	1.28	1.19	1.47	1.31	Empirical Post-2015 Bioaccumulation Factor
Sediment Interim Target (mg/kg)	0.16	0.17	0.14	0.15	To meet interim target of 0.2 mg/kg in fish
Sediment Remediation Goal (mg/kg)	0.039	0.042	0.034	0.038	To meet remediation goal of 0.05 mg/kg in fish

Dredging needs to meet the empirical BAF-based sediment thresholds (at the completion of the dredging) are listed in Table 35. As the acreage required exceeds the estimated dredging needs to restore LHR fishing services based on the Emulated Model, a dredging program meeting the remediation goal for sediment contamination would also restore fishing services in the LHR, to the extent water concentrations from the UHR still control the fish contamination in the LHR. Based on the mean sediment PCB concentrations calculated by Louis Berger and Kern (2019), and a recovery (attenuation) rate of 6% per year, natural recovery of the UHR would take 53 years in RS1 to 322 years in RS3C. Natural recovery would take up to 977 years if the sediment concentrations decrease only 2% per year (Table 35).

Table 35: Dredging to Remove all Sediments Exceeding Sediment Tri-PCB Thresholds Compared to Years Required for Natural Attenuation to Meet the Thresholds

Alternative	River Section					Total
	RS1	RS2	RS3A	RS3B	RS3C	
Acres Dredged to Meet 0.038 mg/kg Remediation Goal	428	466	1,215	343	485	2,937
Acres Dredged to Meet 0.15 mg/kg Interim Target	342	443	1,060	289	375	2,509
Years Required to Meet Remediation Goal by Natural Attenuation at 6%/year	53	115	168	262	322	322
Years Required to Meet Interim Target by Natural Attenuation at 6%/year	30	69	100	149	170	170

6.5 Dredging Costs

The cost of dredging, treating, and disposing of PCB-contaminated sediments was estimated in 2006 as over $300 per cubic yard.[262] Assuming the cost would be $500 per cubic yard in 2020 (i.e., including some oversight costs), and dredging would involve removing 5698 yard^3/acre (mean volume dredged per acre,

[262] Hudson River Natural Resource Trustees 2006.

based on the Parsons[263] completion report for the 2011-2015 program), dredging is estimated to cost $2.85 million/acre. As a comparison, in the press, GE is reported to have spent $1.7 billion dredging the Upper Hudson River, indicating $3.46 million/acre.[264]

Table 36 presents the calculated dredging costs, along with dredged acreage and sediment volume. As dredging would require planning, it would not occur until at least 2025; hence the total dredging costs, $10.7 billion, are in 2025 dollars.

Table 36: Dredging Needs/Costs to Meet USEPA UHR and LHR Fish Remediation Goal

Dredge All Areas > 0.038 mg/kg	RS1	RS2	RS3A	RS3B	RS3C	Total
Area Dredged (Acres)	428	466	1,215	343	485	2,937
Sediment Volume Dredged (Million yd^3)	2.4	2.7	6.9	2.0	2.8	16.7
Dredging Cost in Millions of 2020 $	$1,221	$1,328	$3,462	$ 977	$1,381	$8,368
Dredging Cost in Millions of 2025 $	$1,557	$1,694	$4,417	$1,246	$1,762	**$10,677**

6.6 Discussion

Both modeling approaches estimate the scale of dredging required to bring fish tissue concentrations below human health advisory thresholds. If the dredging is not comprehensive enough to bring the sediment concentrations down to meet the health advisory-based thresholds by the end of the dredging project effort, some period of natural attenuation will be required to reduce the sediment concentrations to those levels. The estimated natural recovery rates are highly uncertain, but generally low, such that many years of natural attenuation would be required. Natural attenuation would take 322 or 977 years if the sediment concentrations decrease by 6% or 2% per year, respectively. Thus, additional dredging beyond the selected remedy[265] performed in 2011–2016 is needed to remediate the ongoing injuries in the UHR, as well as PCB contamination from the GE plants that will otherwise continue to enter the LHR.

The limitations of the Emulated Model (and the mechanistic models upon which it is based) include that it assumes that Tri+ PCB concentrations in water at Waterford (RS3B) control the water concentrations in the LHR and Tri+ PCB concentrations in fish in LHR (emulating FISHRAND) are result of water concentrations. Note that HUDTOX, the Farley model and FISHRAND were calibrated to historical (pre-2009) conditions when PCB concentrations were orders of magnitude higher.

However, the needed dredging to meet the remediation goal in the LHR (based on the Emulated Model) is less than that needed to meet the goal in the UHR (based on the empirical site-specific bioaccumulation model). Thus, a dredging plan to meet the goal in the UHR will also remediate the ongoing PCB contamination flowing into the LHR from the UHR at Troy. This obviates the dependence of this dredging

263 Parsons 2019.
264 https://poststar.com/news/local/epa-dec-officials-disagree-on-hudson-river-pcb-data/article_80ff67e4-b1bd-55fb-bd9f-4024b2bb36d9.html
265 US EPA 2002

scaling quantification on the assumptions of the Emulated Model and the calibrations of the underlying mechanistic models to a different state of contamination in the river.

However, the calculations of dredging requirements are dependent on the degree to which the 2016–2017 sediment and 2016–2017 fish samples represent the conditions over the present and next decades. Quoting from the independent evaluation by Farley et al. (2017): "Continued evaluation of post-dredging monitoring data, re-assessment of PCB mass inventory in sediment and re-evaluation of PCB model projections should be performed. This work should include congener-based analyses and modeling of specific PCB congeners and/or PCB homolog groups to enhance the interpretation of post-dredging data and increase the reliability of model projections. This work will be critical in determining if natural attenuation will be sufficient in reducing PCB concentrations to acceptable levels in a reasonable time frame or if additional remedial action will be required." While we agree with their assessment, it is quite clear that natural attenuation will not reduce PCB concentrations sufficiently to protect human health in a reasonable time frame.

In addition to any remediation still needed, the NRDA should include compensation for the historical injuries and those suffered until the additional dredging and/or natural attenuation has brought the sediment concentrations down to levels where fish in the UHR and LHR do not exceed the health advisory-based remediation goal. Thus, the restoration and damage scaling presented in previous chapters would still apply, and the dredging costs would be additive to those other damages.

A summary of the different resource categories is shown in Table 37 with the damage quantification assessments that have been completed in this report, including the primary restoration dredging. For many of the resources, a partial assessment has been completed in that a restoration for one resource (e.g. dredging to remove the fish consumption restriction) will also improve conditions for another category (e.g. fish and invertebrates), although it may not inclusively comprise a full recovery.

Table 37

Affected Resource	Injuries		Restoration/Damages	
	Past	Future	Primary	Compensatory
ECOLOGICAL SERVICES				
Mink	●	●	○	●
Wetland Dependent Wildlife (Birds, Mammals other than Mink, Reptiles, Amphibians)	○	○	○	◍
Riverine Wildlife (Birds, Mammals, Reptiles, Amphibians)	○	○	◍	○
Estuarine Wildlife (Birds, Mammals, Reptiles)	○	○	○	○
Wetland Dependent Fish and Invertebrates	○	○	○	◍
Riverine Fish and Invertebrates	○	○	●	○
Estuarine Fish and Invertebrates	○	○	◍	○
Sturgeon (Threatened & Endangered Species)	○	○	◍	○
Mussels and Other Benthic Communities	○	○	○	○
Surface Water	○	○	◍	○
HUMAN USE SERVICES				
Recreational Fishing	●	●	◍	●
Commercial Fishing	○	○	○	○
Drinking Water Quality	●	●	○	●
Navigation	○	○	◍	○
Recreational Boating	○	○	◍	○
Contact Recreation (Swimming)	○	○	◍	○
Subsistence	○	○	◍	○
Wildlife Hunting	○	○	◍	○
Indoor Air Quality (Vapor Intrusion)	○	○	◍	○
Wildlife Viewing/ Passive Use	○	○	◍	○

Chapter 7: Comparison with Other NRDA Settlements

Each NRDA case is unique with different factors determining the degree and scope of damages and the monetary settlement amounts.

7.1 Factors for Degree and Scope of NRDA Damages in Settlements

In comparing the Hudson River PCB case to any other NRDA settlement, it is important to consider the factors that would affect the degree and scope of damages:

- The relative toxicity of the pollutant, including the degree to which the pollutant biomagnifies in the food web;
- The length of time of the contaminant exposure and presence in the environment;
- The degree to which primary restoration, remediation, and cleanup activities prior to the NRDA phase may already have mitigated pollutant effects and injuries (which also affects the number of years over which injuries occurred);
- The human population that has been affected (since injuries for human services are proportional to the number of people suffering the injury);
- The ecological receptors in the affected location (i.e., densities and sensitivities);
- The extent of the geographic area affected;
- Availability of scientific data with which to quantify injuries;
- The use of cooperative NRD agreements, which would tend to lower the NRD settlement amount;
- The availability of data and studies on pollutant effects at the time of the NRDA phase; and
- General changes that have occurred in the way in which NRDAs are calculated and the scope of damages that are considered.

7.2 NRDA Settlements

The vast majority of NRDA settlements have been for cases involving crude oil or refined petroleum products, though a few have involved other types of contaminants. In general, oil spills do not cause the long-term contamination issues seen with PCB cases. With oil, the effects are more acute in that there is a spill that causes immediate effects with some longer-term residual effects. Most components of oil break down in days to weeks, while some remains for months to years. PCB contamination cases, such as the Hudson River case, have contamination effects for decades or longer, especially if not remediated. The PCB cases are also different in that the discharges have generally occurred over decades as well.

7.3 Deepwater Horizon NRDA Settlement

The most recent and largest oil spill NRDA settlement to date was for the Macondo MC252 (Deepwater Horizon) spill in the Gulf of Mexico. This incident involved a well blowout that resulted in 4.9 million barrels of crude oil entering the Gulf of Mexico. The settlement came to $9.2 billion (in 2018 dollars). When comparing that settlement with potential damages for the Hudson River, there are a number of important factors should be considered:

- The Deepwater Horizon case involved an acute situation, i.e., a spill of a very large amount of oil occurred over the course of 87 days, compared with the longer-term (i.e., decades of) inputs of PCBs into the Hudson River.

- While there were documented effects of the spilled oil, the Gulf of Mexico has largely "recovered" at this point (eight years later), particularly with regard to commercial and recreational fisheries, the Hudson River commercial fisheries have been closed for decades and recreational fishing has been significantly affected.
- Drinking water was not affected in the Gulf of Mexico, whereas there were significant long-term effects on drinking water in the Hudson River due to PCB contamination.
- The most toxic components of crude oil evaporate relatively quickly, and the persistence of PAHs and other petroleum components is on the order of months to years, as opposed to PCBs, which are persistent in river substrates for decades or longer.
- In the Hudson River case, PCB contamination above established standards and thresholds for injury have existed since before 1980 when CERCLA became law and is expected to continue for many more decades or more, absent significantly more remediation to remove the contamination. The trustee resources and effort (financially supported by the responsible party, RP) that went into assessing the injuries and potential damages from the Deepwater Horizon spill far exceeded any other NRDA case that has been settled to date. The research produced by the Gulf of Mexico Research Initiative contributed to trustee- and RP-sponsored research as well.
- For the Deepwater Horizon spill, the trustees claim covered essentially all ecosystem components, as well as socioeconomic-related injuries. Numerous publications in peer-reviewed literature resulted from trustee-supported and other research efforts. The Hudson River PCB case would be expected to be similarly comprehensive and based on sound scientific research.
- In the Hudson River case, trustees are pursuing many scientific studies to support injury quantification. Several studies are now published in peer-reviewed journals that establish bases for injury quantification. We expect more well-documented studies will be forthcoming.

7.4 Factors Specific to PCB Damages

PCBs are persistent organic pollutants (POPs) and remain in the environment far longer than hydrocarbons originating from oil spills. PCBs biomagnify (i.e., increase in concentrations in the tissues of organisms at successively higher levels in a food chain), and so their effects are most suffered by predators high in the food web. Hydrocarbons in oil do bioaccumulate (increase in concentration in tissues of organisms' bodies due to absorption from food and the environment) but are metabolized to varying degrees by organisms and do not biomagnify up the food web. Thus, especially for longer-lived predators near the top of the food web, injuries would be expected to be much larger for PCBs than oil per weight of material released into a given environment. The effects of PCBs in the Hudson River have been very well documented with a large number of studies over several decades. For this report, 77 reports and cited papers from the Hudson River Natural Resource Trustees were reviewed. An additional 61 PCB studies conducted specifically on the Hudson River, and 206 other studies on PCB effects and toxicology were also identified.

7.5 Other PCB NRDA Cases

In reviewing past PCB cases, it is important to consider that the other cases generally involved considerably less geographic area of contamination above standards and injury thresholds, and smaller affected human populations suffering the loss. In addition, much more scientific evidence related to ecological injuries is available today than when these settlements occurred. For example, the New Bedford Harbor, Massachusetts, PCB case was settled for $160 million (in 2018 dollars) in 1996, but only involved an area of about 18.5 square miles and affected about 153,000 people. In addition, there were relatively small areas contaminated with most of them remediated by the time of the settlement.[266] In contrast, the Hudson River PCBs case involves at a minimum 150 square miles of river,[267] in addition to at least 60 square miles of wetland, and effects on about 2 million people.[268] The 2000 Montrose Chemical case in Los Angeles, California, was settled for $206 million plus interest (in 2018 dollars).[269] That case involved about 27 square miles of contamination with 100 tons of dichlorodiphenyltrichloroethane (DDT) and 10 tons of PCBs. The settlement involved restoration projects conducted in an alternate location (bald eagle nesting sites on Catalina Island). In contrast, in the Hudson River PCBs case, at least 15 tons of PCBs remain in the environment in the Upper Hudson even after remediation efforts.[270]

The Lower Duwamish River (LDR) Superfund Site includes a seven-mile stretch of river that was contaminated with PCBs, PAHs, metals, phthalates, and dioxins/furans from industrial activities beginning in the early 1900s.[271] Declared a "Superfund" site in 2001, cleanup activities have removed approximately 50% of the PCB contamination to bring the PCB concentration down to 40 ppb from an initial 80 ppb. The final Record of Decision cleanup plan was estimated at $368.7 million.[272] The case was settled in 2010 in a consent decree with Boeing for $2.25 million (in 2018 dollars), plus $417,000 for a project stewardship program. An addition $96,000 was paid by the City of Seattle in 2016. It had been found that practices of the city (storm drain systems, etc.) had contributed to the contamination problem.

In terms of removal percentage, according to the US EPA, 2016 and 2017 sediment samples showed that dredging in the Upper Hudson River had removed between 54% to 82% of PCBs along a 40-mile stretch of the river. In the six-mile Hudson River Section 1 (Fort Edward to Thompson Island Dam), average PCB concentrations in surface sediments were reduced from 3.9 ppm to 1.8 ppm, or 54%. In the five-mile long River Section 2 (Thompson Island Dam to Lock 5), average PCB concentrations in surface sediments were reduced from 7.3 ppm to 1.3 ppm, or 82%. In the 29-mile River Section 3 (Lock 5 to Troy), average PCB concentrations in surface sediments were reduced from 3.0 ppm to 0.8 ppm, or 73%. Based on the EPA analysis, the length-weighted mean reduction for the 41 miles of the Upper River (Fort Edward Dam to Troy Dam) is 72%. However, this percentage reduction estimate does not include the remaining contamination in the floodplain, abandoned segments of the Old Champlain Canal, the 10 miles of river between the GE Hudson Falls plant and Fort Edward Dam, and the 154 miles of the Hudson River below Troy Dam. Thus, overall, the percent reduction accomplished by remediation is likely much less than this 72% estimate.[273] In addition, the concentrations remaining in the Hudson River after dredging are nearly 2,000 times higher than in the Lower Duwamish case. In addition to the degree of contamination, the Hudson River case differs significantly from the Lower Duwamish case with respect to the population affected. The Hudson River PCB contamination affects an estimated 2 million people, whereas the Lower Duwamish contamination affects about 500,000 people.

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266 New Bedford Harbor Trustee Council 1997.
267 Assuming 200 miles of river with an average of 0.75 miles width.
268 See Table 16.
269 Montrose Settlements Restoration Program 2005.
270 https://www.epa.gov/sites/production/files/2019-04/documents/seggos_to_lopez_4-5-19.pdf
271 NOAA 2013; https://www.seattle.gov/Documents/Departments/SPU//CMsbriefOct2014.pdf
272 NOAA 2013.
273 https://www3.epa.gov/hudson/faqs.htm.

Other PCB cases have involved much smaller areas. For example, the contamination of two square miles in the Lower Fox River and Green Bay in Wisconsin was settled for $6 million (2018 dollars). This case involved damages from historic placement of PCB-contaminated dredged material and not for the original contamination. The contamination of five square miles of PCB contamination in the Sheboygan River and Harbor in Wisconsin was partially settled for $4.6 million (2018 dollars). This case affects about 50,000 people. Other settlements with other potential responsible parties are pending. The settlement took into account $32 million paid in cleanup costs. A case in the Lower Duwamish River in Eliot Bay, Washington, was settled for $2.3 million based on one square mile of contamination in an industrial area. Additional settlements with other responsible parties are pending.[274]

Several PCB cases have not yet been settled, including the contamination of two square miles of the Passaic River by Diamond Alkali in Newark, New Jersey. The Diamond Alkali Company had produced, among other products, 687,000 gallons of "Agent Orange," a by-product of which was 2,3,7,8-TCDD (2,3,7,8-tetrachlorodibenzo-*p*-dioxin), which was released into the Passaic River. Production ceased in August 1969. The Occidental Chemical Corporation is responsible for pollution discharged from the former Diamond Alkali pesticide manufacturing plant in Newark, New Jersey, during 1951 through 1969. An 8.3-mile stretch of the Lower Passaic River contained polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), PCB, polycyclic aromatic hydrocarbons (PAH), DDT, dieldrin, mercury, lead, and copper related to the release of Agent Orange.[275] This case has not yet been settled. Again, the contaminated area is smaller than that of the Hudson River PCBs case, where PCB contamination stretches over 200 miles of river. PCB contamination of five square miles of the Willamette River in Portland, Oregon, have involved $1.1 billion in cleanup costs, but there have been no damage settlements to date.[276]

7.6 Perspectives on NRDA Settlement Comparisons

Under CERCLA, the goal of remediation is to reduce the contamination in the environment and so resulting injuries. The more effective and complete the remediation, the more likely it is that injuries would be reduced (assuming the remediation decreases exposure and resulting effects). Thus, cases where remediation has reduced the contamination below potential effects thresholds should result in lower damage claims per amount discharged than those where remediation has not eliminated the risk of injuries to the same extent. This should be kept in mind when comparing the magnitudes of the NRDA settlements for PCB contamination.

Damages (i.e., dollars paid in a settlement or by court decision) are paid in a particular year or years (either directly or via pursuit of restoration projects) that may be many years or decades after the injuries occurred. Thus, the claim is adjusted for the interim losses through compounding. For contamination that began decades ago, injuries should be summed over many years and the earliest injuries are compounded forward to adjust to present-day equivalent values. This infers that damages increase dramatically the longer the contamination has existed in the environment.

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[274] NOAA 2013.

[275] Rosman et al. 2005; State of New Jersey DEP et al. 2004; *Federal Register* Vol. 83 (No. 9), January 12, 2018, p. 1,612.

[276] Sheldrake and Knudsen 2017; Portland Harbor Natural Resource Trustee Council 2007, 2010.

The extent of the contamination. and the dilution and degradation that has occurred, affect the areas and volumes of exposure. Exposures in locations where biota are in higher densities will result in more injuries. Thus, injuries would be expected to be larger in constricted and inland water bodies than in open ocean waters.

In comparisons of PCB NRDA cases with oil spill NRDA cases, these factors apply as well. In addition, the much greater biomagnification potential, relative toxicity, and persistence of PCBs compared to components of oil, including PAHs, should be considered.

Finally, over the years scientific knowledge has greatly improved and there are considerably more peer-reviewed publications upon which to draw evidence and backup for injury quantification and claims. It was far more difficult years ago for trustees to make their case and obtain settlements from PRPs than it is today. Further, the public has become increasingly aware and knowledgeable of the NRDA process, which both lends support to trustee claims and influences PRPs to settle claims.

Each pollution case has its own unique circumstances that affect the degree of damages. There are biological, geographical, ecological, chemical, and even political considerations that factor into determining NRDA settlements. Comparisons between cases should always be viewed with caution.

Chapter 8: Conclusions Regarding Hudson River Damage Estimates

The research team evaluated available data, studied existing Hudson River Natural Resource Trustee reports and factsheets, and conducted a literature review to gain an understanding of the overall state of the Hudson River PCB natural resource damage assessment (NRDA) case. Generally established injury and damage quantification methodologies were applied to estimate the potential magnitude of injuries and damages. Other PCB case studies were also reviewed to provide a perspective for a potential NRDA settlement for the Hudson River. The research team was not able to evaluate all potential damages to resources and have limited estimates to those where existing data are sufficient to produce results and where damages are expected to be significant.

8.1 Summary of Approximate Preliminary Estimates of Damages

The preliminary estimates of compensatory damages for some of the injuries to Hudson River natural resources due to PCB contamination are summarized in Table 38. In the estimation of the damages to wetland-dependent wildlife, it is assumed that wetland restoration scaled for quantified mink losses would compensate for all wetland-dependent wildlife injuries. Additional damages could be claimed for other resource service losses not quantified here, such as interim service losses related to fish and invertebrates, ecological communities in the river and floodplain, surface water quality, groundwater, navigation, contact recreation (e.g., swimming), and recreational boating.

Table 38: Potential Damage Estimates due to Hudson River PCB Contamination

Resource Category	Estimated Potential Damages (2020 dollars)	% Total Estimated Damages
Wetland-Dependent Wildlife: Upper Hudson[277]	$5.73 billion	26%
Wetland-Dependent Wildlife: Lower Hudson[278]	$1.65 billion	7%
Drinking Water	$1.4 billion	7%
Navigation (Primary Restoration Only)	> $225 million	1%
Recreational Fishing: Lost Value due to Consumption Restrictions	$1.9 billion	9%
Recreational Fishing: Lost Value due to Closures	$523 million	2%
Dredging of Upper Hudson River to Meet Remediation Goal as Primary Restoration of Recreational Fishing Services[279]	$10.7 billion	48%
Total	**$22.1 billion**	**100%**

In addition to the compensatory damages for past and ongoing injuries to wildlife, drinking water, navigation and recreational fishing, the estimated damages include the cost of additional dredging in the UHR, as primary restoration to prevent additional injuries from accruing in future decades to centuries in

[277] Compensatory restoration assumed performed in 2024

[278] Federal Dam to Catskill, assuming up to 10% reduction in wildlife densities within 6km of the main river; compensatory restoration assumed performed in 2024.

[279] Dredging assumed performed in 2025

the Upper and Lower Hudson River. Additional dredging is needed to reduce UHR sediment PCB concentrations such that Hudson River fish meet US EPA's fish consumption advisory-based remediation goal.[280] Future ecological services would also be restored by the additional dredging, as the thresholds to restore recreational fishing services are below those for protecting wildlife and aquatic biota. Dredging would also restore surface drinking water services in future years. However, lost ecological and human services in the past decades and in the future up until this dredging is completed would still be compensable as part of an NRD claim.

8.2 Comparison to Other Cases and the Deepwater Horizon Spill

Each pollution case has its own unique circumstances that affect the magnitude of damages. There are biological, geographical, ecological, chemical, and even political considerations that factor into determining NRDA settlements. Comparisons between cases should always be viewed with caution. However, they can provide a general sense of orders of magnitude of potential damages.

The effects of PCBs on resource and services in the Hudson River have been very well documented with a large number of studies over several decades. The benchmarking provides a framework and perspective on a future Hudson River PCB settlement, as shown in Chapter 6. However, it should be noted that settled PCB cases have generally involved considerably less geographic area of coverage and smaller affected human populations suffering the loss than the Hudson River case. Often, the methodologies used to derive the settlement figures are not publicly available, making comparisons difficult.

The largest oil spill NRDA settlement to date was for the Macondo MC252 (Deepwater Horizon) spill in the Gulf of Mexico. The settlement came to $9.2 billion. The preliminary estimates of damages for the Hudson River in Table 38 are of the same order of magnitude as the settlement in the Macondo MC252 (Deepwater Horizon) case.

The largest oil spill in the US and the Hudson River PCB contamination do not provide an "apples-to-apples" comparison by any means. However, there are a number of important factors that should be considered to provide a perspective on the magnitude of the Hudson River PCB case. The Deepwater Horizon spill occurred over the course of just over 3 months, and eight years later, the Gulf of Mexico has largely "recovered" with regard to commercial and recreational fishing, while the Hudson River has been closed for commercial fishing for decades and recreational fishing has been significantly curtailed. The Hudson River PCB contamination caused significant drinking water service losses, while there were no such losses with the oil spill. The most toxic components of crude oil evaporate or degrade relatively quickly, and the persistence of PAHs and other petroleum components is on the order of months to years, as opposed to PCBs, which are persistent in river substrates for decades or longer. PCBs have bioaccumulated in many wildlife species, and good evidence exists that predators such as mink, great blue herons, spotted sandpiper, catbirds, raptors, and turtles have suffered impaired reproduction for decades.

A comparison of the Hudson River PCBs case and the Deepwater Horizon case is shown in Table 39.

[280] USEPA 2002.

Table 39: Deepwater Horizon NRDA Settlement and Hudson River PCB Comparison		
Factor	**Hudson River PCBs**	**Deepwater Horizon Oil Spill**[281]
Natural Resource Damages	$20.9 billion (estimated potential)	$9.2 billion (settled)
Duration of Release	Decades	Three months
Persistence in Environment	Highly persistent (decades)	Degradation in months to years
Toxicity	Highly toxic	PAHs less toxic than PCBs
Biomagnification	Biomagnification in food web	PAHs metabolized by organisms
Exposure Period	Decades	Months
Fishery Injuries	Fisheries injuries and closures for decades	Fisheries recovered by 8 years
Drinking Water Effects	Extensive drinking water effects	No drinking water effects

Thus, we argue that the Hudson River NRDA should be "worth" at least as much as, and actually more than, the Macondo MC252 (Deepwater Horizon) case.

[281] PAHs are polycyclic aromatic hydrocarbons that occur naturally in oil (also called polynuclear aromatic hydrocarbons).

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