
Randall's Island Park looking towards the Hudson River; Photo Credit: Rosana Pedra Nobre

Economic Analysis of the New York – New Jersey Harbor Estuary

May 2023

NY/NJ HARBOR & ESTUARY PROGRAM
NEIWPCC
ICF

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List of Acronyms

BOD	Biological oxygen demand
CFU	Colony-forming unit
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DO	Dissolved oxygen
EC	Enterococcus
EPA	Environmental Protection Agency
GM	Geometric mean
GSP	Gross State Product
Harbor Estuary	New York-New Jersey Harbor Estuary
HEP	Harbor Estuary Program
HRECOS	Hudson River Environmental Observing System
IBI	Index of Biotic Integrity
IEC	Interstate Environmental Commission
LTCP	Long Term Control Plan
MERI	Meadowlands Environmental Research Institute
MS4	Municipal Separate Storm Sewer Systems
MSA	Metropolitan Statistical Area
MTAC	Mid-Atlantic Tributary Assessment Coalition
NASA	National Aeronautics and Space Administration
NEIWPCC	New England Interstate Water Pollution Control Commission
NJDEP	New Jersey Department of Environmental Protection
NJHDG	New Jersey Harbor Dischargers Group
NLCD	National Land Cover Database
NYCDEP	New York City Department of Environmental Protection
One-point WTP	Willingness-to-pay per unit of water quality improvement
POTW	Publicly Owned Treatment Work
RUM	Random Utility Model
RWQC	Recreational Water Quality Criteria
SEDAC	Socioeconomic Data and Applications Center
SSP2	Shared Socioeconomic Pathway 2
STV	Statistical threshold value
SPARROW	SPAtially Referenced Regression On Watershed
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
TWTP	Total willingness-to-pay
US	United States
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WTP	Willingness-to-pay
WQI	Water Quality Index
WQP	Water Quality Portal

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Executive Summary

Introduction and Overview

Clean water in the New York-New Jersey Harbor Estuary (referred to throughout the report as the Harbor Estuary) is key to recreational activities such as safe swimming and boating, environmental safety for shoreline parks and waterfront neighborhoods, and healthy aquatic environments for wildlife. Since the passage and implementation of the federal Clean Water Act (CWA) in 1972, significant investments have been made to improve water quality in the Harbor Estuary. However, there are still areas of the Harbor Estuary where further investments are needed to achieve the "swimmable and fishable" (including shell fishing) goals of the CWA.

This study estimates the economic value of meeting these goals through analysis of four illustrative scenarios of water quality improvement. These scenarios reflect the water quality improvements, relative to current water quality, that would occur if the Harbor Estuary met swimmable and fishable goals of the CWA as well as other standards linked to healthy ecosystems for aquatic life.[1] The four scenarios considered in this study are summarized in Table ES-1. Two of the scenarios (primary and secondary contact recreation) are based on water quality targets of planned improvements in the Harbor Estuary. The remaining two scenarios (aquatic life and combined) are illustrative scenarios intended to show the range of benefits for larger water quality improvements. For each of these scenarios, we estimated the economic benefits that would be realized directly by households that value water quality improvements in the Harbor Estuary.

Table ES-1. Summary of Water Quality Scenarios

Scenario Name	Threshold Values[a]
Scenarios Based on Water Quality Targets of Planned Improvements	
Primary Contact Recreation	130 CFU/100 mL for daily values of enterococcus (EC) and 35 CFU/100 mL for average values of EC
Secondary Contact Recreation	70 CFU/100 mL for average values of EC
Illustrative Scenarios	
Aquatic Life	3.0 mg/L for daily values of dissolved oxygen (DO) and 4.8 mg/L for mean values of DO
	0.4 mg/L for daily values of total nitrogen (TN)
	0.03 mg/L for daily values of total phosphorus (TP)
Combined	130 CFU/100 mL for daily values of EC and 35 CFU/100 mL for average values of EC
	3.0 mg/L for daily values of DO and 4.8 mg/L for mean values of DO
	0.4 mg/L for daily values of TN
	0.03 mg/L for daily values of TP

[a] Parameter-specific thresholds expected to be achieved under the different water quality scenarios.

Economic benefits (or values – the two are synonymous) for the water quality scenarios in Table ES-1 are calculated using benefit transfer methods that follow contemporary best practices, analogous

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[1] We note that estimating the cost of treatment technologies and best management practices that would be needed to achieve the scenario goals is beyond the scope of this study.

to methods applied commonly by EPA for regulatory benefits analysis under the CWA. Benefits are quantified in terms of households' individual and total willingness-to-pay (WTP) for water quality improvements under each scenario. WTP is the most common measure (or theoretical construct) used to quantify economic values for environmental improvements that benefit individuals or households, as part of benefit-cost analysis. Within the present application to water quality benefits, a WTP estimate may be thought of as measuring, conceptually, what each household would be willing to pay in binding terms (for example within the context of a binding statewide bond referendum) to achieve a particular set of water quality improvements, rather than to forgo those improvements and maintain the status quo. WTP represents the total value of that improvement to the household, in monetary terms.

As discussed in the main report, these WTP values implicitly include values for numerous underlying ecosystem services that would be affected by different types of water quality improvements, and are valued by the public. These include values such as (1) improved value of water-based recreation and reduced human health risks from water contact, (2) improved fishing catch rates and recreational fishing experience, (3) improved aesthetics (*e.g.,* water clarity) for recreation occurring near the water, (4) existence value for aquatic species and healthy ecosystems, (5) enhanced aesthetic values and sense of place, (6) avoided household costs (*e.g.,* costs associated with water treatment), and (7) increased property values. Because these ecosystem service values are already be captured in large part by a comprehensive measure of household WTP, they are not measured separately (to avoid double-counting).

The estimates provided in this report thereby represent the large majority of economic benefits that are expected due to water quality changes in the Harbor Estuary. Other potential benefits, which are not expected to be captured by household WTP and are not measured by the analysis, are described in narrative terms, with reference to studies that quantify similar benefits elsewhere.

Methods

The study's main objective is to estimate the economic benefits of achieving the goals of the CWA. To achieve this goal, the ICF team developed and applied a benefit function transfer to estimate ecosystem service values linked to water quality in the Harbor Estuary. The function used to conduct this benefit transfer was derived via a meta-analysis (a "study of studies") that statistically combines information from 58 previously published studies on water quality benefits that were conducted in different regions across the United States. By synthesizing information from different studies, the model supports more accurate benefit predictions for the Harbor Estuary that can be linked to the specific characteristics of water quality changes and households in particular areas. The resulting benefit-transfer approach, which is grounded in methods previously developed by the project team to evaluate water quality values for EPA federal rulemakings under the CWA, entails the following steps:

1) **Define water quality baselines (*i.e.,* current conditions) and changes under the four water quality scenarios using a water quality index (WQI).** The WQI incorporates six parameters: DO, biological oxygen demand (BOD), EC, TN, TP, and total suspended solids (TSS). The WQI uses a 0-100 scale to reflect varying water quality, with 100 representing the highest possible quality and 0 the lowest (although index values <10 do not generally occur).
2) **Define the "extent of market" of affected households, or locations of households likely to hold values for water quality improvements in the Harbor Estuary.** ICF used two different market extents when calculating benefits, including (1) the 30 counties corresponding to the

scope of the Harbor Estuary Program and (2) the two states in which the Harbor Estuary resides (New York and New Jersey). The county-level market extent is the primary market extent for the analysis, while the state-level market extent serves as an alternative to assess the sensitivity of benefit estimates to the market extent selection.

3) **Monetize (i.e., calculate the economic benefit to households of) water quality improvements using a meta-analysis of surface water valuation studies that provide data on the public's WTP for water quality changes.** For each of the four water quality scenarios, the model produced average annual WTP values per household in the selected market extent. ICF then estimated the aggregated, or population-level, total present value[2] over a 20-year analysis period, assuming that water quality targets would be met at the beginning of 2043 and persist through 2062. Estimating the total present value of water quality improvements entailed multiplying the per household WTP values by the projected number of households expected to benefit from water quality improvements in a given analysis year, discounting values to 2023 using a 3 percent discount rate, and summing across analysis period years. We then used the total present value estimates to estimate annualized benefits.[3]

The approach accounted for specific characteristics of the Harbor Estuary and surrounding watershed and enabled estimation of water quality values linked to a wide range of policies and programs focused on conserving and restoring the Harbor Estuary and enhancing ecosystem services. As explained earlier in this Executive Summary, the resulting per household WTP and total present values estimates were designed to capture the total value of water quality improvement to households, and hence capture underlying values for numerous services provided by the Harbor Estuary, including recreational and aesthetic values.

Summary of Results

ICF estimated WQI changes under the four water quality scenarios, relative to current water quality conditions in the Harbor Estuary. Each scenario characterized water quality changes that could occur throughout the Harbor Estuary, based on different possible water quality targets related to achieving the fishable and swimmable goals of the 1972 CWA. These targets, as shown in Table ES-1, were primary contact recreation, secondary contact recreation, aquatic life, and a combined scenario which considered both primary contact recreation and aquatic life.

The associated mean WQI changes, on a 100-point scale, were 6.3 points for the primary contact recreation scenario, 2.5 points for the secondary contact recreation scenario, 17.8 points for the aquatic life scenario, and 28.0 points for the combined scenario. For each of the four water quality scenarios, Table ES-2 presents the average annual number of households within the market extent assumed to value the water quality improvements, average annual household WTP values estimated via the meta-regression model, total present value of benefits accrued over the 20-year analysis period using a 3 percent discount rate, and annualized benefits using a 3 percent discount rate. The estimated benefits are based on the county-level market extent (all households living in counties that border the Harbor Estuary) and an assumption that the Harbor Estuary remains unavailable for

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[2] Total present value is the current value of future benefits over a given analysis period, with benefits in future years discounted to account for how benefits accrued today are valued more than benefits accrued in the future.

[3] Annualized benefits are benefits over a time period (*i.e.,* the 20-year analysis period) scaled down to a 12-month period, enabling comparison of values over any time period.

swimming following the water quality improvements under each scenario (sensitivity analyses provided in the report show how benefit estimates change under different market extent and swimming use assumptions). These benefit estimates reflect values realized directly by households from water quality improvements (*e.g.,* improved water-based recreation, reduced health risks from water contact, enhanced aesthetic values).

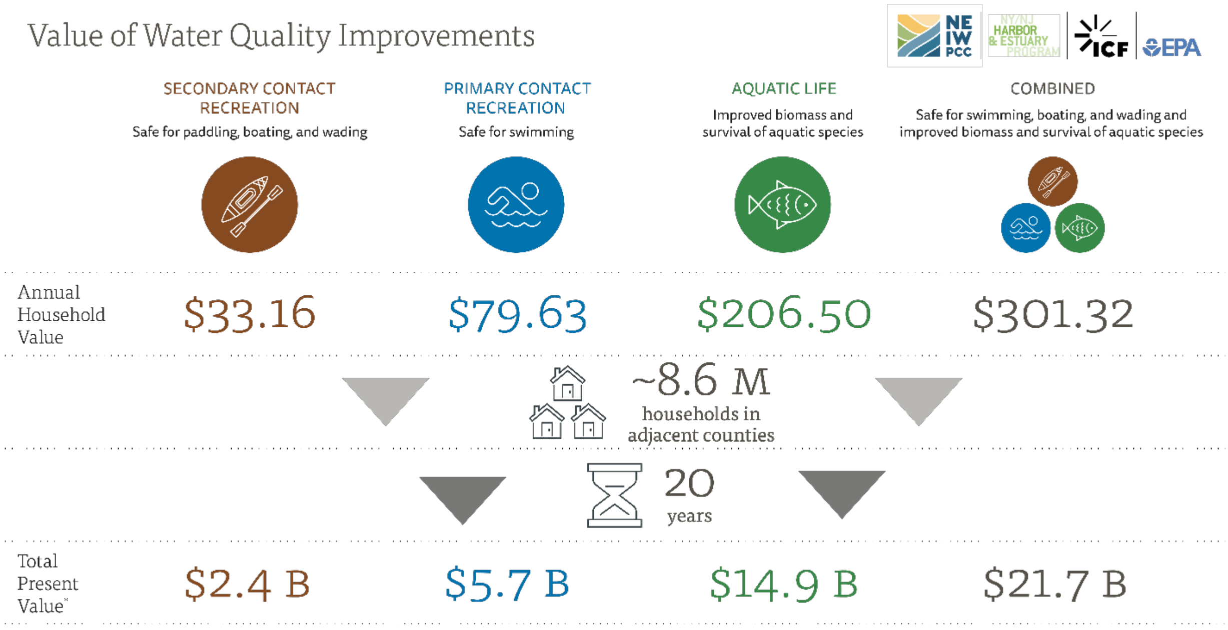
Table ES-2. Estimated Benefits for Water Quality Improvements Under All Water Quality Scenarios

Scenario	Average Annual Number of Households[a]	Average Annual Household WTP (2021$)	Total Present Value (3% Discount Rate; Millions 2021$)	Annualized Value (3% Discount Rate; Millions 2021$)
Scenarios Based on Water Quality Targets of Planned Improvements				
Primary Contact Recreation	8,639,847	$79.63	$5,744	$375
Secondary Contact Recreation	8,639,847	$33.16	$2,392	$156
Illustrative Scenarios				
Aquatic Life	8,639,847	$206.50	$14,896	$972
Combined Scenario	8,639,847	$301.32	$21,735	$1,418

[a] Average annual number of affected households during the 20-year analysis period (2043-2062). Number of households for each year in the analysis period accounts for projected population growth,

Figure ES-1 visually demonstrates the estimation of the total present value estimates by aggregating average annual household WTP value over space (*i.e.,* all households in counties that border the Harbor Estuary) and time (*e.g.,* 20 years).

Figure ES-1. Graphic Representation of Estimated Benefits for Water Quality Improvements Under All Water Quality Scenarios



Total present values account for: (1) projected population changes in counties adjacent to the Harbor Estuary over the 20-year analysis period and (2) discounting of future values to 2023 (since benefits accrued today are valued more than benefits accrued in the future).

Results of the analysis reveal that even relatively modest water quality improvements, such as those under the Secondary Contact Recreation scenario, generate large values for households in New York and New Jersey. For example, the estimated average annual household WTP under the Secondary Contact Recreation Scenario is $33.16, leading to a total present value (or total economic benefit) of $2.4 billion. The economic value of water quality improvements depends on how much water quality improves and where. Scenarios with larger water quality improvement targets, such as the aquatic life and combined scenarios, generate even higher values for surrounding households once these water quality targets are met. If water quality targets were to be met sooner than anticipated, economic benefits would increase even further.

Prior to this study, no economic valuation studies have been conducted for the Harbor Estuary. The lack of economic literature for the Harbor Estuary region to date makes this economic analysis valuable for raising awareness of the tremendous value that the Harbor Estuary provides. As noted above, however, there are some types of potential benefits that are not quantified by this report. For example, this report does not quantify benefits that could potentially be realized by commercial businesses (*e.g.,* businesses that rent boats or fishing equipment or operate charter fishing trips) due to the same water quality changes. Commercial benefits are typically many times smaller than household benefits for these types of water quality improvements. The report also does not quantify additional ecosystem services (*e.g.,* improved wildlife habitat, improved flood protection) of restored wetland habitats used to meet water quality targets or benefits to tourists who visit the Harbor Estuary. Future work would be needed to capture the economic values of these additional benefit categories.

1 Introduction

The New York–New Jersey Harbor Estuary (referred to throughout the report as the Harbor Estuary) is the largest public resource in the nation's largest and most densely developed metropolitan area (Da Silva, 2021). The Harbor Estuary is a naturally diverse ecological environment. The Harbor Estuary also sits at the mouth of several large rivers, including the Hudson, Hackensack, Passaic, and Raritan Rivers, allowing it to serve as a conduit for land-based aquatic species to move southward toward the coast. As a result, the Harbor Estuary is a rich environment for different species of fish, birds, and shellfish and was designated as one of the nation's 28 "Estuaries of National Significance" in 1988 (Stinnette et al., 2018). The Harbor Estuary is also the location of the nation's largest and most densely developed metropolitan area, and hence supports major transportation and industrial uses.

Clean water in the Harbor Estuary is key to recreational activities such as safe swimming and boating, environmental safety for shoreline parks and waterfront neighborhoods, and healthy aquatic environments for fish, birds, and other wildlife. Since the passage and implementation of the federal Clean Water Act (CWA) in 1972, significant investments have been made to improve water quality in the Harbor Estuary (Da Silva, 2021). In particular, there have been significant steps made to improve the practices implemented at the 25 Publicly Owned Treatment Works (POTWs) that discharge to the Harbor Estuary, and to increase the implementation of practices that reduce the volume of combined sewer overflows (CSOs) and stormwater discharging into waterbodies that flow to the Harbor Estuary. For example, New York City, 17 different CSO municipalities, and four utilities in New Jersey are working to develop and implement Long Term Control Plans (LTCPs) to reduce the volume of CSOs. In addition, 211 municipalities across both states are working to improve stormwater management by implementing plans via municipal separate storm sewer system (MS4) permits. The benefits from these activities are apparent in the public's demand and enjoyment for waterfront access, the number of new residences and offices built along the waterfront, and the growing numbers of fish, whales, seals, and other marine organisms.

However, there are still areas of the Harbor Estuary where further investments will be needed to achieve the swimmable and fishable (including shellfishing) goals of the CWA.[4] For example, according to a 2021 Harbor-Wide Water Quality Monitoring Report (Da Silva, 2021), pathogenic bacteria levels in the Lower Passaic River and Newark Bay, Hackensack River, and the Lower Raritan River are not consistently at levels that permit safe contact with the water, including activities like swimming and boating. Some of the pathogen levels for smaller waterways in the Harbor Estuary could limit the public's ability to enjoy the waterways for even non-contact recreation such as boating. In addition, as reflected in the data from the water quality monitoring report, the Bronx River and Western Long Island Sound, Jamaica Bay, and the Hackensack Rivers show combined levels of dissolved oxygen (DO), total nitrogen (TN), and chlorophyll-a levels that may be harmful to fish and other aquatic organisms.

The objectives of this study are to (1) identify and characterize the ecosystem goods and services linked to water quality in the Harbor Estuary; (2) estimate the monetary value of benefits provided by improvements to water quality to local communities, visitors, and other affected populations; and (3) help community members better assess the relative importance of clean water in the Harbor

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[4] As noted in the Executive Summary, estimating the cost of treatment technologies and best management practices that would be needed to achieve CWA goals is beyond the scope of this study.

Estuary when considering future restoration and conservation actions. The advisory board committee who helped support this study are listed in *Appendix C: Advisory Board Committee*.

1.1 New York-New Jersey Harbor Estuary

The Harbor Estuary is distinguished from the rest of the Hudson-Raritan Estuary by its saline waters and urban character. There are more than 250 square miles of open water and approximately 1,600 miles of shoreline from the Mario Cuomo (previously known as the Tappan Zee) Bridge south to Sandy Hook, NJ, including the lower reaches of the Hudson, Passaic, Hackensack, and Raritan Rivers (see Figure 1-1).

The Harbor Estuary is a uniquely shaped estuary, with the east-west oriented shoreline of the New England and Long Island coasts intersecting the north-south oriented shorelines of the mid-Atlantic coast. This creates a natural funnel for bird, insect, and fish species, which leads to high ecological diversity and richness (USFWS, 1997). For example, the Atlantic Flyway, one of four major avian migratory routes in North America, passes directly over the Harbor Estuary. The US Fish and Wildlife Service (USFWS) lists almost 400 plant, animal, and fish species of special emphasis as occurring within the Harbor Estuary (USFWS, 1997).

The estuary also provides crucial resources for the more than 14 million people living along the Harbor Estuary's waterways, including recreational and economic benefits (Stinnette et al., 2018). Five million people live within a ten-minute walk from the Harbor Estuary shoreline, with more than 500 waterfront parks and public spaces accessible to the public (Pirani et al., 2018). Along the 1,600-mile waterfront, there are around 166 locations where the public can launch a human powered boat (NY-NJ Harbor & Estuary Program, 2021) and 28 permitted bathing beaches (Da Silva, 2021; Pirani et al., 2018). The Harbor Estuary also hosts the nation's third largest port operation, which, in turn, supports jobs associated with port and maritime operations (Pirani et al., 2018). The counties that encompass the immediate watershed of the Harbor Estuary, as defined by the Harbor Estuary Program (HEP), are shown in Figure 1-2. The Harbor Estuary is outlined with a grey dotted line and the immediate watershed of the Harbor Estuary is outlined with a blue dotted line.

Over time, human impacts have adversely affected water and sediment quality in the Harbor Estuary through discharges of human and industrial wastes and debris. For example, the Harbor Estuary used to be a location for extensive oyster beds, but the historically abundant eastern oyster has all but disappeared over their once expansive range due to high sedimentation rates, overharvesting, and overall poor water quality (USACE, 2009). Although the establishment of federal water quality regulations for the CWA has led to gradual improvements to water quality, primary water quality parameters that challenge the health of the Harbor Estuary include pathogen contamination, low DO, and excessive levels of nutrients. Excessive levels of nutrients can affect DO concentrations, causing decreased fish production, less aquatic vegetation, and noxious odors (Steinberg et al., 2004). The topography of the Harbor Estuary also contributes to its water quality issues. In locations with reduced or limited flushing (*e.g.,* bays and confined waterways), high organic loads reduce DO and can cause periods of poor water quality (USACE, 2009).

Figure 1-1. New York-New Jersey Harbor Estuary

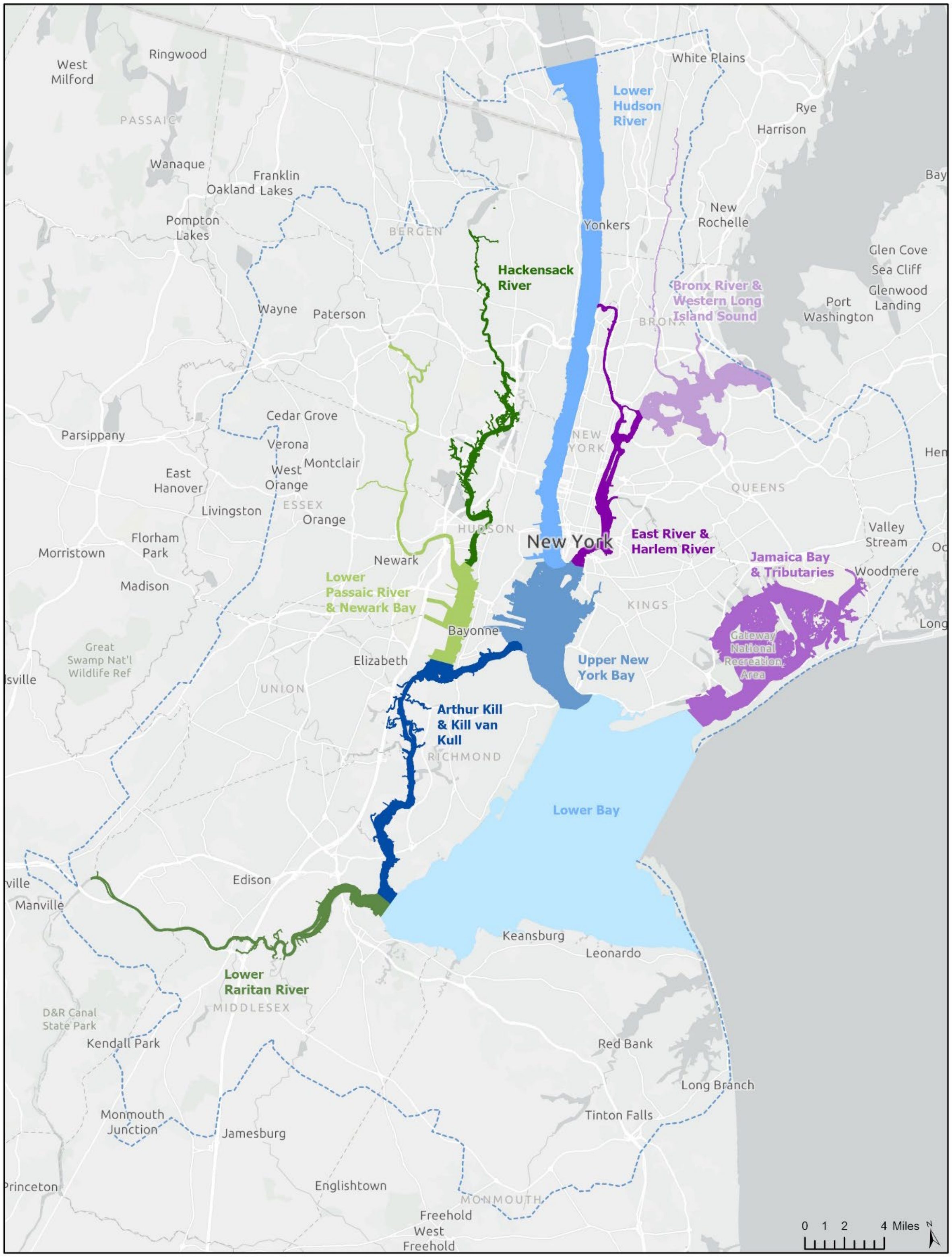
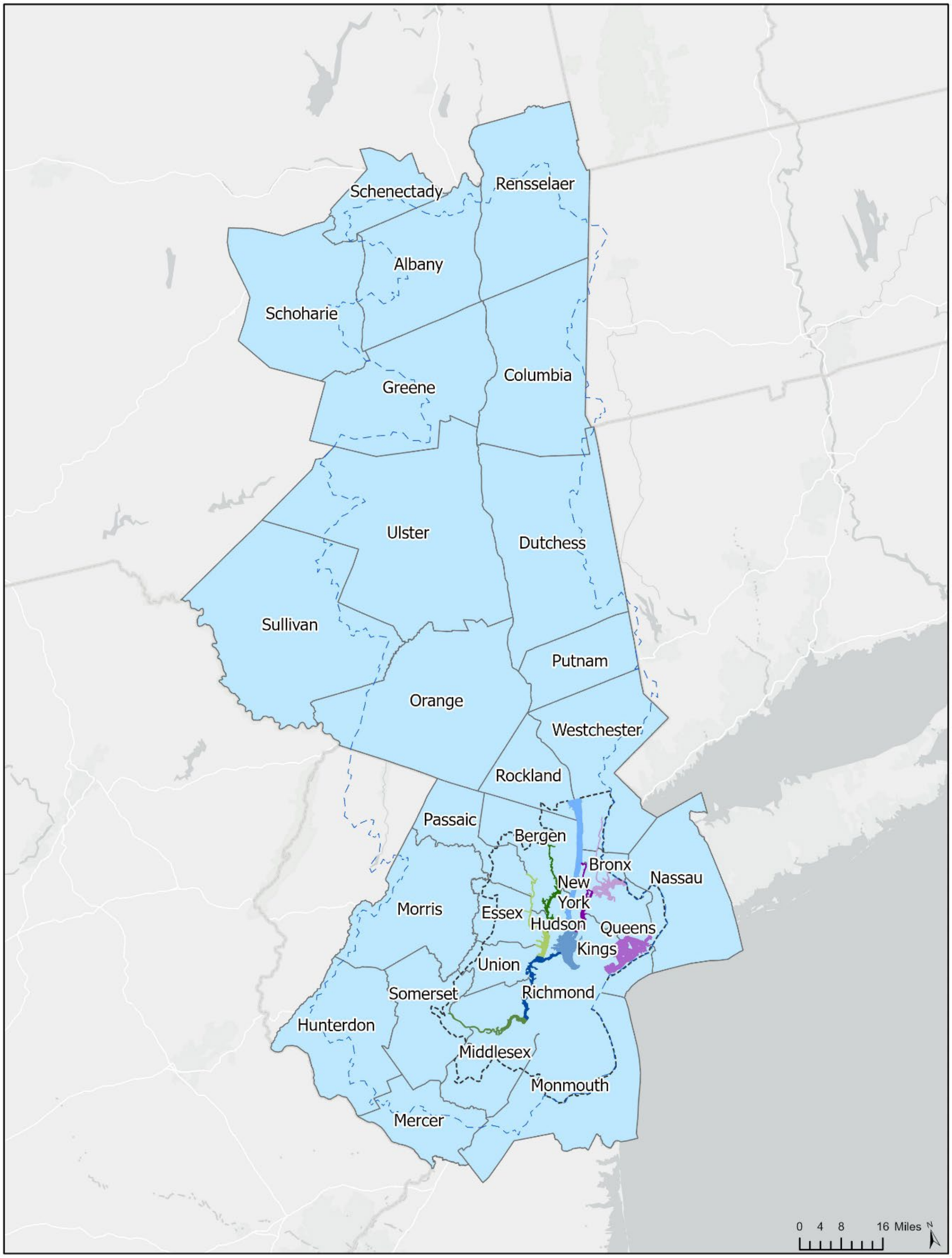


Figure 1-2. Counties that encompass the immediate watershed of the Harbor Estuary. The Harbor Estuary is outlined with a grey dotted line and the immediate watershed of the Harbor Estuary is outlined with a blue dotted line.



2 Ecosystem Service Benefits—Theory and Measurement

The main objective of this study is to estimate and communicate the economic value of clean water and associated healthy ecosystems in the Harbor Estuary. To achieve this objective, the ICF team applied cutting-edge, best-practice methods for benefit transfer. Benefit transfer is defined as use of pre-existing empirical estimates of economic value from one or more settings where research has been conducted previously to predict similar measures of economic value for other settings (Johnston et al., 2021). More specifically, this study synthesizes information from economic value estimates reported in existing nonmarket valuation studies of water-quality benefits realized by the public in various regions in the United States, and uses this synthesized information to calculate benefit estimates for similar water quality improvements to the NY-NJ Harbor Estuary, reflecting the total value to households of ecosystem service improvements that are anticipated due to these measurable changes in water quality.

To provide a relatively comprehensive estimate of the value of clean water in Harbor Estuary, ICF estimates how total ecosystem service values realized by households (including use and nonuse values) vary with water quality changes, using meta-analytic benefit transfer that draws information from dozens of previously published studies that estimate values for water quality and aquatic ecosystem service improvements. This section of the report provides a brief overview of ecosystem service valuation as related to the methods used by ICF to develop value estimates for water quality improvements in the Harbor Estuary.

Ecosystem services are defined as the outputs of natural systems that benefit society (Daily, 1997). These services (or goods produced directly from these services) are sometimes bought and sold directly in markets (*e.g.,* fish caught by commercial fishing vessels). However, most ecosystem service values related to surface water quality improvements are characterized as *nonmarket values,* defined as values for outcomes that cannot be purchased directly on markets (Champ et al., 2017). Examples include benefits due related to recreational opportunities or the quality of life realized by households living close to high-quality bodies of water (*e.g.,* due to aesthetic properties). Given the vast number of direct and indirect ways that surface water quality improvements (and associated improvements in aquatic ecosystem services) can benefit society, benefit-cost analyses for water quality improvements typically quantify only a subset (and typically the largest) sources of value (U.S. EPA, 2010).

The ecosystem services supplied by the Harbor Estuary provide tremendous economic value regionally and beyond. Some ecosystem goods and services are valued due to direct contributions to human well-being realized through active and observable human uses (goods with “use” value), such as fishing, shellfishing, and other recreational activities. Other ecosystem goods and services are valuable independent of observable human use (called “nonuse” goods and services). The associated nonuse values are created by people’s appreciation for the fact that high-quality waters, ecosystems and habitats exist along the coast, apart from any direct use of these areas for fishing, recreation or other activities. Hence, although some people (incorrectly) associate “economic benefits” solely with commercial or market activities, the primary economic benefit of water quality improvements in areas such as the Harbor Estuary is driven primarily by “nonmarket” ecosystem services—services that are *not* bought and sold directly in markets.

Given the myriad of ways that water quality improvements benefit households via impacts on multiple ecosystem goods and services—providing both use and nonuse values—it is not feasible (nor even possible in theory) to disentangle and independently estimate *all* possible sources of value (for example providing unique estimates of different types of use and nonuse value realized by different households). Instead, economic analyses used for large scale benefit-cost analysis typically quantify households' *total value* for these improvements, where these total value estimates incorporate the value of associated changes in ecosystem services. Assuming that it is measured correctly, a household's total economic value for a water quality change (for example in the Harbor Estuary) should include the underlying values for all the ecosystem services that are affected by that change and valued by the household.[5]

These total value estimates are typically measured in terms of households' total willingness to pay (or WTP). WTP is the most common measure (or theoretical construct) used to quantify economic values for both market and non-market goods that benefit individuals or households. Within the present application to water quality benefits, a WTP estimate may be thought of as measuring, conceptually, what each household would be willing to pay in binding terms (for example within the context of a binding statewide bond referendum) to achieve a particular set of water quality improvements, rather than to forgo those improvements and maintain the status quo. For market goods such as automobiles where only use values are typically considered, WTP estimates are produced using information on prices and quantities observed in markets. However, when measuring values for environmental quality changes when non-market values are important (as they are here), alternative non-market valuation methods are required (Champ et al., 2017). When estimated originally (*i.e.,* using primary data), value estimates for water quality improvements are typically produced using stated preference valuation methods, as these are the only methods capable of measuring both use and nonuse values (Johnston, Boyle, et al., 2017)

Here, however, the absence of high-quality primary valuation studies of this type for water quality and ecosystem services within the Harbor Estuary, combined with the high cost (in time and resources) to conduct studies of this type, necessitates the use of "benefit transfer" to quantify these total values (Johnston and Bauer, 2020). As described by Johnston et al. (2021) and introduced above, "benefit transfer is the use of pre-existing empirical estimates from one or more settings where research has been conducted previously to predict measures of economic value or related information for other settings." Benefit transfer methods support virtually all large-scale benefit cost analyses conducted in the US and elsewhere, for example by EPA when evaluating water quality benefits due to proposed rulemaking (Newbold et al., 2018; Wheeler, 2015).

As introduced above, the benefit transfer approach used by ICF for the present analysis is adapted from that used by EPA to measure benefits for CWA rulemaking (*e.g.,* U.S. EPA, 2020; U.S. EPA, 2015), considering the value of water quality improvements in US waterbodies such as the Harbor Estuary. This approach relies on a synthesis of data drawn from many prior (stated preference) estimates of WTP for water quality improvements, implemented via statistical meta-analysis (Johnston et al., 2005; Johnston, Besedin, et al., 2017; Johnston et al., 2019; see Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis). This synthesis produces a broadly applicable "umbrella" benefit function that is suitable for predicting benefits for many different settings, such as that in the

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[5] To consider a parallel illustration in markets, when a person purchases an automobile, they implicitly purchase *all* of the anticipated future "services" that would be provided by that automobile. The value of these combined services is captured in the household's total WTP for the car. It is therefore not necessary to develop separate value estimates for each possible service provided by that car, for example commuting, transporting family members, etc.

Harbor Estuary. Data synthesis methods of this type have been shown to be among the most accurate forms of benefit transfer (Johnston et al., 2021).

To inform and subsequently develop these value estimates, ICF first identified and characterized the ecosystem services linked to water quality in the Harbor Estuary, as shown in Figure 2-1. This is framed in terms of a conceptual "causal chain" or means-ends diagram that links a set of actions (here represented by a set of water quality scenarios) to the ecological changes, ecosystem services and ultimately to a set of measurable economic values (Olander et al., 2018). From this causal change (Figure 2-1), it is possible to assess which of these underlying ecosystem service values are expected to be subsumed within the broader measure of households' total value for water quality change produced by ICF. This conceptual model provides insight into the types of values that are included (implicitly) within the resulting benefit estimates, along with those that are not included. As introduced above, ICF then applied a flexible, benefit transfer approach to estimate these economic values of water quality improvements to households living in surrounding areas (including both counties and states), based on a meta-analysis of previously published water quality improvement valuation studies.

Section 2.1 provides additional details about the ecosystem services linked to water quality in the Harbor Estuary, including which services are quantified in the economic analysis and which services are outside of the scope of the analysis. Section 2.2 provides details about the benefit transfer approach used to quantify benefits of water quality improvements in the Harbor Estuary.

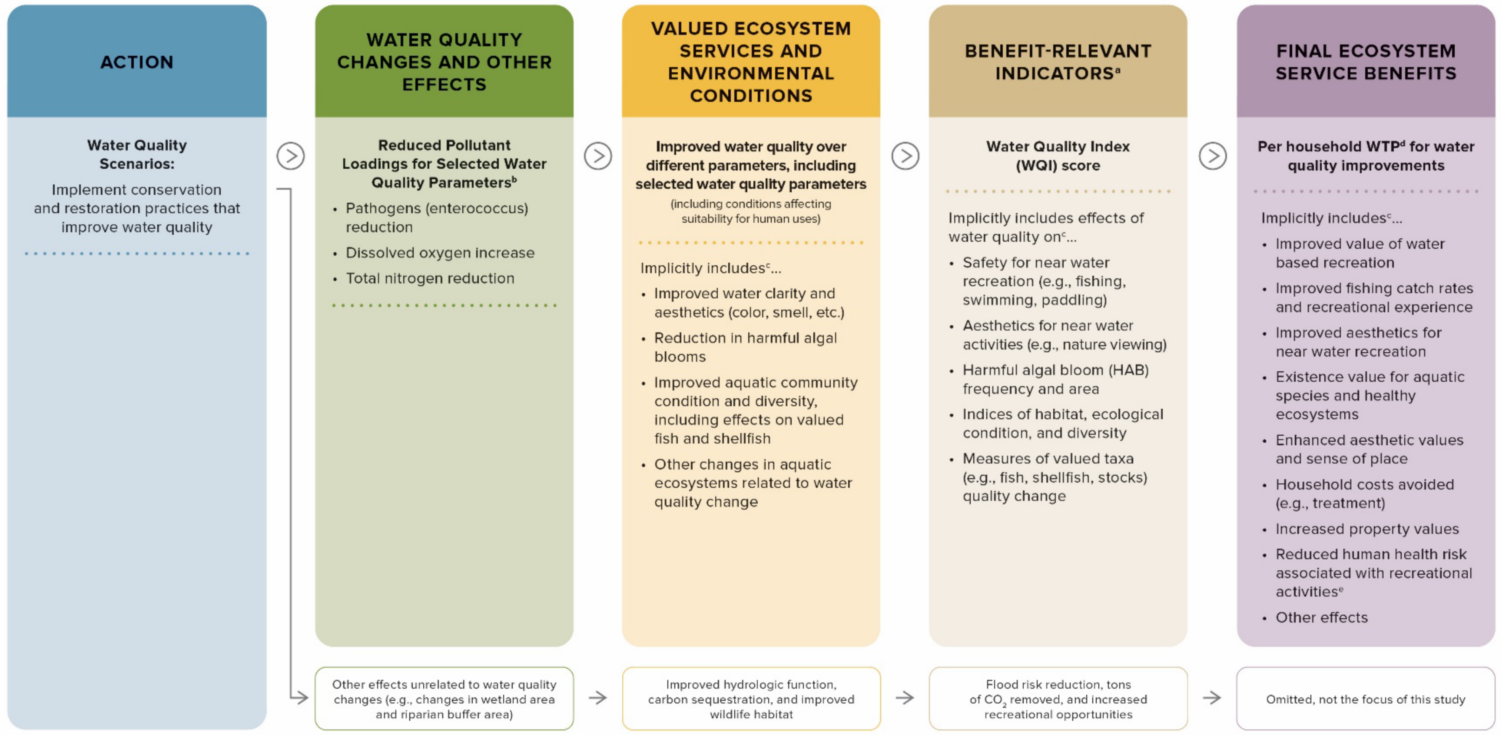

Figure 2-1. Conceptual diagram of public ecosystem service values resulting from water quality improvement scenarios. Describes the cause and effect relationships between water quality scenarios (on the left) and public ecosystem service benefits generated (on the right). The middle of the diagram shows the water quality changes resulting from the water quality scenarios and how these changes translate to benefits indicators and ecosystem service benefits.

[a] *Benefit-relevant indicators* (BRIs) are measurable ecological indicators that are linked directly and causally to something important to people (*e.g.,* harvested shellfish is safe to consume).

[b] Water quality parameters highlighted in the *Harbor Wide Water Quality Monitoring Report*. Chlorophyll-a is not included as a selected parameter because it is highly correlated with changes in TN.

[c] "Implicitly includes" implies that these benefits are at least partially captured (and sometimes fully captured), but does not *necessarily* translate to fully capturing the effects, environmental indicators, or benefits

[d] Per household willingness to pay (WTP) for water quality improvements reflects the total amount that a household would be willing to voluntarily pay (their total value) for all improvements that they understand to be caused by a given water quality improvement, rather than go without those improvements. This is the conceptually correct measure of economic values for households. This total value, in theory, includes all other values that households realize from water quality, including recreational benefits, aesthetic benefits, etc. However, other values may not be captured completely.

[e] An example of human health risk associated with recreational activities is the consumption of contaminated shellfish.

2.1 Qualitative Description of All Benefits

To provide a comprehensive estimate of the value of clean water in the Harbor Estuary, ICF estimated how total ecosystem service value (including use and nonuse value) varies with water quality changes using a meta-analytic benefit transfer approach, which is described in more detail in Section 2.2. The benefit transfer methodology estimates how much households would be willing to pay for water quality improvements in the Harbor Estuary, as an estimate of the total economic benefit realized by these households.

As introduced above, Figure 2-1 summarizes the potential effects of improving water quality in the Harbor Estuary, the expected environmental and ecological changes, and categories of benefits that are expected to arise from these changes. The analysis begins by identifying relationships between changes in water quality and human benefits, including the biophysical pathways through which benefits are realized and the linkages between actions, changes in ecosystem services, and the effect of these changes on economic values (Johnston et al., 2015; Bateman et al., 2011; Olander et al., 2018; Wainger et al., 2017). The middle panes of Figure 2-1 show the water quality changes resulting from conservation and restoration practices in the Harbor Estuary and how these changes translate to benefit indicators and ecosystem service benefits.

As shown in the purple box in Figure 2-1, the household WTP values implicitly include values for numerous underlying ecosystem services that would be affected by different types of water quality improvements. These include values such as (1) improved value of water-based recreation and reduced human health risks from water contact, (2) improved fishing catch rates and recreational fishing experience, (3) improved aesthetics (*e.g.,* water clarity) for recreation occurring near the water, (4) existence value for aquatic species and healthy ecosystems, (5) enhanced aesthetic values and sense of place, (6) avoided household costs (*e.g.,* costs associated with water treatment), and (7) increased property values.

These values are included, implicitly, in a correctly estimated, comprehensive measure of households' total WTP. But why is this the case? Consider a simple and stylized illustration, in which a household is considering whether to vote for a bond referendum that would lead to the household paying $100 more per year in additional taxes, in exchange for a specified set of programs that would improve water quality in the Harbor Estuary. In theory, the household should vote "yes" for this referendum only if the household's total value for the program is at least $100—such that the anticipated benefits of the program to the household would outweigh the additional costs. When deciding whether it is "worth it" to vote "yes" for this referendum, the household should consider *all of the possible ecosystem service benefits* that it would receive from this program, such as those listed above. For example, if the household anticipated improved recreational opportunities or increases in property value, they should consider these values when deciding how to vote. Following the same logic, the household's total WTP for the water quality improvement—if correctly measured—should also include these underlying use and nonuse benefits. Hence, adding the total WTP for a water quality improvement to similar values for each separate (and related) ecosystem service would double count some components of water quality value. To obtain an accurate measure of economic benefit, each component value must be counted once and only once.

However, the analysis of increased ecosystem service values resulting from water quality improvements does *not* capture changes in ecosystems services that are unrelated to water quality change, or that are not realized directly by households. For example, conservation and restoration activities in the Harbor Estuary used to achieve water quality improvements may *also* add additional acres of wetland or riparian buffer. The analysis will capture associated water quality improvements resulting from the additional wetland or riparian buffer acres, but it will not capture other benefits (unrelated to water quality) such as flood risk reductions, increased wildlife habitat, and removal of greenhouse gases due to additional vegetative cover. Such benefits could be a focus for future economic analysis, as discussed in Section 5.

Similarly, benefits realized only by commercial entities (but not by households) are also omitted from the analysis. As an illustrative example, additional profits that might be realized by businesses that rent boats or fishing equipment (or operate charter fishing trips) within the studied area are not included in the presented benefit estimates. These estimates are omitted due to a lack of necessary data and because (for the type of surface water quality improvements considered in this report) they are typically many times smaller than total household benefits. If values of this type are expected to be substantial in the Harbor Estuary, they could also be the focus of future work.

Given this underlying theoretical and conceptual foundation for economic benefit estimation (and reflecting available data to support valuation for the Harbor Estuary), this report emphasizes the estimation and interpretation of total economic benefits realized by households due to prospective water quality change in the Harbor Estuary. This emphasis notwithstanding, it is possible to provide *qualitative* insight on other types of values and impacts, including (a) values that are already included, implicitly, in total WTP for water quality change but might be of interest, and (b) changes in economic activity, or economic impacts, that are not included in economic benefit measures (cf. D. S. Holland et al., 2010).

The remainder of this section provides a qualitative discussion of some other key benefits and impacts that may result from conservation and restoration practices in the Harbor Estuary, including human health benefits (Section 2.1.1), ecological benefits (Section 2.1.2), property value benefits (Section 2.1.3), and economic impacts (*e.g.,* job creation) (Section 2.1.4). This discussion is drawn from existing data and analyses of these benefit categories drawn from previous studies in other regions (*e.g.,* Long Island Sound). Section 2.2 then provides details about the methods used in the *quantitative* assessment of water quality improvements in the Harbor Estuary. Later, Section 5 discusses potential future work that could be done to expand on the existing analysis and quantify additional changes in ecosystem service benefits associated with conservation and restoration activities in the Harbor Estuary.

2.1.1 Health Benefits

Water quality improvements in the Harbor Estuary will likely reduce human exposure to pathogens and the associated adverse health effects, while potentially facilitating additional recreational activities that are beneficial to health such as exercise. Primary contact recreation (*e.g.,* swimming, bathing, surfing, and water skiing) typically includes activities where immersion and ingestion are likely and there is a high degree of bodily contact with the water. The health hazards associated with recreational activities in waters affected by fecal contamination include gastroenteritis, respiratory illness, ear infections, eye infections, and infected cuts (Pond et al., 2005; U.S. EPA, 2012b). Given the uncertainty associated with estimating recreational and other possible behaviors through which people might be exposed to Harbor Estuary waters in future years (and hence an associated exposure to pathogens), ICF was unable to quantify this benefit category individually. Additionally, WTP for water quality improvements that affect suitability for recreational activities such as swimming is already incorporated in the meta-analysis of surface water valuation studies, which is used in the quantitative analysis of WTP for water quality improvements. More specifically, many of the studies in the meta-analysis measure WTP for water quality changes that potentially impact human health, and therefore the value of these anticipated health improvements is already captured in those WTP estimates—and thereby in the meta-analytic benefit estimates calculated by ICF for the Harbor Estuary. Thus, estimating separate benefits of reduced enterococci (EC) exposure from primary contact recreation would overlap with (double count) other quantified benefit estimates in this analysis. Moreover, prior work suggests that "health risk reductions are only a small fraction of the total social benefits of water quality improvements" and are dominated by other components of household WTP (Machado and Mourato, 2002).

2.1.2 Other Ecosystem Service Benefits Associated with Improvements in Surface Water Quality

Water quality improvements in the Harbor Estuary are expected to provide a wide range of benefits through improvements in recreational safety and enhancement of aquatic habitats or ecosystems. Society values such ecological improvements through several mechanisms, including increased frequency and value of use of the improved surface waters for recreational and educational activities. In addition, individuals also value the protection of habitats and species that are adversely affected by decreased DO that results from CSO discharges, even when those individuals do not use or anticipate future use of the affected waterways for recreational or other purposes, resulting in nonuse values.

Several studies document significant demand for water-based recreation, including swimming, in the counties abutting Harbor Estuary waters (*e.g.,* Lawler, 2005). According to Riverkeeper.org, nearly 6,500 people took part in 36 organized swimming events in the Hudson River in 2014 despite water quality concerns (Smart Growth Economics LLC., 2020). Water-based recreational activities that could be enhanced by surface water quality improvements include:

- *Swimming*. Swimmers will benefit from an increased number of recreational sites suitable for swimming and enhanced recreational experience stemming from the knowledge that waters are safe for swimming. Reducing loadings of other stormwater pollutants (*e.g.,* suspended solids and nutrients) is likely to also increase the aesthetic appeal (*i.e.,* clarity and odor) of the affected waters, thereby enhancing swimmer's aesthetic enjoyment of a waterbody and associated recreational benefits (such that additional recreational visits may take place and each visit has greater value, on average). Multiple studies across the US have quantified the economic value of recreational trips taken for beach visits and/or swimming, or have estimated WTP for improvements in the suitability of waters for similar uses. As an illustration of the type of benefits that can emerge, Johnston et al. (2016) calculated the WTP of households in Kennebunk, Sanford and Wells, Maine for increases in the percentage of days that area beaches that are safe for swimming (based on bacterial levels). Results suggest a value of $1.90 (2014 USD) per household, per year, for each percentage point improvement in safe swimming days. This benefit estimate applies to all households across the three sampled towns. An older study by Johnston, Grigalunas, et al. (2002) reports a value to swimmers of $1.3 million (1995 USD, equal to $2.4 million in 2021 USD) for a 10 percent improvement in water quality within Long Island's Peconic Estuary.

- *Recreational Fishing*. Degraded water can reduce fish populations by inhibiting reproduction, growth, and survival of aquatic species found in the Harbor Estuary[6] (Mason, 2011; Kahn et al., 2014; Alkire et al., 2020), resulting in fewer and smaller fish and thereby reducing the value of a fishing trip (Lipton et al., 2003). Reduction in stormwater discharges from additional CSO controls and other conservations and restoration practices could improve DO conditions in the Harbor Estuary, thereby increasing survival rates for juvenile fish for a number of recreationally important species, including striped bass and American shad (Alkire et al., 2020). Increased number, size, diversity, and health of recreational fish species will in turn enhance the value of recreational fishing. Models are available to estimate the benefits linked to quantifiable improvements in recreational fish harvest (Johnston et al., 2006). Using one of these models, EPA (2014) estimated a value of $6.17 (2011 USD, equal to $7.43 in 2021 USD) for each additional "small game fish" (*e.g.,* striped bass) caught by recreational anglers due to implementation of the Final Section 316(b) Existing Facilities Rule, and $5.88 (2011 USD, equal to $7.08 in 2021 USD) for each additional flatfish. Given estimates of anticipated changes in recreational fish catch, estimates such as these can be used to quantify changes in recreational fishing benefits due to water quality improvements.[7] In addition, improved aesthetic qualities of the waterbody (*e.g.,* clarity and odors) and knowledge that the water is cleaner and contains fewer pollutants increases individuals' enjoyment of their recreational fishing, which can also lead to enhanced recreational benefits.[8] As noted above, these recreational benefits should be largely captured in measures of household's total WTP for water quality improvements, and the meta-analysis includes a mechanism to account for the additional value provided by water quality improvements that affect fishing (see Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis).
- *Boating*. Boaters benefit from enhanced water quality, opportunities for companion activities, such as fishing and wildlife viewing (*e.g.,* piscivorous birds), and from improved aesthetic quality. As noted above for recreational fishing and swimming, these recreational benefits should be captured in measures of household's total WTP for water quality improvements. However, separate estimates of boating values have been provided by prior studies in nearby water bodies (*e.g.,* Johnston, Grigalunas, et al., 2002 for the Peconic Estuary). As with other types of recreation, significant benefits can be measured for boating uses alone. For example, Johnston, Grigalunas, et al. (2002) report a total recreational value of (non-fishing related) boating trips in the Peconic Estuary of $18.0 million (1995 USD), equivalent to $32.9 million in 2021 USD. This is a total value estimate, however, and does not reflect how these values might *change* with improvements in water quality.

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[6] Harbor Estuary waters support a number of recreationally important species, including striped bass, American shad, and iconic species such as Atlantic sturgeon (New York State Department of Environmental Conservation, n.d.).

[7] These values, if quantified, should not be added to estimates of households total WTP for water quality improvements. This is because, as noted above, these total WTP estimates already include recreational benefits anticipated by households due to these improvements.

[8] ICF acknowledges that while improving pathogen levels via CSO controls may have beneficial effects on other pollutants, the effects on some may be limited or insufficient to overcome legacy levels. Thus, while the fishing experience may improve, the fish caught may not be safe to eat, per fish advisories (see https://www.health.ny.gov/environmental/outdoors/fish/health_advisories/regional/new_york_city.htm).

- *Outings*. Participants in other recreational activities such as hiking, jogging, picnicking, and wildlife viewing also benefit from knowledge that waters are safe for all recreational activities and from improved aesthetic quality of surface waters (*e.g.,* clarity and odors) that enhances the recreational experience. In addition, wildlife viewers may benefit from improved abundance of aquatic species and piscivorous birds (*e.g.,* osprey, eagle) resulting from an increase in forage fish populations (U.S. EPA, 2015).

Improved aesthetic quality and health safety of surface water and recreational sites could also enhance the value of additional "cultural" ecosystem services such as education, further benefitting local communities. For example, a study by Hutcheson et al. (2018) found that the Hudson River Park's environmental educational programs for elementary and high school-age children are well attended by organizations in school districts with high proportions of minority students. The estimated ecosystem service values for the park's estuary education programs ranged from $7.5 thousand to $25.5 thousand per year based on data on school and summer camp visits from 32 New York City school districts in 2014 and 2015. Since water quality improvements in the Harbor Estuary could lead to improved aesthetics and subsequent increased use for educational purposes, additional opportunities for environmental education programs could result in significant benefits to local communities.

2.1.3 Property Values

Water quality improvements and associated changes in ecosystem services can impact nearby property values. Numerous economic studies (*e.g.,* Leggett et al., 2000; Bin et al., 2013; Walsh et al., 2011; Tuttle et al., 2014; Klemick et al., 2018; Walsh et al., 2011, Kung et al., 2022) suggest that waterfront property is more desirable when located near less polluted water. For example, a study by Kung et al. (2022) found that a 10 percent increase in EC in Long Island Sound results in an average depreciation of housing value of 0.16 percent in the Westchester County, New York for houses located within 500 meters of the water. Based on the average home price of $1.15 million this translates to an average decrease in home value of $1,810 (2021 USD). Previously published hedonic property studies (*e.g.,* Walsh et al., 2011; Netusil et al., 2014; Liu et al., 2017; Klemick et al., 2018) found that property depreciation extends to homes up to one kilometer from the water. Therefore, the value of properties located in proximity to Harbor Estuary waters is expected to increase. Although this benefit would accrue to the current property owners only, it represents an overall increase in societal wealth.

ICF was not able to quantify or monetize the potential increase in property values associated with water quality improvements in the Harbor Estuary. The magnitude of the potential increase depends on many factors, including the number of housing units located near the affected waterbodies, community (*e.g.,* residential density), housing stock (*e.g.,* single family or multiple family), and aesthetic effects of water quality improvements. Additionally, there is likely (although not total) overlap between changes in property values and WTP values for water quality improvements. Thus, estimating separate property value benefits would double count at least some of the quantified benefit estimates in this analysis. Nonetheless, although a study of this type is beyond the scope of the current report, it would be possible (with suitable primary data collection and additional analysis) to estimate these effects for communities bordering the Harbor Estuary. Methods for this type of analysis are well established (Champ et al. 2017).

2.1.4 Economic Impacts

Economic impacts are different from economic benefits, in that the former represent measures of economic *activity* rather than measures of social value or benefit. New York's and New Jersey's investments in additional CSO controls and implementation of green infrastructure (*e.g.,* increase in vegetation and open space areas) to reduce stormwater discharges, as described in LTCPs for Harbor Estuary waters, are likely to have positive impacts on the local economy. These impacts include effects on employment, personal income, and gross state product (GSP) (Bess et al., 2011).[9]

In addition, the use of green infrastructure to improve water quality often involves enhancing the waterfront and "creating landscapes that can clean water, reducing pollution and restoring habitat while providing significant economic and social benefits to local communities and municipalities" (The Trust for Public Land, 2012). Waterfront enhancement aimed at water quality improvements, such as the creation of walking trails, parks, and recreational access points, will create recreational opportunities for the Harbor Estuary's residents and tourists, and increase commercial activity in affected neighborhoods.

Although information on economic impacts such as these can help reveal the effects of water quality improvements on economic activity (*e.g.,* jobs, income, spending), it is important to recognize that economic impacts are *not* equivalent to economic benefits and are not included in well-defined measures of economic value (D. S. Holland et al., 2010). In general, there is no expectation that economic values (or benefits) will be closely related to economic impacts, and in some instances they are of opposite signs (*i.e.,* a change that produces positive economic values can sometimes produce negative economic impacts, and vice versa). Hence, care is required when estimating, interpreting and reporting measures of this type. As economic benefits and economic impacts are distinct types of measures, with different interpretations, they are measured via different methods.

2.2 Valuation Methods for Water Quality Improvements

Building on the introduction and conceptual foundation provided above, this section describes the benefit transfer methods used by ICF to predict households' total values for water quality improvements. To assess the economic value of these improvements in the Harbor Estuary, ICF followed the approach used in several federal rulemakings that quantified the economic benefit of similar types of surface water quality improvements in different regions across the US (*e.g.,* U.S. EPA, 2020; U.S. EPA, 2015), as summarized in the following three steps:

- For each scenario considered, characterize and quantify the changes in water quality relative to baseline (status quo) conditions using a water quality index (WQI), and link these changes to ecosystem services or potential uses that are valued by society. See Section 2.2.1 for the WQI methodology and Section 4.1 for WQI results.
- Select the area encompassing the set of households for which values are estimated (*i.e.,* extent of the market) based on the goal of the analysis (see Section 2.2.2.1).[10]
- Monetize (or calculate the economic value of) water quality improvements using a meta-analysis of surface water valuation studies that provide data on the public's willingness to

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[9] To the extent that funding for the controls would come from ratepayers, the resulting loss of income would be expected to have a negative economic impact.

[10] The market extent used in this analysis is different from the market extent typically used by EPA for federal rulemakings due to the differences in geographic scale (*i.e.,* regional vs. national) of water quality improvements.

pay for water quality changes. See Section 2.2.2.2 for an overview of the meta-regression model, Section 4.2 for results of the meta-regression applications, and Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis for additional details about the meta-regression model.

The scenarios of water quality change for which benefits are estimated using these steps are described in Section 3. These scenarios were developed in coordination with Harbor Estuary partners and stakeholders, as described below.

2.2.1 Water Quality Index

As a precursor to measuring the economic value of water quality change, it is necessary to measure these changes in a manner that is consistent with economic valuation. Among the challenges in this area is reconciling the different ways that water quality can change into one or more consistent indicators that are suitable for use within the models used to implement benefit transfer (Johnston et al., 2005). An evaluation of water quality for benefit analysis hence requires a holistic analysis that can reconcile the many different ways that water quality can change into one or more standardized measures that can then be readily linked to measurable economic benefits. A holistic and standardized analysis also enables benefit measures to be compared across different prior studies in the literature.

To meet this objective, benefit transfers for water quality improvements commonly measure these changes using a WQI that translates multiple parameters that measure various aspects of water quality into a single numerical indicator. The WQI links specific constituent levels, as reflected in individual index parameters (*e.g.,* TP and DO concentrations), to the health of aquatic species and suitability for particular uses. WQIs of this type provide a means to link water quality levels with meta-analytic benefit transfer (Walsh and Wheeler, 2013; U.S. EPA, 2015; U.S. EPA, 2020).

The WQI used in this analysis is based on pioneering work of McClelland (1974), who developed a WQI that could translate complex water quality information into one indicator that could then be used in analyses that quantify and monetize water quality changes. Although based on the framework of the WQI developed by McClelland (1974), the WQI used in this analysis was adapted for use by EPA in their benefit-cost analyses for economically significant rules (U.S. EPA, 2020; U.S. EPA, 2015). It has been widely used by EPA in regulatory analysis and by environmental agencies elsewhere. Modifications are based on the Oregon WQI (Dunnette, 1979) and Cude (2001) as well as adjustments necessary to use the water quality parameters most salient to the Harbor Estuary. The modifications help to account for spatial and morphological variability in the natural characteristics of streams and make it more site-specific to the Harbor Estuary. The WQI incorporates six parameters: DO, biological oxygen demand (BOD), EC, TN, total phosphorus (TP), and total suspended solids (TSS). The parameters included in the WQI are based on a Delphi survey of over 100 different water quality experts who evaluated the importance of a wide variety of water quality indicators (Brown et al., 1970). The 0-100 WQI value reflects varying water quality, with 100 representing the highest possible quality and 0 the lowest (although index values <10 do not generally occur).

The implementation of the WQI includes three main steps: (1) obtaining water quality levels for each parameter for each waterbody, under both the baseline conditions and each water quality scenario; (2) transforming the parameter measurements into subindex values that express water quality conditions on a common scale of 10 to 100; and (3) combining the individual parameter subindices into a single WQI value that reflects overall water quality across the parameters. These WQI measures—for both the water quality baseline and change—are then used within the meta-analytic benefit transfer model to predict WTP for households in different areas surrounding the Harbor Estuary.

2.2.1.1 Step 1 – Establishing Water Quality Levels

Baseline water quality levels were based on average conditions for the 10 regions represented in Figure 1-1 and the six parameters of the WQI, using a compilation of data from a variety of sources, including:[11]

- New York City Department of Environmental Protection (NYCDEP) harbor-wide monitoring program
- New Jersey Harbor Dischargers Group (NJHDG) harbor surveys
- Interstate Environmental Commission (IEC)
- Meadowlands Environmental Research Institute (MERI)
- Hudson River Environmental Observing System (HRECOS)
- New Jersey Department of Environmental Protection (NJDEP)
- United States Geological Survey (USGS), and
- National Water Quality Portal (WQP)

For the most part, these data align with the data represented in HEP's 2021 Harbor-Wide Water Quality Report (Da Silva, 2021), generally ranging from May 1st through October 31st for the eight years from 2010 to 2017. Where a top and bottom sample were taken, the surface measurement was used.

Water quality levels under the various scenarios are discussed in Section 3.

2.2.1.2 Step 2 – Subindex Curve Transformation

The subindex transformation curves used for this analysis translate measurements or levels for individual water quality parameters to a common scale. The subindex curves for BOD and DO were originally developed by Dunnette (1979) and Cude (2001) for the Oregon WQI. The subindex curves for TN, TP, suspended sediment, and EC were developed using an adapted approach from Cude (2001) that fits an exponential equation to two concentration points. The updated subindex curves for TN, TP, and suspended sediment are based on the distribution of water quality within each Level III ecoregion (Omernik et al., 2014), as estimated by the most current SPAtially Referenced Regression On Watershed attributes (SPARROW) regional models (Ator, 2019, Hoos et al., 2019, Robertson et al., 2019, Wise, 2019, and Wise et al., 2019). The subindex curve for a single region (Northeastern Coastal Zone) was used for all water bodies in the analysis, given the similar geologic and geographic context. The Northeastern Coastal Zone subindex curves for TN and TP also closely match the distribution expected from threshold values reported by the Mid-Atlantic Tributary Assessment Coalition (MTAC) (EcoCheck, 2011) and used as reference in HEP's 2021 Harbor-Wide Water Quality Report.

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[11] There were not sufficient BOD data for the Bronx River and East River and Harlem River regions. Average concentrations across all of the other regions were used as a substitute.

The subindex curve for EC is based on EC concentrations related to various water uses as identified by data from Russo (2022).

Table 2-1 presents the parameter-specific functions used for transforming water quality data into water quality subindices for the six pollutants with individual subindices. The curves include threshold values below or above which the subindex score does not change in response to changes in parameter levels. For example, improving DO levels from 10.5 mg/L to 12 mg/L or from 2 mg/L to 3.3 mg/L would result in no change in the DO subindex score.

Table 2-1. Freshwater Water Quality Subindices

Parameter	Concentrations	Concentration Unit	Subindex
Dissolved Oxygen (DO)			
DO	$DO \le 3.3$	mg/L	10
DO	$3.3 < DO < 10.5$	mg/L	$-80.29+31.88\times DO-1.401\times DO^2$
DO	$DO \ge 10.5$	mg/L	100
Enterococcus (EC)			
EC	$EC \ge 139$	Geomean CFU/100 mL	10
EC	$16 < EC < 139$	Geomean CFU/100 mL	$134.91 \times \exp(EC \times -0.019)$
EC	$EC \le 16$	Geomean CFU/100 mL	100
Total Nitrogen (TN)			
TN	$TN > 2.58$	mg/L	10
TN	$0.33 < TN \le 2.58$	mg/L	$139.63 \times \exp(TN \times -1.02)$
TN	$TN \le 0.33$	mg/L	100
Total Phosphorus (TP)			
TP	$TP > 0.18$	mg/L	10
TP	$0.02 < TP \le 0.18$	mg/L	$125.36 \times \exp(TP \times -13.84)$
TP	$TP \le 0.02$	mg/L	100
Suspended Solids			
SSC	$SSC > 112.63$	mg/L	10
SSC	$4.47 < SSC \le 112.63$	mg/L	$109.98 \times \exp(SSC \times -0.02)$
SSC	$SSC \le 4.47$	mg/L	100
Biochemical Oxygen Demand, 5-day (BOD)			
BOD	$BOD > 8$	mg/L	10
BOD	$BOD \le 8$	mg/L	$100 \times \exp(BOD \times -0.1993)$

2.2.1.3 Step 3 – Aggregate Subindex Values into Single WQI Value

The final step in implementing the WQI involves combining the individual parameter subindices into a single WQI value that reflects the overall water quality across the parameters. Following McClelland's approach, the overall WQI for a given waterbody is calculated using a weighted geometric mean function as follows:

$$WQI = \prod_{i=1}^{n} Q_i^{W_i} \qquad \text{Equation 2-1}$$

where:

WQI = the multiplicative water quality index (from 10 to 100)
Q_i = the water quality subindex measure for parameter *i*
W_i = the weight of the *i-th* parameter
n = the number of parameters

The WQI parameter weights used in Equation 2-1 are based on the parameter weights originally developed by McClelland (1974), but revised by EPA for a rulemaking for the Construction and Development industry in 2009 (U.S. EPA, 2009) to redistribute the weights to the six parameters (excluding temperature and pH from McClelland's WQI) so that the ratio of the parameters is maintained and the weights sum to one.

2.2.2 Assessing Willingness-to-Pay for Water Quality Improvements

Following calculation of the WQI, the next steps in the methodology for estimating benefits of water quality improvements are to: (1) select the market extent(s) for the analysis (Section 2.2.2.1), and (2) perform meta-analytic benefit transfers to estimate WTP values for water quality improvements (Section 2.2.2.2).

2.2.2.1 Market Extent

The selection of the appropriate market extent(s), or the selected locations of households likely to hold values for water quality improvements, is important to support valid and reliable benefit transfers. Simply put, the extent of the market reflects whose values "count" and are therefore measured in any given benefit-cost analysis. For the Harbor Estuary, it would be possible to measure benefits for many different groups—including residents of neighboring cities and towns, residents of neighboring counties, residents of New York and New Jersey, or residents of the northeast US, among many other possibilities. For example, many EPA benefit-cost analyses consider a national extent of the market, such that all US households are considered. There is no universal "correct answer" when determining the extent of the market—it depends on the purpose of the analysis, the needs of decision makers, and other factors. Decisions over the extent of the market can have major impacts on the size of total benefit estimates, because they determine the number of households whose benefits are considered in the analysis (Bateman et al., 2006).

As an illustration, Johnston and Bauer (2020) measured the effects of three different market extents on per household and total (population-level) WTP for water quality improvements in Great Bay (New Hampshire). The study demonstrated that both the estimated per household WTP and the total WTP values are sensitive to the assumed extent of the market. More specifically, as one aggregates benefits for households over larger market extents (and typically farther from the waterbody that is improved), WTP *per household* declines due to distance decay. That is, the values for environmental improvements, per household, tend to decline with greater distance between the household and improved areas. This is an expected pattern, because households tend to hold higher values for improvements that occur closer to home (Bateman et al., 2006; Johnston et al., 2019). However, as the market extent increases, the *total number of households* over which values are aggregated typically increases. As a result, total WTP values often increase as the extent of the market increases, even though average values per household decline. Given patterns such as these, it is important to clarify the extent of the market for benefit aggregation, particularly since (as noted above) there is no "correct" market extent for economic valuation. The appropriate market extent depends on whose values are of interest for a given analysis.

Based on common best practices used in benefit transfer applications, stakeholder input, and the market extents used in underlying meta-data studies,[12] ICF used two different market extents when calculating both per household and total benefits.[13] By using two different market extents, ICF can assess the sensitivity of benefit estimates to the market extent selection. The two market extents are:

- **County-level extent:** The 30 counties that encompass the watersheds of the Hudson-Raritan Estuary and correspond to the scope of the Harbor Estuary Program[14] are shown in Figure 1-2 and Figure 2-2. These counties align with communities likely to be most affected by, and therefore likely to hold both use and nonuse values for, water quality changes in the Harbor Estuary. The counties are limited to the states of New York and New Jersey, although communities in western Connecticut or eastern Pennsylvania may also value water quality changes in the Harbor Estuary, at least at some level.
- **State-level extent:** A market extent at the state level, which includes states that intersect with the study area of interest, is common for water quality improvements since many improvement programs are funded via state-level taxes. A state-level market extent for the Harbor Estuary includes New York and New Jersey (including the 30 HEP counties plus other non-adjacent counties). Although this market extent aligns with other water quality improvement valuation studies, households located in upstate New York or southern New Jersey may have different values for water quality changes in the Harbor Estuary (*e.g.,* nonuse values only) than households located closer to the waterbody.

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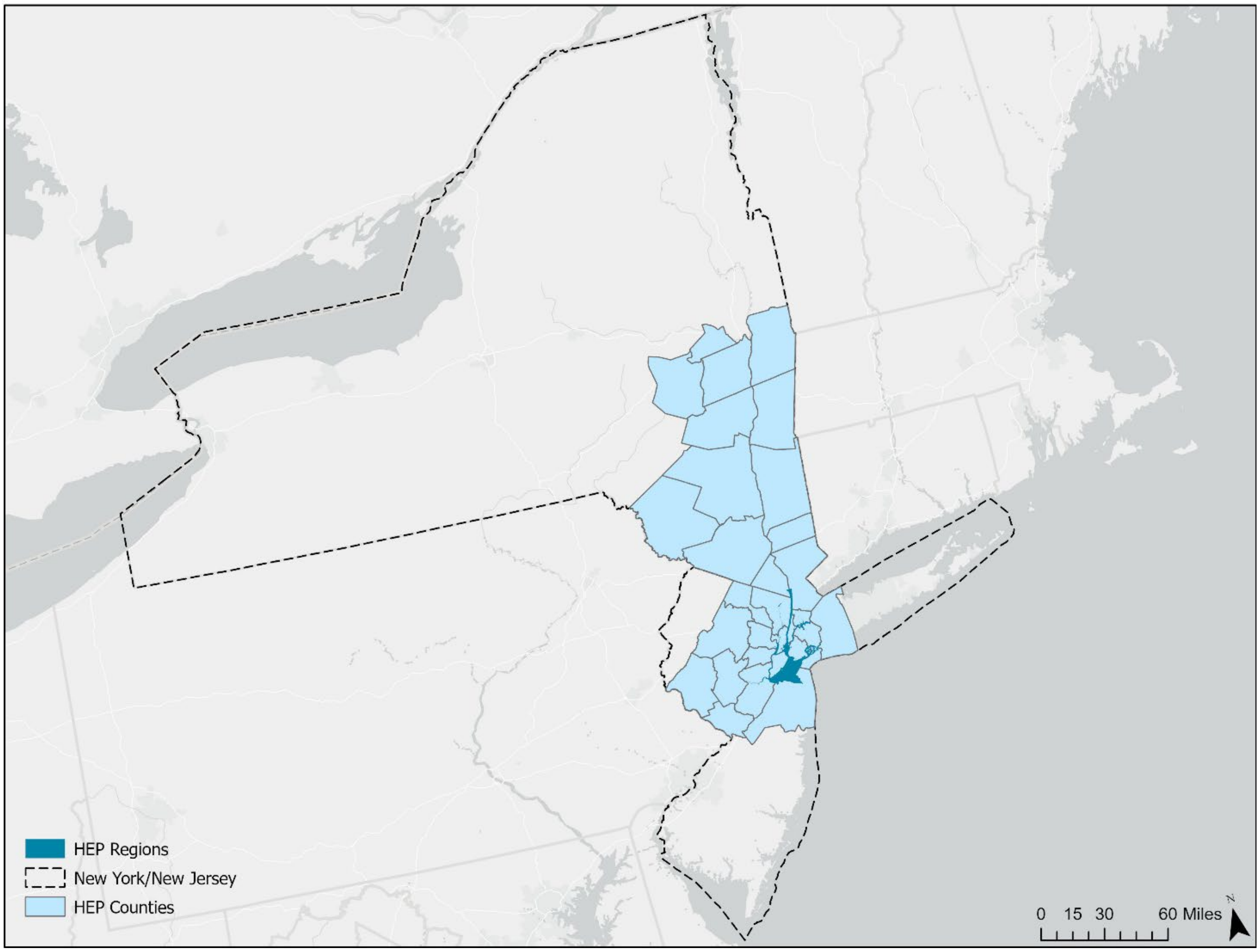
[12] The underlying meta-data for the meta-analytic benefit transfer model contains observations from 59 primary stated preference studies of WTP for surface water quality changes. The primary studies estimated WTP values based on surveyed populations from several different market extents, including one entire state (37%), counties surrounding the affected waters (29%), cites/towns around the affected waters (19%), and buffers around the affected waters/watersheds (5%). Other market extents from the primary valuation studies include metropolitan statistical areas (3%), multiple states (3%), watershed boundaries (2%), and the entire United States (2%).

[13] In addition to the two selected market extents, we also considered using the New York-Newark-Jersey City, NY-NJ-PA metropolitan statistical area (MSA), which covers portions of New York, New Jersey, and Pennsylvania. However, we dropped the MSA-based market extent due to the similarities in geographic extent and number of households with the county-level extent.

[14] Identified by Rob Pirani (HEP) in email communication with Emma Gildesgame (NEIWPCC) on November 2, 2021. The 30 counties include 11 counties in New Jersey (Bergen, Essex, Hudson, Hunterdon, Mercer, Middlesex, Monmouth, Morris, Passaic, Somerset, and Union) and 19 counties in New York (Albany, Bronx, Columbia, Dutchess, Greene, Kings, Nassau, New York, Orange, Putnam, Queens, Rensselaer, Richmond, Rockland, Schenectady, Schoharie, Sullivan, Ulster, and Westchester).

Figure 2-2. County- and State-level Market Extents[a]



[a] The 30 HEP counties include 11 counties in New Jersey (Bergen, Essex, Hudson, Hunterdon, Mercer, Middlesex, Monmouth, Morris, Passaic, Somerset, and Union) and 19 counties in New York (Albany, Bronx, Columbia, Dutchess, Greene, Kings, Nassau, New York, Orange, Putnam, Queens, Rensselaer, Richmond, Rockland, Schenectady, Schoharie, Sullivan, Ulster, and Westchester).

2.2.2.2 Meta-Regression Model

To estimate the economic value of water quality improvements in the Harbor Estuary resulting from conservation and restoration activities (see Section 3 for details about the water quality scenarios), ICF utilized a meta-analytic benefit transfer model grounded in methods previously developed by the project team to evaluate water quality changes for EPA regulatory analyses (*e.g.,* U.S. EPA, 2020; U.S. EPA, 2015), including water quality changes realized within the Harbor Estuary. These analyses draw from underlying methods published in Johnston et al. (2005), Johnston, Besedin, et al. (2017), and Johnston et al. (2019). A meta-analytic benefit transfer predicts benefits using a synthesis of information from multiple sources rather than relying on values from a single study (*i.e.,* value transfer), or a benefit function similarly drawn from one prior study (*i.e.,* single study benefit function transfer). The main advantage of this approach is that the resulting meta-regression model allows predicted estimates to be tailored to the needs of a particular program evaluation, such as the four water quality scenarios for the Harbor Estuary (see Section 3). Methods of this type are among the most accurate forms of benefit transfer (Johnston et al., 2021).

Technical details of the meta-regression model are described in Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis. Additional details on models of this type may be found in sources such as Johnston et al. (2005), Johnston, Besedin, et al. (2017), Johnston et al. (2019), and Johnston and Bauer (2020). The modeling approach utilizes meta-data drawn from primary stated preference studies of WTP for surface water quality changes to estimate per household and total economic value estimates for different types of water quality changes within the Harbor Estuary. The meta-regression model , which is based on 189 estimates of total WTP (including both use and nonuse values) for water quality improvements provided by 59 original studies conducted between 1981 and 2017, allows calculation of total WTP for water quality changes that incorporate values for a variety of environmental services affected by water quality and valued by humans, such as changes in recreational fishing opportunities or other water-based recreation and existence services such as aquatic life, wildlife, and habitat designated uses (see Figure 2-1). These relationships are described in Section 2 above.

The model also allows ICF to adjust WTP values based on spatial dimensions of water quality changes and the location of households who value those changes. Economic theory and past empirical evidence show that these spatial dimensions exert important influences on the value of water quality changes to the public (Bateman et al., 2006; Johnston, Besedin, et al., 2017; Johnston et al., 2019). Geospatial factors that are considered in the present analysis of WTP include: scale (the size of affected water resources or areas), market extent (the size of the market area over which WTP is estimated), and the availability of substitutes (here defined as other nearby surface waters that might be valued by households, other than the Harbor Estuary).

Section 2.2.2.1 provides details about the two selected market extents (state, county). To estimate benefits of water quality improvements under each scenario, ICF applied the meta-regression model for each county/state in the given market extent to estimate average annual per household WTP values for each county/state. ICF then determined the appropriate analysis period, or the length of time over which benefits would accrue from water quality improvements, by consulting with NEIWPCC, HEP, and members of the advisory board committee. The start year of the analysis period, or the year when water quality targets of the water quality scenarios (see Section 3) could reasonably be met, is based on the timing of planned or expected conservation and restoration activities. Based on planned or estimated actions, water quality targets under the water quality scenarios could reasonably be met by the end of 2042. Thus, benefits from the water quality improvements under the four scenarios would begin accruing in 2043. ICF assumed that benefits would accrue for 20 years from 2043 to 2062 and accounted for population growth throughout the analysis period using population projections from the 2021 National Aeronautics and Space Administration (NASA) Socioeconomic Data and Applications Center (SEDAC) (Hauer et al., 2021).

Note that assuming a 20-year delay before benefits begin under each water quality scenario has the effect of diminishing total economic value estimates, due to discounting. Following standard procedures for benefit-cost analysis, future benefits are discounted at a fixed rate (here, 3 percent annually) to reflect the fact that outcomes in the future are valued less by society than otherwise identical outcomes realized today. Were the analysis to assume that water quality improvements were to occur immediately (rather than after 20 years), the predicted benefits would be considerably higher. All else equal, the more rapidly water quality benefits are achieved, the higher are the predicted benefits. For example, discounted at an annual 3 percent rate, a water quality change that occurs in year 20 has approximately half (0.55) of the present value (value to society now) of an otherwise identical change realized today, solely due to the impacts of discounting. It is straightforward to illustrate how total estimated benefits change as a function of the time at which water quality improvements occur.

Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis provides technical details about the meta-regression model, including details about the underlying primary stated preference valuation studies used to estimate the model, the estimated regression equation, variable definitions, and model coefficients. The appendix also provides details about how ICF applied the meta-regression model to predict per household WTP for each county/state in the assumed market extents, including variable setting values for the different benefit transfer applications. Several variable settings in the meta-regression model benefit transfer applications vary by either market extent or water quality scenario (see Table A-4). Johnston and Bauer (2020) provide an in-depth discussion of these and other steps required when using an meta-regression model of this type to predict water quality benefits.

When implementing the benefit transfer, ICF considered two alternative value settings for the *swim_use* variable, a binary variable[15] indicating that the uses affected by the valuation scenario include swimming. These alternative treatments were applied to the two water quality scenarios that include a primary contact recreation component (primary contact recreation and combined scenarios; see Section 3). When predicting values, ICF first assumed a value of 0 for this variable to indicate that although water quality would meet primary contact recreation standards under these two scenarios, additional steps would be needed for the Harbor Estuary waters to be useable for swimming, such as obtaining permits that allow swimming uses at beaches. This produces a conservative estimate of value and reflects the fact that even though water quality would improve in a way that *could* enhance swimming uses, these new uses would not necessarily occur without additional policy changes. For comparison, ICF also assumed a value of 1 for this variable to demonstrate how estimated benefits increase when all steps are taken to allow swimming within improved Harbor Estuary waters (*i.e.,* how much more affected households are WTP if swimming uses improve in the Harbor Estuary).

The benefit estimates provided in Section 4.2 are based on the county-level market extent and a *swim_use* variable setting of 0. Appendix B: Sensitivity Analyses presents benefit estimates from two sensitivity analysis: (1) state-level market extent (*swim_use* variable still set to 0), and (2) benefit estimates for the primary contact recreation and combined scenarios when *swim_use* is set to 1 for the county-level market extent. Sensitivity analyses such as these are useful to help understand how water quality benefits change under different situations and assumptions.

3 Water Quality Scenarios

The following section describes the water quality scenarios used to evaluate the value of water quality improvements in the Harbor Estuary. These scenarios were developed with significant input from Harbor Estuary partners and stakeholders obtained through various methods, including workgroup meeting discussions, polls and forms, and email requests. For this analysis, the definition of clean water focuses on improvements to four water quality parameters: EC, TN, TP, and DO.

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[15] A binary variable is a variable with only two values, 1 (true) and 0 (false).

These scenarios are meant for illustrative purposes only—to show the benefits that are predicted under various future possibilities for water quality change. It is important to recognize that the scenarios are *not* intended to replace any guidance or information in New York's or New Jersey's Integrated Water Quality Reports, nor are they meant to be used for compliance purposes or regulatory analysis. The purpose of this valuation study is to advance discussions on the benefits of achieving the fishable and swimmable goals of the 1972 CWA. While the water quality scenarios estimate the value of improvements to specific water quality parameters, the water quality improvements and the associated monetary benefits are likely underestimated without a more holistic analysis of improvements to the other parameters included in the WQI (*e.g.,* BOD and TSS). In addition, the water quality levels suggested by any of the scenarios evaluated for this report are specifically tied to cited criteria or threshold levels and do not reflect water quality levels achievable by any potential restoration or conservation activities.

Finally, ICF emphasizes that these water quality scenarios are not meant to imply that any set of water quality improvements is feasible or recommended for the Harbor Estuary. The presented benefit estimates should be interpreted as conditional on water quality improvements occurring as specified in each scenario, without any assessment on whether these improvements should or will occur, or whether the scenarios are consistent with extant guidance or policies applicable in either New York or New Jersey (or municipalities, counties, etc., therein).

Table 3-1 summarizes the water quality scenarios at a high-level, with detailed descriptions in the subsequent subsections. Two of the water quality scenarios (primary and secondary contact recreation) are based on water quality targets of planned improvements in the Harbor Estuary. The remaining two scenarios (aquatic life and combined) are illustrative scenarios intended to show the range of benefits for large water quality improvements.

Table 3-1. Summary of Water Quality Scenarios

Scenario Name	Threshold Values^{a}	Data Source
Scenarios Based on Water Quality Targets of Planned Improvements		
Primary Contact Recreation	130 CFU/100 mL for daily values of EC and 35 CFU/100 mL for average values of EC	EPA's 2012 Recreational Water Quality Criteria for EC (U.S. EPA, 2012a)
Secondary Contact Recreation	70 CFU/100 mL for average values of EC	New York State's site-specific criteria for EC relevant to portions of Arthur Kill and Alley Creek (6 NYCRR 703.4)
Illustrative Scenarios		
Aquatic Life	3.0 mg/L for daily values of DO and 4.8 mg/L for mean values of DO	EPA's 2000 aquatic life chronic criteria for DO (U.S. EPA, 2000) and New York State's acute criteria for DO (6 NYCRR 703.3) relevant to juvenile survival in saline waters
	0.4 mg/L for daily values of TN	MTAC thresholds established for tidal tributaries and estuaries (EcoCheck, 2011)
	0.03 mg/L for daily values of TP	
Combined	130 CFU/100 mL for daily values of EC and 35 CFU/100 mL for average values of EC	EPA's 2012 Recreational Water Quality Criteria for EC (U.S. EPA, 2012a)

Table 3-1. Summary of Water Quality Scenarios

Scenario Name	Threshold Values[a]	Data Source
	3.0 mg/L for daily values of DO and 4.8 mg/L for mean values of DO	EPA's 2000 aquatic life chronic criteria for DO (U.S. EPA, 2000) and New York State's acute criteria for DO (6 NYCRR 703.3) relevant to juvenile survival in saline waters
	0.4 mg/L for daily values of TN	MTAC thresholds established for tidal tributaries and estuaries (EcoCheck, 2011)
	0.03 mg/L for daily values of TP	

[a] Parameter-specific thresholds expected to be achieved under the different water quality scenarios.

3.1 Primary Contact Recreation

The primary contact recreation scenario focuses on valuing water quality changes that are needed to make water safe for primary contact recreation (*i.e.,* swimming) across the Harbor Estuary. As a result, this scenario focuses on improvements to EC concentrations, a pollutant that has public health implications.

EPA's 2012 Recreational Water Quality Criteria (RWQC) for pathogens consists of two values, a geometric mean (GM) and a statistical threshold value (STV). A GM is a metric used to represent the central tendency of a dataset (*i.e.,* typical value or median across the waterbody) for a given period. An STV is a metric used to represent the frequency of pathogenic concentrations above a safe limit.

Epidemiological studies evaluated for the development of EPA's 2012 RWQC found that waters having a 30-day GM of 35 or less colony-forming units (CFU) of EC per 100 milliliters (mL) of water (35 CFU/100 mL) and no more than 10 percent of water samples within a 30-day time period exceeding 130 CFU/100 mL is protective of public health, meaning it is acceptable for primary contact such as swimming.[16] Exceeding these values means that the water is not considered to be generally safe for primary contact.

Regulatory Definitions for Primary Contact Recreation

New York (10 NYCRR Part 700.1): Primary contact recreation means recreational activities where the human body may come in direct contact with raw water to the point of complete body submergence. Primary contact recreation includes, but is not limited to, swimming, diving, water skiing, skin diving and surfing.

New Jersey (NJAC 7:9B-1.4): Primary contact recreation means water related recreational activities that involve significant ingestion risks and includes, but is not limited to, wading, swimming, diving, surfing, and water skiing.

The primary contact recreation scenario assumes EPA's 2012 RWQC have been achieved across all ten waterbody regions in the Harbor Estuary. This was implemented in two parts: (1) by setting any EC values within the eight-year time series of observed data across the recreational season to the STV threshold value if exceeded and (2) by setting any average values (from the adjusted time series after step (1)) for each waterbody region to the GM threshold value if exceeded.

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[16] EPA's 2012 RWQC for pathogens allows for a geometric mean of either 30 or 35 CFU/100 mL and a STV of 110 or 130 CFU/100 mL. The difference lies in the associated illness rates (32 or 36, respectfully, out of 1,000 individuals with swimming-related illnesses) and both values are protective of public health.

3.2 Secondary Contact Recreation

The secondary contact recreation scenario focuses on valuing water quality changes that are expected to correlate with achieving secondary contact recreation (*i.e.,* fishing and boating) across the Harbor Estuary. As a result, this scenario focuses on improvements to EC concentrations, a pollutant that has public health implications.

New York State issued an amendment to NYCRR 703.4, effective in October 2021, that revised site-specific criteria for select Class I and Class SD waterbodies. In particular, there was a progressive GM standard for EC (70 CFU/100 mL) set for portions of Arthur Kill and Alley Creek. The amendments were intended to improve protection for the secondary contact recreation and fishing best uses of Class I and Class SD waters.[17]

Regulatory Definitions for Secondary Contact Recreation

New York (10 NYCRR Part 700.1): Secondary contact recreation means recreational activities where contact with the water is minimal and where ingestion of the water is not probable. Secondary contact recreation includes, but is not limited to, fishing and boating.

New Jersey (NJAC 7:9B-1.4): Secondary contact recreation means recreational activities where the probability of water ingestion is minimal and includes, but is not limited to, boating and fishing.

The secondary contact recreation scenario assumes this progressive GM standard has been achieved across all ten waterbody regions in the Harbor Estuary. This was implemented by setting any average values for each waterbody region to the GM threshold value if exceeded. Currently, the East River & Harlem River, Arthur Kill & Kill van Kull, Passaic River & Newark Bay, and Lower Raritan River exceed the defined threshold. No changes in water quality were evaluated for other waterbody regions.

3.3 Aquatic Life

The aquatic life scenario focuses on achieving water quality suitable for support of aquatic life, including fish caught for recreational purposes like Striped Bass and Menhaden. As a result, this scenario focuses on improvements to TN, TP, and DO concentrations. Low DO levels cause hypoxia and can reduce the amount of habitat available for fish and shellfish. Nitrogen is essential for marine life, but elevated nutrient levels can lead to excessive growth of algae and other microscopic plants. These organisms and the marine species that feed on them respire, die, and decompose, depleting the oxygen in the water.

EPA's 2000 DO Criteria (U.S. EPA, 2000) recommends following two threshold values for hypoxia: acute hypoxia, the DO level at which marine life has a greater potential to die and chronic hypoxia,

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[17] The Harbor Estuary includes Class SA (Shellfish), SB (Bathing), I (Boating/Fishing), SD (Fish Survival), FW2-NT (Fishing/Fish Propagation/Bathing), SE1 (Shellfish/Bathing), SE2 (Fishing/Fish Propagation), and SE3 (Fishing/Fish Migration) waters.

the continuous level at which DO levels hinder growth of marine life. These threshold values aim to be protective of biological health—survival of juvenile and adult fish and other aquatic organisms, their growth, and larval recruitment. For this analysis, EPA's 2000 chronic DO criteria (4.8 mg/L) was used in combination with New York State's acute DO criteria (3.0 mg/L).[18]

Unlike pathogens and DO, nutrients do not have threshold value recommendations from EPA. The states of New York and New Jersey have narrative water quality standards that lay out a descriptive condition that needs to be met. However, other estuaries in the country, like the Chesapeake Bay, have begun to define numeric threshold values for nitrogen and phosphorus. In particular, for tidal tributaries and estuaries in the Chesapeake Bay, MTAC recommends using 0.4 mg/L of TN and 0.03 mg/L of TP to represent good water quality conditions (EcoCheck, 2011).

Narrative Water Quality Standards for Nutrients

New York: None in amounts that result in the growths of algae, weeds and slimes that will impair the waters for their best usages.

New Jersey: Except as due to natural conditions, nutrients shall not be allowed in concentrations that render the waters unsuitable for the existing or designated uses due to objectionable algal densities, nuisance aquatic vegetation, diurnal fluctuations in DO or pH indicative of excessive photosynthetic activity, detrimental changes to the composition of aquatic ecosystems, or other indicators of use impairment caused by nutrients.

The aquatic life scenario assumes that all of these standards have been achieved across all ten waterbody regions in the Harbor Estuary. For DO, the scenario was implemented in two parts: (1) by setting any DO values within the eight-year time series of observed data across the recreational season to New York State's acute criteria threshold value if exceeded and (2) by setting any average values (from the adjusted time series after step (1)) for each waterbody region to the chronic criteria threshold value if exceeded. For nutrients, the scenario was implemented by setting any average values for each waterbody region to MTAC's nutrient threshold values if exceeded.

3.4 Combined Scenario

The combined scenario evaluates water quality changes from both the primary contact recreation and aquatic life scenarios. In other words, this scenario focuses on the value of achieving EPA's 2012 RWQC, EPA's 2000 chronic DO criteria, New York State's acute DO criteria, and MTAC's threshold values.

4 Summary of the Results

The following sections summarize the analysis results by first discussing the WQI calculation results and then discussing the application of the meta-regression model to estimate the value of clean water in the Harbor Estuary.

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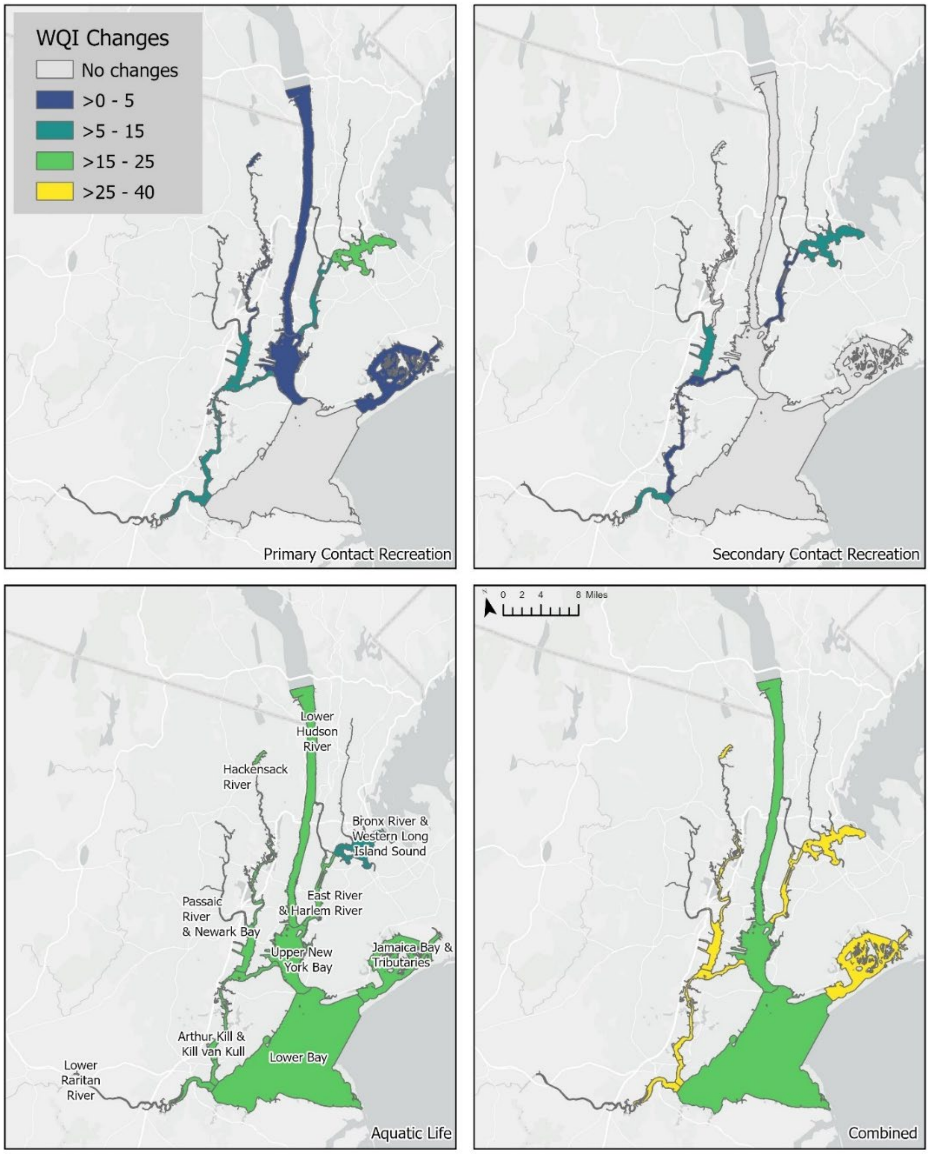
[18] New York State also references EPA's 2000 chronic DO criteria (4.8 mg/L).

4.1 WQI Calculations

Table 4-1 summarizes average WQI values under the baseline and then each of the water quality scenarios.[19,20] Based on the average WQI values, baseline water quality is the poorest in the Lower Raritan River and best in Upper New York Bay. Considering water quality changes from achieving the threshold values of the combined scenario, the greatest water quality improvements are also located in the Lower Raritan River, but the smallest water quality improvements are located in the Lower Bay.

Figure 4-1. WQI Changes by Waterbody Region



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[19] For reference, the baseline represents observed water quality during the recreational season from 2010-2017 (see Section 2.2.1.1).

[20] As a note, the WQI values are only based on the six parameters included in the WQI and may not reflect water quality conditions as suggested by other parameter values or metrics.

As shown in **Error! Reference source not found.**, WQI improvements are typically much greater in the Aquatic Life and Combined scenarios than in either the Primary or Secondary Contact scenarios.[21] This is largely driven by the baseline nutrient concentrations and associated change in nutrient concentrations to achieve the MTAC threshold values. In other words, baseline observations across the waterbody regions indicated high average nutrient levels. Accordingly, reducing these levels to the MTAC threshold values resulted in significant changes to the average WQI value. Hence, the latter two scenarios should translate to greater benefits, reflecting the larger improvements in overall water quality as measured by the WQI.

For the meta-regression model applications, we used one overall baseline WQI value and one scenario WQI value for each scenario. To obtain the overall values, ICF weighted the waterbody region-level WQI values by the number of monitoring stations (*i.e.,* multiplied each regional WQI by the ratio of the number of stations for the region relative to the total number of stations and summed the resulting values across regions). The weighted WQI values are presented in the bottom row of Table 4-1.

Table 4-1. Average WQI by Waterbody Region

Waterbody Region	**# of Stations**	**Average WQI Value**				
		Baseline	*Primary Contact Recreation*	*Secondary Contact Recreation*	*Aquatic Life*	*Combined*
Arthur Kill and Kill van Kull	13	31.1	39.8	32.4	47.9	61.2
Bronx River and Western Long Island Sound	7	26.9	42.9	35.8	39.1	62.5
East River and Harlem River	3	33.3	41.0	34.3	49.1	60.4
Hackensack River	7	28.4	31.8	28.4	49.2	55.0
Jamaica Bay and Tributaries	7	43.8	45.0	43.8	68.2	70.1
Lower Bay	8	48.5	48.5	48.5	64.5	64.5
Lower Hudson River	12	44.6	45.6	44.6	63.0	64.4
Lower Raritan River	5	22.5	33.6	29.1	41.3	61.8
Lower Passaic River and Newark Bay	11	21.3	32.7	28.3	38.6	59.3
Upper New York Bay	3	51.9	53.0	51.9	70.5	72.0
Weighted WQI	**76 total**	**34.5**	**40.8**	**37.0**	**52.4**	**62.6**

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[21] The only exception to this general observation is the Bronx River and Western Long Island Sound, for which the Aquatic Life scenario leads to an average WQI that is lower than the WQI value under the Primary Contact Recreation scenario.

4.2 Meta-Regression Model Applications

Table 4-2 presents benefit estimates for each water quality scenario, based on the county-level market extent and an assumption that the Harbor Estuary remains unavailable for swimming (*swim_use* = 0).[22] Appendix B: Sensitivity Analyses provides sensitivity benefit estimates based on the state-level market extent and an assumption that swimming becomes available within the Harbor Estuary (*swim_use* = 1) under the primary contact recreation and combined scenarios. The model predicts representative mean value applicable (on average) to all households within the chosen market extent. As described in Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis, the structure of the meta-analysis allows these predictions to account for characteristics of households within each of these market extents – for example household income and proximity to the Harbor Estuary. For example, when comparing predicted values for residents of counties neighboring the Harbor Estuary to parallel values for all New York and New Jersey state residents, the model accounts for the fact that neighboring-county residents, are (on average) closer to the Harbor Estuary and have different average incomes from those in the two states considered as a whole.

Table 4-2. Benefits for Water Quality Improvements under all Water quality scenarios, Based on the County-Level Market Extent and a *swim_use* Variable Setting of 0

Scenario[a]	Average Annual Number of Households[b]	Average Annual Household WTP (2021$)	Total Present Value (3% Discount Rate; Millions 2021$)	Annualized Value (3% Discount Rate; Millions 2021$)
Scenarios Based on Water Quality Targets of Planned Improvements				
Primary Contact Recreation	8,639,847	$79.63	$5,744	$375
Secondary Contact Recreation	8,639,847	$33.16	$2,392	$156
Illustrative Scenarios				
Aquatic Life	8,639,847	$206.50	$14,896	$972
Combined Scenario	8,639,847	$301.32	$21,735	$1,418

[a] See Section 3 for descriptions of the four water quality scenarios.

[b] Average annual number of affected households during the 20-year analysis period (2043-2062). Number of households for each year in the analysis period accounts for projected population growth, based on population projections from the 2021 NASA SEDAC (Hauer et al., 2021).

For each water quality scenario, Table 4-2 presents the average annual number of households within the market extent assumed to value the water quality improvements, average annual household WTP values estimated via the meta-regression model, total present value[23] of benefits accrued over the 20-year analysis period using a 3 percent discount rate, and annualized benefits[24] using a 3 percent

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[22] See Section 2.2.2.2 for details about why ICF assumed that the Harbor Estuary remains unavailable for swimming in the main analysis.

[23] Total present value is the current value of future benefits, with benefits in future years discounted to account for how benefits accrued today are valued more than benefits accrued in the future.

[24] Annualized benefits are benefits over a time period (*i.e.,* the 20-year analysis period) scaled down to a 12-month period, enabling comparison of values over any time period.

discount rate. Table 4-2 separates the results for scenarios based on planned improvements versus illustrative scenarios (see Section 3). As noted above, these estimates assume that water quality improvements are realized as of 2043. Benefit predictions increase if improvements occur more rapidly.

As anticipated, the Combined Scenario (with a weighted WQI improvement of 28.1 over all areas) is predicted to generate an average annual household WTP that is much higher than that under other scenarios, with smaller improvements. For example, the Secondary Contact scenario, implying a weighted WQI improvement of 2.5, is associated with average annual household WTP that is 89 percent lower than that under the Combined Scenario ($33.16 versus $301.32). However, due to diminishing marginal returns to successively larger WQI improvements (see Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis), the differences in value predicted between different scenarios are proportionally smaller than the difference in predicted WQI improvements. For example, the predicted weighted WQI improvement is roughly 11 times larger in the Combined Scenario than in the Secondary Contact Recreation scenario. However, the corresponding WTP difference is roughly 9 times larger. Differences such as these demonstrate that the size of economic values is not directly proportional to the size of average water quality changes.

Despite these differences, even relatively modest water quality improvements, such as those under the Secondary Contact Recreation scenario, can generate large values for households in the surrounding counties. Even if not realized until 2043, this scenario (with a 2.5-unit weighted WQI improvement) produces a predicted total value of $156 million per year (2021 USD) (or $2,392 million over 20 years), and this only considers values realized by households in the surrounding counties. Scenarios with larger water quality improvement targets, such as the aquatic life and combined scenarios, would generate even higher values for surrounding households once the water quality targets are met. Note that all estimates are conditional on the specific water quality targets assumed under each scenario, the timing of these improvements, and the assumed extent of the market.

Results also demonstrate that the economic value of water quality improvements depends on how much water quality improves. Results of this type show the hazards of studies that seek to calculate a total (fixed) "value of water quality" over large areas such as the Harbor Estuary, without quantifying a scope of change. Economic values can only be calculated for *changes* in environmental quality or ecosystem services (D. S. Holland et al., 2010), and the total value of water quality improvements depends on the magnitude (or scope) of the change. The "value of water quality" in total (without any reference to a quantified change in quality) is not a meaningful concept.

4.3 Comparison to Other WTP Estimates

The estimated household WTP values for the four water quality scenarios are in line with estuary-based WTP values from the literature. Since available studies valued different magnitudes of water quality change (i.e., different WQI changes between the baseline and scenario), comparing estimated household WTP values *per unit of water quality change* enables easier comparison across studies. Table 4-3 presents household WTP values per unit of water quality change for the four water quality scenarios. The values range from a low of $10.72 (combined scenario) to a high of $13.26 (secondary contact recreation).

Figure 4-2 compares household WTP values per unit of water quality change for the four water quality scenarios to mean values from the meta-data for estuary-based studies in eastern and gulf coast states (nine total studies). The household WTP values per unit of water quality change for the four scenarios (denoted in green) fall within the range of mean values from the literature (denoted in blue), which range from a low value of $4.36 (Chesapeake Bay, MD) to a high value of $20.24 (Mobile Bay, AL; Barataria–Terrebonne estuary, LA).

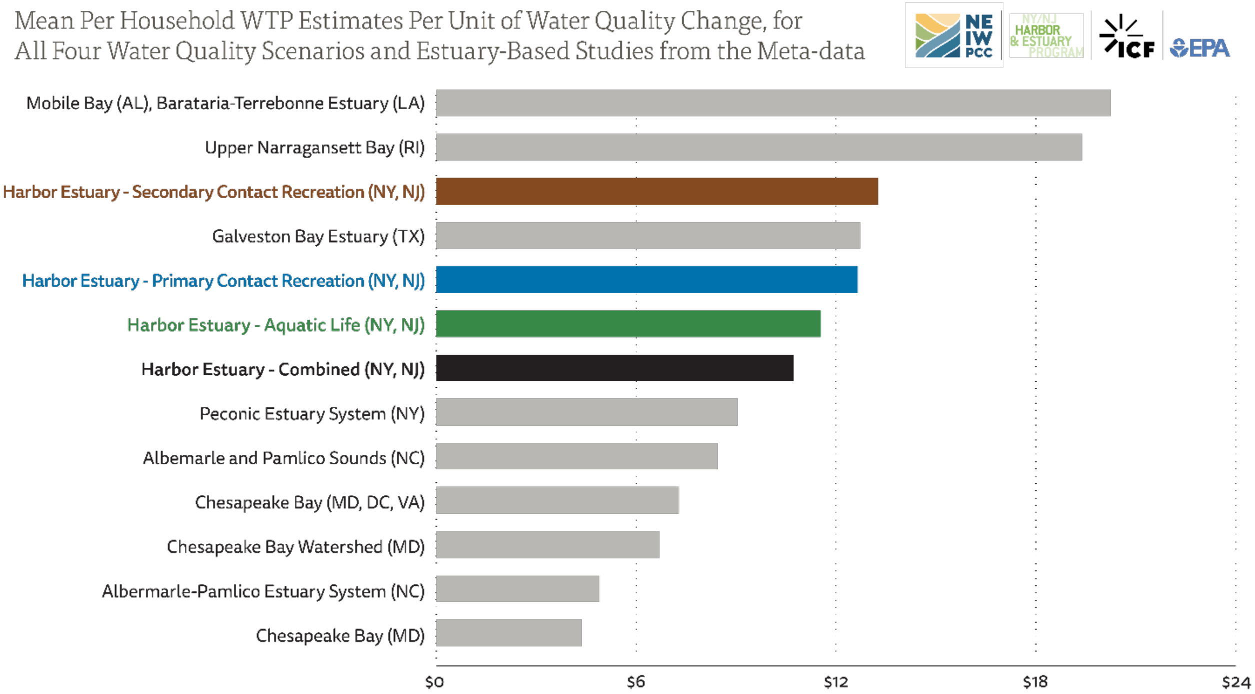
Table 4-3. Per Household WTP Estimates Per Unit of Water Quality Change, for All Four Water Quality Scenarios

Scenario[a]	Average Annual Household WTP (2021$)	Estimated Water Quality Change (WQI)[b]	Average Annual Household WTP Per Unit of Water Quality Change (2021$)
Scenarios Based on Water Quality Targets of Planned Improvements			
Primary Contact Recreation	$79.63	6.3	$12.64
Secondary Contact Recreation	$33.16	2.5	$13.26
Illustrative Scenarios			
Aquatic Life	$206.50	17.9	$11.54
Combined Scenario	$301.32	28.1	$10.72

[a] See Section 3 for descriptions of the four water quality scenarios.

[b] See Table 4-1 for details about the estimated WQI change for each water quality scenario.

Figure 4-2. Mean Per Household WTP Estimates Per Unit of Water Quality Change, for All Four Water Quality Scenarios and Estuary-Based Studies from the Meta-data



NOTE: See Table A-1 for more details about the meta-data studies, including author(s) and publication year, waterbody type, and geographic scope.

4.4 Limitations and Uncertainty

The illustrated estimates are based on best practices for large-scale benefit transfers (Johnston et al., 2021), as applied by EPA for nationwide benefit-cost analyses. Nonetheless, as is the case with all types of economic analysis, the methodologies and data used in the estimation of the value of clean water in the Harbor Estuary involve limitations and uncertainties.

Among these, it is important to recognize that large-scale benefit estimation of this type – whether using primary studies or benefit transfer – is designed to accurately measure per household and total benefits (and underlying water quality baselines and changes) averaged over large areas and numbers of households. The presented methods cannot, nor are they designed to, predict micro-scale differences in benefits that might be realized by individual households in specific areas, or to clarify benefits that are realized in very small areas due to particular uses or situations. For example, the presented meta-analysis cannot be used to accurately identify the benefits that might be realized by a specific household on the waterfront of the Hackensack River (or in any other specific area), due to the unique situation in that micro-scale area. Moreover, there may be unique uses or ecological conditions in very small areas that are not reflected accurately by a WQI score that is (necessarily) averaged over larger areas. Results should be interpreted accordingly – as averages that accurately portray ecological and economic conditions and changes over large spatial areas.

Other limitations and uncertainties reflect those that are common for this type of analysis. Table 4-4 summarizes some of these key limitations and uncertainties and indicates whether they are expected to cause under- or overestimation of value (or have uncertain impacts).

Table 4-4: Limitations and Uncertainties of the Harbor Estuary Clean Water Valuation

Uncertainty/Limitation	Effect on Water Quality Effects Estimation	Notes
Changes in WQI reflect illustrative changes to specific parameters (not all possible changes that could occur)	Underestimate	The estimated changes in WQI reflect changes to specific parameters (as described in Section 3) and do not include likely changes in other water quality parameters that are part of the WQI (*i.e.,* other parameters are held constant). Because the omitted water quality parameters are also likely to respond to changes in pollutant loads (*e.g.,* reductions in pathogen loadings would likely result in reductions in nutrient loadings), the analysis underestimates the water quality changes.

Table 4-4: Limitations and Uncertainties of the Harbor Estuary Clean Water Valuation

Uncertainty/Limitation	Effect on Water Quality Effects Estimation	Notes
Use of nonlinear subindex curves	Uncertain	The methodology used to translate suspended sediment and nutrient concentrations into subindex scores employs nonlinear transformation curves. Water quality changes that fall outside of the sensitive part of the transformation curve (*i.e.,* above/below the upper/lower bounds, respectively) yield no changes.
Limiting the extent of benefitting households to the two selected market extents (county- and state-level)	Underestimate	Values that might be held by residents of states beyond New York and New Jersey are not considered. Extending the benefits analysis to households in the 30 HEP counties or the states of New York and New Jersey assumes that, due to their proximity to the Harbor Estuary, these households are likely to either use or have knowledge of the Harbor Estuary and value water quality improvements. The analysis omits the values that people living outside the two market extents may place on water quality improvements in the Harbor Estuary. Economic literature shows that while WTP tends to decline with distance from the waterbody, people place value, such as nonuse values, on the quality of waters outside their region (Johnston et al., 2019).
Use of population projections extrapolated through 2062	Uncertain	To account for population growth through the end of the analysis period (2062), ICF used population projections from the 2021 NASA SEDAC (Hauer et al., 2021). These population projections are subject to uncertainty, particularly in years further into the future.

Table 4-4: Limitations and Uncertainties of the Harbor Estuary Clean Water Valuation

Uncertainty/Limitation	Effect on Water Quality Effects Estimation	Notes
Potential bias in underlying stated preference results	Uncertain	Following standard benefit transfer approaches, this analysis proceeds under the assumption that study included in the meta-data provides a valid, unbiased estimate of the welfare measure under consideration (Moeltner et al., 2007; Rosenberger and Phipps, 2007). To minimize the impact of any potential bias in the stated preference studies that are included in the meta-data, ICF set independent variable values to reflect best practices for these studies.
Use of different water quality metrics in the underlying meta-data	Uncertain	The estimation of WTP may be sensitive to differences in the presentation of water quality changes across studies in the meta-data. Studies that did not use the WQI were mapped to the WQI, so a comparison could be made across studies. To account for potential effects of the use of a different water quality metric, the index of biotic integrity (IBI), on WTP values, ICF included a binary variable in the model to indicate studies that used the IBI (see Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis for details). In benefit transfer applications, the IBI variable is set to zero, which is consistent with using the WQI.

Table 4-4: Limitations and Uncertainties of the Harbor Estuary Clean Water Valuation

Uncertainty/Limitation	Effect on Water Quality Effects Estimation	Notes
Transfer error	Uncertain	Transfer error may occur when benefit estimates from a study site are adopted to forecast the benefits of a policy site. Rosenberger et al. (2006) define transfer error as the difference between the transferred and actual, generally unknown, value. Although meta-analyses are often more accurate compared to other types of transfer approaches, due to the data synthesis from multiple source studies (Rosenberger and Phipps, 2007; Johnston et al., 2021), there is still a potential for transfer errors (Shrestha et al., 2007) and no transfer method is always superior (Johnston et al., 2021).
The model assumes zero benefit until 2043.	Underestimate	In reality, water quality would improve gradually over the next 20 years, during which time partial benefits would be realized.

5 Potential Future Work

As documented in the Smart Growth Economics LLC. (2020) literature review and validated by ICF via a subsequent literature search,[25] prior to this study, no economic valuation studies have been conducted for the Harbor Estuary. Economic valuation studies do exist for the nearby Peconic Estuary System (80 miles east of New York City) and are summarized in the Smart Growth Economics LLC. (2020) literature review. The study that estimates the value of improving water quality in the Peconic Estuary (Opaluch et al., 1998) is included in the meta-data underlying the meta-regression model used in this analysis. Johnston, Grigalunas, et al. (2002), which summarizes values of water quality improvements for the Peconic Estuary based on four economic valuation methods (hedonic analysis, travel cost, wetland productivity valuation, and contingent choice), is discussed in Section 2.1.2. This study is also presented below as a potential source to support future economic valuation research in the Harbor Estuary region. This published article is drawn from the same data reported in Opaluch et al. (1998).

The lack of economic literature for the Harbor Estuary region to date makes this economic analysis particularly valuable for raising awareness of the tremendous value that the Harbor Estuary provides. The estimated benefits presented in Section 4.2 account for increases in ecosystem service values resulting from water quality improvements in the Harbor Estuary, as realized by households living in

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[25] ICF conducted a literature search focused on finding studies published in 2020 or later to supplement the Smart Growth Economics LLC. (2020) literature search but did not find any recent publications.

the surrounding counties and neighboring states. As discussed in Section 1.1, the conservation and restoration activities used to achieve these water quality improvements may result in additional ecosystem service value beyond water quality improvements, but these additional benefits are not quantified in this analysis. For example, restoring wetland and riparian buffer areas is a common method of improving water quality. In addition to providing water quality benefits, the restored wetland or riparian areas could improve habitat integrity for wildlife, reduce flood risk, and increase removal of greenhouse gases. Future work could quantify these additional ecosystem services, using methodologies such as the following:

- For scenarios that result in significant change in wetland areas, one can use existing meta-analytic functions developed by the project team (*i.e.,* Vedogbeton and Johnston, 2020; Moeltner et al., 2019) to value additional ecosystem service benefits provided by these wetlands. However, the value of increased wetland areas implicitly includes wetland contribution to water quality along with other ecosystem services provided by wetlands (*e.g.,* flood risk reduction and wildlife habitat). Given the overlap between the value for water quality improvements and total value of wetlands, these values are not directly additive.
- Insight into other ecosystem service values related to estuarine and riparian habitat changes, such as the economic value from improvements in riparian habitat integrity, can be approximated via benefit transfer from other studies conducted previously by the project team in the Northeast US (*e.g.,* Johnston, Grigalunas, et al., 2002; Johnston, Holland, et al., 2014).
- With additional data collection or targeted benefit transfers, it would be possible to estimate additional, targeted value estimates linked to specific uses or ecosystem services. For example, one could estimate potential gains in recreational benefits alone or potential changes in property values (see Section 2). As described in Section 2, these values at least partially overlap the total WTP estimates calculated in this report, and hence are not directly additive. However, additional analyses of this type can be useful to help illustrate the magnitude of specific types of ecosystem service values, as they might be realized in specific areas.

Conservation and restoration efforts may also focus on concerns other than water quality. Quantifying benefits of such efforts would require additional analyses. For example, restoration efforts may target clean-up of contaminated sediments, which can harm fish and shellfish populations or make fish and shellfish unsuitable for human consumption. The project team has completed analyses to value human health benefits related to reduced pollutant exposure via fish consumption for EPA rulemakings (*e.g.,* U.S. EPA, 2020; U.S. EPA, 2015) and could implement a similar approach to value benefits associated with contaminated sediment clean-up.

Moreover, the estimated benefits from this analysis are based on WTP values of households located near the Harbor Estuary. Although many tourists visit the Harbor Estuary region, due to methodology limitations, the value that tourists place on water quality improvements in the Harbor Estuary are not included. The project team could develop and implement a visitor survey to assess tourists' values for water quality improvements in the Harbor Estuary, perhaps as part of a broader analysis of recreational benefits to both tourists and residents.

Lastly, estimating costs associated with the four water quality scenarios was beyond the scope of this study. We note that assessment of both costs and benefits is needed to better inform the selection of water quality restoration options and could be a potential avenue for future work.

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Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis

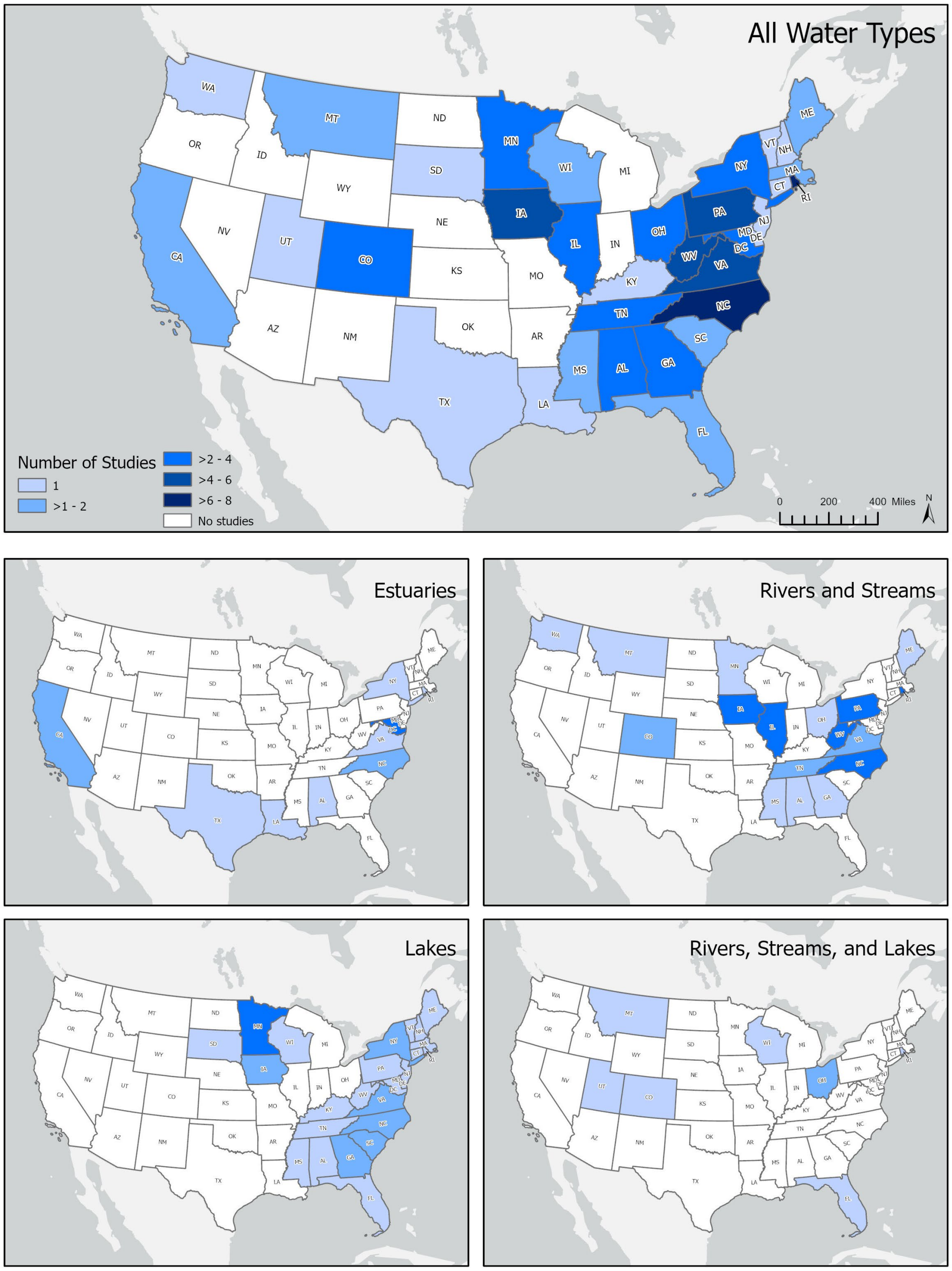
This appendix provides details about the meta-regression model used to estimate benefits of water quality improvements in the Harbor Estuary under several water quality scenarios, including (1) information on the primary stated preference studies included in the underlying meta-data, (2) information about the meta-regression model specification and regression results, (3) details about the benefit transfer applications to assess the value of water quality improvements, (4) the equations used to estimate per household WTP and total WTP, and (5) limitations and uncertainties of the meta-regression model and application. Section 2.2.2 provides a high-level overview of the meta-regression model and market extent used to estimate benefits of water quality Improvements. Section 4.2 presents the quantified benefits for water quality improvements.

As described by Vedogbeton and Johnston (2020), "Meta-analyses are commonly used to estimate the systematic influences of study, economic, resource and population attributes on willingness to pay (WTP) for environmental quality or quantity improvements. When used for benefit transfer, meta-analyses are typically implemented using meta-regression models. Within these models, the dependent variable is often a comparable mean or median measure of economic value (such as per household WTP for water quality improvements) drawn from prior primary valuation studies. Independent variables represent observable factors hypothesized to explain variation in this value measure across observations. The resulting statistical functions are then used to predict similar values for other locations of interest, often called "policy sites," for which value estimates are needed but suitable primary valuation studies have not been conducted. Primary valuation studies are often infeasible due to high cost and data requirements, such that benefit transfers are typically required for large-scale benefit cost analysis (Newbold et al., 2018; Johnston et al., 2021).

Primary Stated Preference Studies in the Meta-data

Among the key advantages of a meta-analysis for benefit transfer is that information is combined (or synthesized) from many different prior valuation studies that, together, can *jointly* represent conditions and changes in the policy sites for which benefits are to be predicted—here the Harbor Estuary. This type of data synthesis obviates the need for a very close match between the water bodies considered by any one prior valuation study and the situation in the Harbor Estuary. The meta-analysis applied here builds on a model and underlying meta-data that was first published by Johnston et al. (2005), with continual improvements since that time (*e.g.,* Johnston, Besedin, et al., 2017; Johnston et al., 2019; Moeltner, 2019). It has been widely applied to estimate water quality benefits across the US, and an adapted version of this model supports EPA's new integrated assessment model for water quality valuation, *BenSPLASH* (Corona et al., 2020).

The most recent version of the meta-data of studies estimating WTP for surface water quality changes includes 59 stated preference studies (189 observations), published between 1985 and 2019, that estimated total WTP (use and nonuse values) per household for water quality changes in US waterbodies. The studies address various waterbody types, including estuaries, rivers, lakes, and salt ponds/marshes.



All Water Types

Estuaries

Rivers and Streams

Lakes

Rivers, Streams, and Lakes

Figure A-1. State-level study locations of studies included in the meta-data, by waterbody type. Note: several studies have study areas spanning multiple states and are, thus, represented more than once in the maps. The "All Water Types" panel also includes counts for salt pond/marsh studies (two in RI, one in MA).

Figure A-1 shows the state-level study locations of the studies included in the meta-data by waterbody type. The largest panel combines all waterbody types into one map, while the four smaller panels show counts of studies focused on estuaries, rivers/streams, lakes, and rivers/streams/lakes.[26] Several studies have study areas spanning multiple states, so these studies are counted more than once in the Figure A-1 maps. As shown in Figure 1, studies included in the meta-data - considered as an integrated whole - provide a relatively good match to the Harbor Estuary study characteristics in terms of both geographic location and type of waterbodies considered in the original studies. Many of the water quality valuation studies were conducted in New England and Mid-Atlantic states, with four studies focused on waterbodies in New York and New Jersey. Eleven studies included in the meta-data focused on valuing water quality in estuaries.

Table A-1 summarizes characteristics of the 59 studies included in the meta-data, including number of observations from each study, state-level study location, waterbody type, geographic scope, and household WTP summary statistics.

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[26] Figure A-1 does not include a separate panel for salt pond/marsh studies (two in RI, one in MA), but these counts are included in the "All Water Types" panel.

Table A-1. Primary Studies Included in the Meta-data

Study	Obs. in Meta-data	State (s)	Water-body Type(s)	Geographic Scope	WTP Per Household (2019$)		
					Mean	Min	Max
Aiken (1985)	1	CO	river/ stream and lake	Entire state	$238.19	$238.19	$238.19
Anderson et al. (1986)	1	RI	salt pond /marsh	Coastal salt ponds (South Kingstown, Charlestown, Narragansett)	$222.82	$222.82	$222.82
Banzhaf et al. (2006)	2	NY	lake	Adirondack Park, New York State	$70.86	$66.69	$75.03
Banzhaf et al. (2016)	1	VA, WV, TN, NC, GA	river/ stream	Southern Appalachian Mountains region	$18.67	$18.67	$18.67
Bockstael et al. (1989)	2	MD, DC, VA	estuary	Chesapeake Bay (Baltimore-Washington Metropolitan Area)	$137.31	$93.30	$181.32
Borisova et al. (2008)	2	VA/WV	river/ stream	Opequon Creek watershed	$42.54	$22.25	$62.83
Cameron et al. (1989)	1	CA	estuary	San Francisco Bay	$61.07	$61.07	$61.07
Carson et al. (1994)	2	CA	estuary	Southern California Bight	$73.24	$50.81	$95.67
Choi et al. (2019)	6	PA	river/ stream	Three creek watersheds: Spring, Mahantango, and Conewago	$4.56	$1.73	$10.40
Clonts et al. (1990)	2	AL	river/ stream	15 free-flowing rivers, AL	$112.28	$96.56	$128.00
Collins et al. (2007)	1	WV	river/ stream	Cheat River Watershed	$22.43	$22.43	$22.43
Collins et al. (2009)	1	WV	river/ stream	Deckers Creek Watershed	$229.82	$229.82	$229.82
Corrigan (2008)	1	IA	lake	Clear Lake	$152.03	$152.03	$152.03
Croke et al. (1986-1987)	6	IL	river/ stream	Chicago metropolitan area river system	$90.25	$75.60	$107.18

Table A-1. Primary Studies Included in the Meta-data

Study	Obs. in Meta-data	State (s)	Water-body Type(s)	Geographic Scope	WTP Per Household (2019$)		
					Mean	Min	Max
De Zoysa (1995)	1	OH	river/ stream	Maumee River Basin	$86.53	$86.53	$86.53
Desvousges et al. (1987)	12	PA	river/ stream	Monongahela River basin (PA portion)	$72.98	$24.46	$169.24
Downstream Strategies LLC (2008)	2	PA	river/ stream	West Branch Susquehanna River watershed	$15.70	$13.19	$18.21
Farber et al. (2000)	6	PA	river/ stream	Loyalhanna Creek and Conemaugh River basins (western PA)	$93.91	$20.45	$183.21
Hayes et al. (1992)	2	RI	estuary	Upper Narragansett Bay	$490.05	$481.71	$498.38
Herriges et al. (1996)	1	IA	lake	Storm Lake watershed	$76.09	$76.09	$76.09
Hite (2002)	2	MS	river/ stream	Entire state	$74.09	$71.81	$76.36
B. M. Holland et al. (2017)	6	ME	river/ stream	Merriland, Branch Brook and Little River Watershed	$13.90	$8.16	$21.27
Huang et al. (1997)	2	NC	estuary	Albemarle and Pamlico Sounds	$318.92	$314.43	$323.40
Interis et al. (2016)	10	AL/LA	estuary	Mobile Bay, AL; Barataria-Terrebonne estuary, LA	$87.91	$45.00	$140.47
Irvin et al. (2007)	4	OH	river/ stream and lake	Entire state	$26.72	$24.22	$28.64
Johnston and Ramachandran (2014)	3	RI	river/ stream	Pawtuxet watershed	$14.11	$7.05	$21.16
Johnston, Swallow, et al. (2002)	1	RI	river/ stream	Wood-Pawcatuck watershed	$48.08	$48.08	$48.08

Table A-1. Primary Studies Included in the Meta-data

Study	Obs. in Meta-data	State (s)	Water-body Type(s)	Geographic Scope	WTP Per Household (2019$)		
					Mean	Min	Max
Johnston, Schultz, et al. (2017)	3	RI	river/ stream	Pawtuxet watershed	$4.79	$2.40	$7.19
Kaoru (1993)	1	MA	salt pond /marsh	Martha's Vineyard	$269.56	$269.56	$269.56
Lant et al. (1990)	3	IA/IL	river/ stream	Des Moines, Skunk, English, Cedar, Wapsipinicon, Turkey; Illinois: Rock, Edwards, La Moine, Sangamon, Iroquois, and Vermillion River basins	$177.47	$152.94	$190.26
Lant et al. (1989)	9	IA/IL	river/ stream	Edwards River, Wapsipinicon River, and South Skunk drainage basins	$68.59	$50.04	$83.40
Lichtkoppler et al. (1999)	1	OH	river/ stream and lake	Ashtabula River and Ashtabula Harbor	$51.69	$51.69	$51.69
Lindsey (1994)	8	MD	estuary	Chesapeake Bay	$82.37	$41.18	$126.02
Lipton (2004)	1	MD	estuary	Chesapeake Bay Watershed	$78.88	$78.88	$78.88
Londoño Cadavid et al. (2013)	2	IL	river/ stream	Cities of Champaign and Urbana	$47.70	$44.30	$51.10
Loomis (1996)	1	WA	river/ stream	Elwha River	$114.75	$114.75	$114.75
Lyke (1993)	2	WI	river/ stream and lake	Wisconsin Great Lakes	$97.10	$73.68	$120.52
Mathews et al. (1999)	1	MN	river/ stream	Minnesota River	$22.36	$22.36	$22.36

Table A-1. Primary Studies Included in the Meta-data

Study	Obs. in Meta-data	State (s)	Water-body Type(s)	Geographic Scope	WTP Per Household (2019$)		
					Mean	Min	Max
Moore et al. (2018)	2	MD, VA, DC, DE, NY, PA, WV, CT, FL, GA, ME, MA, NH, NJ, NC, RI, SC, VT	lake	Chesapeake Bay Watershed	$131.21	$77.75	$184.67
N. M. Nelson et al. (2015)	2	UT	river/ stream and lake	Entire state	$259.70	$167.07	$352.33
Opaluch et al. (1998)	1	NY	estuary	Peconic Estuary System	$170.73	$170.73	$170.73
Roberts et al. (1997)	1	MN/SD	lake	Mud Lake	$10.30	$10.30	$10.30
Rowe et al. (1985)	1	CO	river/ stream	Eagle River	$165.95	$165.95	$165.95
Sanders et al. (1990)	4	CO	river/ stream	Cache la Poudre, Colorado, Conejos, Dollores, Elk, Encampment, Green, Gunnison, Los Pinos, Piedra, and Yampa rivers	$198.13	$99.89	$258.99
Schulze et al. (1995)	4	MT	river/ stream	Clark Fork River Basin	$75.19	$56.62	$95.54
Shrestha et al. (2004)	2	FL	river/ stream and lake	Lake Okeechobee watershed	$192.92	$170.12	$215.72
Stumborg et al. (2001)	2	WI	lake	Lake Mendota Watershed	$103.94	$82.28	$125.59
Sutherland et al. (1985)	1	MT	river/ stream and lake	Flathead River drainage system	$180.05	$180.05	$180.05

Table A-1. Primary Studies Included in the Meta-data

Study	Obs. in Meta-data	State (s)	Water-body Type(s)	Geographic Scope	WTP Per Household (2019$)		
					Mean	Min	Max
Takatsuka (2004)	4	TN	river/ stream	Clinch River watershed	$353.72	$224.28	$483.16
Van Houtven et al. (2014)	32	VA, NC, SC, AL, GA, KY, MS, TN	lake	Entire state (separate observations for each state)	$316.16	$260.91	$374.11
Wattage (1993)	2	IA	river/ stream	Bear Creek watershed	$53.68	$49.61	$57.76
Welle (1986)	4	MN	lake	Entire state	$175.44	$135.13	$227.59
Welle et al. (2011)	3	MN	lake	Lake Margaret and Sauk River Chain of Lakes watersheds	$178.91	$13.06	$351.48
Wey (1990)	1	RI	salt pond /marsh	Great Salt Pond (Block Island)	$78.85	$78.85	$78.85
Whitehead (2006)	3	NC	river/ stream	Neuse River watershed	$230.79	$33.93	$450.72
Whitehead et al. (1992)	2	NC	river/ stream	Tar-Pamlico River	$43.08	$39.33	$46.82
Whitehead et al. (1995)	1	NC	estuary	Albermarle-Pamlico estuary system	$115.56	$115.56	$115.56
Whittington (1994)	1	TX	estuary	Galveston Bay estuary	$240.09	$240.09	$240.09
Zhao et al. (2013)	3	RI	river/ stream and lake	Pawtuxet watershed	$7.19	$3.59	$10.78

Meta-Regression Model

To synthesize information from the primary water quality valuation studies described in Table A-1, ICF developed a meta-regression model that estimates WTP for water quality improvements as a function of attributes extracted from the studies as well as spatial attributes estimated via geospatial analyses. The model specification is based on prior peer-reviewed and published meta-regression models that utilized earlier iterations of the meta-data (Johnston, Besedin, et al., 2017; Johnston et al., 2019; U.S. EPA, 2015; U.S. EPA, 2020), with revisions to account for recent advances in meta-analysis and to better account for methodological differences in the underlying studies. ICF also revised regional indicators to match the US Census regions (U.S. Census Bureau, n.d.).

As noted above, the resulting meta-regression model is a flexible function that allows predicted estimates to be tailored to the needs of particular benefit transfer applications, such as the water quality scenarios based on restoration and conservation activities in the Harbor Estuary. The dependent variable in the meta-analysis is the natural log of the per-household WTP per unit of water quality improvement (*i.e.,* household WTP divided by the water quality change; hereafter, one-point WTP), with these estimates drawn from the studies shown in Table A-1. The independent variables included in the meta-regression model (that explain why estimated WTP differs across these studies) fall into four general categories:

- *Study methodology and year variables* characterize such features as the year in which a study was conducted, payment vehicle and elicitation formats used in the original stated preference study, WTP estimation methods, and publication types. These variables are included to explain differences in WTP across studies but are not expected to vary across different scenario applications when conducting benefit transfer.
- *Region and surveyed populations variables* characterize such features as the US region in which the study was conducted, the average income of respondent households and the representation of users and nonusers within the survey sample used to estimate values.
- *Sampled market and affected resource variables* characterize features such as the geospatial scale (or size) of affected water bodies, the size of the market area (or extent) over which populations were sampled, as well as land cover and the quantity of substitute water bodies.
- *Water quality (baseline and change) variables* characterize baseline conditions and the extent of the water quality change.

Additional information on these variable categories (and why they are included in the model) is provided by Johnston et al. (2005), Johnston, Besedin, et al. (2017), and Johnston et al. (2019). To correct for heteroskedasticity, the model is estimated using weighted least squares with observations weighted by sample size, and robust standard errors (J. P. Nelson et al., 2009). Detailed discussion of this statistical approach can be found in Vedogbeton and Johnston (2020). A comprehensive review of statistical methods for meta-analysis in general is provided by Stanley (2005).

Table A-2 provides definitions and descriptive statistics for variables included in the meta-regression model, based on the meta-data studies.

Table A-2. Definition and Summary Statistics for Model Variables

Variable	Definition	Units	Mean	St. Dev.
Dependent Variable				
ln_onepoint_wtp	Natural log of WTP per unit of water quality improvement (hereafter, one-point WTP), per household.	Natural log of 2019$	1.873	1.391
onepoint_wtp[a]	WTP per unit of water quality improvement (hereafter, one-point WTP), per household.	2019$	15.931	23.595
Study Methodology and Year				
OneShotVal	Binary variable indicating that the study's survey only included one valuation question.	Binary (Value: 0 or 1)	0.534	0.500
tax_only[b]	Binary variable indicating that the payment mechanism used to elicit WTP is increased taxes.	Binary (Value: 0 or 1)	0.397	0.491
user_cost[b]	Binary variable indicating that the payment mechanism used to elicit WTP is increased user costs.	Binary (Value: 0 or 1)	0.021	0.144
RUM	Binary variable indicating that the study used a Random Utility Model (RUM) to estimate WTP.	Binary (Value: 0 or 1)	0.566	0.497
IBI	Binary variable indicating that the study used the index of biotic integrity (IBI) as the water quality metric.	Binary (Value: 0 or 1)	0.079	0.271
lnyear	Natural log of the year in which the study was conducted (*i.e.,* data was collected), converted to an index by subtracting 1980.	Natural log of years (year ranges from 1981 to 2017).	2.629	0.979
volunt[b]	Binary variable indicating that WTP was estimated using a payment vehicle described as voluntary as opposed to, for example, property taxes.	Binary (Value: 0 or 1)	0.058	0.235
non_reviewed	Binary variable indicating that the study was not published in a peer-reviewed journal.	Binary (Value: 0 or 1)	0.159	0.366
thesis	Binary variable indicating that the study is a thesis.	Binary (Value: 0 or 1)	0.079	0.271
lump_sum	Binary variable indicating that the study provided WTP as a one-time, lump sum or provided annual WTP values for a payment period of five years or less. This variable enables the benefit transfer analyst to estimate annual WTP values by setting *lump_sum*=0.	Binary (Value: 0 or 1)	0.180	0.385

Table A-2. Definition and Summary Statistics for Model Variables

Variable	Definition	Units	Mean	St. Dev.
Region and Surveyed Populations				
census_south[c]	Binary variable indicating that the affected waters are located entirely within the South Census region, which includes the following states: DE, MD, DC, WV, VA, NC, SC, GA, FL, KY, TN, MS, AL, AR, LA, OK, and TX.	Binary (Value: 0 or 1)	0.349	0.478
census_midwest[c]	Binary variable indicating that the affected waters are located entirely within the Midwest Census region, which includes the following states: OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, and KS.	Binary (Value: 0 or 1)	0.228	0.420
census_west[c]	Binary variable indicating that the affected waters are located entirely within the West Census region, which includes the following states: MT, WY, CO, NM, ID, UT, AZ, NV, WA, OR, and CA.	Binary (Value: 0 or 1)	0.090	0.287
nonusers	Binary variable indicating that the survey was implemented over a population of nonusers (default category for this variable is a survey of any population that includes both users and nonusers).	Binary (Value: 0 or 1)	0.058	0.235
lnincome	Natural log of the median income (in 2019$) for the sample area of each study based on historical US Census data. It was designed to provide a consistent income variable given differences in reporting of respondent income across studies in the meta-data (*i.e.,* mean vs. median). Also, some studies do not report respondent income. This variable was estimated for all studies in the meta-data regardless of whether the study reported summary statistics for respondent income.	Natural log of income (2019$)	10.946	0.160
Sampled Market and Affected Resource				
swim_use	Binary variable indicating that the affected use(s) stated in the study include swimming.	Binary (Value: 0 or 1)	0.222	0.417

Table A-2. Definition and Summary Statistics for Model Variables

Variable	Definition	Units	Mean	St. Dev.
gamefish	Binary variable indicating that the affected use stated in the study is game fishing.	Binary (Value: 0 or 1)	0.190	0.394
ln_ar_agr[d]	Natural log of the proportion of the affected resource area that is agricultural based on National Land Cover Database (NLCD), reflecting the nature of development in the area surrounding the resource. The affected resource area is defined as all counties that intersect the affected resource(s).	Natural log of proportion (Proportion Range: 0 to 1; km^2/km^2)	-1.648	0.912
ln_ar_ratio	A ratio of the sampled area, in km^2, relative to the affected resource area. When not explicitly reported in the study, the affected resource area is measured as the total area of counties that intersect the affected resource(s), to create the variable *ar_total_area*. From here, *ln_ar_ratio* = log(*sa_area* / *ar_total_area*), where *sa_area* is the size of the sampled area in km^2.	Natural log of ratio (km^2/km^2)	-0.594	2.408
sub_proportion[e]	The water bodies affected by the water quality change, as a proportion of all water bodies of the same hydrological type in the sampled area. The affected resource appears in both the numerator and denominator when calculating *sub_proportion*. The value can range from 0 to 1.	Proportion (Range: 0 to 1; km/km)	0.351	0.401
Water Quality				
ln_Q	Natural log of the mid-point of the baseline and scenario water quality: Q = *(1/2)(WQI-BL + WQI-S)*.	Natural log of WQI units	3.944	0.295

[a] Provided for informational purposes. Model uses the natural log version of the *onepoint_wtp* variable as the dependent variable.

[b] The payment types omitted from the payment type binary variables are: (1) increased prices, (2) increased prices and/or taxes, (3) multiple methods, (4) earmarked fund, and (5) not specified/unknown.

[c] The regions omitted from the regional binary variables are the Northeast Census region (ME, NH, VT, MA, RI, CT, NY, PA, and NJ) and the Chesapeake Bay (studies focused on the Chesapeake Bay or Chesapeake Bay Watershed since the Chesapeake Bay Watershed spans two Census regions).

[d] In addition to the *ln_ar_agr* variable, ICF tested a variable for the proportion of the affected resource area that is developed, but it did not improve model fit.

[e] The *sub_proportion* estimation method differs by waterbody type. For rivers, the calculation is the length of the affected river reaches as a proportion of all reaches of the same order. For lakes and ponds, the

Table A-2. Definition and Summary Statistics for Model Variables

Variable	Definition	Units	Mean	St. Dev.
	calculation is the area of the affected waterbody as a proportion of all water bodies of the same National Hydrography Dataset classification. For bays and estuaries, the calculation is the shoreline length of the waterbody as a proportion of all analogous (*e.g.,* coastal) shoreline lengths. To account for observations where multiple waterbody types are affected, the variable *sub_proportion* is defined as the maximum of separate substitute proportions for rivers, lakes, and estuaries/bays.			

Model Specification

The specification of the model follows "MRM2" in Moeltner (2019). One-point WTP (*onepoint_ WTP*), or the WTP per unit of water quality improvement, is modeled in the meta-regression model as follows:

$$\ln\left(\frac{WTP_i}{\Delta Q_i}\right) = \alpha_0 + \alpha_1 X_i + b\left(\frac{q_{1,i} + q_{0,i}}{2}\right) + e_i \qquad \text{Equation A-1}$$

Here, WTP_i is the per household welfare (or economic value) measure[27] for observation *i* in the meta-data, $\mathbf{\Delta Q}_i$ is the magnitude of the water quality change for meta-data observation *i*, $\mathbf{X}_i$ is the vector of independent variables discussed above. The vector **a** represents a conforming vector of parameters to be estimated, $q_{1,i}$ and $q_{0,i}$ are the corresponding baseline and scenario-endpoint water quality measures (the latter being the WQI value after improvement), respectively, and $\mathbf{e}_i$ is a standard i.i.d. error term with zero mean and variance $\mathbf{s}^2$. Other aspects of the econometric model follow standard conventions for valuation meta-regression models (*e.g.,* Johnston, Besedin, et al., 2017; Johnston et al., 2019). The estimated parameters from this equation can be used to generate an expression for WTP associated with a one-point WQI change (or one-point WTP):

$$onepoint\_WTP = \exp\left(\hat{\alpha}_0 + \hat{\alpha}_1 X + b\left(\frac{q_{1,i} + q_{0,i}}{2}\right) + \hat{\sigma}^2/2\right) \qquad \text{Equation A-2}$$

Regression Results

Table A-3 presents regression results for the meta-regression model. As noted above, the meta-regression model is estimated using precision weights (weighted least squares with observations weighted by sample size) and robust standard errors, to correct for potential heteroskedasticity (Stanley, 2005; J. P. Nelson et al., 2009).

The meta-regression model presented in Table A-3 was selected after the estimation of preliminary models with different specifications and groups of explanatory variables. The selection was based on both statistical fit and correspondence with theoretical expectations. Measures of fit for the illustrated models compare favorably to prior meta-analyses in the published literature and to previous versions of the meta-analysis in U.S. EPA (2015) and U.S. EPA (2020).

The model performs well, with intuitive results for virtually all statistically significant variables. The model identifies numerous statistically significant coefficients for variables characterizing (1) study

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[27] A welfare measure is a measure of well-being of an individual or society. WTP represents an average change in the measure of well-being resulting from the proposed water quality improvement and indicates what change in income would have resulted in the same change in well-being.

methodology, (2) region and surveyed populations, (3) extent of the market, study site, and affected resources, and 4) water quality. In total, 11 out of 22 non-intercept coefficient estimates are statistically significant at $p<0.05$. All variables show patterns similar to those discussed in prior meta-regression model iterations (Johnston, Besedin, et al., 2017; Johnston et al., 2019; U.S. EPA, 2015; U.S. EPA, 2020).

As expected, *sub_proportion* has a positive coefficient estimate, indicating that WTP increases as the affected resource constitutes a larger fraction of available substitutes (total water bodies in the same area). The coefficient for *ln_ar_ratio* is negative because the sampled market extent is in the numerator, indicating that marginal WTP decreases as the sampled market extent increases relative to the affected size of the improved body of water. This is consistent with the expectation that a larger sampled market extent will include a greater proportion of respondents who are resource nonusers, who are less familiar with the resource, and/or who live at a greater distance from the affected waters. It also accommodates a *positive* anticipated relationship between the size of the improved water body and WTP (because water body size is in the denominator). This result is intuitive. All else equal, improvements to larger water bodies are associated with larger per household values.

A negative coefficient on the agricultural area variable (*ln_ar_agr*) suggests that areas dominated by agricultural land uses have lower per household WTP to improve water quality, holding all else constant. Because areas dominated by agriculture may be significantly different in terms of both resource and population characteristics (and may be associated with different water body uses), this result is not surprising (Johnston, Besedin, et al., 2017; Johnston et al., 2019).

The negative coefficient of the absolute water quality variable (*Q*) suggests diminishing marginal utility to successive water quality improvements. That is, each additional unit of successive water quality improvement is worth slightly less than the prior unit of improvement. This also implies that improvements to areas with very high baseline WQI scores are worth less than otherwise identical improvements to waters that begin at lower baseline quality. This finding is intuitive. Additionally, results indicate that studies that use the IBI as the water quality metric tend to have lower marginal WTP compared to other studies included in meta-data, as shown by a negative coefficient on *IBI* (although this effect is not relevant to the Harbor Estuary benefit transfer application).

Table A-3. Meta-Regression Model Results

Parameter	Parameter Estimate	Robust Standard Error
OneShotVal	0.247	-0.266
tax_only	-0.177	-0.254
user_cost	-0.873	-0.658
RUM	0.901*	-0.187
IBI	-2.355*	-0.428
lnyear	-0.135	-0.201
volunt	-1.656*	-0.299
non_reviewed	-0.233	-0.249

Table A-3. Meta-Regression Model Results

Parameter	Parameter Estimate	Robust Standard Error
thesis	0.431	-0.436
lump_sum	0.534*	-0.216
census_south	0.693*	-0.325
census_midwest	0.667*	-0.31
census_west	0.393	-0.37
nonusers	-0.283	-0.214
lnincome	0.478	-0.49
swim_use	0.3	-0.321
gamefish	0.871*	-0.3
ln_ar_agr	-0.572*	-0.136
ln_ar_ratio	-0.157*	-0.0369
sub_proportion	0.993*	-0.249
ln_Q	-0.666*	-0.216
intercept[28]	-2.823	-5.208
Observations		189
R^2		0.656

* denotes $p<0.05$

Benefit Transfer Applications

ICF used the meta-regression model in a benefit transfer approach that follows standard methods described by Johnston and Bauer (2020), Johnston et al. (2005), Shrestha et al. (2007), and Rosenberger et al. (2007), among many others. Based on the benefit transfer literature (*e.g.,* Stapler et al., 2009; Boyle et al., 2018), methodological variables are assigned values that either reflect "best practices" associated with reducing measurement errors in primary studies or set to their mean values over the meta-data. The literature also recommends setting variables representing program outcomes (*i.e.,* resource and population characteristics) at the levels that might be expected from a program (*i.e.,* from conservation and restoration activities under the four water quality scenarios).

ICF used these benefit transfer applications to estimate benefits related to water quality improvements for each of the four water quality scenarios described in Section 3. As discussed in Section2.2.2.1, ICF used two market extents in the benefit transfer applications, one based on HEP counties and one based on the two states in which the estuary resides (New York, New Jersey). For both market extents, benefits are estimated using counties as the geographic unit of analysis. The county-level market extent includes the 30 HEP counties, while the state-level market extent includes remaining counties in New York and New Jersey in addition to the 30 HEP counties.

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[28] The intercept, or constant, term in regression analysis is the value at which the regression line crosses the y-axis.

The benefit transfer approach involved estimating benefits in each county and year for each water quality scenario, based on the following general benefit function:

$$\ln(OWTP_{Y,C,S}) = Intercept + \sum(coefficient_i) \times (independent\ variable\ value_i)$$ **Equation A-3**

where:

$\ln(OWTP_{Y,C,S})$ = The predicted natural log of one-point household WTP for a given year (*Y*), county (*C*), and water quality scenario (*S*).

$coefficient_i$ = A vector of variable coefficients from the meta-regression for each variable (i).

$independent\ variable\ value_i$ = A vector of explanatory variable values. Variables include baseline water quality level ($WQI\text{-}BL_{Y,C}$) and expected water quality under a given water quality scenario ($WQI\text{-}S_{Y,C}$) for a given year (*Y*) and county (*C*) for each variable (i).

Here, $ln(OWTP_{Y,C,S})$ is the dependent variable in the meta-analysis—the natural log of approximated one-point WTP per household, for water quality in a given county *C* and year *Y* under a given water quality scenario (*S*). The baseline water quality level ($WQI\text{-}BL_{Y,C}$) is based on the implementation of the water quality scenarios. Because one-point WTP is assumed to depend, according to Equation A-3, on both baseline water quality level ($WQI\text{-}BL_{Y,C}$) and expected water quality under a given water quality scenario ($WQI\text{-}S_{Y,C}$), ICF estimated the one-point WTP at the mid-point of the range over which water quality was changed, $Q_{Y,C,S} = (1/2)(WQI\text{-}BL_{Y,C} + WQI\text{-}S_{Y,C})$.

Table A-4 provides details on how ICF used the meta-regression model to predict household one-point WTP for each year and county under each water quality scenario. The table presents the estimated variable coefficients ($coefficient_i$) for the meta-regression model, the corresponding explanatory variables names, and the assigned values for the meta-regression model applications for each water quality scenario. ICF assigned variable values to correspond with theory and characteristics of the affected water resources and market extents. The meta-regression model allows ICF to forecast WTP based on assigned values for model variables that are chosen to represent the geographic scale of the affected resources relative to the market extent, the affected waterbody size relative to available substitutes, and the characteristics of surveyed populations (*e.g.*, users, nonusers) in the context of each water quality scenario. This methodology follows general guidance from economic literature (*e.g.*, Bergstrom et al., 2006; Johnston et al., 2020) that meta-analysis benefit transfer should incorporate theoretical expectations and structures, at least in a weak form.

ICF assigned six study and methodology variables, (*thesis, volunt, non_reviewed, lump_sum, and user_cost, IBI*) a value of zero. Three methodological variables (*OneShotVal, tax_only, RUM*) were included with an assigned value of 1. For the study year variable *(lnyear)*, ICF assigned a value of 3.611 (or the ln(2017-1980)), which is the maximum value in the meta-data. This value assignment reflects a time trend interpretation of the variable. In this analysis, all Census regional variables (*census_south, census_midwest, census_west*) were set to 0 since the northeast Census region, which includes New York and New Jersey, is the default region in the model. ICF set the variable *nonusers* to zero because water quality changes are expected to enhance both use and nonuse values of the affected resources (*i.e.,* Harbor Estuary) and thus benefit both users and nonusers (a *nonuser* value of 1 implies WTP values that are representative of nonusers only, whereas the default value of 0 indicates that both users and nonusers are included in the surveyed population). For median household income (*lnincome*), ICF used median household income for each county in a given market extent from the 2019 American Community Survey (5-year data).

The geospatial variables (*ln_ar_agr*, *ln_ar_ratio*, *sub_proportion*) are calculated using the Harbor Estuary as the affected resource and the counties that intersect the estuary as the affected resource area. The market extent represents the transfer area (*i.e.,* sampled area). Thus, the two geospatial variables that incorporate the transfer area in their calculations (*ln_ar_ratio*, *sub_proportion*) have different values for the two market extents (i.e., county-level or state-level).

Both use variables (*swim_use*, *gamefish*) were set to 0 for all water quality scenarios. The treatment of *swim_use* is discussed above. The variable *gamefish* was assigned a value of 0, because the water quality scenarios do not purposefully target game fishing improvements. ICF calculated the *ln_Q* variable using the calculated WQI values under the baseline and under each scenario (see Section 4.1).

Table A-4. Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable	Coefficient	Assigned Value	Explanation
Study Methodology and Year			
intercept	-2.823		
OneShotVal	0.247	1	Binary variable indicating that the study's survey only included one valuation question. Set to one because one valuation scenario follows best practices for generating incentive-compatible WTP estimates (Carson et al., 2014; Johnston, Boyle, et al., 2017).
tax_only	-0.177	1	Binary variable indicating that the payment mechanism used to elicit WTP is increased taxes. Set to one because using taxes as the payment mechanism generates incentive-compatible WTP estimates and is inclusive of both users and nonusers.
user_cost	-0.873	0	Binary variable indicating that the payment mechanism used to elicit WTP is increased user cost. Set to zero because user cost payment mechanisms are less inclusive of nonusers than tax-based payment mechanisms.
RUM	0.901	1	Binary variable indicating that the study used a Random Utility Model (RUM) to estimate WTP. Set to one because use of a RUM to estimate WTP is a standard best practice in modern stated preference studies.
IBI	-2.355	0	Binary variable indicating that the study used the IBI as the water quality metric. Set to zero because the meta-regression uses the WQI as the water quality metric, not the IBI.

Table A-4. Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable	Coefficient	Assigned Value	Explanation
lnyear	-0.135	ln(2017-1980)	Natural log of the year in which the study was conducted (*i.e.,* data were collected), converted to an index by subtracting 1980. Set to the natural log of the maximum value from the meta-data (ln(2017-1980)) to reflect a time trend interpretation of the variable.
volunt	-1.656	0	Binary variable indicating that WTP was estimated using a payment vehicle described as voluntary as opposed to, for example, property taxes. Set to zero because hypothetical voluntary payment mechanisms are not incentive compatible (Mitchell and Carson, 1989).
non_reviewed	-0.233	0	Binary variable indicating that the study was not published in a peer-reviewed journal. Set to zero because studies published in peer-reviewed journals are preferred.
thesis	0.431	0	Binary variable indicating that the study is a thesis or dissertation. Set to zero because studies published in peer-reviewed journals are preferred.
lump_sum	0.534	0	Binary variable indicating that the study provided WTP as a one-time, lump sum or provided annual WTP values for a payment period of five years or less. Set to zero to reflect that most studies from the meta-data estimated an annual WTP, and to produce an annual WTP prediction.
OneShotVal	0.247	1	Binary variable indicating that the study's survey only included one valuation question. Set to one because one valuation scenario follows best practices for generating incentive-compatible WTP estimates (Carson et al., 2014; Johnston, Boyle, et al., 2017).
volunt	-1.656	0	Binary variable indicating that WTP was estimated using a payment vehicle described as voluntary as opposed to, for example, property taxes. Set to zero because hypothetical voluntary payment mechanisms are not incentive compatible (Mitchell and Carson, 1989).
Region and Surveyed Population			
census_south	0.693	0	Binary variable indicating that the affected waters are located entirely within the South Census region, which includes the following states: DE, MD, DC, WV, VA, NC, SC, GA, FL, KY, TN, MS, AL, AR, LA, OK, and TX. Set to zero since the Harbor Estuary study area is in the omitted northeast Census region.

Table A-4. Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable	Coefficient	Assigned Value	Explanation
census_midwest	0.667	0	Binary variable indicating that the affected waters are located entirely within the Midwest Census region, which includes the following states: OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, and KS. Set to zero since the Harbor Estuary study area is in the omitted northeast Census region.
census_west	0.393	0	Binary variable indicating that the affected waters are located entirely within the West Census region, which includes the following states: MT, WY, CO, NM, ID, UT, AZ, NV, WA, OR, and CA. Set to zero since the Harbor Estuary study area is in the omitted northeast Census region.
nonusers	-0.283	0	Binary variable indicating that the sampled population included nonusers only; the alternative case includes all households. Set to zero to estimate the total value for water quality changes for all households, including users and nonusers.
lnincome	0.478	**HEP Counties range:** ln($40,088) – ln($116,100) **Non-HEP NY/NJ Counties range:** ln($46,820) – ln($101,031)	Natural log of the median household income for each county in each market extent, based on median household income estimates from the 2019 American Community Survey (5-year). The county-level market extent uses the household median income for each of the 30 HEP counties. The state-level market extent uses the median household income for both HEP and non-HEP counties in New York and New Jersey.
Sampled Market and Affected Resource			
swim_use	0.300	0 (main analysis) 1 (sensitivity analysis, primary contact recreation and combined scenarios)	Binary variable that indicates studies in which swimming use is specifically identified. This variable is set to zero for the main analysis, which corresponds to all recreational uses. In a sensitivity analysis, ICF set the variable to 1 for water quality scenarios aimed at meeting primary contact recreation standards (primary contact recreation and combined scenarios; see Section 3) since swimming uses are a focus point for these water quality scenarios. A *swim_use* value of 1 assumes that other steps required to allow swimming in the Harbor Estuary (*e.g.,* additional permits) occur.
gamefish	0.871	0	Binary variable that indicates studies in which gamefish use is specifically identified. This variable is set to zero since game fishing is not specifically affected in any of the water quality scenarios considered in this analysis.

Table A-4. Independent Variable Assignments for Surface Water Quality Meta-Analysis

Variable	Coefficient	Assigned Value	Explanation
ln_ar_agr	-0.572	ln(0.04695)	Natural log of the proportion of the affected resource area which is agricultural based on NLCD, reflecting the nature of development in the area surrounding the resource. Since the affected resource area does not vary by market extent, the value is the same across the county-level and state-level market extents.
ln_ar_ratio	-0.157	**HEP County-level:** ln(3.340) **State-level:** ln(17.31)	The natural log of the ratio of the transfer area (*i.e.,* area of the market extent) relative to the affected resource area. For the county-level market extent, the value is set to the natural log of the ratio of the combined area of the 30 HEP counties included in the market extent relative to the area of the counties intersecting the Harbor Estuary.[a] For the state-level market extent, the value is set to the natural log of the ratio of the combined area of New York and New Jersey relative to the area of the counties intersecting the Harbor Estuary.
sub_proportion	0.993	**HEP County-level:** 0.05578 **State-level:** 0.01943	The size of the resources within the scope of the analysis relative to available substitutes. For the county-level market extent, the value is calculated as the ratio of reach miles in the Harbor Estuary relative to the total number of reach miles within the HEP counties. For the state-level market extent, the value is calculated as the ratio of reach miles in the Harbor Estuary relative to the total number of reach miles within New York and New Jersey. Its value can range from 0 to 1.
Water Quality			
ln_Q	-0.666	**Primary Contact:** ln(37.66) **Second. Contact:** ln(35.79) **Nutrients:** ln (43.45) **Combined:** ln(48.55)	Because one-point WTP is assumed to depend on both baseline water quality and expected water quality under the given water quality scenario, this variable is set to the mid-point of the baseline and scenario WQI values: $WQI_{Y,C} = (1/2)(WQI\text{-}BL_{Y,C} + WQI\text{-}S_{Y,C})$. The value varies for each of the four water quality scenarios.

[a] Counties intersecting the Harbor Estuary include eight counties in New Jersey (Bergen, Essex, Hudson, Middlesex, Monmouth, Passaic, Somerset, and Union) and eight counties in New York (Bronx, Kings, Nassau, New York, Queens, Richmond, Rockland, and Westchester).

WTP Calculations

The estimated meta-regression model allows calculation of total WTP for changes in a variety of environmental services affected by water quality and valued by humans, including changes in recreational fishing opportunities, other water-based recreation, and existence services such as aquatic life, wildlife, and habitat designated uses. The flexible model estimates WTP tailored to the given valuation scenario and accounts for geospatial factors predicted by theory to influence WTP, including: scale (the size of affected resources or areas), market extent (the size of the market area over which WTP is estimated), and the availability of substitutes. The model also allows for different use variable settings, depending on analysis assumptions (*e.g., swim_use* = 0 or *swim_use* = 1).

To estimate benefits of water quality improvements under the four scenarios in the Harbor estuary, ICF multiplied the coefficient estimates for each variable by the variable settings appropriate for the Harbor Estuary study area and each water quality scenario (see Table A-4). The sum of these products represents the predicted natural log of one-point household WTP (*ln_OWTP*) for a representative household. ICF then used Equation A-4 to estimate average annual household WTP for the estimated water quality improvements under each scenario.[29]

$$HWTP_{C,S} = OWTP_{C,S} \times \Delta WQI_{C,S}$$ **Equation A-4**

where:

$HWTP_{C,S}$ = Average annual household WTP for households located in a given county (*C*) under a given water quality scenario (*S*)

$OWTP_{C,S}$ = Annual one-point WTP, or annual WTP per point of improvement on the WQI, for a given county (C) and water quality scenario (*S*), estimated based on the meta regression model,

$\Delta WQI_{C,S}$ = Estimated annual average water quality change for a county (*C*) and water quality scenario (*S*).

To estimate total WTP (TWTP) for water quality changes for each county, ICF multiplied the per-household WTP values for the estimated water quality improvement by the number of households within each county in a given year and calculated the present value of the stream of WTP over the 20-year analysis period (2043-2062). ICF consulted with NEIWPCC, HEP, and members of the advisory board committee to determine the start year of the analysis period, or the year when water quality targets of the water quality scenarios could reasonably be met. Based on the timing of planned conservations and restoration activities, the water quality targets under the four scenarios are likely to be met by the end of 2042. Thus, benefits from the water quality improvements under the scenarios would begin accruing in 2043. ICF assumed that benefits would accrue for 20 years from 2043 to 2062 and accounted for population growth through the analysis period using

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[29] ICF estimated average annual household WTP based on *swim_use* = 0 for the main analysis (see Section 4.2 for results). For a sensitivity analysis, ICF estimated average annual household WTP based on *swim_use* = 1.

population projections from the 2021 NASA SEDAC (Hauer et al., 2021).[30] As noted above, this implies a conservative assumption that no benefits would be realized until water quality changes were fully realized (*i.e.,* in 2043).

For each water quality scenario and market extent, ICF then calculated annualized WTP values for each county using a 3 percent discount rate (Equation A-5). ICF then summed estimated values across the counties in each market extent to obtain total WTP at the market extent level. Benefit estimates are reported in 2021$ and are discounted to the year 2023. The benefit estimates presented in Section 4.2 are based on the county-level market extent and a *swim_use* variable setting of 0. *Appendix B: Sensitivity Analyses* provides alternative benefit estimates based on the state-level market extent and a *swim_use* variable setting of 1.

$$TWTP_{C,S} = \left(\sum_{T=2043}^{2062} \frac{HWTP_{C,S} \times HH_{Y,C}}{(1+i)^{Y-2023}} \right) \times \left(\frac{i \times (1+i)^{n}}{(1+i)^{n+1} - 1} \right)$$

Equation A-5

where:

$TWTP_{C,S}$ = Annualized total household WTP in 2021$ for households located in a given county (*C*) under a given water quality scenario (*S*),

$HWTP_{C,S}$ = Annual household WTP in 2021$ for households located in a given county (*C*) under a given water quality scenario (*S*),

$HH_{Y,C}$ = the number of households residing in a given county (*C*) in year (*Y*),

T = Year when benefits begin to accrue

i = Discount rate (3 percent)

n = Duration of the analysis (20 years)

Limitations and Uncertainty

The validity and reliability of benefit transfer—including that based on meta-analysis—depends on a variety of factors (Rosenberger et al., 2006; Rosenberger, 2015; Johnston et al., 2021; Desvousges et al., 1998; VandenBerg et al., 2001; Smith et al., 2002; Shrestha et al., 2007). Benefit transfers are increasingly applied as a core component of benefit-cost analyses conducted by EPA and other government agencies (Wheeler, 2015; Newbold et al., 2018; Bergstrom et al., 1999; Rosenberger et al., 2007). Moreover, Smith et al. (2002) argue that “nearly all benefit-cost analyses rely on benefit transfers, whether they acknowledge it or not.” Newbold et al. (2018) notes similarly that “it is impossible to conduct a prospective [federal benefit–cost analysis] without the use of at least some form of benefit (and cost) transfers.” Given the increasing [or as Smith et al. (2002) and Newbold et

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[30] These projections are based on Shared Socioeconomic Pathway 2 (SSP2) (Hauer et al., 2021). SSP2 is a “middle-of-the-road” projection, where social, economic, and technological trends do not shift markedly from historical patterns.

al. (2018) might argue, universal] use of benefit transfers, an increasing focus is on the empirical properties of applied transfer methods and models.

Although the statistical performance of the meta-regression model is good, we note several limitations. These limitations stem largely from information available from the original studies, as well as degrees of freedom and statistical significance. An important factor in any benefit transfer is the ability of the study site or estimated valuation equation to approximate the resource and context under which benefit estimates are desired. As is common, the meta-regression model presented here provides a close but not perfect match to the context in which values are desired. Although all the studies used in the meta-analysis valued changes in water quality improvements, many studies did not specify the cause of water quality impairment in the baseline or focused on causes that are different from the sources of impairment affecting the Harbor Estuary. Preliminary models, however, suggest no systematic patterns in WTP associated with such factors, at least in the present meta-data.

Additional limitations relate to the paucity of demographic variables available for inclusion in the model. Only one demographic variable is incorporated in the meta-regression model (*lnincome*), which is statistically significant at p<0.05. Other demographic variables are unavailable.

The estimated meta-regression model produces statistically significant coefficients and allows estimation of WTP based on study and site characteristics. However, strictly speaking, model findings are relative to the specific case studies considered and must be viewed within the context of the 189-observation data set, with all the appropriate caveats. Model results are also subject to choices regarding functional form and statistical approach, although many of the primary model effects are robust to reasonable changes in functional form and/or statistical methods. The rationale for the specific functional form chosen here is detailed above. More general observations on the properties of meta-regression analyses used for benefit transfer are provided by Nelson and Kennedy (2009) and Boyle and Wooldridge (2018).

As in all cases, results of the meta-analysis are dependent on the sample of studies available for the given resource change (Navrud et al., 2007) and may be subject to various selection biases if the available literature does not provide a representative, unbiased perspective on welfare estimates associated with resource changes (Rosenberger et al., 2009). In this case, however, ICF took several steps to ameliorate such potential biases, including the incorporation of both peer-reviewed and gray literature to avoid possible publication biases (Rosenberger et al., 2009) and the use of a comprehensive literature review in the attempt to avoid—as much as possible—other types of selection biases.

Appendix B: Sensitivity Analyses

Alternative Market Extent

The benefit estimates presented in Section 4.2 are based on the county-level market extent, which includes the 30 counties within HEP's jurisdiction. To assess the impact of market extent on the value of benefits from water quality improvements in the Harbor Estuary , ICF also assessed benefits using an alternative market extent (the states of New York and New Jersey). Section 2.2.2.1 provides additional details on selection of the two different market extents for this analysis.

Table B-1 provides benefit estimates under the alternative, state-level market extent, based on a *swim_use* variable setting of 0, for all four water quality scenarios. The state-level application builds upon the results presented in Section 4.2 by assuming that remaining households in New York and New Jersey, outside of the 30 HEP counties, would also value water quality improvements in the Harbor Estuary. Household WTP values for non-HEP counties in New York and New Jersey are based on a meta-regression model application using state-level geospatial variable values and median household WTP values for non-HEP counties in New York and New Jersey (Table A-4). The resulting household WTP values are applied to all households in the non-HEP counties in New York and New Jersey. Lastly, the HEP-county and non-HEP county results are summed to obtain total WTP for the state-level market extent. Table B-1 separates results for HEP counties and non-HEP counties to clearly show how much adding WTP for households in non-HEP counties contributes to total WTP for the state-level market extent. The HEP county results are identical to the results presented in Table 4-2.

Household WTP values for non-HEP counties in New York and New Jersey are lower than household WTP values for HEP counties (*i.e.,* the county-level market extent) due to different value settings for the *lnincome*, *ln_ar_ratio*, and *sub_proportion* variables (see Table A-4). The different geospatial variable settings (*ln_ar_ratio* and *sub_proportion*) account for the distance decay effects discussed in Section 2.2.2.1, or how per household values for environmental improvements tend to decline with greater distance between the household and improved areas.

Table B-1. Benefits for Water Quality Improvements under all Water quality scenarios, Based on the State-Level Market Extent and a swim_use Variable Setting of 0

County Extent	Average Annual Number of Households[a]	Average Annual Household WTP (2021$)	Total Present Value (3% Discount Rate; Millions 2021$)	Annualized Value (3% Discount Rate; Millions 2021$)
Primary Contact Recreation Scenario[b]				
30 HEP Counties (*i.e.,* county-level)[d]	8,639,847	$79.63	$5,744	$375
Non-HEP NY/NJ Counties	3,335,887	$52.02	$1,573	$103
Total	**11,975,733**	**$71.94**	**$7,317**	**$478**
Secondary Contact Recreation Scenario[b]				
30 HEP Counties (*i.e.,* county-level)[d]	8,639,847	$33.16	$2,392	$156
Non-HEP NY/NJ Counties	3,335,887	$21.66	$655	$43

Table B-1. Benefits for Water Quality Improvements under all Water quality scenarios, Based on the State-Level Market Extent and a swim_use Variable Setting of 0

County Extent	Average Annual Number of Households[a]	Average Annual Household WTP (2021$)	Total Present Value (3% Discount Rate; Millions 2021$)	Annualized Value (3% Discount Rate; Millions 2021$)
Total	**11,975,733**	**$29.95**	**$3,047**	**$199**
Aquatic Life Scenario[c]				
30 HEP Counties (*i.e.,* county-level)[d]	8,639,847	$206.50	$14,896	$972
Non-HEP NY/NJ Counties	3,335,887	$134.89	$4,079	$266
Total	**11,975,733**	**$186.55**	**$18,975**	**$1,238**
Combined Scenario[c]				
30 HEP Counties (*i.e.,* county-level)[d]	8,639,847	$301.32	$21,735	$1,418
Non-HEP NY/NJ Counties	3,335,887	$196.82	$5,952	$388
Total	**11,975,733**	**$272.21**	**$27,687**	**$1,807**

[a] Average annual number of affected households during the 20-year analysis period (2043-2062). Number of households for each year in the analysis period accounts for projected population growth, based on population projections from the 2021 NASA SEDAC (Hauer et al., 2021).

[b] Scenario is based on water quality targets of planned improvements.

[c] Illustrative scenario.

[d] Values are identical to results presented in Table 4-2.

Alternative Swimming Use Assumption

The benefit estimates presented in Section 4.2 are based on a *swim_use* variable setting of 0 for all water quality scenarios. Although two of the scenarios, primary contact recreation and combined (see Section 3), account for water quality improvements sufficient to meet primary contact recreation standards, a *swim_use* variable setting of 0 indicates that additional steps are needed for the Harbor Estuary waters to be useable for swimming, such as obtaining permits that allow swimming uses at beaches.

To demonstrate how estimated benefits increase when, in addition to meeting primary contact recreation standards, all steps are taken to allow swimming within the Harbor Estuary, ICF also assessed benefits using a *swim_use* variable setting of 1. Table B-2 provides benefit estimates using the alternative *swim_use* variable setting for the two water quality scenarios with a primary contact recreation component under the county-level market extent. ICF performed this analysis at the county-level market extent since the only people who would truly benefit from swimming uses would be residents of adjacent counties.

Since the *swim_use* variable coefficient is positive and large (0.3; see Appendix A: Estimating WTP for Water Quality Improvements Using Meta-Analysis for more details), switching the variable setting from 0 to 1 increases benefit estimates. This increase is logical because nearby households value swimming as a potential use and are WTP higher values for water quality improvements (and other associated changes) that make waters swimmable. Relative to when *swim_use* = 0, annualized WTP values increase when *swim_use* = 1 by approximately 35 percent, or by $131 million for the primary contact recreation scenario and by $496 million for the combined scenario.

Table B-2. Benefits for Water Quality Improvements under Relevant Water quality scenarios, based on a swim_use Variable Setting of 1 and the County-Level Market Extent

Scenario	Average Annual Number of Households[a]	Average Annual Household WTP (2021$)	Total Present Value (3% Discount Rate, Millions 2021$)	Annualized Value (3% Discount Rate, Millions 2021$)
Primary Contact Recreation[b]	8,639,847	$107.49	$7,754	$506
Combined Scenario[c]	8,639,847	$406.74	$29,340	$1,915

[a] Average annual number of affected households during the 20-year analysis period (2043-2062). Number of households for each year in the analysis period accounts for projected population growth, based on population projections from the 2021 NASA SEDAC (Hauer et al., 2021).

[b] Scenario is based on water quality targets of planned improvements.

[c] Illustrative scenario.

Appendix C: Advisory Board Committee

The following table summarizes the members of the project's advisory board committee and their affiliation.

Table C-1. Advisory Board Committee

Name	Affiliation	Email
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[a] The affiliations noted in this table are relevant to when the individual participated in the study and do not necessarily reflect their current affiliation.