Evaluation of the Technical, Economic, and Social Impacts Associated with Updating Major Wastewater Treatment Infrastructure to Address Aquatic Life Uses and Values for the Delaware Estuary

Draft Report June 25, 2021

Prepared by:

Gerald Kauffman, Andrew Homsey, and Hayley Rost
University of Delaware
Water Resources Center
Biden School of Public Policy & Administration
Newark, Del. 19711

Prepared for:

Delaware River Basin Commission
State Police Dr.
West Trenton, NJ

Table of Contents

List of Tables iii
List of Figures v
Chapter 1: Introduction 1
Chapter 2: Costs 9
Chapter 3: Benefits 15
Chapter 4: Summary 43
References 47

List of Tables

Table 1.1 Water quality criteria along the Delaware River and Bay 2
Table 1.2 Population in the Delaware Estuary watershed in 2020 3
Table 1.3 Maximum dissolved oxygen saturation in freshwater 5
Table 2.1 Flow and service area population for 12 wastewater largest dischargers in the Delaware Estuary....10
Table 2.2 Cost of ammonia reduction from wastewater dischargers in the Delaware Estuary 12
Table 3.1 Recreation benefits in the Delaware Estuary 15
Table 3.2 Economic benefits of improved water quality in the U.S. 16
Table 3.3 Estuary recreation activity in the Delaware Estuary 16
Table 3.4 Benefits of improved water quality....17
Table 3.5 Strengths and weaknesses of the benefits transfer approach....18
Table 3.6 Links between recreation activities and improved water quality....18
Table 3.7 Per person recreation benefits due to improved water quality along rivers 19
Table 3.8 Adult population in the Wastewater Service Area of the Delaware Estuary Watershed....19
Table 3.9 Low bound recreation benefits of improved water quality in the Delaware Estuary 19
Table 3.10 Adult population of the Delaware Estuary Watershed in 2020....19
Table 3.11 High bound benefits of improved water quality in the Delaware Estuary Watershed 20
Table 3.12 Low bound recreation benefits by state for improved water quality in Delaware Estuary....21
Table 3.13 High bound recreation benefits by state for improved water quality in Delaware Estuary....21
Table 3.14 National Sanitation Foundation water quality index....22
Table 3.15 Summary of recreational activity consumer surplus studies in $2000 22
Table 3.16 Recreational powerboat expenditures in the Delaware Estuary watershed....23
Table 3.17 Recreational boat registrations in the Delaware River Basin....23
Table 3.18 Recreational boating participants along the Delaware Estuary 23
Table 3.19 Consumer surplus for recreational boating....24
Table 3.20 Recreational boating benefits due to improved water quality in the Delaware Estuary....24
Table 3.21 Recreational fishing days in the Delaware River and Bay 25
Table 3.22 Recreational fishing activity along the Delaware River and Bay 25
Table 3.23 Recreational fishing in Delaware Bay and Atlantic Coast, Delaware and New Jersey....25
Table 3.24 Delaware Estuary recreational fishing days, 2000 26
Table 3.25 Recreational fishing value studies 26
Table 3.26 Recreational fishing benefits due to improved water quality in the Delaware Estuary 26
Table 3.27 Bird/wildlife watching along the Delaware Estuary 27
Table 3.28 Bird/wildlife watching activities along the Delaware River....28
Table 3.29 Consumer surplus for recreational bird/wildlife watching....28
Table 3.30 Recreational wildlife/bird watching benefits in the Delaware Estuary....28
Table 3.31 Waterfowl hunting along the Delaware Estuary in Delaware and New Jersey....29
Table 3.32 Recreational waterfowl hunting benefits in the Delaware Estuary....29
Table 3.33 Beach activity in the Delaware Estuary....30
Table 3.34 Beach visitor studies in the mid-Atlantic U.S....30
Table 3.35 Recreational beach visitor benefits in the Delaware Estuary....30
Table 3.36 Commercial fishery benefits from improved water quality in the Delaware Estuary 33
Table 3.37 Increased property values resulting from improved water quality....34
Table 3.38 Increased property value due to improved water quality in the Delaware River....34
Table 3.39 Benefits of improved water quality for municipal water supplies....36
Table 3.40 Public water supply benefits due to improved water quality in the Delaware Basin....36
Table 3.41 National water values by use converted from $1994 to $2020....37
Table 3.42 Industrial water supply benefits of improved water quality in the Delaware Basin 37
Table 3.43 Summary of publications concerning WTP for improved water quality in $2000 38

Table 3.44 Typical benefits from improved freshwater quality 38
Table 3.45 Water quality ladder values 39
Table 3.46 Annual willingness to pay for improved water quality..........40
Table 3.47 Nonuse benefits of improved water quality in the Delaware Estuary ($2020) 40
Table 3.48 Low bound WTP for improved water quality in the Delaware River 41
Table 3.49 High bound WTP for improved water quality in Delaware Estuary..........42
Table 4.1 Ammonia reduction costs for largest wastewater dischargers in the Delaware Estuary..........44
Table 4.2 Benefits of improved water quality in the Delaware River in $2020 45
Table 4.3 Net benefits of ammonia reduction at wastewater dischargers along Delaware Estuary 46

List of Figures

Figure 1.1 Delaware River water quality zones 3
Figure 1.2 Delaware Estuary watershed 3
Figure 1.3 DRBC dissolved oxygen criteria along the Delaware Estuary in 1968 4
Figure 1.4 Dissolved oxygen along the Delaware River at Philadelphia 4
Figure 1.5 Dissolved oxygen and water temperature of the Delaware River at Philadelphia (2007-2013) 5
Figure 1.6 Dissolved oxygen saturation and water temperature relationship 5
Figure 1.7 Water quality along the Delaware River at Reedy Island, Chester, and Philadelphia 6
Figure 1.8 Water quality along the Delaware River for conductivity, water temperature, dissolved oxygen, and pH 7
Figure 1.9 Dissolved oxygen requirements, temperatures, and salinities for sensitive species in the Delaware Estuary 8
Figure 1.10 Costs to achieve DO objectives (1975-1980) in the Delaware Estuary near Philadelphia 8
Figure 2.1 Costs to achieve DO objectives (1975-1980) in the Delaware Estuary near Philadelphia 9
Figure 2.2 Largest wastewater treatment plant dischargers in the Upper Estuary 10
Figure 2.3 Annual average flow of wastewater dischargers in the Delaware Estuary 10
Figure 2.4 Annual and per capita cost of ammonia reduction at wastewater treatment plants in the Delaware Estuary 11
Figure 2.5 Annual cost of ammonia reduction at wastewater dischargers in the Delaware Estuary 13
Figure 2.6 Annual cost of ammonia reduction at wastewater dischargers in the Delaware Estuary 14
Figure 3.1 Net benefits to achieve DO objectives in Delaware Estuary near Philadelphia 15
Figure 3.2 Economic benefits of improved water quality in the Delaware River 17
Figure 3.3 Annual recreation benefits due to improved water quality in Delaware River 20
Figure 3.4 Relationship between dissolved oxygen and fish catch in the Delaware Estuary 32
Figure 3.5 Increased property value due to improved water quality 34
Figure 3.6 Property within 2000 feet of the Delaware River between Trenton and Wilmington 35
Figure 3.7 Water quality ladder 39
Figure 3.8 Nonuse benefits willingness to pay for improved water quality in Delaware Basin 41
Figure 3.9 Nonuse benefits by state due to improved water quality in the Delaware River 42
Figure 4.1 Annual and per capita cost of ammonia reduction at wastewater treatment plants in the Delaware Estuary 43
Figure 4.2 Lower and upper bound benefits of improved water quality in the Delaware River 44
Figure 4.3 Upper bound benefits of improved water quality in the Delaware River 45

Evaluation of the Technical, Economic, and Social Impacts Associated with Updating Major Wastewater Treatment Infrastructure to Address Aquatic Life Uses and Values for the Delaware Estuary

Draft June 25, 2021

Chapter 1: Introduction

Background

In September 2017 the Delaware River Basin Commission (DRBC) approved Resolution 2017-4 directing DRBC staff to perform fish and dissolved oxygen (DO) studies, modeling studies, and cost/feasibility studies to define the appropriate aquatic life use for the Delaware Estuary and its supporting DO criteria, and directed DRBC's Executive Director to initiate DRBC rulemaking to revise the designated aquatic life uses consistent with those studies. The Academy of Natural Sciences (Stoklosa et al. 2018) completed a review of dissolved oxygen requirements for aquatic species in the Delaware Estuary. In May 2020 Kleinfelder submitted a report to DRBC that estimated the costs of nitrogen and ammonia reduction at the 12 largest wastewater treatment plants that discharge to the Delaware Estuary. The University of Delaware Water Resources Center (UDWRC) applied for and received (along with co-applicant DRBC) a grant under the Delaware Watershed Research Fund (DWRF) to estimate the Economic and Social Impacts of Improved Water Quality in the Delaware Estuary in accordance with the following approach.

The UDWRC estimated costs and benefits from increased levels of wastewater treatment (ammonia and nitrogen) to improve dissolved oxygen in the Delaware Estuary. The present DO water quality standard in zones 2, 3, 4, and 5 between Trenton, Philadelphia, and Wilmington is 3.5 mg/L as a 24-hour mean during summer and 6 mg/L seasonal mean criteria during spring and fall (Table 1.1 and Figure 1.1). Costs are derived from ammonia treatment levels of 10 mg/L, 5 mg/L, and 1.5 mg/L as per Kleinfelder (2020) report. Benefits are derived for population residing in the service areas of the 12 wastewater dischargers (low range) and population within Delaware Estuary watershed as a high range (Figure 1.2 and Table 1.2). The economic analysis is conducted at DO increasing from present standard of 3.5 mg/l to 5.0 mg/l (65% saturation of DO at 30 deg C).

Scope

The UDWRC estimated costs and benefits at increased levels of wastewater treatment as measured by ammonia and nitrogen in discharge effluent and improved dissolved oxygen in the Delaware Estuary.

1. **Stakeholder Advisory Committee:** Form a stakeholder committee of the dischargers to provide guidance with methodology during the performance of the cost benefit analysis. The SAC met via ZOOM call on Feb 4, 2021, March 11, 2021, and April 8, 2021

2. **Costs:** Utilize costs of load reductions established by Kleinfelder (2020) at the 12 largest wastewater treatment plants in the urban Delaware Estuary between Trenton, Philadelphia, and Wilmington to achieve improved water quality. Estimate capital, operation and maintenance costs for these WWTPs using the Kleinfelder report. Compute ammonia load reduction costs ($/yr) for treatment plant improvement options at ammonia treatment levels 10 mg/l, 5 mg/l, and 1.5 mg/l. Define marginal abatement cost curves to estimate most cost effective level of treatment at the least increase in marginal cost. Finance and rate setting programs to fund load reductions are not examined based on comments from the dischargers.

3. **Benefits:** What are the economic benefits of improved water quality due to ammonia waste load reductions in the Delaware River? This task estimates benefits of improved water quality for recreation, boating, fishing, wildlife-viewing, property value, and other uses.

   Recreation: Benefits are estimated fo**r** improved water quality to go from nonsupport (impaired) to viewing, boatable (3.5 mg/), and fishable (5.0 mg/l) and above uses in the Delaware River. Annual recreation benefits to achieve boating and fishing water quality are conducted by selecting per person values from travel cost studies and multiplying by the U.S. Census (2010 adult population (>18 yr old) for the agreed upon study area (i.e. the basin and/or service areas). The value of recreation will be estimated due to improved water quality using the unit day value method by multiplying the number of visitor days by the unit value ($/day) of a recreation day. Recreation benefits of improved water quality are measured by increase in number of activity days by participants at the river.

Use values: Economic benefits of improved water quality are estimated for boating, fishing, bird watching, waterfowl hunting, and beach going by estimating number of visitors participated in recreational activities in the Delaware River. Define (1) boating, fishing, wildlife watching recreation from net factor income, productivity, and travel cost methods, (2) commercial fishing using market price method from National Marine Fisheries Service, (3) water supply (municipal/industrial), which may be marginal, using market price and productivity methods due to decreased treatment costs, (4) viewing/aesthetics from willingness to pay and contingent valuation methods, and (5) increased property value using hedonic pricing methods for river-side parcels.

Benefits Transfer: If primary valuation data collected from studies in the Delaware Basin were not available, then benefits transfer techniques are employed to translate data from other watersheds. Due to uncertainty in the selection of parameters and transferring data to the Delaware River, lower and upper bound benefits are defined based on the population in the basin who benefit, assuming a range in the percent change in benefit due to improved water quality, and selecting low and high range unit values (WTP in $/person). Benefits from the original base year were converted to 2020 dollars based on the annual change (2.6% rounded to 3%) in the Consumer Price Index (CPI) in the Northeast Region reported by the Bureau of Labor Statistics.

Nonuse values: From stated preference and contingent valuation surveys, determine willingness to pay by the public and customers (rate payers) in the service areas for improved water quality for existing/future generations. Nonuse values are defined as willingness to pay (WTP) to improve water quality and include existence values from the satisfaction that a water resource exists and is protected but may never be visited and bequest values from satisfaction that the river is preserved for future generations.

4. **Report:** Prepare report detailing cost/benefit analysis of improved water quality measured by decreased ammonia and nitrogen discharge from WWTPs and resulting increase in dissolved oxygen in the Delaware Estuary.

Table 1.1 Water quality criteria along the Delaware River and Bay (DRBC 2008 and 2019)

Water Quality Zone	River Mile	DO Criteria (mg/l)	Aquatic Life	Recreation
1A. Hancock to Narrowsburg, NY	330.7-289.9	6.0 (24 hr) 7.0 (trout)	NS	S
1B. Narrowsburg to Pt. Jervis, NY 1C. Pt. Jervis, NY to Tocks Is. PA 1D Tocks Island to Easton, PA. 1E. Easton, PA to Trenton, NJ	289.9-254.7 254.7-217.0 217.0-183.7 183.7–133.4	5.0 (24 hr)	NS	S
2. Trenton, NJ to RM 108.4	133.4-108.4	5.0 (24 hr) 6.5 (Spr/fall)	NS	S
3. R.M. 108.4 to Big Timber Cr., NJ	108.4 - 95.0	3.5 (24 hr) 6.5 (spr./fall)	NS	S
4. Big Timber Cr., NJ to PA-DE line	95.0 - 78.8	3.5 (24 hr) 6.5 (spr/fall)	NS	S
5. DE-PA Line to Liston Point (maintenance of resident fish and other aquatic life, propagation of resident fish from R.M. 70.0 to 48.2)	78.8 - 48.2	3.5 (RM 78.8) 4.5 (RM 70.0 6.0 (RM 59.5) 6.5 (spr./fall)	NS	S
6. Liston Point to Atlantic Ocean	48.2 - 0.0	6.0 (24 hr)	NS	S

S = supports designated use, NS = not support designated use.

Figure 1.1 Delaware River water quality zones (DRBC 2010)

Figure 1.2 Delaware Estuary watershed

Table 1.2 Population in the Delaware Estuary watershed in 2020

State	County	Population.
DE	Kent	158,383
DE	New Castle	538,040
DE	Sussex	51,913
MD	Cecil	6,458
NJ	Atlantic	5,728
NJ	Burlington	452,744
NJ	Camden	450,648
NJ	Cape May	33,025
NJ	Cumberland	155,287
NJ	Gloucester	268,785
NJ	Mercer	241,242
NJ	Monmouth	12,508
NJ	Ocean	12,086
NJ	Salem	65,850
PA	Berks	401,724
PA	Bucks	528,344
PA	Carbon	5,010
PA	Chester	478,767
PA	Delaware	572,794
PA	Lancaster	872
PA	Lebanon	18,421
PA	Lehigh	10,874
PA	Montgomery	828,856
PA	Schuylkill	78,440
		6,973,834

Water Quality

In 1968, the DRBC projected that if wasteload abatement plans were implemented at 80 dischargers in the Delaware Estuary watershed, dissolved oxygen would improve from hypoxic conditions at Philadelphia (RM 90) to at least 3.5 mg/l (Figure 1.3). These estimates paid off because indeed the Delaware River DO mostly exceeds 3.5 mg/l now at Philadelphia now (Figure 1.4)

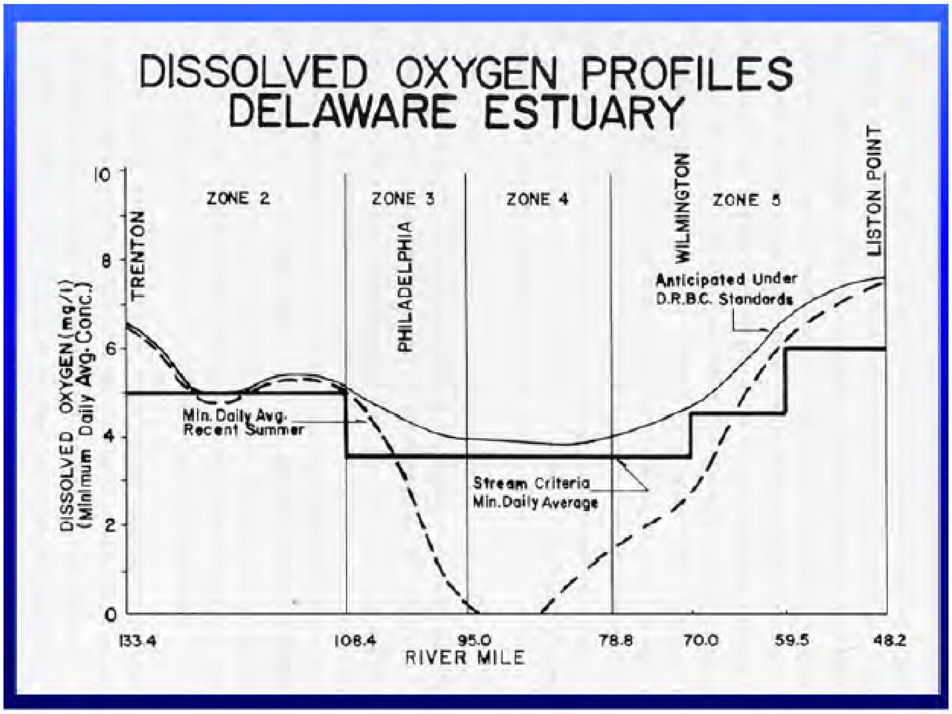


Figure 1.3 DRBC dissolved oxygen criteria along the Delaware Estuary in 1968

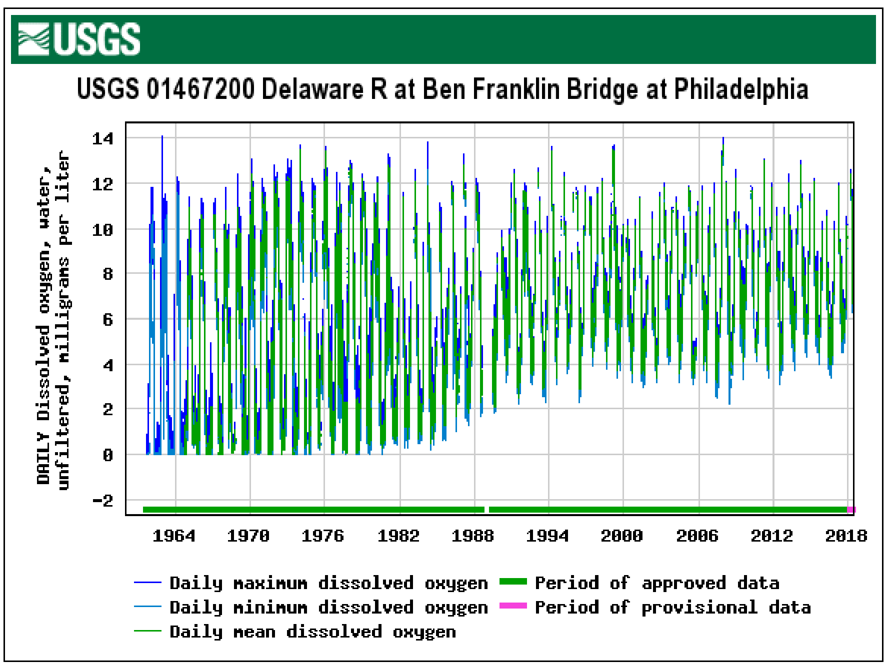


Figure 1.4 Dissolved oxygen along the Delaware River at Philadelphia

Since DO saturation and water temperature are inversely proportional, the maximum DO in the Delaware River at water temperatures that approach 30 deg C during the summer at Philadelphia (Figure 1.5) is 7.54 mg/l at 100% saturation (Table 1.3 and Figure 2). At 5 mg/l DO saturation is 60% at 30 deg C.

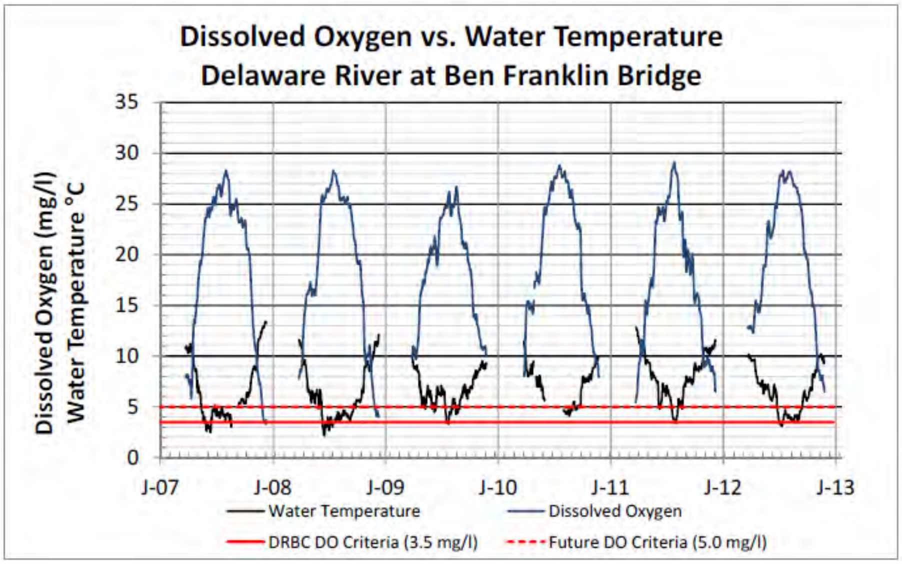


Figure 1.5 Dissolved oxygen and water temperature of the Delaware River at Philadelphia (2007-2013)

Table 1.3 Maximum dissolved oxygen saturation in freshwater

Temp. (°C)	DO (mg l)
15	10.07
20	9.07
25	8.24
30	7.54
35	6.93

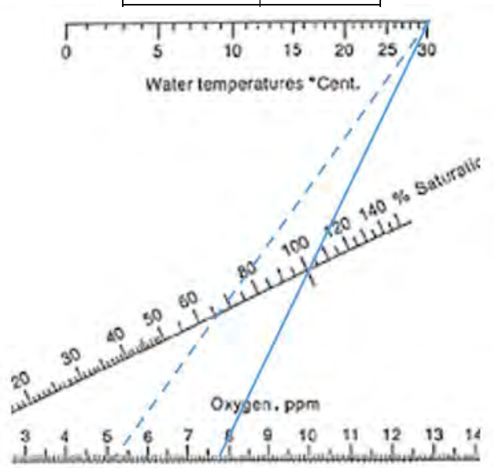


Figure 1.6 Dissolved oxygen saturation and water temperature relationship

Delaware River water chemistry is monitored as conductivity (salinity), water temperature, dissolved oxygen, and pH at Reedy Island, Chester, and Ben Franklin Bridge at Philadephia (Figures 1.7 and 1.8). While conductivity, water temperature, and ph have changed, DO has increased during all seasons at each of the 3 stations since the 1960s.

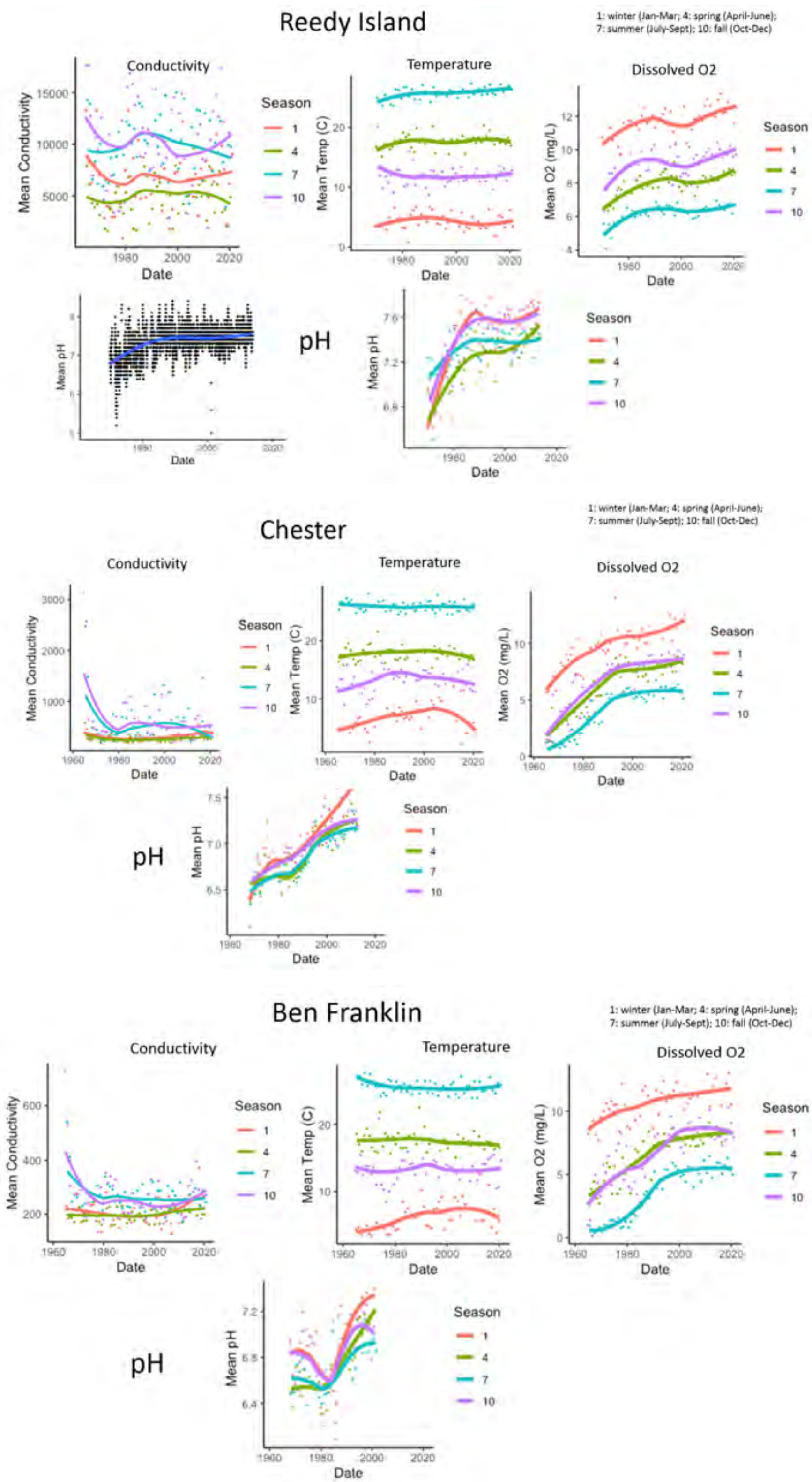


Figure 1.7 Water quality along the Delaware River at Reedy Island, Chester, and Philadelphia (Kirchman 2021 from USGS)

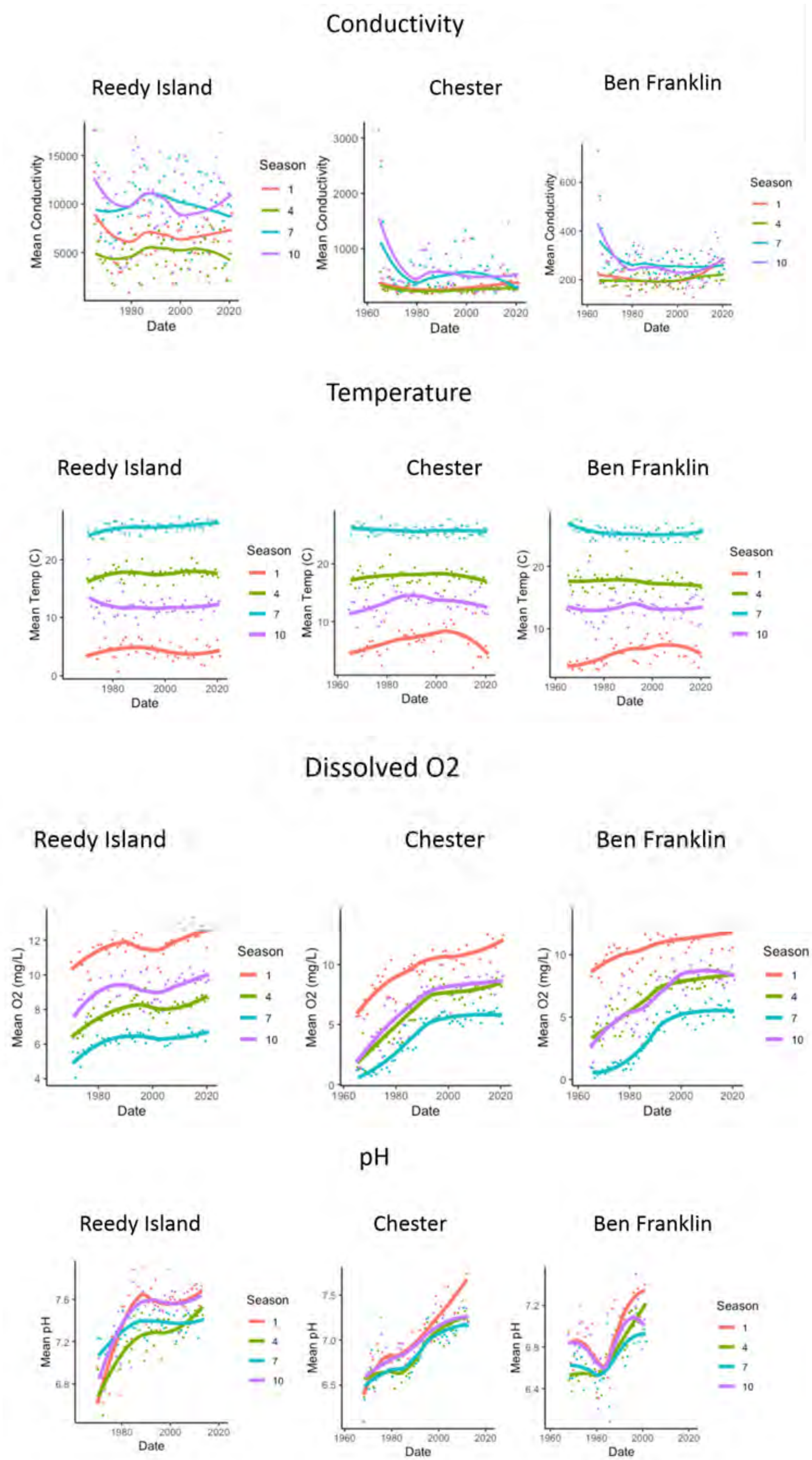


Figure 1.8 Water quality along the Delaware River for conductivity, water temperature, dissolved oxygen, and pH (Kirchman 2021 from USGS)

The Academy of Natural Sciences (Stoklosa et al. 2018)) conducted a synthesis of the literature that found Atlantic sturgeon and American shad require dissolved oxygen levels of 4.3, 5.0, and 6.3 mg/l for spawning and survival. (Table 1.4).

Figure 1.9 Dissolved oxygen requirements, temperatures, and salinities for sensitive species in the Delaware Estuary (Stoklosa et al. 2018, Academy of Natural Sciences)

Species Common Name	Stage	DO (mg/l)	Temp. (°C)	Salinity (‰)	Description	Reference
Shortnose Sturgeon	Juvenile	3.0	23	0-5	Significant decrease in percent survival.	Jenkins et al. 1993
Shortnose Sturgeon	Juvenile	2.2-3.1	22-30	2-4.5	LC50.	Campbell and Goodman 2004
Atlantic Sturgeon	Juvenile	6.3	20	1	Optimal for survival.	Niklitschek and Secor 2009a
Atlantic Sturgeon	Juvenile	4.3	12	1	Optimal for survival.	Niklitschek and Secor 2009a
Atlantic Sturgeon	Juvenile	4.3	26	-	Higher than this needed to protect survival (S. Atlantic DPS).	Federal Register 2017
American Shad	Juvenile	2.0-4.0	-	-	Surival possible with limited exposure.	Tagatz 1961
American Shad	Egg/Larval	2.5-2.9	-	-	LC50.	Stier and Crance 1985
American Shad	All	5.0	-	-	Required for spawning.	Stier and Crance 1985; Walburg and Nichols 1967
Blue Crab	Juvenile	4.1	20	10	LC50.	Stickle et al. 1989
Blue Crab	Juvenile	4.6	30	30	LC50.	Stickle et al. 1989
Blue Crab	Juvenile	5.0	24	22	28-day LC50.	Das and Stickle 1993
Blue Crab	Juvenile	5.2	30	20	LC50.	Stickle et al. 1989
Blue Crab	Juvenile	5.6	30	10	LC50.	Stickle et al. 1989
Blue Crab	Juvenile	6.0	20	30	LC50.	Stickle et al. 1989
Blue Crab	Juvenile	6.4	20	20	LC50.	Stickle et al. 1989
Atlantic Rock Crab	Larval	4.2-6.0	30	30	LC50.	Vargo and Sastry 1977
Atlantic Rock Crab	Larval	3.8	20	28-32	LC10.	Miller, Poucher, and Coiro 2002
Atlantic Rock Crab	Megalops	4.7	30	30	LC50.	Vargo and Sastry 1977
Scud (G. fasciatus)	Adult	4.3	20	-	24-hour LC50.	Sprague 1963
Scud (G. psuedolimnaeus)	Adult, Female	4.1	20	0*	Lowest DO resulting in significant mortality.	Hoback and Barnhart 1996
Channel Catfish	Egg/Larval	4.2	25	-	Decreased hatching success and survival.	Carlson, Siefert, and Herman 1974
Striped Bass	Egg	2.0-3.5	-	-	Complete absence.	Chittenden 1971
Striped Bass	Egg	4.0	-	-	Reduced survival.	Turner and Farley 1971
Striped Bass	Egg/Larval	5.0	18	-	Decreased hatching success and survival.	Turner and Farley 1971
Striped Bass	Juvenile	5.0	-	-	Threshold for high survival.	Krouse 1968 as in Bain and Bain 1982
Yellow Perch	Juvenile/Adult	4.3	26	-	Lowest DO for 100% survival.	Moore 1942
Yellow Perch	Juvenile/Adult	4.8	4	-	Lowest DO for 100% survival.	Moore 1942
Yellow Perch	Juvenile/Adult	5.1	19	-	Lowest DO for 100% survival.	Moore 1942

Where: "-" indicates absence of a temperature or salinity given in the reference; and * means test was done in "freshwater" and salinity is likely close to 0

In 1966, the Federal Water Pollution Control Administration (the precursor to EPA) estimated the cost to achieve DO objectives would range from $120 to $180 million for 3 mg/l DO to $220 to $330 million for 4 mg/l DO (Figure 1.10).

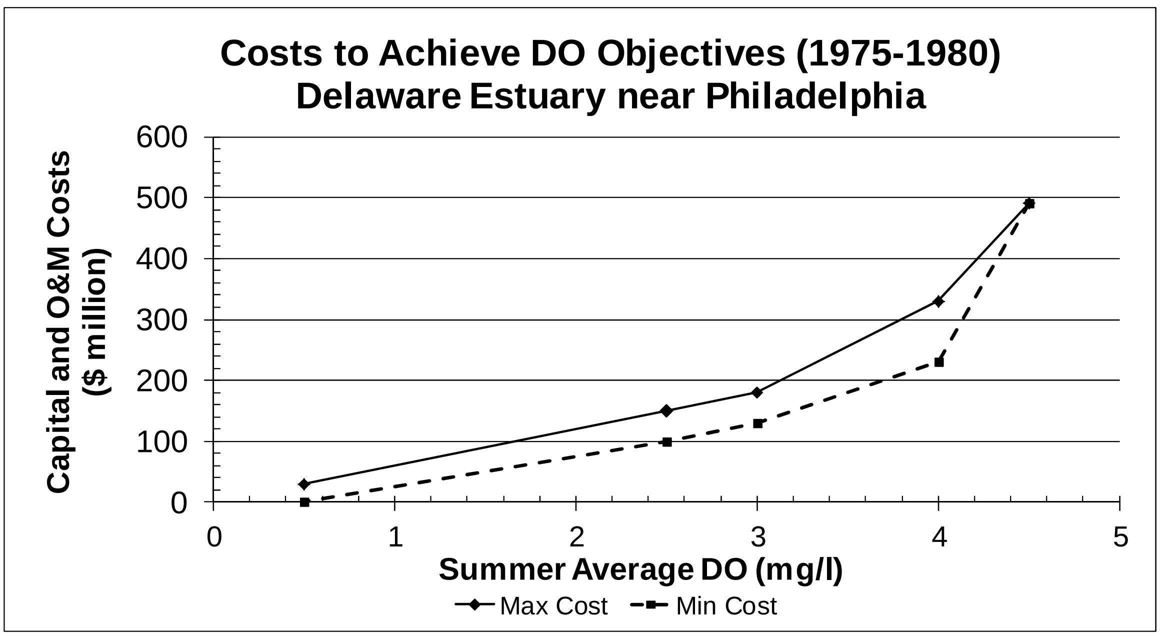


Figure 1.10 Costs to achieve DO objectives (1975-1980) in the Delaware Estuary near Philadelphia (FWPCA 1966)

Chapter 2: Costs

In 1966, the Federal Water Pollution Control Administration (precursor to EPA) estimated the costs to achieve DO objectives in the Delaware Estuary near Philadelphia would range from $120 to $180 million for 3 mg/l DO to $220 to $330 million for 4 mg/l DO (Figure 2.1).

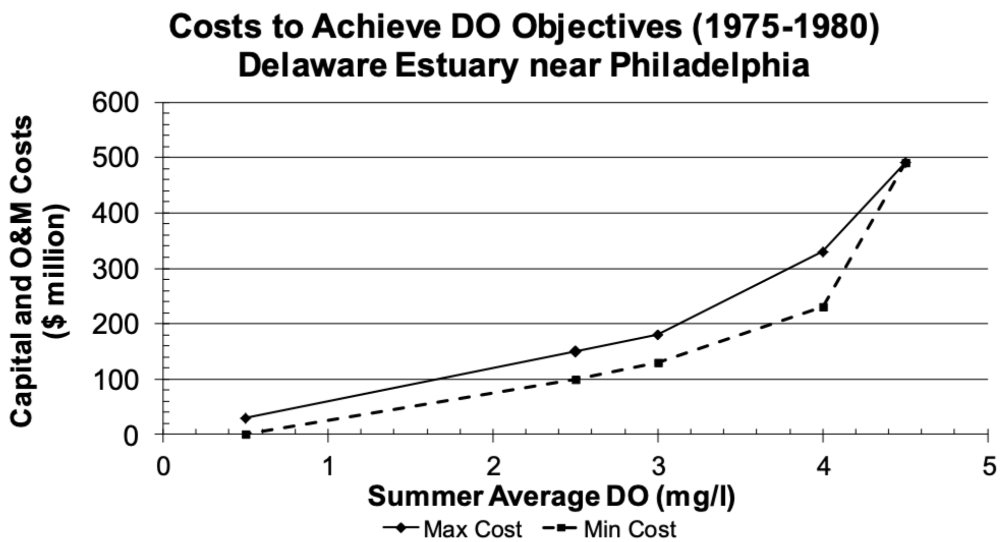


Figure 2.1 Costs to achieve DO objectives (1975-1980) in the Delaware Estuary near Philadelphia (FWPCA 1966)

In May 2020, Kleinfelder produced a Technical Memorandum Summarizing Nitrogen Reduction Cost Estimation Study Plant Specific Cost Estimates that presented plant specific cost estimates and corresponding cost curves for achieving the three (3) agreed upon effluent levels for ammonia nitrogen (NH_3-N) reduction and the one (1) agreed upon effluent level for total nitrogen (TN) at the twelve (12) plants listed below by plant type that discharge to the lower Delaware River.

Conventional Activated Sludge
- City of Wilmington
- Delaware County Regional Water Authority Western Regional Treatment Plant (DELCORA)
- Gloucester County Utilities Authority (GCUA)
- Philadelphia Water Department Southeast WPCP (PWD SEWPCP)
- PWD Northeast WPCP (PWD NEWPCP)
- Lower Bucks County Joint Municipal Authority (LBCJMA)

Pure Oxygen Activated Sludge
- PWD Southwest WPCP (PWD SWWPCP)
- Delaware #1 WPCP / Camden County Municipal Utilities Authority (CCMUA)
- Morrisville Borough Municipal Authority (MMA)

Fixed Film
- Trenton Sewer Utility
- Willingboro MUA Water Pollution Control Plant (Willingboro MUA)
- Hamilton Township Water Pollution Control Facility (Hamilton Township)

The 12 wastewater treatment plant dischargers (Figure 2.2) are arranged in the upper estuary (Hamilton, Morrisville MMA, Trenton, Bucks County, Willingboro), Philadelphia Water Department (SEWPCP, NEWPCP, SWWPCP), New Jersey counties (CCMUA, GCUA), and lower estuary (DELCORA, Wilmington). The total flow is 705 mgd with 2/3 from the PWD and the population served is 3.5 million (Figure 2.3 and Table 2.1).

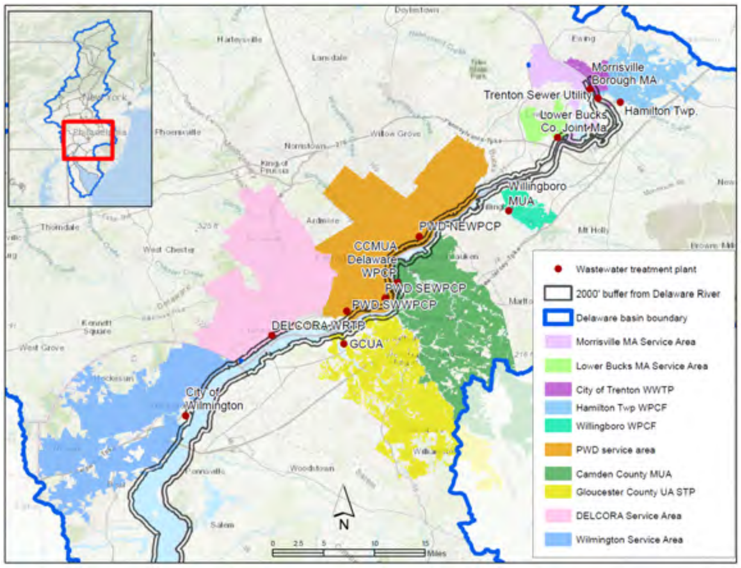


Figure 2.2 Largest wastewater treatment plant dischargers in the Upper Estuary

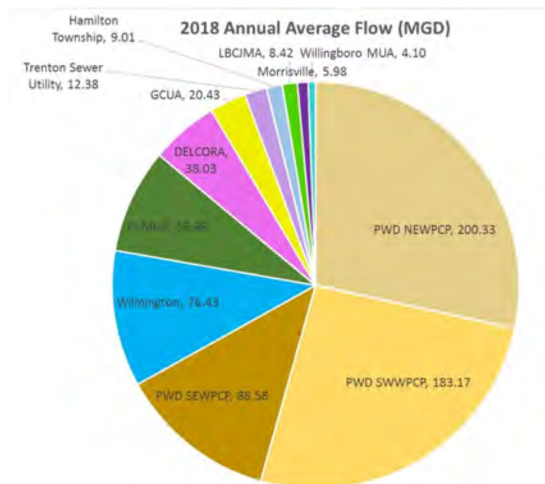
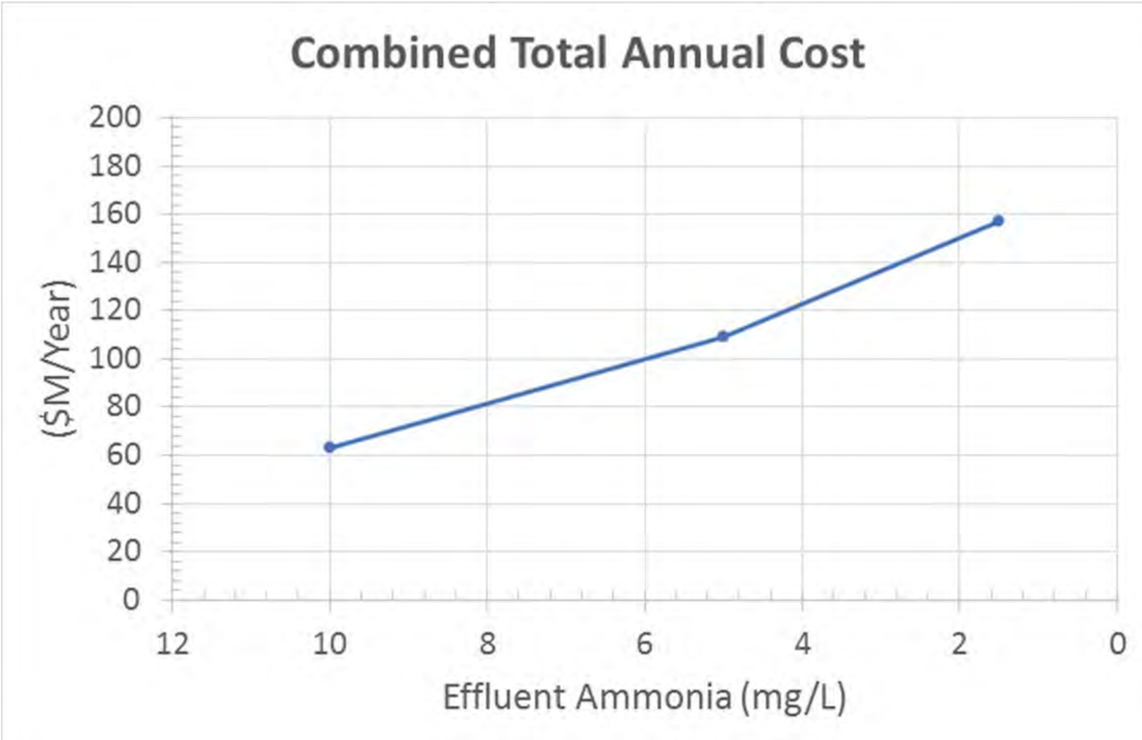


Figure 2.3 Annual average flow of wastewater dischargers in the Delaware Estuary

Table 2.1 Flow and service area population for 12 wastewater largest dischargers in the Delaware Estuary

Discharger	**2018 Annual Average Flow (mgd)**	**Pop Served**
PWD NEWPCP	200.3	316,813
PWD SWWPCP	183.2	934,598
PWD SEWPCP	88.6	332,653
City of Wilmington	76.4	395,782
CCMUA Delaware WPCP	58.7	474,200
DELCORA WRTP	38.0	519,827
GCUA	20.4	231,146
Trenton Sewer Utility	12.4	80,618
Hamilton Twp.	9.0	84,293
LBCJMA	8.4	55,006
Morrisville Borough MA	6.0	40,186
Willingboro MUA	4.1	37,064
SUM	**705.5**	**3,502,186**

The total annual cost to reduce ammonia to 10, 5, and 1.5 mg/l from the 12 largest wastewater dischargers to the Delaware Estuary is $1.1, $1.9, and $2.7 billion, respectively and the annual cost is $63, $109, and $157 million/yr or $18, $31, and $45 per capita for the 3.5 million people served by WWTPs (Table 2.2 and Figures 2.4, 2.5, and 2.6). For individual dischargers, the annual cost to reduce ammonia to 10, 5, and 1.5 mg/l ranges from $0, $0, and $2 million/yr for Willingboro or $54 per capita to $0, $10, and $28 million/yr for PWD NEWPC for $32, $88, and $189 per capita.



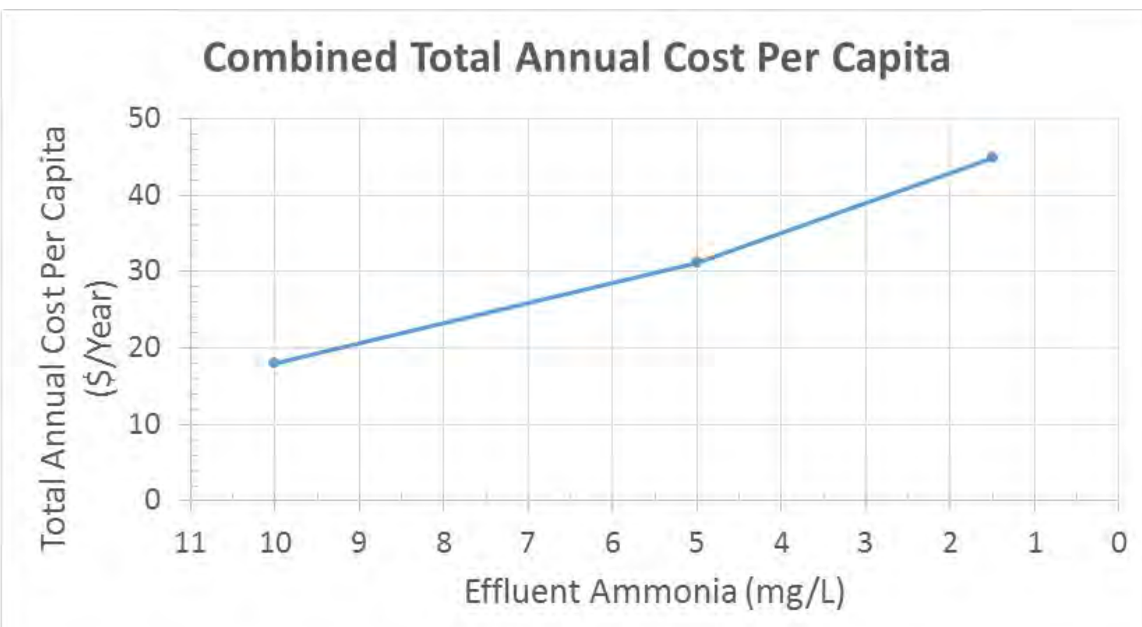


Figure 2.4 Annual and per capita cost of ammonia reduction at wastewater treatment plants in the Delaware Estuary

Table 2.2 Cost of ammonia reduction from wastewater dischargers in the Delaware Estuary

Scenario NH3-N (mg/L)	Flow (mgd)	Capital Cost ($M)	O&M ($M)	Present Worth ($M 2019)	Debt Service ($M/yr)	Annual O & M ($M/yr)	Annual Cost ($M/Yr)	Pop. Served	Cost/Capita ($/yr)
Morrisville MMA (PA)									
21					0	0	0		0
10	6.0	25	9	34	2	0.4	2	40,186	50
5	6.0	28	12	40	2	1	2	40,186	50
1.5	6.0	31	16	46	2	1	2	40,186	50
Willingboro MUA (NJ)									
10					0	0	0		0
10	4.1	0	0	0	0	0	0	37,064	0
5	4.1	0	0	0	0	0	0	37,064	0
1.5	4.1	26	5	31	2	0.3	2	37,064	54
Hamilton Township (NJ)									
28.7					0	0	0		0
10	9.0	30	26	56	2	1	3	84,293	36
5	9.0	33	32	66	2	2	4	84,293	47
1.5	9.0	35	39	74	2	2	4	84,293	47
Trenton Sewer Utility (NJ)									
12.3					0	0	0		0
10	12.4	1	0.5	2	0.1	0.02	0.1	80,618	1
5	12.4	31	8	38	2	0.4	2	80,618	25
1.5	12.4	39	14	53	3	1	3	80,618	37
LBCJMA(PA)									
33					0	0	0		0
10	8.4	9	18	27	0.9	0.9	2	55,006	36
5	8.4	9	27	37	1	1	2	55,006	36
1.5	8.4	9	34	43	1	2	2	55,006	36
PWD SWWPCP (PA)									
12.4					0	0	0		
10	183.2	209	272	481	14	13	13	934,598	14
5	183.2	270	360	630	18	17	17	934,598	18
1.5	183.2	313	425	739	20	21	21	934,598	22
PWD SEWPCP (PA)									
12.4					0	0	0		0
10	88.6	66	8	73	4	0.4	5	332,653	14
5	88.6	66	19	85	4	1	5	332,653	18
1.5	88.6	209	28	237	14	1	15	332,653	22
PWD NEWPCP (PA)									
10		0	0	0	0	0	0		0
7.2	200.3				0	0	0	316,813	32
5	200.3	125	39	164	8	2	10	316,813	88
1.5	200.3	383	61	444	25	3	28	316,813	189
CCMUA (NJ)									
27.8					0	0	0		0
10	58.7	94	128	221	6	6	12	474,200	25
5	58.7	114	164	278	7	8	15	474,200	32
1.5	58.7	129	189	318	8	9	18	474,200	38
GCUA (NJ)									
32.4					0	0	0		0
10	20.4	19	14	61	1	2	3	231,146	13
5	58.7	19	64	84	1	3	4	474,200	17
1.5	58.7	19	80	99	1	4	5	474,200	22
DELCORA (PA)									
18.4					0	0	0		0
10	38.0	31	7	39	2	0.4	2	519,827	4
5	38.0	89	36	125	6	2	8	519,827	15
1.5	38.0	99	65	164	6	3	10	519,827	19
Wilmington (DE)									
48.3					0	0	0		0
10	76.4	74	22	95	5	1	6	395,782	15
5	76.4	221	108	330	15	5	20	395,782	51
1.5	76.4	248	186	434	17	9	26	395,782	66
Combined Summary									
10.0	705.5	559	530	1,090	37	26	63	3,502,186	18
5.0	705.5	1,007	869	1,876	65	42	109	3,502,186	31
1.5	705.5	1,541	1,142	2,683	102	55	157	3,502,186	45

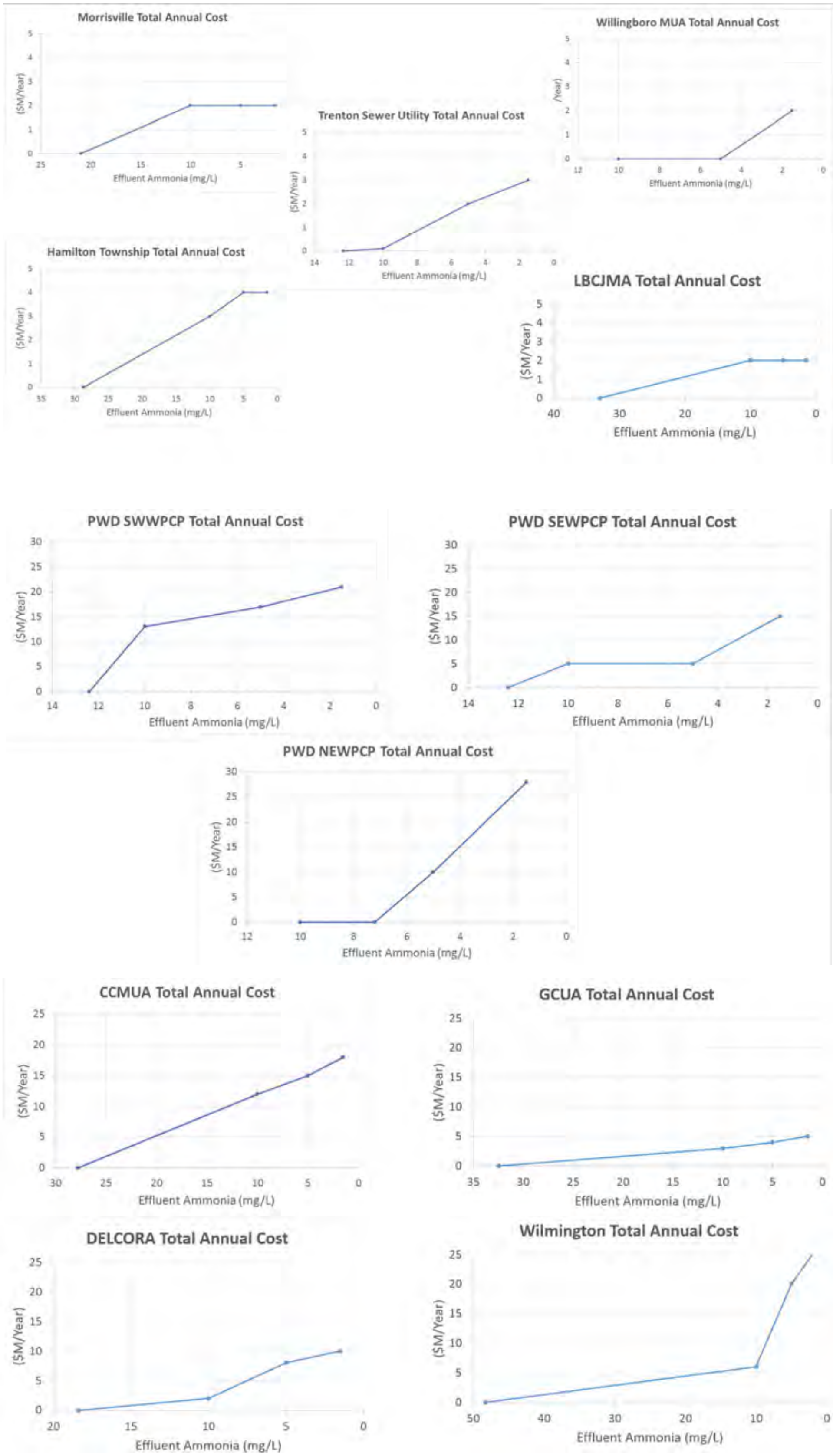


Figure 2.5 Annual cost of ammonia reduction at wastewater dischargers in the Delaware Estuary

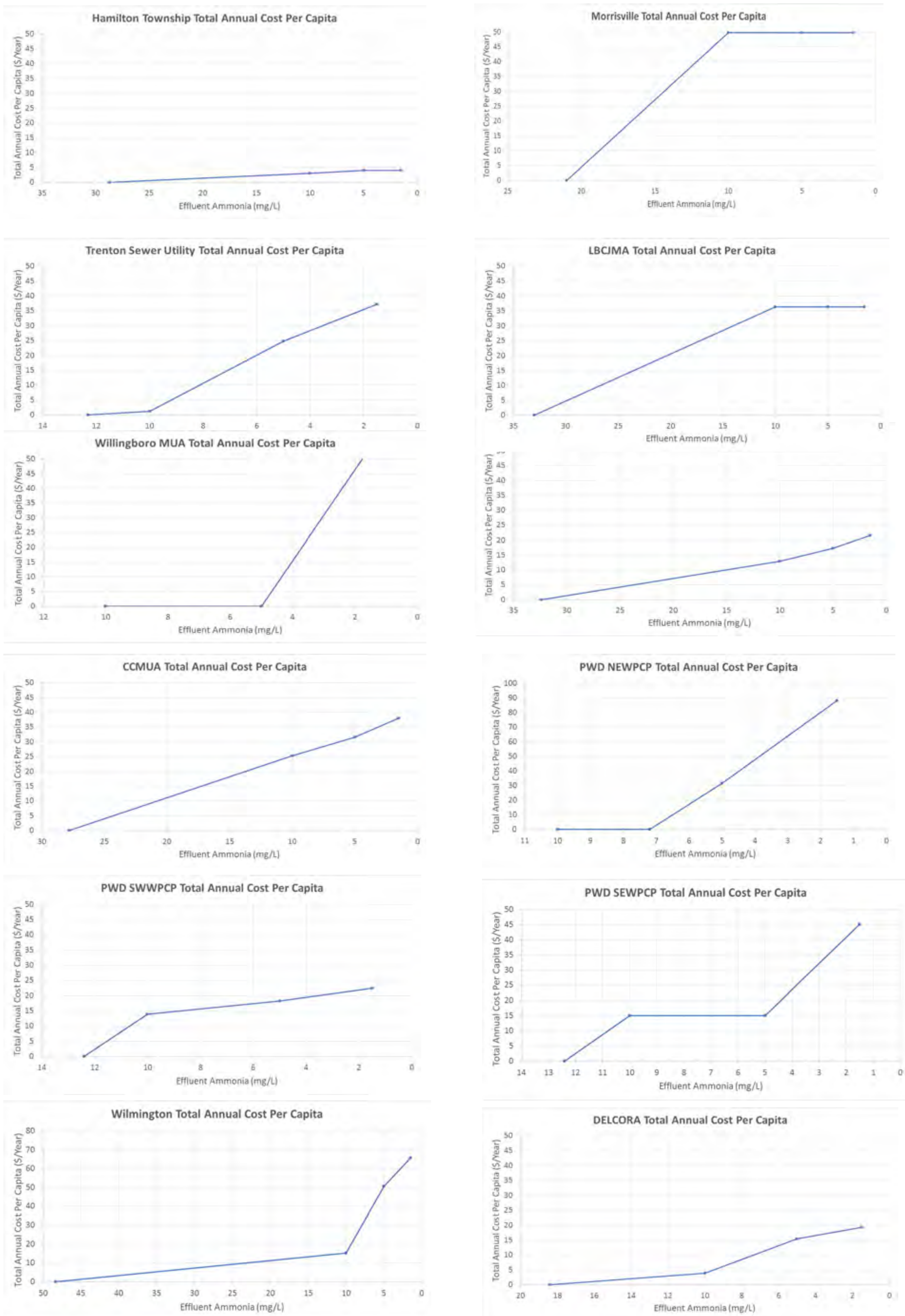


Figure 2.6 Annual cost of ammonia reduction at wastewater dischargers in the Delaware Estuary

Chapter 3: Benefits

Introduction

What are the economic benefits of improved water quality due to ammonia waste load reductions in the Delaware River? This task estimates benefits of improved water quality as DO improves from current (3.5 mg/l) to future conditions for recreation, boating, fishing, wildlife-viewing, property value, other uses. We estimate the economic benefits of improved water quality to increase dissolved oxygen from the existing DRBC 3.5 mg/l criteria to 5 mg/l (potentially) for recreation, boating, fishing, fish/wildlife-viewing, property value, and water supply uses in the Delaware Estuary from Wilmington and Philadelphia to Trenton. Ammonia (NH3-) reductions from the 12 largest wastewater treatment plants between Trenton and Wilmington can increase dissolved oxygen from 3.5 mg/l (existing) to a more protective DRBC standard in the Delaware River and boost boating/fishing trip expenditures, raise property values, and reduce water treatment costs.

In 1966 the FWPCA estimated the benefits of improving DO in the Delaware Estuary from 0 mg/ to to 4.5 mg/l ranged from $160 to $350 million in $1964 and net benefits (benefits minus costs) peaked at $130 million at 3 mg/l DO (Figure 3.1 and Table 3.1).

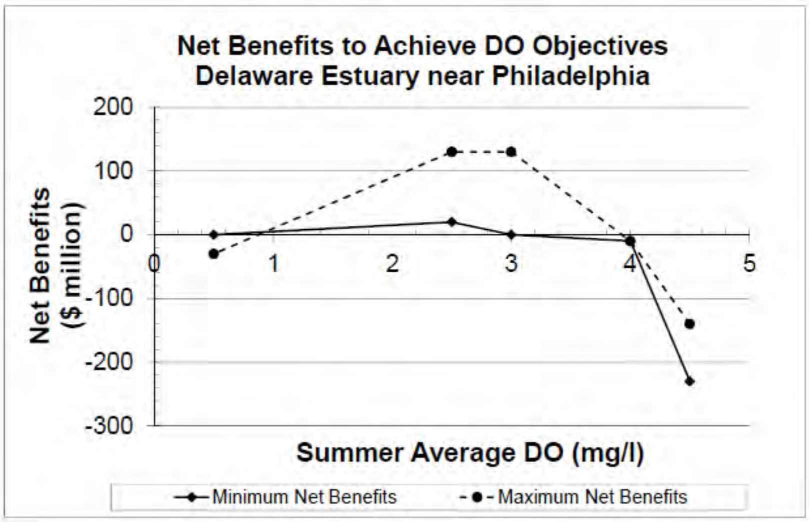


Figure 3.1 Net benefits to achieve DO objectives in Delaware Estuary near Philadelphia (FWPCA 1966)

Table 3.1 Recreation benefits in the Delaware Estuary (FWPCA 1966)

Objective	DO Summer (mg/l)	BOD/COD Residual (lb/day)	% Pollution Removal	Total Benefits ($1964) ($ million)	Marginal Benefits ($1964) ($ million)
I	4.5	100,000	92%-98%	160-350	
II	4.0	200,000	90%	140-320	20-30
III	3.0	500,000	75%	130-310	10-10
IV	2.5	500,000	50%	120-280	10-30
V	0.5	status quo		0	0

Ecological valuation studies have found that benefits of improved water quality in the U.S. range from $5.2 to $42.3 billion/yr (Table 3.2). For instance, water pollution programs authorized by the 1972 and 1977 Federal Clean Water Act amendments resulted in national benefits of $11 billion/yr (Bingham et al. 2000). Leeworthy and Wiley (2001) estimated New Jersey and Delaware on the Delaware River ranked 4th and 19th in estuary recreation activity (Table 3.3).

Table 3.2 Economic benefits of improved water quality in the U.S.

Location	Reference	Benefits ($ billion/yr)	Comments
U.S.	Freeman 1990	5.2	Water treatment/commercial fishing
Urban U.S.	EPA 1994	6.0	Pres. Clinton's Clean Water Initiative
U.S.	Bingham et al. 1995	11.0	Clean Water Act of 1972/1977
U.S.	Carson & Mitchell 1993	39.1	WTP for boatable, fishable, swimmable
U.S.	Freeman 1982	39.6	From 1972 Clean Water Act base
Lower 48 states	Brown 2004	42.3	U.S. Forest Service value of streamflow

Table 3.3 Estuary recreation activity in the Delaware Estuary (Leeworthy and Wiley 2001)

State	Participation (% US pop.)	Participants in State	National Rank
New Jersey	3.02	6,224,769	4
Delaware	1.05	2,168,108	19

Economic benefits from improved water quality are the sum of use and nonuse values (Figure 3.2). Use values include direct market benefits such as sale of fish and drinking water and increased trip and equipment expenditures for recreational viewing, boating, fishing, and hunting (Hodge and Dunn 1992). Indirect use benefits accrue from increased value of properties along restored rivers and water treatment services by wetlands and forests (EPA 2012). Nonuse values are willingness to pay (WTP) by individuals to improve water quality and include existence values from satisfaction that a water resource exists but may never be visited and bequest values from satisfaction that the river will be preserved for future generations (Ingraham and Foster 2008). Nonuse values can be significant (Loomis 2006) and were allowed in court to settle the 1989 Exxon Valdez oil spill in Alaska but were difficult to quantify (Brown 2004).

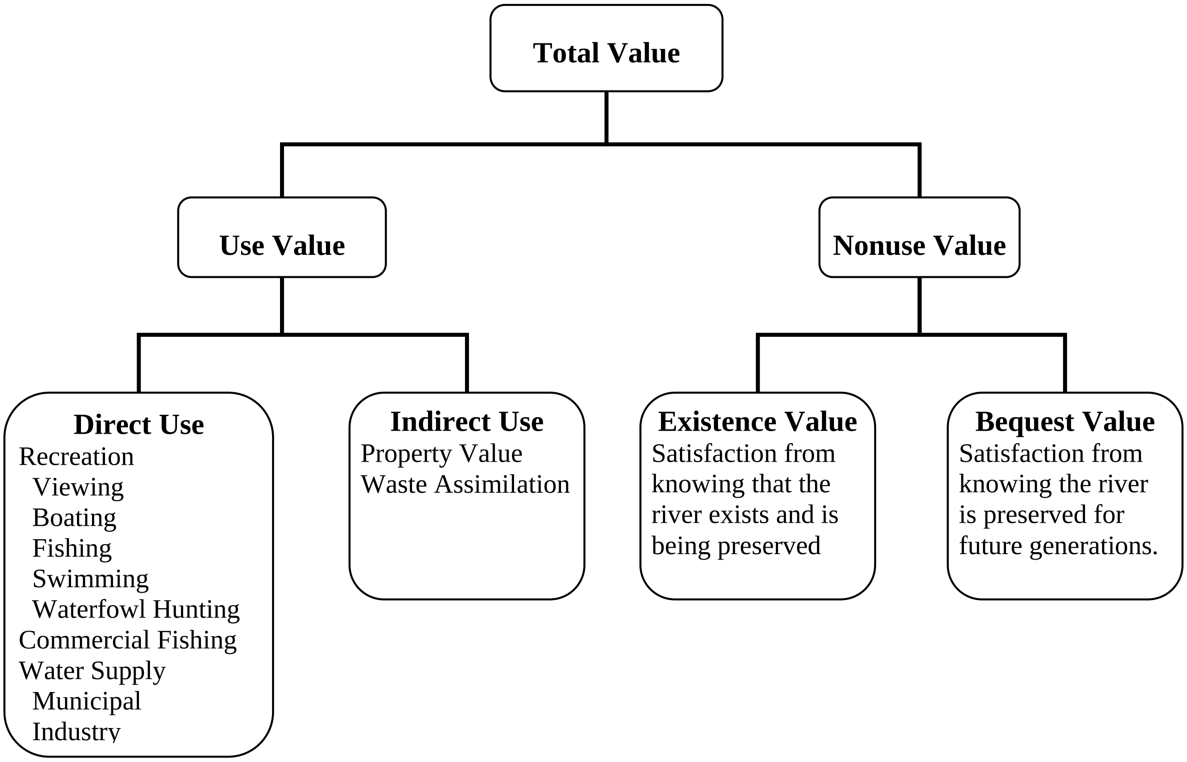


Figure 3.2 Economic benefits of improved water quality in the Delaware River

Methods

The benefits of improved water quality from the existing DRBC DO standard (3.5 mg/l) in the Delaware River to a future year-round fishable standard (5.0 mg/l) are estimated for use (market and nonmarket) and nonuse values (Table 3.4). Use values include recreation (boating, fishing, and swimming), aesthetic (viewing), commercial fishing, waterfowl hunting, navigation, water supply, and property ownership benefits. Nonuse values include existence and bequest benefits based on WTP for improved water quality for existing/future generations.

Table 3.4 Benefits of improved water quality
(Carson and Mitchell 1993, EPA 2012, WBCSD 2011)

Benefit	Category	Examples	Methods
Use	Recreation	Increased boating, fishing, swimming expenditures	Travel Cost
	Aesthetic/Viewing	Commuting, hiking, picnicking, photography	Travel Cost
	Fishing	Commercial	Market Price
	Water Supply	Lowered municipal/industrial water treatment costs	Avoided Cost
	Property Value	Increased river-side property value	Hedonic Price
	Ecosystem	Boating, fishing, bird watching, waterfowl Hunting	Travel Cost
	Navigation	Reduced dredging costs	Avoided Cost
Nonuse	Existence	Relatives, friends, American public	Contingent Valuation
	Bequest	Family, future generations	Contingent Valuation

If primary economic valuation data from the Delaware River are not available, then benefits transfer is used to translate data to the estuary from other watersheds. Benefits transfer extrapolates the benefits from studies in other sites to the watershed in question with appropriate adjustments (EPA 2010). While it has shortcomings, benefit transfer is used to estimate benefits of improved water quality in the Delaware River by applying WTP data from similar settings (Table 3.5).

Table 3.5 Strengths and weaknesses of the benefits transfer approach (EPA 2010 and WBCSD 2011)

Strengths	Weaknesses
Relatively inexpensive and quick to implements	Must be applied transparently to avoid double counting
Most reliable when the original site and study site are similar.	Benefits transfer only as good as the original study site
Used when too expensive or not enough time to conduct original valuation study for watershed	Higher degrees of uncertainty

Due to uncertainty in selection of parameters and transferring data to the Delaware River, low bound benefits are defined based on the population in the wastewater treatment services areas who benefit and upper bound benefits are subscribed to the population in the Delaware Estuary watershed below Trenton and assuming a range in the percent change in benefit due to improved water quality and selecting low and high range unit values (WTP in \$/person). Benefits are converted to 2020 dollars based on the average annual change (2.6% rounded to 3%) in the Consumer Price Index (CPI) in the Northeast Region as reported by the Bureau of Labor Statistics using the following formula.

$$B_{\$2020} = B_b(1+r)^t$$

Where:
$B_{\$2020}$ = Benefit in 2020 dollars
B_b = Benefits estimated for the base year from the literature
r = Change in Consumer Price Index, CPI (3%)
t = time in years between the base year to 2020

For example, benefits of \$1 million estimated in 2010 are worth \$1.34 million in 2020 dollars $1,000,000(1+0.03)^{10}$ = \$1,340,000.

Recreation (Viewing/Boating/Fishing/Swimming)

River and estuary recreational activities such as boating, fishing, swimming, and wildlife watching benefit from improved water quality as measured by dissolved oxygen (Table 3.6).

Table 3.6 Links between recreation activities and improved water quality

Activity	Link to Water Quality
Boating	Dissolved oxygen and clarity
Fishing	Dissolved oxygen and nutrients
Swimming	Bacteria
Bird/Wildlife Viewing	Dissolved oxygen and fish habitat

Recreation benefits due to improved water quality to meet a future year-round fishable DO standard in the Delaware River are estimated by travel cost studies that measure willingness to pay (WTP) to achieve viewing, boatable, fishable, and swimmable uses. Parsons et al. (2003) estimated per person annual benefits for high water quality along rivers are \$2.25 for viewing, \$2.51 for boating, and \$1.86 for fishing in $1994. Converting to $2020 based on a 3% annual change in the CPI, per person benefits to achieve high water quality are $4.85 for viewing, 5.42 for boating, and $4.00 for fishing (Table 3.7).

Table 3.7 Per person recreation benefits due to improved water quality along rivers

Use Support	($1994)[1]	($2020)[2]
Viewing	2.25	4.85
Boating	2.51	5.42
Fishing	1.86	4.00
Total	6.62	14.3

1. Parsons et al. 2003. 2. Adjusted from $1994 to $2020 by 3% annually based on change in CPI.

Low bound annual benefits due to improved water quality are estimated by multiplying the per person benefit in $2020 by the 2020 adult population (3,502,186) in the 12 largest waste water treatment service areas in the Delaware Estuary watershed. From the U.S. Census, 78% of the population is over 18 therefore the WWTP are adult population is 2.73 million (Table 3.8).

Table 3.8 Adult population in the Wastewater Service Area of the Delaware Estuary Watershed

State	2020 Population	% Adult Pop. (> 18 yr)	Adult Pop. (> 18 yr)
Delaware	395,782	78%	308,710
New Jersey	907,321	78%	707,710
Pennsylvania	2,199,084	78%	1,715,286
WWTP Service Area	**3,502,186**	**78%**	**2,731,706**

Low bound annual viewing, boating, and fishing benefits due to attaining high water quality (DO 5 mg/l) in the wastewater service areas in the Delaware Estuary total $38.9 million or $13.2 million for viewing, $14.8 million for boating, and $10.9 million for fishing. (Table 3.9).

Table 3.9 Low bound recreation benefits of improved water quality in the Delaware Estuary

WQ Use	WWTP Area Adult Pop.[1]	High WQ[2] ($2020/person)	Low Bound WQ Benefits ($ mi)
Viewing	2,731,706	4.85	13.2
Boating	2,731,706	5.42	14.8
Fishing	2,731,706	4.00	10.9
Total	**2,731,706**	**14.3**	**38.9**

1. Adult population >18 years old (US Census). 2. Parsons et al. 2003 adjusted to $2020 based on 3% annually.

High bound benefits of improved water quality are defined by multiplying per person benefits in $2020 by the adult population in the Delaware Estuary watershed. Since 78% of the population is over 18 the adult population in the estuary watershed is 5.44 million (Table 3.10).

Table 3.10 Adult population of the Delaware Estuary Watershed in 2020 (U.S. Census)

State	2020 Population	% Adult Pop. (> 18 yr)	Adult Pop. (> 18 yr)
Delaware	748,336	78%	583,702
Maryland	6,458	78%	5,037
New Jersey	1,697,901	78%	1,324,363
Pennsylvania	4,521,138	78%	3,526,488
Delaware Watershed	**6,973,833**	**78%**	**5,439,590**

High bound viewing, boating, and fishing benefits from attaining high water quality (DO 5 mg/l) in the Delaware River is $77.7 million or $26.4 million for viewing, $29.5 million for boating, and $21.8 million for fishing (Tables 3.11, 3.12, and 3.13 and Figure 3.3).

Table 3.11 High bound benefits of improved water quality in the Delaware Estuary Watershed

WQ Use	Estuary Watershed Adult Population[1]	High WQ[2] ($2020/person)	High WQ Benefits ($ mil)
Viewing	**5,439,590**	4.85	26.4
Boating	**5,439,590**	5.42	29.5
Fishing	**5,439,590**	4.00	21.8
Total	**5,439,590**	**14.3**	**77.7**

1. Adult population >18 years old (US Census). 2. Parsons et al. 2003 adjusted to $2020 by 3% annually.

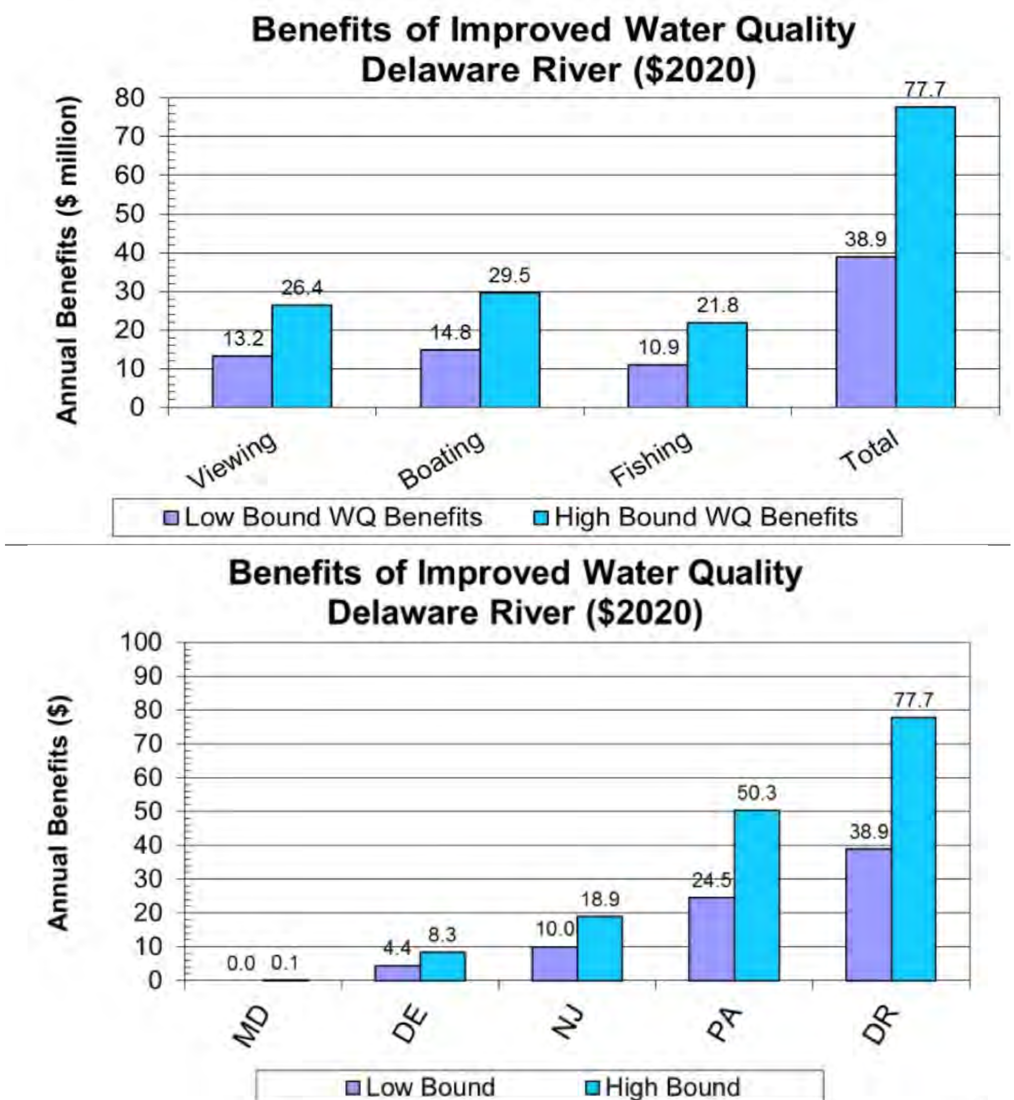


Figure 3.3 Annual recreation benefits due to improved water quality in Delaware River (Parsons et al. 2003 adjusted to $2020 based on 3% annually.)

Table 3.12 Low bound recreation benefits by state for improved water quality in Delaware Estuary

WQ Use Support	2020 Pop.[1]	% Adult Pop. (> 18 yr)	Adult Pop. (> 18 yr)	WQ[2] ($2020/person)	Low Bound WQ Benefits ($ mil)
WWTP Service Area	**3,502,186**	**78%**	**2,731,706**	**14.3**	**38.9**
Viewing	3,502,186	78%	2,731,706	4.85	13.2
Boating	3,502,186	78%	2,731,706	5.42	14.8
Fishing	3,502,186	78%	2,731,706	4.00	10.9
Delaware	**395,782**	**78%**	**308,710**	**14.3**	**4.4**
Viewing	395,782	78%	308,710	4.85	1.5
Boating	395,782	78%	308,710	5.42	1.7
Fishing	395,782	78%	308,710	4.00	1.2
Maryland	**0**	**78%**	**0**	**14.3**	**0.0**
Viewing	0	78%	0	4.85	0.0
Boating	0	78%	0	5.42	0.0
Fishing	0	78%	0	4.00	0.0
New Jersey	**907,321**	**78%**	**707,710**	**14.3**	**10.0**
Viewing	907,321	78%	707,710	4.85	3.4
Boating	907,321	78%	707,710	5.42	3.8
Fishing	907,321	78%	707,710	4.00	2.8
Pennsylvania	**2,199,084**	**78%**	**1,715,286**	**14.3**	**24.5**
Viewing	2,199,084	78%	1,715,286	4.85	8.3
Boating	2,199,084	78%	1,715,286	5.42	9.3
Fishing	2,199,084	78%	1,715,286	4.00	6.9

1. Adult population >18 years old (US Census). 2. Parsons et al. (2003) adjusted to $2020 based on 3% annually.

Table 3.13 High bound recreation benefits by state for improved water quality in Delaware Estuary

WQ Use Support	2020 Pop.[1]	% Adult Pop. (> 18 yr)	Adult Pop. (> 18 yr)	High Bound WQ[2] ($2020/person)	High Bound WQ Benefits ($ million)
Delaware Estuary	**6,973,833**	**78%**	**5,439,590**	**14.3**	**77.7**
Viewing	6,973,833	78%	5,439,590	4.85	26.4
Boating	6,973,833	78%	5,439,590	5.42	29.5
Fishing	6,973,833	78%	5,439,590	4.00	21.8
Delaware	**748,336**	**78%**	**583,702**	**14.3**	**8.3**
Viewing	748,336	78%	583,702	4.85	2.8
Boating	748,336	78%	583,702	5.42	3.2
Fishing	748,336	78%	583,702	4.00	2.3
Maryland	**6,458**	**78%**	**5,037**	**14.3**	**0.07**
Viewing	6,458	78%	5,037	4.85	0.02
Boating	6,458	78%	5,037	5.42	0.03
Fishing	6,458	78%	5,037	4.00	0.02
New Jersey	**1,697,901**	**78%**	**1,324,363**	**14.3**	**18.9**
Viewing	1,697,901	78%	1,324,363	4.85	6.4
Boating	1,697,901	78%	1,324,363	5.42	7.2
Fishing	1,697,901	78%	1,324,363	4.00	5.3
Pennsylvania	**4,521,138**	**78%**	**3,526,488**	**14.3**	**50.3**
Viewing	4,521,138	78%	3,526,488	4.85	17.1
Boating	4,521,138	78%	3,526,488	5.42	19.1
Fishing	4,521,138	78%	3,526,488	4.00	14.1

2. Adult population >18 years old (US Census). 2. Parsons et al. (2003) adjusted to $2020 based on 3% annually.

Recreation and Tourism

There are strong connections between a healthy tourist economy and clean water. In 2009, the travel and tourism industry contributed $379 billion to the U.S. economy or 2.7% of total GDP. Fishing is one of the most profitable recreation sectors in the nation as the American Sportfishing Association found more people in the U.S. fish (30 million) than play golf (24 million) or tennis (10 million). Use values such as fishing depend on adequate DO as a change in DO could reduce the fish catch and decrease the quality of a fishing experience. The National Sanitation Foundation Water Quality Index (Brown et al. 1970) defined water quality levels for fecal coliform bacteria, DO, 5-day BOD, and turbidity (Table 3.14). By the WQI, the Delaware River at Ben Franklin Bridge supports boating (but not rough fishing) in July when DO dips below 3.5 mg/l (46% saturation at 30 deg C). At a future DRBC DO criteria of 5.0 mg/l (66% saturation at 30 deg C), water quality would improve to support game fishing.

Table 3.14 National Sanitation Foundation water quality index (Brown et al. 1970)

Water Quality Classification	Fecal Coliform (#/100 ml)	DO[1] (mg/l)	5-day BOD (mg/l)	Turbidity (NTU)
Drinking w/o Treatment	0	7.0 (90%)	0.0	5
Swimming	200	6.5 (83%)	1.5	10
Game Fishing	1,000	5.0 (66%)	3.0	50
Rough Fishing	1,000	4.0 (51%)	3.0	50
Boating	2,000	3.5 (46%)	4.0	100

1. Dissolved oxygen in mg/l and % saturation at 30 deg C.

Rosenberger and Loomis (2000) from Oregon State University College of Forestry compiled a national database of mean consumer surplus for recreational activities (Table 3.15). In the Mid-Atlantic census division (NY, NJ, PA), the Outdoor Industry Association (2006) estimated fishing has 1.9 million participants who purchase $1.8 billion in gear/trip sales, paddling has 1.6 million participants who purchase $784 million in gear/trip sales, and wildlife viewing has 5 million participants who purchase $1.8 million in gear/trip sales. The Delaware Estuary watershed is home to 6,973,833 people in NJ, NY, and PA or 18.5% of the mid-Atlantic region's population of 40,800,000. Scaling by population, outdoor recreation in the Delaware Basin contributes to the fishing ($327 million in sales), paddling ($145 million in sales), and wildlife viewing ($325 million in sales) economies.

Table 3.15 Summary of recreational activity consumer surplus studies in $2000 (Rosenberger and Loomis 2000)

Recreation Activity	No. of Studies	No. of Use Value Estimates	Consumer Surplus ($/person/day)
Motorboating	2	2	24.05
Rafting/Canoeing	1	2	36.44
Freshwater Fishing	8	14	29.53
Sightseeing/Wildlife Viewing	7	8	25.32
Picnicking	2	2	17.33
Hiking	3	4	53.96

Boating

Recreational boating provides significant contributions to the water-based economy. The U.S. Forest Service estimated 89 million people or 36% of the U.S. population participate in recreational boating such as kayaking, canoeing, sailing, and motor boating (EPA 2012). While water quality standards for non-contact recreation boating are not as stringent as fishing and swimming, the benefits are sizeable due to the large number of registered boats that cruise on estuaries (Cropper and Isaac 2011).

The National Marine Manufacturers Association (2018) reported Delaware, Pennsylvania, and New Jersey were ranked 7th, 17th, and 23rd in the U.S. in expenditures for powerboats, outboard engines, boat trailers, and accessories. Based on proportion of estuary watershed to state population, scaled estimate of estuary powerboat expenditures is $392 million/yr (Table 3.16).

Table 3.16 Recreational powerboat expenditures in the Delaware Estuary watershed (NMMA 2010)

State	Rank in Expenditures	Powerboat Expenditures ($ million)	% Pop. of State in watershed	Del. Estuary Watershed ($ mil)
Delaware	7	344	77%	265
New Jersey	23	183	19%	35
Pennsylvania	17	226	35%	79
Total		**753**		**379**

Pennsylvania, New Jersey, and Delaware were ranked 13th, 28th, and 40th in recreational boat registrations in 2018 with a scaled estimate of 198,643 registrations in the Delaware Estuary watershed (Table 3.17).

Table 3.17 Recreational boat registrations in the Delaware River Basin (NMMA 2018)

State	Rank Registrations	Total Boat Registrations	% Pop. of State in watershed	Del. Basin Boat Registrations
Delaware	40	61,523	77%	47,373
New Jersey	28	173,994	19%	33,059
Pennsylvania	13	337,747	35%	118,211
Total		**573,264**		**198,643**

Recreational boating benefits are estimated by multiplying the number of boating activity days in the Delaware Estuary by lower and upper bound estimates of daily recreation value ($/day) from the literature and then multiplying by a percentage increase in benefits as water quality improves from existing DO (3.5 mg/l) to a future DRBC standard (5.0 mg/l). Approximately 394,000 recreational boaters participate in 5.3 million activity days per year in the Delaware Estuary (Table 3.18). In the Delaware Estuary, approximately 100,000 people in Delaware and 149,000 in New Jersey participated in recreational boating such as motorboating, sailing, canoeing, kayaking, and rowing based on scaled estimates from the National Survey on Recreation and the Environment (Leeworthy et al. 2001). In Pennsylvania 145,000 boaters visit the estuary based on a scaled estimate of boat registrations reported by NMMA (2010).

Table 3.18 Recreational boating participants along the Delaware Estuary

Boating Activity	Delaware Participants		New Jersey Participants		Pennsylvania Participants		Estuary Watershed
	State	**Watershed[1]**	**State**	**Watershed[1]**	**State**	**Watershed[2]**	
Motorboat	381,000	72,000	894,000	98,000	338,000	145,000	315,000
Sailing	70,000	13,000	252,000	28,000			
Canoeing	39,000	7,000	66,000	7,000			
Kayaking	21,000	4,000	96,000	11,000			
Rowing	16,000	3,000	47,000	5,000			
Total	527,000	100,000	1,355,000	149,000	338,000	145,000	394,000
	Delaware Boating Days		**New Jersey Boating Days**		**Penna. Boating Days**		**Estuary Days**
	State	Watershed[1]	State	Watershed[1]	State	Watershed[2]	
	6,200,000	1,178,000	18,900,000	2,079,000	4,718,000	2,030,000	5,287,000

1. Leeworthy et al. 2001 and 2005, then scaled by percent of marinas in watershed in Del. (19%) and NJ (11%).
2. Scaled by boat registrations from NMMA 2010.

The unit value of recreational boating ranges from $40.32/day on the Peconic Estuary on Long Island, NY to $88.46/day based on a survey of 287 studies by the US Forest Service in $2020 (Table 3.19).

Table 3.19 Consumer surplus for recreational boating

Source	Consumer Surplus ($/person)		Comments
	($)	($2020)[1]	
Johnston et al. 2002	19.23	40.32	Peconic Estuary on Long Island, NY
Bergstrom and Cordel 1991	22.53	45.72	Recreation visitors studies at 200 sites
Kaval and Loomis 2003	24.73	50.18	Northeast Region National Park Service
Walsh et al. 1992	43.59	88.46	Survey of 287 TC and CV studies for Forest Service

1. Converted to $2020 based on average 3% change in CPI.

Several studies demonstrate that improved water quality measured by DO provides significant recreational boating benefits. Smith and Desvouges (1986) found that if DO saturation increases by 1% due to pollution abatement, then boatable benefits improve by $1.54/trip in $1986 or $4.21/trip in $2020. Therefore, if DO in the Delaware River improves from existing 3.5 mg/l (46% saturation at 30 deg C) to 5.0 mg/l (66% saturation), then boatable benefits improve by $84/trip (20% increase in DO saturation x $4.21/trip).

The low bound value of existing recreational boating is $212 million determined by multiplying the low estimate of $40/trip by 5.3 million activity days. The low bound benefit of improved water quality is $61 million determined by multiplying 394,000 boaters by per participant benefits of $156/yr per boater in $2020 translated from Bockstael et al. (1989). The upper bound value of recreational boating is $472 million determined by multiplying 5.3 million activity days by the high estimate of $89/trip. The high bound benefit of improved water quality is $350 million determined by multiplying 394,000 added participants by unit benefits of $84/trip in $2020 translated from Smith and Desvouges (1986). Improved water quality in the Delaware Estuary provides annual recreational boating benefits that range from $61 to $350 million (Table 3.20).

Table 3.20 Recreational boating benefits due to improved water quality in the Delaware Estuary

Estimate	Unit Value ($2020/day)	Boating Activity (million days	Existing Value ($ million)	Boating Participants	WQ Benefit ($)	Benefit ($ million)
Lower Bound	40	5.3	212	394,000	$156/boater	61
Upper Bound	89	5.3	472	394,000	$84/trip	350

The estimates of existing value ($212 to $472 million/yr) from the unit day method compares favorably to the National Marine Manufacturers Association (2018) study that revealed scaled powerboat expenditures within the Delaware Estuary watershed were $379 million/yr with $265 million in Delaware, $35 million in Pennsylvania, and $79 million in New Jersey.

Recreational Fishing

Recreational fishing is one of the most popular outdoor recreation activities in America (EPA 2012). The U.S. Fish and Wildlife Service (2008) reported 25 million anglers fished 433 million days and took 337 million trips while spending $26 billion on fishing trips and equipment or $78 per trip. If improved water quality led to just a 10% increase in fishing enjoyment and trip/equipment expenditures, then added national benefits would be $2.6 billion.

Impaired water quality can have negative impacts on recreational fishing (EPA 2012). Contamination of fisheries from toxics such as metals, PCBs, and pesticides causes public health problems for people who eat fish. Excess nutrient loads coupled with high temperatures cause eutrophication that depresses DO and fish abundance and produces algae blooms that increase turbidity and cause undesirable aesthetic issues. Bacteria and pathogens contaminate shellfish.

Improved water quality increases the fish that anglers catch and enhances the value of fishing trips. Revealed preference studies measure fish catch and travel costs to estimate the value of a fishing day. Stated preferences sum the increased value of fishing by asking fishers what they would pay for increased catch or how many more trips they would take if the catch increased.

Using the unit day approach, the existing value of recreational fishing is estimated by multiplying the number of fishing activity days by the participant's willingness to pay for fishing from a synthesis of travel cost studies. Recreational fishing benefits due to improved water quality in the Delaware Estuary (DO 3.5 mg/l to future 5.0 mg/l) are defined by multiplying existing value by a percentage increase in value acquired from the literature. Recreational fishing benefits are derived from WTP literature for lower and upper bound estimates.

Recreational anglers take 4.2 million to 7.9 million fishing trips per year to the Delaware River and Bay (Table 3.21). Scaled data from the National Survey of Fishing, Hunting, and Wildlife Recreation (USFWS 2016) indicate anglers spent $333 million on 5.2 million fishing trips during 2020 to the Delaware River and Bay or $64/day (Table 3.22). The NMFS (2001) and EPA (2002) reported that recreational anglers spent 5.4 million days fishing in the Delaware Bay and nearby Atlantic Ocean in Delaware and New Jersey. The National Survey on Recreation and the Environment (Leeworthy and Wiley 2001) reported marine anglers participated in 8.1 million and 14.7 million fishing activity days in Delaware and New Jersey which when scaled by proportion of watershed area to state area, indicates that anglers in Delaware and New Jersey participated in 7.9 million fishing days in the Delaware Estuary (Table 3.23).

Table 3.21 Recreational fishing days in the Delaware River and Bay

Source	Fishing Days (million)
USFWS 2011	5.2
NMFS 2001, EPA 2002	5.4
Leeworthy and Wiley 2001	7.9

Table 3.22 Recreational fishing activity along the Delaware River and Bay

Activity	DE by State[1]	NJ by State[1]	PA by State[1]	Total by State	DE watershed[2]	NJ watershed[2]	PA watershed[2]	Watershed Total
Fishing Days (mil)	1.8	8.8	18.0	28.6	0.9	2.3	2.0	5.2
Expenditures ($ mil)	97	753	1,293	2,142	48	195	90	333
$/Day	53	85	72	75	53	85	45	64

1. USFWS 2011. 2. Scaled by ratio area of state in watershed to state area, Del. (0.50), NJ (0.26), Pa. (0.07).

Table 3.23 Recreational fishing in Delaware Bay and Atlantic Coast, Delaware and New Jersey (EPA 2002 and NMFS 2001)

Fishing Mode	Delaware Fishing Days	New Jersey Fishing Days	Estuary Fishing Days
Private/Rental Boat	391,000	2,596,000	2,987,000
Shore	367,000	1,597,000	1,964,000
Charter Boat	43,000	404,000	447,000
Total	801,000	4,597,000	5,398,000

Table 3.24 Delaware Estuary recreational fishing days, 2000 (Leeworthy and Wiley 2001)

State	Statewide Fishing (million days)	% of State Area in Watershed	Del. Estuary Fishing (million days)
Delaware	8.1	50%	4.0
New Jersey	14.7	26%	3.8
Total			7.9

The value of recreational fishing ranges from $53/trip to $101/trip in $2020 (Table 3.25). The national survey of marine fishing found average recreational fishing trip cost was $65.99 (EPA and NMFS 2002). The U.S. Fish and Wildlife Service (2008) reported fishing equipment and travel expenditures averaged $100.79 per trip in Delaware, New Jersey, and Pennsylvania.

Table 3.25 Recreational fishing value studies

Region/State	Source	Value ($/trip)	2020[1] ($/trip)	Methods
National	Rosenberger and Loomis 2000	29.53	53.32	Mean of Studies
Northeast Region	Kaval and Loomis 2003	27.17	55.14	Mean of Studies
Delaware	McConnell and Strand 1994	26.59	57.34	Travel Cost/Random Utility
National	Walsh et al. 1992	32.52	49.11	Travel Cost/CV studies
National	EPA and NMFS 2002		65.99	Travel Cost
New York	Johnston et al. 2002	40.25	84.38	Travel Cost
DE, NJ, PA	USFWS 2008	75.00	100.79	Trip/Equipment Expenditures

1. Converted to $2020 based on 3% change in CPI.

Improved water quality can increase the number of fish that anglers catch on a fishing day and increase the value of fishing trips. Using a travel cost model, Lipton and Hicks (1999 and 2003) found a 2.4 mg/l increase in DO in Chesapeake Bay could increase recreational striped bass and other recreational species catch rates by 95%. By interpolation, a 1 mg/l improvement in DO would increase recreational catch rates by 40%; therefore, a 1.5 mg/l improvement in DO from existing level of 3.5 mg/l in the Delaware River to a future standard of 5.0 mg/l would increase recreation benefits by 60%. Van Houtven (2009) assumed that the change in catch for a 1-mg/l change in DO is the same for striped bass and flounder as well as other species

The annual value of recreational fishing in the Delaware Estuary ranges from $286 to $454 million estimated by multiplying the low bound trip value ($53/trip) by 5.4 million fishing trip days and upper bound value ($101/trip) by 4.5 million fishing trip days. If a 1.5 mg/l improvement in DO in the Delaware Estuary (from 3.5 mg/l to 5.0 mg/l) leads to a 60% increase in recreational fishing activity/expenditures, the added benefits range from $172 to $315 million/yr (Table 3.26).

Table 3.26 Recreational fishing benefits due to improved water quality in the Delaware Estuary

Estimate	Unit Value ($2020/day)	Activity (million days)	Existing Value ($ million)	Benefit with Improved DO (3.5-5.0 mg/l)	Rec. Fishing Benefit ($ million)
Lower Bound	53	5,400,000	286	60%	172
Upper Bound	101	5,200,000	525	60%	315

The existing value of recreational fishing from the unit day approach ($286-$525 million) compares favorably with scaled estimates from the Outdoor Industry Association (2006) that reported fishing in the Delaware Estuary watershed is practiced by 350,000 participants who spend $327 million for gear and trip expenditures.

Recreational Shad Fishing

The Pennsylvania Fish and Boat Commission (2011) referenced a 1986 study of shad fishing on the Delaware River that estimated anglers made 63,000 trips over 299,597 hours and spent an average of $25.40 per trip on gasoline, food, lodging, and tackle. Multiplied by 63,000 trips in 1986, anglers spent $1.6 million during a nine-week season which adjusts to $3.2 million in $2010. The average shad angler was willing to pay $50 per day of shad fishing or $102 per day when adjusted to $2010. Multiplied by 63,000 angler days, the annual economic value based on willingness to pay for the Delaware River shad fishery was $3.2 million in 1986 or $6.5 million adjusted to $2010. If DO in the Delaware Estuary improves from 3.5 mg/l to a future standard of 5.0 mg/l, shad fishing activity is projected to increase by 60% for benefits of $3.9 million/yr.

Wildlife and Bird Watching

Wildlife and bird watching are water-dependent activities that significantly contribute to the U.S. recreation economy. Approximately 15 million people spent 900 million days on bird watching trips along waterways and another 13 million people spend 341 million days watching wildlife. (Pendleton undated). The U.S. Fish and Wildlife Service (2008) recorded that 71 million people or 22% of the U.S. population participated in bird and wildlife watching. Improved water quality increases bird and wildlife abundance and reduces unpleasant odors from water pollution and therefore enhances the aesthetic appeal to the viewer during the recreation trip (EPA 2012).

Bird and wildlife watching is a significant part of the Delaware Estuary ecological economy. In 2006, the John Heinz National Wildlife Refuge at Tinicum Marsh in Philadelphia had 106,491 visitors who spent $1.1 million on trip and equipment expenditures. An EPA (1994) national demand for water recreation report estimated 1.4 million people took 5.1 million trips for recreational wildlife viewing along the Delaware River. Scaling based on the area of each state within the watershed, the National Survey on Recreation and the Environment (Leeworthy et al. 2001) indicates that 325,000 bird/wildlife watchers in Delaware participated in 9.7 million activity days and 360,000 bird/wildlife watchers in New Jersey participated in 7.0 million days along the Delaware Estuary (Table 3.27).

Table 3.27 Bird/wildlife watching along the Delaware Estuary

	Delaware		New Jersey	
Recreation Activity	**State Participants**	**Watershed[1] Participants**	**State Participants**	**Watershed[1] Participants**
Bird Watching	428,000	214,000	795,000	207,000
Viewing Other Wildlife	221,000	111,000	592,000	154,000
Total	650,000	325,000	1,386,000	360,000
Recreation Activity	**State Activity Days**	**Watershed Activity Days**	**State Activity Days**	**Watershed Activity Days**
Bird-Watching	14,027,000	7,013,000	18,804,000	4,889,000
Viewing other Wildlife	5,461,000	2,730,000	8,293,000	2,156,000
Total	19,488,000	9,744,000	27,097,000	7,045,000

1. Leeworthy et al. (2001, 2005). Scaled by area of watershed in Delaware (50%) & New Jersey (26%).

About 861,000 to 923,000 visitors spent $430 to $437 million on trip/equipment expenditures to go wildlife watching in the Delaware Estuary watershed in Delaware, New Jersey, and Pennsylvania. Scaled data from the USFWS (2011) indicates 860,860 participants engaged in bird/wildlife watching in the Delaware Basin during 3.1 million visitor days in 2010 and spent $430 million/yr for trip (food, lodging, transportation) and equipment expenditures or $139 per day (Table 3.28). Scaled by estuary population, the Outdoor Industry Association (2006) reported 923,000 people participating in wildlife viewing in a $325 million program in the Delaware Estuary watershed or $437 million in $2020.

User day values for wildlife viewing range from $59.05 (Kaval and Loomis 2003) to $123.64 (USFWS 2011) in $2020 (Table 3.29). In the Delaware Estuary watershed, wildlife and bird watchers spent $123.64/visit in $2020 from the U.S. Fish and Wildlife Service (2008).

Table 3.28 Bird/wildlife watching activities along the Delaware River

Fishing Activity	DE by State[1]	NJ by State[1]	PA by State[1]	Total by State	DE in watershed[2]	NJ in watershed[2]	PA in watershed[2]	Del. Estuary Watershed
Participants	243,000	1,875,000	3,598,000	5,716,000	121,500	487,500	251,860	860,860
Watching Days (mil)	1.6	6.2	9.6	17.4	0.79	1.6	0.67	3.1
Expenditures ($ mil)	170	986	1,271	2,427	85	256	89	430
$/Day	106	159	132	397	108	160	133	139

1. USFWS 2011. 2. Scaled by ratio of area in watershed to state area, Del. (0.50), NJ (0.26), Pa. (0.07).

Table 3.29 Consumer surplus for recreational bird/wildlife watching

Source	Consumer Surplus ($/trip)		Comments
	($)	($2020)[1]	
Kaval and Loomis 2003	29.05	59.05	Northeast Region National Park Service
Walsh et al. 1992	43.59	62.90	Survey of 287 TC and CV studies for Forest Service
Johnston et al. 2002	49.83	104.46	Peconic Estuary on Long Island, NY
U.S. Fish and Wildlife Service 2008	92.00	123.64	Trip and equipment expenditures

1. Converted to $2020 based on average annual 3% change in CPI.

The existing recreational value of bird and wildlife watching ranges from $430 to $437 million in $2020 based on scaled data from the U.S. Fish and Wildlife service (2011) and the Outdoor Industry Association (2006). Bird and wildlife viewing benefits are estimated by multiplying existing recreation value by an estimated 5% and 10% increase in value due to improved water quality. Bird and wildlife watching benefits due to improved water quality along the Delaware Estuary range from $22 million to $43 million per year (Table 3.30).

Table 3.30 Recreational wildlife/bird watching benefits in the Delaware Estuary

Estimate	Participants	Existing Value ($ million)	Increase Improved WQ	Benefit ($ million)
Lower Bound	860,860	437	5%	22
Upper Bound	923,000	430	10%	43

Waterfowl Hunting

Waterfowl hunting satisfaction depends on healthy water quality and habitat. Approximately 1.3 million people in the U.S. hunted for waterfowl such as ducks and geese on 13 million hunting days and spent $900 million in trip/equipment expenditures in 2006 or $69/trip (USFWS 2008). Along the Delaware Estuary, approximately 6,000 people in Delaware hunt for waterfowl during 82,000 activity days with annual trip and equipment expenditures of $1.4 million or $17/trip (USFWS 2008). The National Survey of Coastal Recreation (Leeworthy et al. 2001) reported 11,565 people in Delaware and 4,782 people in New Jersey hunted for waterfowl along the Delaware Estuary during 161,910 days in Delaware and 66,948 days in New Jersey (Table 3.31).

Table 3.31 Waterfowl hunting along the Delaware Estuary in Delaware and New Jersey

Source	Delaware		New Jersey	
Source	State Activity Days	Watershed[1] Activity Days	State Activity Days	Watershed[1] Activity Days
USFWS 2011	83,000	41,500	225,000	58,500
Leeworthy et al. (2001)	324,000	162,000	167,000	67,000

1. Scaled by % of state area within Delaware Basin, Delaware (50%) and New Jersey (26%).

The existing recreational value of waterfowl hunting ranges from $1.9 million to $21.3 million determined by multiplying lower and upper bound estimates of consumer surplus by the number of activity days (Table 3.32). Waterfowl hunting benefits due to improved water quality range from $90,000 to $2.1 million per year by multiplying existing recreation value by an estimated 5% and 10% increase in value due to improved water quality.

Table 3.32 Recreational waterfowl hunting benefits in the Delaware Estuary

Estimate	Unit Value ($2010/day)	Activity Days	Existing Value ($ mil)	WQ Benefit	Benefit ($)
Lower Bound	23	82,000	1.9	5%	0.09
Upper Bound	93	229,000	21.3	10%	2.1

Swimming

Excellent water quality is necessary to support swimming which DRBC defines as primary contact recreation with bacteria criteria not to exceed 100 #/100 ml. High pathogen and bacteria levels can infect swimmers and cause gastrointestinal upset and diseases such as cholera, hepatitis, and dysentery. High nutrient loads can cause algae blooms that reduce water clarity and cause odor problems that are highly disagreeable to swimmers.

Water pollution control programs that improve water quality to the highest standard can significantly enhance the swimming experience. Swimming is the recreational activity that benefits the most from improved water quality. Carson and Mitchell (1993) estimated national Clean Water Act swimmable benefits ranged from $24 to $40 billion per year in $1990.

Public access areas on public and private land along the Delaware River and Bay provide entrance for boating, fishing, swimming, and water-borne recreational activities. Federal, state, and local governments and private marinas own 55 public access areas along 133 miles of the Delaware Estuary between Cape Henlopen and the head of tide at Trenton which is a density of about one access point for every 2 river miles. Recreational swimming benefits from improved water quality may be difficult along the tidal Delaware River. Due to swift tidal currents, high bacteria levels, and lack of sandy public beach access; very little swimming occurs along the Delaware River between Trenton and the C&D Canal. Swimming does occur along Delaware and New Jersey beaches at the southern end of the Delaware Bay where water quality is already quite good due to the cleansing saltwater from the nearby Atlantic Ocean. Economic benefits of achieving swimmable water quality in the Delaware Estuary between Wilmington and Trenton are estimated as willingness to pay under the nonuse benefits analysis.

Beach Going

Beaches are tourist destinations in the U.S. that rely on clean water to support recreational activities such as swimming, boating, fishing, sunbathing, collecting seashells, walking, jogging, and viewing birds and wildlife (Pendleton undated). Every year the public take about 853 million beach day trips throughout the U.S. (Leeworthy and Wiley 2001). Scaling by the state area in the watershed, tourists account for 6.4 million beach visits in Delaware and 9.7 beach visits in New Jersey in the Delaware Estuary watershed (Table 3.33). Approximately 5% of beach visits (322,000 in Delaware and 531,000 in New Jersey) occur on the Delaware River above the C&D Canal in the reach that benefits from improved water quality.

Table 3.33 Beach activity in the Delaware Estuary

Activity	Delaware		New Jersey	
	State Activity Days	Watershed[1] Activity Days	State Activity Days	Watershed[1] Activity Days
Beach Visits (below C&D Canal)	12,233,000	6,117,000	38,837,000	10,098,000
Beach Visits (above C&D Canal)	644,000	322,000	2,044,000	531,000
Beach Visits (Delaware Estuary)	12,877,000	6,438,000	40,881,000	10,629,000

1. Leeworthy and Wiley 2001. 2. Scaled by state area in watershed, Delaware (50%) and New Jersey (26%).

Studies along the mid-Atlantic U.S. concluded that mean consumer surplus for a beach trip ranges from $5.36 to $31.45 per activity day or $10.29 to 74.10 per day in $2020 (Table 3.34).

Table 3.34 Beach visitor studies in the mid-Atlantic U.S.

State	Author/Date	Consumer Surplus ($/day)	Consumer Surplus[1] $2020/day	Methods
Massachusetts	Kline and Swallow 1998	5.36	10.29	
Delaware, New Jersey	Parsons et al. 1999	12.70	23.62	Travel Cost/Random Utility
New Jersey	Leeworthy and Wiley 1991	31.45	74.10	Travel Cost

1. Adjusted to $2010 based on 3% change in Consumer Price Index for Northeast Region (BLS).

Studies in the Chesapeake Bay watershed indicate that water quality improvements can provide beach going benefits (Cropper and Isaac 2011). Bockstael et al. (1989) conducted a travel cost survey of 484 visitors to 11 beaches on the western shore of the Chesapeake Bay and concluded the average per-trip benefits of a 20% reduction in TNP results in a 20% increase in beachgoing activity or $19.86/trip in $1987 which would be $52.68/trip in $2020. Hicks and Strand (2000) reported a mean benefit of $29 per beachgoer in $1987 for a 40% reduction in fecal coliform levels. Krupnick (1988) used Bockstael et al. (1989) to estimate the beach going benefits of 40% reduction in TNP that resulted in 40% increase in beach going activity. Morgan and Owens (2001) used Bockstael et al. (1989) to estimate a 60% increase in beach going benefits due to a 60% reduction in TNP to residents of Maryland, Virginia, and the District of Columbia.

The existing value of beach going to the Delaware Estuary above the C&D Canal ranges from $9 to $63 million/yr based on multiplying the scaled activity day estimates by a low and high estimate of the daily use value/person from the literature. The benefits of improved water quality on beach going in the Delaware Estuary ranges from $3 to $20 million by transferring the findings from Bockstael et al (1989). A 20% reduction in TNP resulted in a 20% increase in beach going activity which by similarity supposes that a 32% reduction in nitrogen would result in a 32% increase in beach going benefits in the Delaware Estuary (Table 3.35).

Table 3.35 Recreational beach visitor benefits in the Delaware Estuary

Estimate	Unit Value ($2020)	Beach Activity Days[1]	Existing Value ($ million)	Increase Improved WQ	Benefit ($ mil)
Lower Bound	10.29	854,000	9	32%	3
Upper Bound	74.10	854,000	63	32%	20

Commercial Fishing

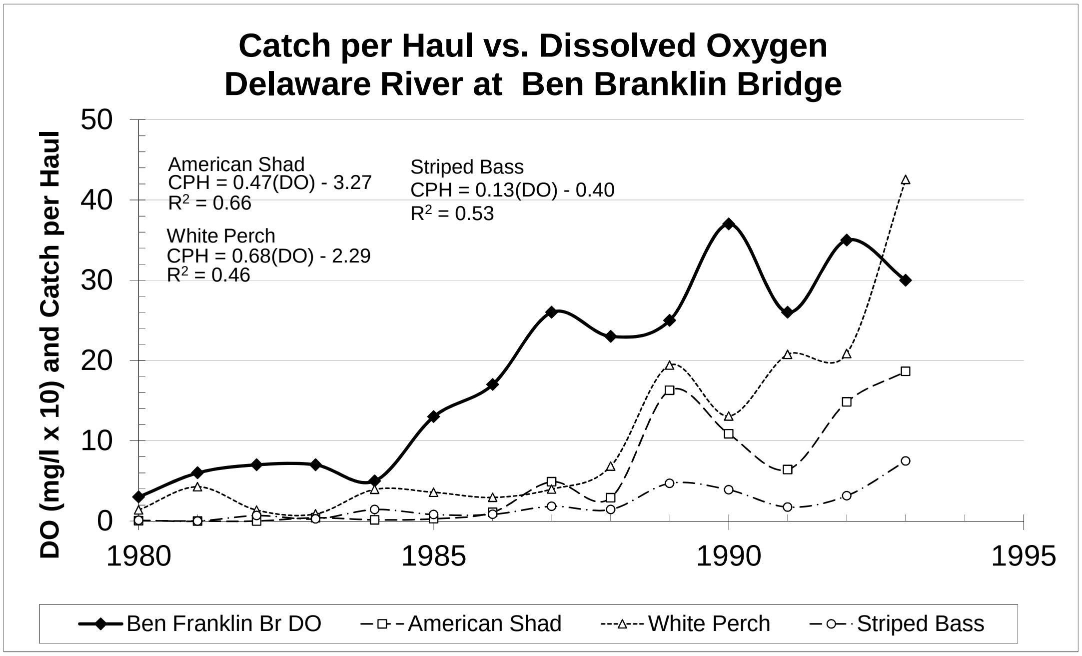
Commercial fishing benefits are calculated by estimating the increase in catch per unit effort from improved water quality. Poor water quality and low dissolved oxygen levels depress fish populations due to disease, mortality, decreased body weight, and disrupted spawning patterns. Commercial fishing is a marine industry so important to the economy that an entire Federal agency within the Department of Commerce, the NOAA National Marine Fisheries Service (NMFS), is charged with its management (Pendleton undated). In 2004, the top 10 U.S. commercial fish species had a landed value of just over $2 billion as recorded by the NMFS. (National Ocean Economics Program 2010).

Improved water quality in estuaries can boost fish harvests, increase fishermen income, and reduce the price paid by the public for seafood (Cropper and Isaac 2011). A 1.6 mg/l decline in DO from 5.6 to 4.0 mg/l in the Patuxent, Chester, and Choptank tributaries of the Chesapeake Bay reduced blue crab harvests by 49% (Mistiaen et al. 2003). Smith (2007) estimated that for every 1% reduction in nitrogen load, the blue crab catch in North Carolina increased by 1%. Weisberg et al. (1996) observed that a 50% increase in dissolved oxygen in the Delaware Estuary led to a 50% increase in catch per unit haul of striped bass, American shad, and white perch.

From 1990-1999, the NMFS reported the commercial market value of striped bass landings in the Delaware Bay was almost $10 million or 3.8 million pounds valued at $3.5 million in Delaware ($0.92/lb) and 10.4 million pounds worth $6.4 million in New Jersey ($0.61/lb).

Improved water quality corresponds with higher fish catch in the Delaware Estuary. In the Delaware Estuary from 1880-1980, Summers et al. (1987) found DO was positively correlated with fish abundance and accounted for at least 65% of stock variation for scup ($r^2 = 0.82$), white perch ($r^2 = 0.82$), summer flounder ($r^2 = 0.75$), bluefish (r^2=0.67), and oyster ($r^2 = 0.65$). A 50% increase in dissolved oxygen in the Delaware Estuary at Ben Franklin Bridge and Chester, Pennsylvania between 1980 and 1993 correlated with a 54% increase in catch per haul of American shad ($r^2 = 0.56$ to 0.66), a 43%-47% increase in striped bass catch ($r^2 = 0.37$ to 0.53), and a 47%-50% increase in white perch catch (r^2=0.46 to 0.49) as shown in Figure 3.4 (Weisberg et al. 1996). If water quality improves by 50% from the existing DRBC DO standard of 3.5 mg/l to a future standard of 5.0 mg/l, fish catch per haul and landed value for American shad, striped bass, and white perch are projected to increase by 50%. Fish catch for other commercial fish species in the Delaware Estuary are projected to increase at rates similar to these three species.

The Delaware Riverkeeper Network found the potential increase in commercial value of fish landing in the Delaware Estuary for 2009-2018 is typically $19, 103 for striped bass, $1,009 for American shad, and $2,284 for white perch (Alkire et al. 2020).



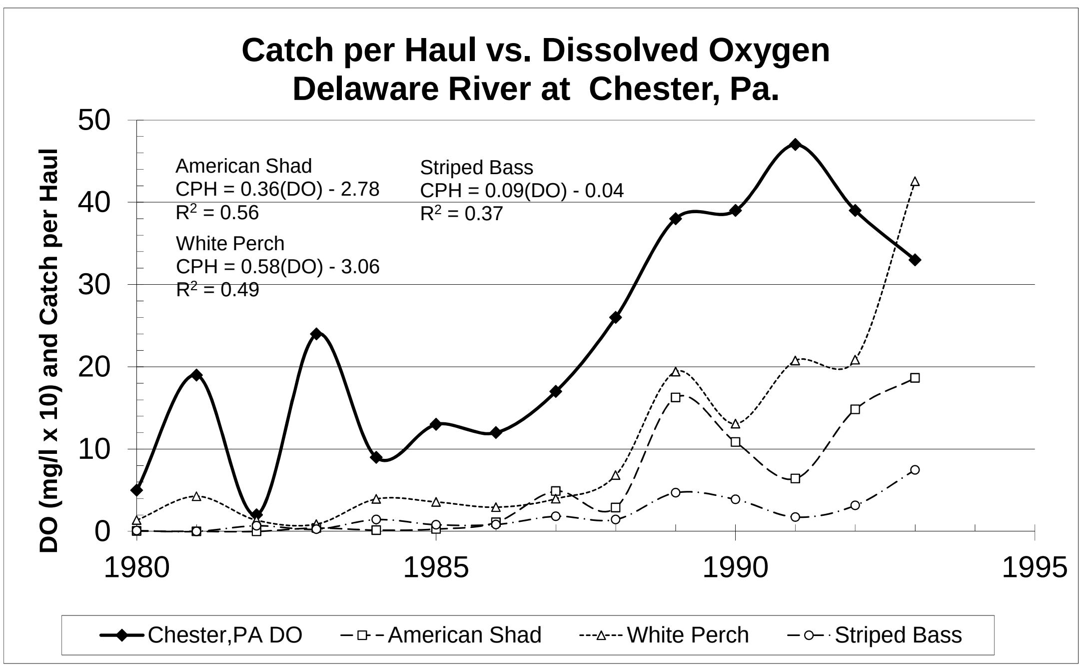


Figure 3.4 Relationship between dissolved oxygen and fish catch in the Delaware Estuary (Weisberg et al. 1996)

The NOEP (2010) reported the annual value of commercial fish landings in the Delaware Estuary was $25 million in $2000 or $46 million in $2020 (Table 3.36). The most valuable commercial fisheries in the Delaware Estuary are blue crab ($14.4 million), summer flounder ($5.3 million), Atlantic menhaden ($4.3 million), Eastern oyster ($3.7 million), striped bass ($2.3 million), and American eel ($0.8 million). If water quality improves by 50% from the existing DO standard (3.5 mg/l) to future criteria (5.0 mg/l) in the Delaware Estuary, then the value of commercial fish landings may increase by 50% or $17 million.

Table 3.36 Commercial fishery benefits from improved water quality in the Delaware Estuary

Species	2000 Landings[1] (lb)	2000 Value[1] ($)	2020 Value[2] ($)	WQ Benefit[3] ($)
Crab, Blue	8,436,188	10,800,000	19,449,158	9,724,579
Flounder, Summer	1,702,977	3,999,000	7,203,392	3,601,696
Menhaden, Atlantic	37,720,009	3,200,000	5,682,078	2,841,039
Oyster, Eastern	524,160	2,721,000	4,901,263	2,450,632
Bass, Striped	752,882	1,717,000	3,092,352	1,546,176
Eel, American	298,940	626,000	1,126,202	563,101
Herring, Atlantic	6,039,473	563,000	1,014,657	507,329
Bluefish	277,217	508,000	915,207	457,604
Whelk,Chan'd/Knob	1,423,282	511,000	929,583	464,792
Weakfish	189,110	261,000	470,371	235,186
Shad, American	130,426	119,000	215,027	107,514
Perch, White	88,060	84,000	151,863	759,315
Shellfish	30,130	76,000	137,079	68,540
Perch, Yellow	20,527	72,000	129,016	64,508
Snails (Conchs)	30,250	59,006	106,169	53,085
Crab, Horseshoe	229,602	49,000	88,698	44,349
Carp. Common	10,488	28,000	49,736	24,868
Drum, Black	39,230	22,000	40,317	20,159
Catfish, Channel	6,922	4,000	6,720	3,360
Herring, Blueback	1,434	600	1,075	538
Total	**57,951,307**	**25,422,000**	**45,709,963**	**23,538,365**

1. NMFS 2010. 2. Adjusted to $2020 based on 3% change in CPI.
3. 50% increase in DO corresponds to 50% increase in fish catch

Property Value

Hedonic valuation studies that estimate the effect that improved water quality on real estate values are critical in informing policy makers about the importance of restoring America's coasts and estuaries since these same property owners are asked to vote on restoration plans to cost hundreds of millions of dollars (Pendleton undated). Important factors that affect property values are water quality, proximity and view of the water, and the recreational benefits that the waterways provide for jobs and boost the local economy. The property benefits of improved water quality are defined by multiplying the area within 2000 ft on either side of the Delaware River between Wilmington and Trenton by the average per acre value of riverfront property. From the literature, we select the appropriate percent increase in property value from improved water quality. The estimated benefits of improved water quality on property ownership are determined by multiplying the percent increase in property value by existing property value.

Several hedonic pricing studies have found that improved water quality can increase shoreline property values by 4% to 18% (Table 3.37). The EPA (1973) estimated improved water quality raised property values by up to 18% next to the water, 8% at 1000 feet from the water, 4% at 2000 feet from the water, and 1.5% at 3000 feet from the water (Figure 3.5). Leggett et al. (2000) estimated improved bacteria levels to meet water quality standards along the western shore of the Chesapeake Bay in Maryland raised shoreline property values by 6%. Austin et al. (2007) from the Brookings Institution projected investments of $26 billion to restore the Great Lakes would increase shoreline property values by up to 10%. Poor et al. (2007) studied 1,377 residential property sales along the Patuxent River in Maryland and using a hedonic price model found a 1 mg/l increase in dissolved inorganic nitrogen decreased the average housing price ($200,936) by 8% ($17,642). Alkire et al. (2020) from Delaware Riverkeeper Network found the total property value gain due to improvement of 1 mg/l in DO in the Delaware River is typically $540.9 million. Due to improved water quality, urban shoreline property values within 2000 feet of the waterways are estimated to increase by a lower bound of 8% and an upper bound of 16% along the tidal Delaware River between Wilmington and Trenton.

Table 3.37 Increased property values resulting from improved water quality

Study	Watershed	Increased Value
EPA (1973)	CA, OH, OR	
Next to water		18%
1000 ft from water		8%
2000 ft from water		4%
Leggett et al. (2000)	Chesapeake Bay	6%
Austin et al. (2007)	Great Lakes	10%
Poor et al. 2007	Patuxent River, MD	8%

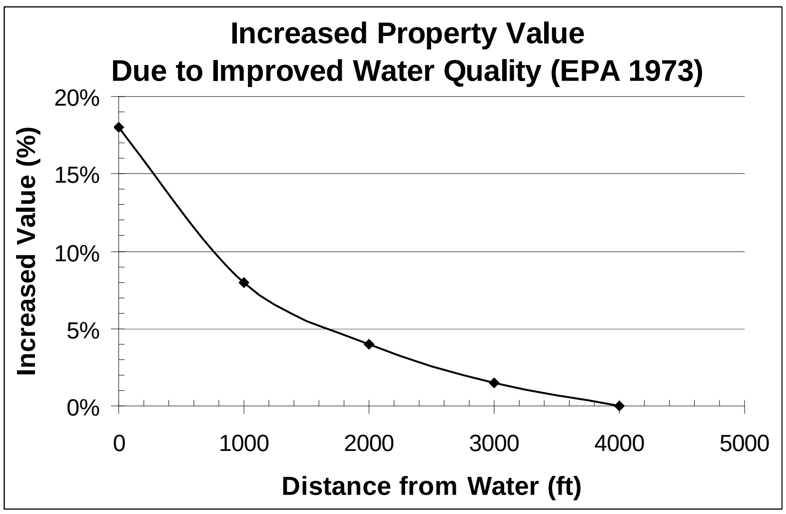


Figure 3.5 Increased property value due to improved water quality (EPA 1973)

Improved water quality can increase urban shoreline property values within 2000 feet of the tidal Delaware River by $61 to 122 million/yr (Table 3.39). At an average real estate value of $1,071,417/ac, the annual value of 21,329 acres of urban riverfront property within 2000 ft of the Delaware River between Wilmington and head of tide at Trenton (Figure 3.6) is $761 million over a 30-year period and $1.5 billion over 15 years. If property value is boosted by 8% to 16% due to improved water quality in the Delaware River, then the amenity value ranges from $61 to $122 million/yr.

Table 3.38 Increased property value due to improved water quality in the Delaware River

State	Urban Shoreline Length[1] (ft)	Area 2000 ft of water (ac)	Value @ 1,071,417/ac ($)	Annual Property Value, 15 yr ($/yr)	Annual Property Value, 30 yr ($/yr)	Increased Property Value @ 8% ($/yr)	Increased Property Value @ 16% ($ /yr)
Delaware	69,328	3,183	3,410,431,487	227,362,099	113,681,050	9,094,484	18,188,968
New Jersey	220,574	10,127	10,850,630,549	723,375,370	361,687,685	28,935,015	57,870,030
Pennsylvania	174,635	8,018	8,590,767,116	572,717,808	286,358,904	22,908,712	45,817,425
Delaware Estuary	**464,537**	**21,329**	**22,851,829,152**	**1,523,455,277**	**761,727,638**	**60,938,211**	**121,876,422**

1. Urban length of Delaware River shore between Wilmington and Trenton. Open space and wetlands excluded.

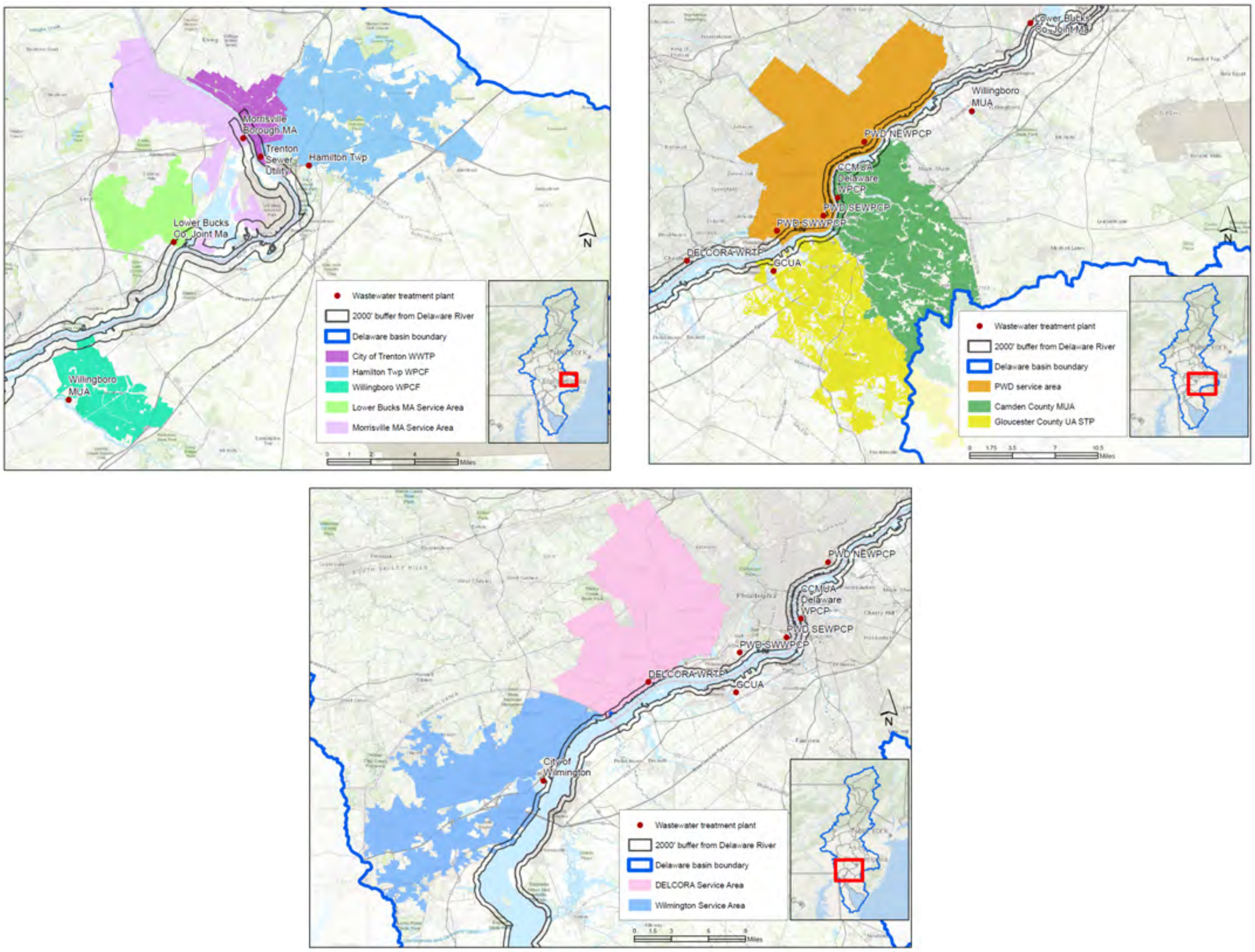


Figure 3.6 Property within 2000 feet of the Delaware River between Trenton and Wilmington

Drinking Water Supply

Improved water quality provides municipal water supply benefits from human health, aesthetic, and water treatment process effects (EPA 2002). Cleaner drinking water provides human health benefits through reduced mortality, cancer risk, illness, and neurological/reproductive risks (Table 3.39). The aesthetic benefits of purified drinking water supplies included improved taste and odor and less discoloration of laundry and plumbing fixtures. Improved water quality reduces scaling and clogging of water treatment plants that leads to lowered processing costs. Municipal water purveyors require water quality at the highest level as inputs to the water treatment process (Koteen et al. 2002). Water supplies with low turbidity have lower water treatment costs due to less filtration and disinfection requirements. Improved water quality can reduce water treatment costs for municipal water utilities along the Delaware River and its large tributaries. Municipal water supply benefits are calculated by estimating reduced water treatment costs associated with improved raw water quality. Poor water quality raises treatment costs due to need for more chemicals, taste/odor control, energy use, and screening/filtration processes. A survey of 27 water utilities found water treatment costs declined 2% for every 1% increase in forest area in a watershed (Trust for Public Land and AWWA 2004). A study by Texas A&M University found water treatment costs increase by 1% for every 4% decrease in water quality as measured by turbidity (McCarl 1997).

Table 3.39 Benefits of improved water quality for municipal water supplies (EPA 2002)

Category	Benefits
Human Health	Reduced mortality Decreased cancer risk Decreased illness Reduced neurological/reproductive effects
Aesthetics	Improved taste Improved odor Reduced discoloration
Water Treatment	Reduced corrosion or scaling Reduced clogging in piping Lowered water treatment costs

Municipal water supply benefits are estimated by tabulating withdrawals (mgd) along the Delaware River and tributaries. The existing value of drinking water treatment is determined by multiplying water withdrawals (mgd) by treatment costs ($/1000 gal). Municipal water supply benefits due to improved water quality in the Delaware Estuary are found by multiplying the existing value by a low bound of 6% and high bound of 12% reduction in water treatment costs. The Delaware River and tributaries provides significant public drinking water supplies (538 mgd) including 39 mgd in Delaware, 182 mgd in New Jersey, and 317 mgd in Pennsylvania (Table 3.40). The cost of water treatment by public and private water utilities in Delaware, Maryland, New Jersey, and Pennsylvania is approximately $1.00/1000 gal. At this unit cost, the existing cost of drinking water treatment is $196 million/yr. Improved water quality based on a 50% increase in DO from current criteria (3.5 mg/l) to a future DRBC DO standard (5.0 mg/l) can reduce water treatment costs by 6% to 12% (McCarl 1997 and Crocket (PWD 2013). If improved water quality in the Delaware River reduces water treatment costs by 6% to 12%, then drinking water supply benefits range from $12 to $24 million/yr.

Table 3.40 Public water supply benefits due to improved water quality in the Delaware Basin

Water Purveyor	Water Supply (mgd)	Treated Water $1.00/1000 gal ($/yr)	Benefit @ 6% ($/yr)	Benefit @ 12% ($/yr)
United Water Del.	18.5	6,752,000	405,000	810,000
Wilmington City	20.4	7,446,000	447,000	893,000
Delaware	**38.9**	**14,198,000**	**800,000**	**1,700,000**
Aqua NJ Phillipsburg	3.5	1,277,000	77,000	153,000
Burlington City	1.5	547,000	33,000	65,000
Camden City	10.9	3,978,000	239,000	477,020
Del. & Raritan Canal	100	36,500,000	2,190,000	4,380,000
Florence Twp.	1.2	438,000	26,000	53,000
NJ American Water	39.4	14,381,000	863,000	1,726,000
Trenton City	26.1	9,5260500	572,000	1,143,000
New Jersey	**182.5**	**66,612,000**	**4,000,000**	**8,000,000**
AQUA PA Bristol	4.1	1,496,000	90,000	180,000
AQUA PA Schuylkill	18.6	6,789,000	407,000	815,000
Easton City	7.1	2,591,000	156,000	311,000
Lower Bucks County	8.4	3,066,000	184,000	368,000
Morrisville City	2.7	985,000	59,000	118,000
PA American Yardley	3.2	1,168,000	70,000	140,000
Philadelphia Belmont	47.2	17,228,000	1,034,000	2,067,000
Philadelphia Queen Lane	73.1	26,681,000	1,601,000	3,202,000
Philadelphia Torresdale	152.5	55,662,000	3,340,000	6,679,000
Pennsylvania	**316.9**	**115,668,000**	**7,000,000**	**14,000,000**
Total	**538.3**	**196,479,000**	**11,800,00**	**23,700,000**

Industrial Water Supply

High nutrient loads can form algae mats that clog industrial water intakes and require back flushing of screens which adds O&M costs. Improved water quality can benefit industrial water users by reducing wear on equipment and reducing water and wastewater treatment costs. Benefits are estimated by multiplying total industrial water withdrawals (mgd) along the Delaware River and tributaries by the withdrawal use value ($/1000 gal) from the literature and then multiplying by a percent reduction in water treatment costs according to the literature.

The DRBC issued industrial water supply withdrawal dockets total 804 mgd in the watersheds that drain to the Delaware Estuary. A study freshwater use value in the U.S. indicates the median value of industrial withdrawals is $132/ac-ft in $1996 (Frederick et al. 1996) or $200/ac-ft ($0.61/1000 gal) in $2010 based on a 3% annual change in the CPI (Table 3.41). The value of industrial withdrawals is $3.8 million per day or $140 million/year. If improved water quality in the Delaware River reduces industrial water treatment costs 6% to 12%, benefits range from $8 to $16 million/yr (Table 3.42).

Table 3.41 National water values by use converted from $1994 to $2020 **(**Frederick et al. 1996)

Water Use	$1994 Median ($/ac-ft)	$1994 Median ($/mil gal)	$2010 Median ($/ac-ft)	$2010 Median ($/mil gal)
Irrigation	40	123	86	265
Industrial	132	405	285	874
Thermoelectric Power	29	89	63	192
Domestic Water Supply	97	298	210	642

Table 3.42 Industrial water supply benefits of improved water quality in the Delaware Basin

Watershed	Withdrawal[1] (mgd)	Value ($0.61/1000 gal) ($ mil/yr)	Benefit @ 6% ($ mil/yr)	Benefit @ 12% ($ mil/yr)
Upper Estuary	132	29	2	4
Lower Estuary	446	99	6	12
Delaware Bay	12	3	0.2	0.4
Total	**590**	**131**	**8**	**16**

1. DRBC water allocations. 2. Frederick et al. 1996 adjusted to $2010 at 3% annually

Nonuse Benefits

Nonuse values are the willingness to pay for the preservation or improvement of natural resources (Haab and McConnell 2002). The contingent value method estimates nonuse benefits through a survey of individual willingness to pay (WTP) for improved water quality for recreational viewing, boating, fishing, and swimming uses. Johnston et al. (2003) synthesized data on benefits of improved water quality and concluded that a $1.00 increase in use value correlated to a $0.50 increase in nonuse values with $p < 0.01$. Therefore, we assume that nonuse value equals 33% of total use plus nonuse value. Houtven et al. (2007) surveyed 90 publications and found 131 estimates of annual WTP for improved water quality ranged from $26 to $331/person with a mean of $83/person in 2000 dollars (Table 3.43). Nonmarket valuation of personal WTP utilized stated preference, travel cost, and hedonic property value methods. Bockstael et al. (1989) conducted a contingent valuation survey that estimated WTP for swimmable water quality in the Chesapeake Bay for Washington, D.C. and Baltimore nonusers was $44.6 million/yr. Van Houtven (2009) estimated WTP to increase the water quality index to swimmable in the Chesapeake Bay provided $159 million/yr in annual benefits for D.C., Maryland, and Virginia nonusers.

Table 3.43 Summary of publications concerning WTP for improved water quality in $2000 (Houtven et al. 2007)

Publication	Geographic Focus	Water Quality Change	Mean WTP ($/p/yr)
Carson and Mitchell 1993	Nationwide	Improve from nonsupport to boatable, fishable, swimmable	168
Croke et al. 1986	Chicago area	Improve for fishing, boating, and outings	88
Desvousges et al. 1987	Monongahela R., PA	Improve from boatable to fishable to swimmable	55
Farber and Griner 2000	Conemaugh R., PA	Severely polluted to moderately polluted to unpolluted.	62
Gramlich 1977	Charles R., MA	Improve from 1973 to swimmable and wildlife viewable	167
Walsh et al. 1978	South Platte R., CO	Avoid reduction in 3-point water quality index	156
Lant and Roberts 1990	Iowa and Illinois	Improve from poor to fair to good to excellent water quality.	61
Lant and Tobin 1989	Iowa and Illinois	Improve from: poor to fair to good to excellent.	110
Nowak et al. 1990	Milwaukee, WI	Improve to fishable/swimmable	87
Azevedo et al. 2001	Clear Lake, IA	WQ clarity, algae blooms, color, odor, swimming advisories	69
Cronin 1982	Potomac R., D.C.	Swimming, boating, fish habitat, odor, appearance.	41
Johnston et al. 1999	Pawcatuck, RI	Improve one unit on 10-point index	124
Binkley & Hanemann 1978	Boston-Cape Cod	Reduced to 1 on scale 1-5 and improved to 5 on 1-5 scale	149
Bockstael et al. 1989	Chesapeake Bay	Improve from "unacceptable for swimming" to "acceptable"	76
Hayes et al. 1992	Narragansett Bay, RI	Safe for swimming and suitable for shell fishing	331
Kaoru 1995	Martha's Vineyard	Raise WQ in ponds for shellfishing year-round	182
Wey 1990	Block Island, RI	Improve on 6-point index of water quality.	32
Lipton 2003	Chesapeake Bay	Change on 4-point scale: very good, good, fair, and poor	77
		Mean individual WTP from 131 estimates	**83**

Carson and Mitchell (1993) conducted a contingent value study to estimate national benefits of freshwater pollution control to meet the Clean Water Act. The study surveyed WTP for improved water quality to achieve use (instream, withdrawal, aesthetic, ecosystem) benefits and nonuse (vicarious consumption and stewardship) benefits (Table 3.44). The authors measured nonmarket benefits through a 1983 contingent valuation survey that asked 813 people at 61 sites willingness to pay more taxes for cleaner water.

Table 3.44 Typical benefits from improved freshwater quality (Carson and Mitchell 1993)

Benefit	Category	Examples
Use	Instream	Recreational (fishing, swimming, boating)
		Commercial (fishing, navigation)
	Withdrawal	Municipal (drinking water, waste disposal)
		Agriculture (irrigation)
		Industrial/commercial (waste treatment)
	Aesthetic	Near water recreation (hiking, picnicking, photography)
		Viewing (commuting, office/home views)
	Ecosystem	Hunting/bird watching
		Ecosystem support (food chain)
Nonuse	Vicarious	Significant others (relatives, friends)
		American public
	Stewardship	Inherent (preserving remote wetlands)
		Bequest (family, future generations)

Individuals were asked their WTP to achieve boatable, fishable, and swimmable uses based on a water quality ladder (Figure 3.7 and Table 3.45). Based on the ladder, the Delaware River between Philadelphia and Wilmington, where DO may decline below 3.5 mg/l during summer, is boatable (C rating) but not yet fishable (B rating). The tidal Delaware River is not yet swimmable (A rating) since fecal coliform bacteria levels often exceed 200 #/100 ml.

Table 3.45 Water quality ladder values
(Mitchell and Carson 1993 from Resources for the Future)

Rating	Beneficial Use	TSS (mg/l)	DO (mg/l)	Bacteria (#/100ml)
A	Swimmable	10	5	200
B	Fishable	50	4	1000
C	Boatable	100	3	2000

Nonuse benefits of improving DO from current 3.5 mg/l standard to future year-round fishable criteria of 5 mg/l in the Delaware River are from contingent valuation surveys that define public WTP to improve water quality from boatable to fishable then swimmable uses. Swimmable benefits are estimated but primary contact recreation is difficult due to severe tidal currents on the Delaware and bacteria can exceed DRBC swimmable criteria (100#/100 ml) after storms.

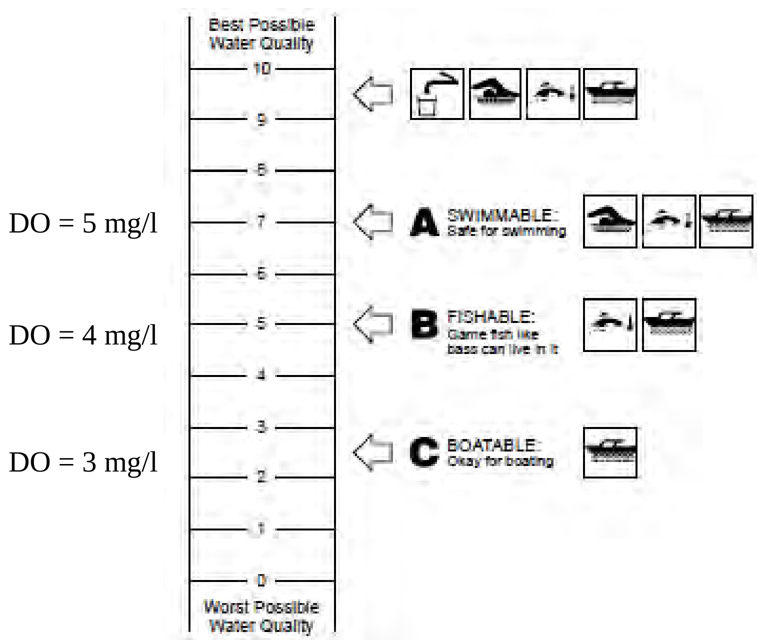


Figure 3.7 Water quality ladder
(Carson and Mitchell 1993 from Resources for the Future)

Nonuse benefits are estimated by benefits transfer from Carson and Mitchell (1993) and Houtven, Powers, and Pattanayak (2007) and others and converting to 2020 dollars based on individual WTP to improve water quality in the Delaware River from boatable use (DO 3.5 mg/l) to fishable use (5.0 mg/l) then swimmable. Nonuse benefits are determined by multiplying individual WTP ($/person) by the adult population (>18 yr old) of the wastewater treatment plant (WWTP) service areas (low bound estimate) and the Delaware Estuary watershed (high bound) and by 33% (Johnston et al. 2003). The low bound estimate includes the population of the wastewater treatment service areas in the Delaware Estuary (3.5 million). The high bound estimate is based on the population of the Delaware Estuary watershed (6.9

million) in Delaware, New Jersey, Maryland, and Pennsylvania. The adult population of the WWTP area and Delaware Estuary watershed is 2.7 million and 5.4 million, respectively.

Carson and Mitchell (1993) concluded mean household WTP to improve water quality from nonsupported to boatable use was $93/yr, from boatable to fishable uses was $70/yr, and from fishable to swimmable was $78/yr in 1983 dollars. Based on 2.9 p/hh per the U.S. Census, mean 1983 WTP per person was $32/yr to improve to boatable and $24/yr to improve to fishable, and $27/yr to improve to swimmable water quality. Adjusting for annual 3% change in CPI due to increased cost of living and improving public views toward clean water, annual WTP per person is $95/yr for boatable, $73/yr for fishable, and $82/yr for swimmable uses in $2020 (Table 3.46).

Table 3.46 Annual willingness to pay for improved water quality

Water Quality Use Support	1983 Mean WTP[1] ($/hhold)	1983 Mean WTP ($/person) [2]	2020 Mean WTP[3] ($/person)
Boatable	93	32	95
Fishable	70	24	73
Swimmable	78	27	82
Total WQ	**241**	**83**	**250**

1. Carson and Mitchell 1993. 2. At 2.9 person/ household. 3. Adjusted to $2020 by 3% change in CPI.

Willingness to pay per person from Carson and Mitchell (1993) to improve water quality from nonsupport to boatable, fishable, and swimmable uses is $250/yr in 2020 dollars which compares favorably to a mean WTP of $83/yr within a range of $31-$331/yr from a survey of 90 publications (Houtven et al. 2007).

Nonuse benefits from WTP for improved water quality to go from boatable (DO 3.5 mg/l) to achieve fishable water quality (DO 5.0 mg/l) ranges from a low bound of $71 million/yr to a high bound of $171 million/yr and to go from fishable to swimmable water quality ranges from a low bound of $71 million/yr to a high bound of $171 million/yr (Tables 3.47, 3.48, and 3.49).

Table 3.47 Nonuse benefits of improved water quality in the Delaware Estuary ($2020)

WQ Use	WWTP Area Adult Pop.[1]	Low WTP[2] ($/person)	Low WTP ($ mil/yr)	Low Nonuse[3] ($ mil/yr)
Boatable	2,713,706	95	258	85
Fishable	2,713,706	73	198	65
Swimmable	2,713,706	82	223	73
WQ Use	**Del. Estuary Adult Pop.[1]**	**High WTP[2] ($/person)**	**High WTP ($ mil/yr)**	**High Nonuse[3] ($ mil/yr)**
Boatable	5,439,590	95	517	171
Fishable	5,439,590	73	397	131
Swimmable	5,439,590	82	446	147

1. Adult pop. (>18 years old). 2. Carson and Mitchell (1993) adjusted to $2020 based on 3% annually.
2. Nonuse benefits are 33% of WTP.

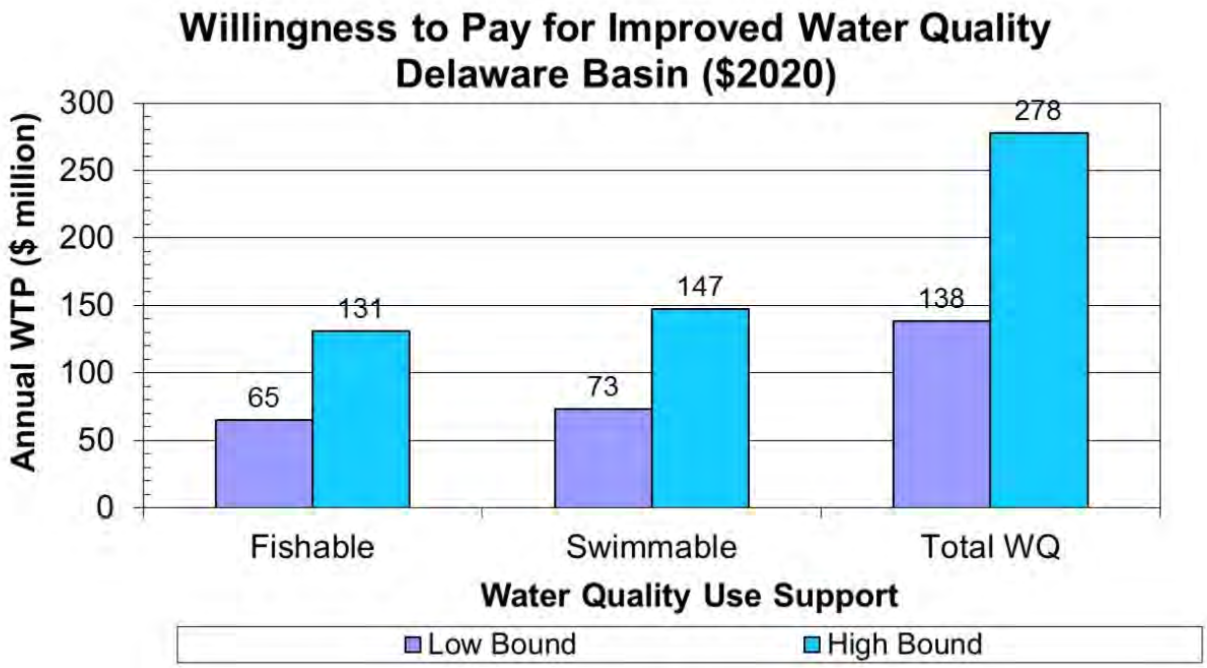


Figure 3.8 Nonuse benefits willingness to pay for improved water quality in Delaware Basin (Carson and Mitchell 1993 adjusted to $2020 at 3% annually. Nonuse benefits are 33% of WTP)

Table 3.48 Low bound WTP for improved water quality in the Delaware River

	2020 Population	% Adult Population. (> 18 yr)	Adult Population.[1] (> 18 yr)	2020 WTP[2] ($/person)	2020 WQ Benefits ($ mil)	Nonuse Benefit[3] ($ mil/yr)
WWTP Service Area	**3,502,186**	**78%**	**2,731,705**	**155**	**423,414,288**	**139,726,714**
Fishable	3,502,186	78%	2,731,705	73	199,414,471	65,806,775
Swimmable	3,502,186	78%	2,731,705	82	223,999,817	73,919,939
Delaware	**395,782**	**78%**	**308,710**	**155**	**47,850,044**	**15,790,515**
Fishable	395,782	78%	308,710	73	22,535,827	7,436,823
Swimmable	395,782	78%	308,710	82	25,314,217	8,353,692
Maryland	**0**	**78%**	**0**	**155**	**0**	**0**
Fishable	0	78%	0	73	0	0
Swimmable	0	78%	0	82	0	0
New Jersey	**907,321**	**78%**	**707,710**	**155**	**109,695,109**	**36,199,386**
Fishable	907,321	78%	707,710	73	51,662,858	17,048,743
Swimmable	907,321	78%	707,710	82	58,032,251	19,150,643
Pennsylvania	**2,199,084**	**78%**	**1,715,286**	**155**	**265,869,256**	**87,736,854**
Fishable	2,199,084	78%	1,715,286	73	125,215,843	41,321,228
Swimmable	2,199,084	78%	1,715,286	82	140,653,413	46,415,626

1. Adult pop. >18 yr. old. 2. Carson & Mitchell 1993 adjusted to $2020 by CPI. 3. Nonuse benefits 33% of WTP.

Table 3.49 High bound WTP for improved water quality in Delaware Estuary

Water Quality Use Support	2020 Population	% Adult Population. (> 18 yr)	Adult Population.[1] (> 18 yr)	2020 WTP[2] ($/person)	2020 WQ Benefits ($ million)	Nonuse Benefit[3] ($ million/yr)
Del. Estuary	**6,973,833**	**78%**	**5,439,590**	**155**	**843,136,410**	**278,235,015**
Fishable	6,973,833	78%	5,439,590	73	397,090,051	131,039,717
Swimmable	6,973,833	78%	5,439,590	82	446,046,359	147,195,298
Delaware	**748,336**	**78%**	**583,702**	**155**	**90,473,822**	**29,856,361**
Fishable	748,336	78%	583,702	73	42,610,252	14,061,383
Swimmable	748,336	78%	583,702	82	47,863,571	15,794,978
Maryland	**6,458**	**78%**	**5,037**	**155**	**780,772**	**257,655**
Fishable	6,458	78%	5,037	73	367,719	121,347
Swimmable	6,458	78%	5,037	82	413,054	136,308
New Jersey	**1,697,901**	**78%**	**1,324,363**	**155**	**205,276,265**	**67,741,167**
Fishable	1,697,901	78%	1,324,363	73	96,678,483	31,903,899
Swimmable	1,697,901	78%	1,324,363	82	108,597,748	35,837,257
Pennsylvania	**4,521,138**	**78%**	**3,526,488**	**155**	**546,605,640**	**180,379,861**
Fishable	4,521,138	78%	3,526,488	73	257,433,598	84,953,087
Swimmable	4,521,138	78%	3,526,488	82	289,171,986	95,426,756

1. Adult pop. >18 yr. old. 2. Carson & Mitchell 1993 adjusted to $2020 by CPI. 3. Nonuse benefits 33% of WTP.

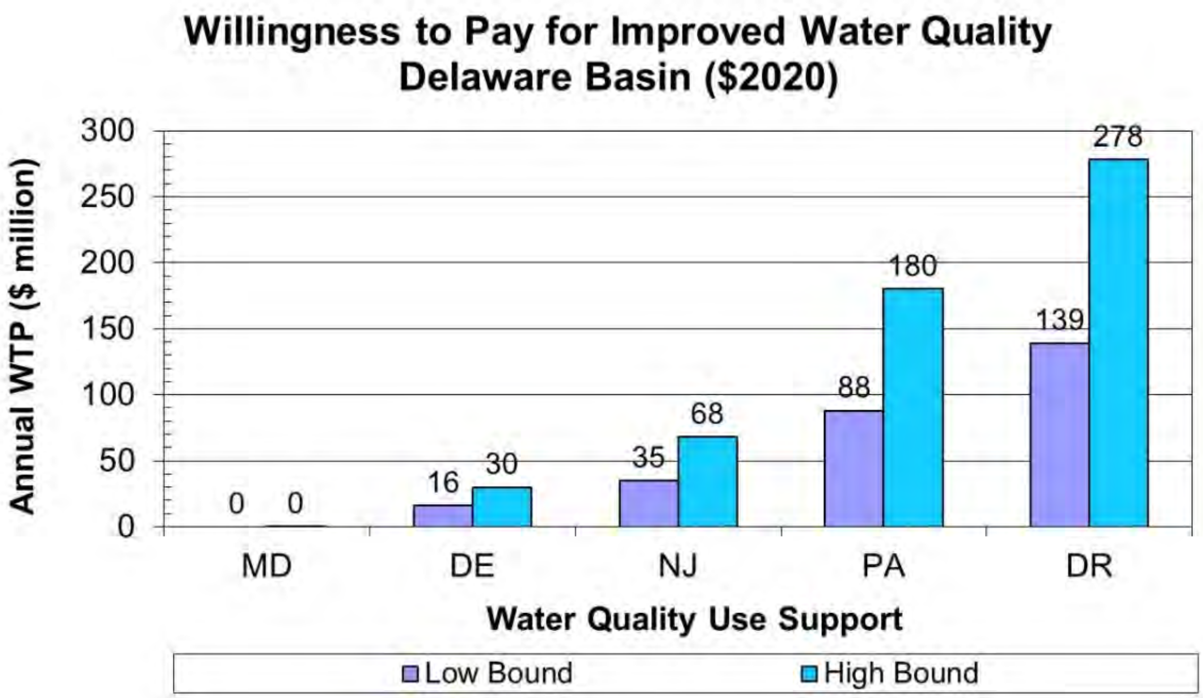
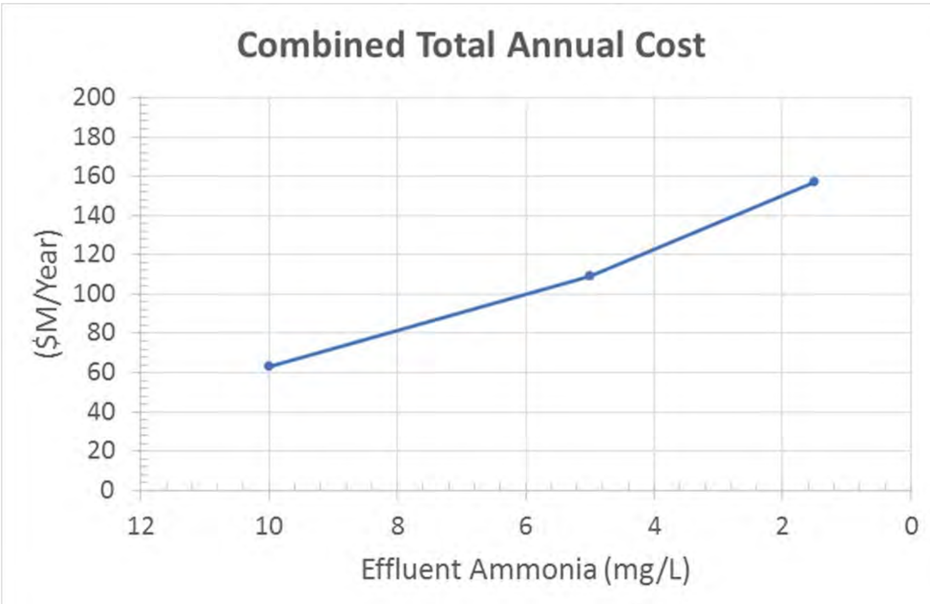


Figure 3.9 Nonuse benefits by state due to improved water quality in the Delaware River

Chapter 4: Summary

Costs

Total annual cost to reduce ammonia to 10, 5, and 1.5 mg/l from the 12 largest wastewater dischargers to the Delaware Estuary are $1.1, $1.9, and $2.7 billion, respectively and annual cost are $63, $109, and $157 million/yr or $18, $31, and $45 per capita for the 3.5 million people in the WWTP service areas (Figure 4.1 and Table 4.1). For individual dischargers, annual costs to reduce ammonia to 10, 5, and 1.5 mg/l range from $0, $0, and $2 million/yr for Willingboro ($54 per capita) to $0, $10, and $28 million/yr for PWD NEWPC ($32, $88, and $189 per capita).



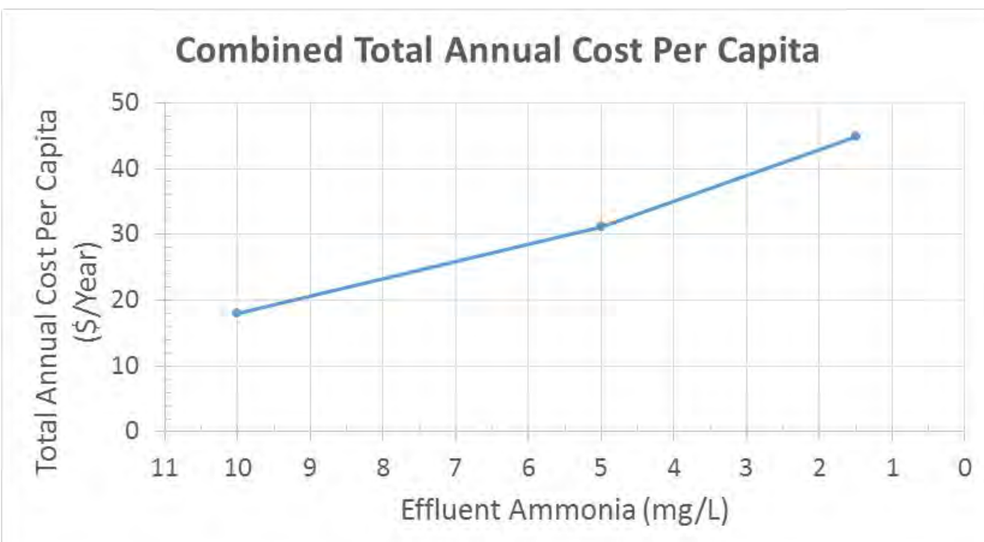


Figure 4.1 Annual and per capita cost of ammonia reduction at wastewater treatment plants in the Delaware Estuary

Table 4.1 Ammonia reduction costs for largest wastewater dischargers in the Delaware Estuary

Wastewater Service Area	Flow (mgd)	Pop. Served	Existing NH3-N	10 mg/L Annual Cost ($M/Yr)	5 mg/L Annual Cost ($M/Yr)	1.5 mg/L Annual Cost ($M/Yr)	10 mg/l Cost/Capita ($/yr)	5 mg/l Cost/Capita ($/yr)	1.5 mg/l Cost/Capita ($/yr)
Morrisville MMA (PA)	6.0	40,186	21	2	2	2	50	50	50
Willingboro MUA (NJ)	4.1	37,064	10	0	0	2	0	0	54
Hamilton Township (NJ)	9.0	84,293	28.7	3	4	4	36	47	47
Trenton Sewer Utility (NJ)	12.4	80,618	12.3	0.1	2	3	1	25	37
LBCJMA(PA)	8.4	55,006	33	2	2	2	36	36	36
PWD SWWPCP (PA)	183.2	934,598	12.4	13	17	21	14	18	22
PWD SEWPCP (PA)	88.6	332,653	12.4	0	5	15	14	18	32
PWD NEWPCP (PA)	200.3	316,813	10	0	10	28	32	88	189
CCMUA (NJ)	58.7	474,200	27.8	12	15	18	25	32	38
GCUA (NJ)	20.4	231,146	32.4	3	4	5	13	17	22
DELCORA (PA)	38.0	519,827	18.4	2	8	10	4	15	19
Wilmington (DE)	76.4	395,782	48.3	6	20	26	15	51	66
Combined Summary	**705.5**	**3,502,186**		**63**	**109**	**157**	**18**	**31**	**45**

Benefits

The benefits of improved water quality by increasing dissolved oxygen from the current standard of 3.5 mg/ to a future DRBC year-round fishable standard of 5.0 mg/l in the Delaware River range from a low bound of $371 million to an upper bound of $1.06 billion per year (Table 4.2). Recreational boating provides the greatest benefits ranging from $46-$334 million followed by recreational fishing ($129-$202 million), viewing/boating/fishing ($55-$68 million), agriculture ($8-$188 million), nonuse value ($76-$115 million), and bird/wildlife watching ($15-$33 million) as depicted in Figure 4.2. Recreational viewing, fishing, and boating provide 45% of the high bound benefits followed by agriculture (17%), nonuse (10%), wildlife/birdwatching, waterfowl hunting, and beach going recreation (6%), water supply (4%), and commercial fishing, navigation, and property value benefits all at 2% of the total (Figure 4.3). Swimming benefits are nill as very little swimming occurs in the Delaware River between Wilmington and Trenton due to dangerous currents and high bacteria levels.

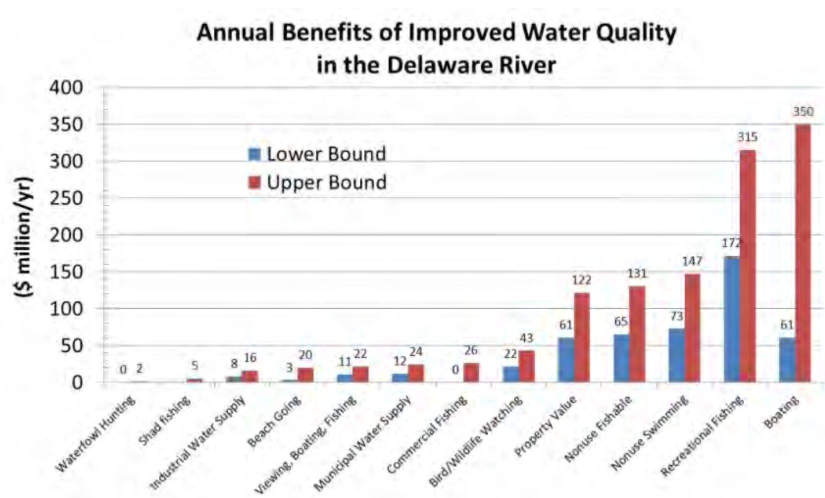


Figure 4.2 Lower and upper bound benefits of improved water quality in the Delaware River

Table 4.2 Benefits of improved water quality in the Delaware River in $2020

Category	Activity	Existing Value (DO 3.5 mg/l) ($ million/yr)		Benefits (DO 5 mg/l) ($ million/yr)	
		Low	**High**	**Low**	**High**
Use					
Recreation	Viewing, Boating, Fishing	28	56	11	22
	Boating	212	472	61	350
	Fishing	286	528	172	315
	Shad fishing	0	0	0	5
	Bird/Wildlife Watching	430	437	22	43
	Waterfowl Hunting	2	22	0.1	2
	Swimming	0	0	0	0
	Beach Going	9	63	3	20
Commercial	Fishing	46	46	0	26
Indirect Use	Property Value	762	1,523	61	122
Water Supply	Municipal Water Supply	196	196	12	24
	Industrial Water Supply	31	31	8	16
Nonuse					
Existence/Bequest	WTP Fishable WQ	85	171	65	131
	WTP Swimmable WQ			73	147
Total		2,087	3,545	488	1,223

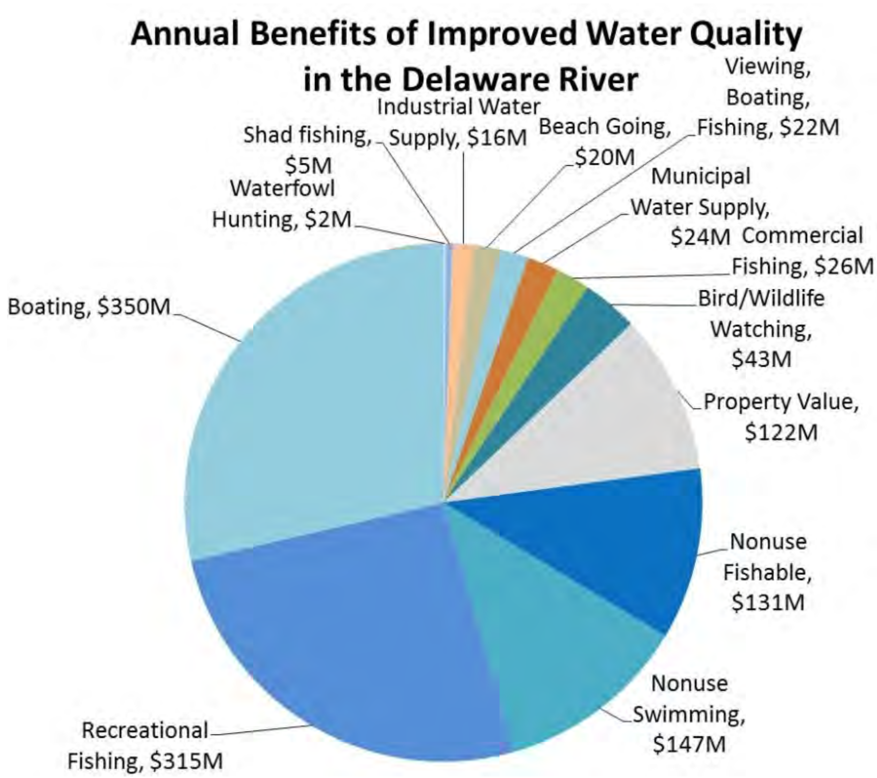


Figure 4.3 Upper bound benefits of improved water quality in the Delaware River

Net Benefits

Ammonia reductions are wastewater treatment infrastructure along the Delaware Estuary are cost effective as the benefits comfortable exceed the costs (Table 4.3). The costs of ammonia reduction at the 12 largest wastewater dischargers along the Delaware Estuary range from $63, $109, and $157 million/yr compared to benefits from low range $488 to high range of $1,223 million/yr. Net benefits (B-C) range from a low end of $331, $379, and $425 million/yr to $1,066, $1,114, and $1,160 million/yr. Benefits/cost (B/C) ratios range from 3 to 19.

Table 4.3 Net benefits of ammonia reduction at wastewater dischargers along Delaware Estuary

NH3-N Reduction	**Cost (C) ($M/yr)**	**Benefits (B) ($M/yr)**		**Net Benefits (B-C) $M/yr)**		**B/C**	
		Low	High	Low	High	Low	High
10 mg/l	63	488	1,223	425	1,160	8	19
5 mg/l	109	488	1,223	379	1,114	4	11
1.5 mg/l	157	488	1,223	331	1,066	3	8

References

Alkire, C., Silldorf, E. L. and Wang, S., 2020. Economic Value of Dissolved Oxygen Restoration in the Delaware Estuary. Delaware Riverkeeper Network.

Austin, J. C., S. Anderson, P. N. Courant, and R. E. Litan, 2007. Healthy Waters, Strong Economy: The Benefits of Restoring the Great Lakes Ecosystem. The Brookings Institution. 16 pp.

Azevedo, C., J. Herriges, and C. Kling, 2001. Valuing Preservation and Improvements of Water Quality in Clear Lake. Working Paper, Center for Agricultural and Rural Development, Iowa State University.

Bergstrom, J. C. and H. K. Cordell, 1991. An Analysis of the Demand for and Value of Outdoor Recreation in the United States. Journal of Leisure Resources. 23(1):67-86.

Bingham, G., 1995. Issues in Ecosystem Valuation: Improving Information for Decision Making. Ecological Economics. 14:73-90.

Bingham, T. H., T. R. Bondelid, B. M. Depro, R. C. Figueroa, A. B. Hauber, S. J. Unger, and G. L. Van Houtven, 2000. A Benefits Assessment of Water Pollution Control Programs Since 1972: Part 1, The

Benefits of Point Source Controls for Conventional Pollutants in Rivers and Streams, Final Report. Prepared for U.S. Environmental Protection Agency, Office of Water. Water Quality Assessment. 46 pp.

Binkley C. S. and W. M. Hanemann, 1978. The Recreation Benefits of Water Quality Improvement: Analysis of Day Trips in an Urban Setting. Prepared for U.S. Environmental Protection Agency.

Bockstael, N.E., K. E. McConnell, and I. E. Strand, 1989. Measuring the Benefits of Improvements in Water Quality: the Chesapeake Bay. Market Resource Economics. 6:1-18.

Brown, R. M., N. J. McLelland, R. A. Deininger, and R. G. Tozer, 1970. A Water Quality Index, Do We Dare? Water & Sewage Works. October:339-343.
e

Brown, T. C., 2004. The Marginal Economic Value of Streamflow from National Forests. USDA Forest Service Discussion Paper DP-04-1. 97 pp.

Carson, R. T., and R. C. Mitchell. 1993. The Value of Clean Water: the Public’s Willingness to Pay for Boatable, Fishable, and Swimmable Quality Water. Water Resources Research 29(7):2445–2454.

Carver, E. and J. Caudill, 2007. Banking on Nature 2006: The Economic Benefits to Local Communities of National Wildlife Refuge Visitation. U.S. Fish and Wildlife Service, Division of Economics. 372 pp.

Cech, T. V., 2005. Principles of Water Resources History, Development, Management and Policy. John Wiley and Sons, Inc. 468 pp.

Corbett, J. J. and H.W. Koehler, 2003. Updated Emissions from Ocean Shipping. Journal of Geophysical Research. Atmospheres. 108(D20):4650-4666.

Crockett, C. S., 2007. Moving from Assessment to Protection, the Delaware River Watershed Source Water Protection Plan. Philadelphia Water Department. 195 pp.

Croke, K., R. Fabian, and G. Brenniman, 1986. Estimating the Value of Improved Water Quality in an Urban River System. Journal of Environmental Systems. 16(1):13-23.

Cronin, F. J., 1982. Valuing Nonmarket Goods through Contingent Markets. Pacific Northwest Laboratory, Richland, Washington.

Cropper, M. L. and W. Isaac, 2011. The Benefits of Achieving the Chesapeake Bay TMDLs (Total Maximum Daily Loads) - A Scoping Study. Resources for the Future. Washington, D.C. 32 pp.

Daily, G. C. and K. Allison, 2002. The New Economy of Nature: The Quest to Make Conservation Profitable. Island Press, Washington, D.C. 260 pp.

Delaware River Basin Commission, 1961. Delaware River Basin Compact. West Trenton, New Jersey. 51 pp.

Delaware River Basin Commission, 2004. Water Resources Plan for the Delaware River Basin. West Trenton, New Jersey. 100 pp.

Delaware River Basin Commission, 2008. Administrative Manual Part III Water Quality Regulations with Amendments through July 16, 2008. 131 pp.

Delaware River Basin Commission, 2008. State of the Delaware River Basin Report. West Trenton, New Jersey. 85 pp.

Delaware River Basin Commission, 2009. Delaware River Basin Water Code with Amendments through March 11, 2009. 174 pp.

Delaware River Basin Commission, 2010. Delaware River and Bay Integrated List Water Quality Assessment. 46 pp.

Desvousges, W. H., V. K. Smith, and A. Fisher, 1987. Option Price Estimates for Water Quality Improvements: A Contingent Valuation Study for the Monongahela River. Journal of Environmental Economics and Management. 14(3):248-67.

Dixon, J. A., L. F. Scura, R. A. Carpenter, and P. B. Sherman, 1994. Economic Analysis of Environmental Impacts. Earthscan. London, UK.

Environmental Protection Agency, 1973. Benefit of Water Pollution Control on Property Values. EPA-600/5-73-005. Washington, D.C.

Environmental Protection Agency, 1994. President Clinton's Clean Water Initiative: Analysis of Benefits and Costs. EPA 800-R-94-022. Washington, D.C.

Environmental Protection Agency, 2002. Assessing the Benefits of Drinking Water Regulations :A Primer for Stakeholders. Office of Groundwater and Drinking Water. 137 pp

Environmental Protection Agency, 2012. The Importance of Water to the U.S. Economy Part 1: Background Report Public Review Draft. 262 pp.

Emerton, L. and E. Bos, 2004. Value: Counting Ecosystems as Water Infrastructure, IUCN. The World Convention Union. Gland, Switzerland and Cambridge, United Kingdom.

Farber, S. and B. Griner, 2000. Valuing Watershed Quality Improvements using Conjoint Analysis. Ecological Economics. 34:63–76.

Frederick, K. D., T. VandenBerg, and J. Hansen, 1996. Economic Value of Freshwater in the United States. Discussion Paper 97-03. Resources for the Future. Washington, D. C. 37 pp.

Freeman, A. M., 1982. Air and Water Pollution Control: A Benefit-Cost Assessment. John Wiley, New York. 196 pp.

Freeman, A. M., 1990. Water Pollution Policy, in Public Policies for Environmental Protection. Edited by P. Portney. Resources for the Future, Washington, D.C. 97-149.

Freeman, M., 2003. The Measurement of Environmental and Resource Values: Theory and Methods. Resources for the Future. Washington, D.C.

Goulder, L. H., and D. Kennedy, 1997. Valuing Ecosystem Services: Philosophical Bases and Empirical Methods. Edited by G. Daily. Nature's Services. Island Press, Washington, D.C. 23-48.

Gramlich, F. W., 1977. The Demand for Clean Water: The Case of the Charles River. National Tax Journal. 30(2):183–194.

Haab, T. C. and K. E. McConnell, 2002. Social Norms and Illicit Behavior: An Evolutionary Model of Compliance. Journal of Environmental Management. 66:67-76.

Hayes, K.M., T. Tyrrell, and G. Anderson, 1992. Estimating the Benefits of Water Quality Improvements in the Upper Narragansett Bay. Marine Resource Economics. 7(1):75-85.

Hicks, R. and I. Strand, 2000. The Extent of Information: Its Relevance for Random Utility Models. Land Economics. 76:374-385.

Hjalte, K., K. Lidgren, and I. Stahl, 1977. Environmental Policy and Welfare Economics. Cambridge University Press. 119 pp.

Hodge, I. and C. Dunn, 1992. Valuing Rural Amenities. Organisation for Economic Co-operation and Development Publication.

Houtven, G. V., J. Powers, and S. K. Pattanayak, 2007. Valuing Water Quality Improvements in the United States Using Meta-analysis: Is the Glass Half-full or Half-empty for National Policy Analysis? Resource and Energy Economics. 29:206-228.

Ingraham, M. and S. G. Foster, 2008. The Value of Ecosystem Services Provided by the U. S. National Wildlife Refuge System in the Contiguous U. S. Ecological Economics. 67:608-818.

Johnston, R. J., E. Y. Besedin, and R. F. Wardwell, 2003. Modeling Relationships Between Use and Nonuse Values for Surface Water Quality: A Meta-Analysis. Water Resources Research. 39(12):1363.

Johnston, R. J., S. K Swallow, and T. F. Weaver, 1999. Estimating Willingness to Pay and Resource Tradeoffs with Different Payment to Mechanisms: an Evaluation of a Funding Guarantee for Watershed Management. Journal of Environmental Economics and Management. 38:97-120.

Johnston, R. J., T. A. Grigalunas, J. J. Opaluch, M. Mazzotta, and J. Diamantedes, 2002. Valuing Estuarine Resource Services Using Economic and Ecological Models: The Peconic Estuary System Study. Coastal Management. 30:47-65.

Kaoru, Y., V. K. Smith, and J. L. Liu, 1995. Using Random Utility Models to Estimate the Recreational Value of Estuarine Resources. American Journal of Agricultural Economics. 77:141–151.

Kardos, J. S. and C. C. Obropta, 2011. Water Quality Model Uncertainty Analysis of a Point to Point Source Phosphorus Trading Program. Journal of the Water Resources Association. 47(6):1317-1337.

Kaval, P. and J. Loomis, 2003. Updated Outdoor Recreation Use Values with Emphasis on National Park Recreation. Prepared by Colorado State University, Department of Agricultural and Resource Economics for the U.S. National Park Service.

King, D. M., M. J. Mazzotta, and K. J. Markowitz, 2000. Essentials of Ecosystem Valuation. USDA Natural Resources Conservation Service and National Oceanographic and Atmospheric Administration.

Kleinfelder, 2020. Technical Memorandum Summarizing Nitrogen Reduction Cost Estimation Study Plant Specific Cost Estimates.

Kline, J. D. and S. K. Swallow, 1998. The Demand for Local Access to Coastal Recreation in Southern New England. Coastal Management. 26(3):177-191.

Koteen, J., S. J. Alexander, and J. B. Loomis, 2002. Evaluating Benefits and Costs of Changes in Water Quality. General Technical Report PNW-GTR-548. Pacific Northwest Research Station. Portland, Oregon. 32 pp.

Kramer, R. A., 2005. Economic Tools for Valuing Freshwater and Estuarine Ecosystem Services. Nicholas School of the Environment and Earth Sciences, Duke University. Durham, North Carolina. 13 pp.

Krupnick, A., 1988. Reducing Bay Nutrients: An Economic Perspective. Maryland Law Review. 47:453–480.

Krutilla, J. V. 1967. Conservation Reconsidered. American Economic Review. 57:777–786.

Lant, C. L. and G. A. Tobin, 1989. The Economic Value of Riparian Corridors in Cornbelt Floodplains: A Research Framework. Professional Geographer. 41(3):337–349.

Lant, C. L. and R. S. Roberts, 1990. Greenbelts in the Cornbelt: Riparian Wetlands, Intrinsic Values and Market Failure. Environment and Planning. 22:1375–1388.

Leeworthy, V. R. and P. C. Wiley, 2001. Current Participation Patterns in Marine Recreation. U.S. Department of Commerce. National Oceanic and Atmospheric Administration. Silver Spring, Maryland. 47 pp.

Leggett, C. G. and N. E. Bockstael, 2000. Evidence of the Effects of Water Quality on Residential Land Prices. Journal of Environmental Economics and Management. 39(2):121-144.

Libecap, G. D., 2005. The Problem of Water. University of Arizona. 49 pp.

Lipton, D., 2003. The Value of Improved Water Quality to Chesapeake Bay Boaters. Working Paper WP 03-16. Department of Agricultural and Resource Economics, University of Maryland, College Park.

Lipton, D. and R. L. Hicks, 2003. The Cost of Stress: Low Dissolved Oxygen and Economic Benefits of Recreational Striped Bass Fishing in the Patuxent River. Estuaries. 26(2):310-315.

Loomis, J., 2006. Importance of Including Use and Passive Use Values of River and Lake Restoration. Journal of Contemporary Water Research and Education. 134(1):4-8.

McCarl, B. A., 1997. Costs of Water Treatment Due to Diminished Water Quality: A Case Study in Texas. Texas A&M University. Department of Agricultural Economics. p. 2.

McConnell, K. and I. Strand, 1989. Benefits from Commercial Fisheries When Demand and Supply Depend on Water Quality. Journal of Environmental Economics Management. 17:2845-2892.

Mistiaen, J. A., I. E. Strand, and D. Lipton, 2003. Effects of Environmental Stress on Blue Crab (Callinectessapidus) Harvests in Chesapeake Bay Tributaries. Estuaries. 26: 316-322.

Morgan, C. and N. Owens, 2001. Benefits of Water Quality Policies: The Chesapeake Bay. Ecological Economics. 39:271–284.

National Marine Manufacturers Association, 2010. 2010 Recreational Boating Statistical Abstract. Chicago, Illinois. 94 pp.

National Ocean Economics Program, 2010. State of the U.S. Ocean and Coastal Economies. Coastal and Ocean Economic Summaries of the Coastal States. 62 pp.

Nowak, P.J., Petchenik, J.B., Carman, D.M., Nelson, E.B., 1990. Water Quality in the Milwaukee Metropolitan Area, the Citizen's Perspective. Submitted to the Wisconsin Department of Natural Resources and the Milwaukee River Basin Citizen Advisory Committee.

Odum, E. P., 1998. Ecological Vignettes: Ecological Approaches to Dealing with Human Predicaments. Essay 18, the Pricing System. Harwood Academic Publishers. 193-196.

Outdoor Industry Association, 2006. The Active Outdoor Recreation Economy. 20 pp.

Parsons, G., D. M. Massey, and T. Tomasi, 1999. Familiar and Favorite Sites in a Random Utility Model of Beach Recreation. Marine Resource Economics. 14(4):299-315.

Parsons, G. R., E. C. Helm, and T. Bondelid, 2003. Measuring the Economic Benefits of Water Quality Improvements to Recreational Uses in Six Northeastern States: An Application of the Random Utility Maximization Model. 25 pp.

Partnership for the Delaware Estuary, 2012. Technical Report for the Delaware Estuary and Basin. PDE Report No. 12-01. 255 pp.

Pendleton, L. H., undated. Restore America's Estuaries, The Economic and Market Value of Coasts and Estuaries: What's At Stake? Arlington, Virginia. 175 pp.

Pennsylvania Fish and Boat Commission, 2011. Economic Value of Fishing and Boating in Pennsylvania.

Pimentel, D., C. Harvey. P. Resosusdarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair, 1995. Environmental and Economic Costs of Soil Erosion and Conservation Benefits. Science. 267(5201):1117-1123.

Poor, P. J., K. L. Pessagno, and R. W. Paul, 2007. Exploring the Hedonic Value of Ambient Water Quality: A Local Watershed-Based Study. Ecological Economics 60:797–806.

Ribaudo, M. O., and D. J. Epp, 1984. The Importance of Sample Determination in Using the Travel Cost Method to Estimate the Benefits of Improved Water Quality. Land Economics. 60(4):397–403.

Rosenberger, R. S., and J. B. Loomis, 2000. Benefit Transfer of Outdoor Recreation Use Values: A Technical Document Supporting the Forest Service Strategic Plan. Rocky Mountain Research Station, U.S. Forest Service. Fort Collins, Colorado.

Searle, B. and S. Cox, 2009. The State of Ecosystem Services. The Bridgespan Group. 32 pp.

Smith, M. D., 2007. Generating Value in Habitat-Dependent Fisheries: The Importance of Fishery Management Institutions. Land Economics. 83:59-73.

Smith, V. K. and W. H. Desvousges, 1986. Measuring Water quality Benefits. Kluwer-Nijhoff, Boston, Massachusetts.

Stoklosa, A. M., Keller, D. H., Marano, R., and Horwitz, R. J., 2018. A Review of Dissolved Oxygen Requirements for Key Sensitive Species in the Delaware Estuary Final Report. The Patrick Center for Environmental Research. Academy of Natural Sciences of Drexel University

Summers, J. K., T. T. Polgar, K. A. Rose, R. A. Cummins, R. N. Ross, and D. G. Heimbuch, 1987. Assessment of the Relationships among Hydrographic Conditions, Macropollution Histories, and Fish and Shellfish Stocks in Major Northeastern Estuaries. NOAA Technical Memorandum. NOS OMA 31.

Thacher, J., M. Marsee, H. Pitts, J. Hansen, J. Chermak, and B. Thomson, 2011. Assessing Customer Preferences and Willingness to Pay: A Handbook for Water Utilities. Water Environment Federation. Denver, Colorado.

Thurston, H. W., M. T. Heberling, and A. Schrecongost, 2009. Environmental Economics for Watershed Restoration. CRC Press. 173 pp.

Trust for Public Land and American Water Works Association, 2004. Protecting the Source: Land Conservation and the Future of America's Drinking Water. 51 pp.

U.S. Army Corps of Engineers and Delaware River Basin Commission, 2008. Enhancing Multi-jurisdictional Use and Management of Water Resources for the Delaware River Basin. 165 pp.

U.S. Census Bureau, 2010. Property Value: 2008-2009. American Community Survey Briefs. 4 pp.

U.S. Department of Agriculture, 2009. 2007 Census of Agriculture.

U.S. Department of Agriculture, Natural Resources Conservation Service, 1995. National Resource Economics Handbook. Part 612 Water Quality. 56 pp.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2011. Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region. 158 pp.

U.S. Fish and Wildlife Service, 2008. 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

Van Houtven, G.L., 2009. Changes in Ecosystem Services Associated with Alternative Levels of Ecological Indicators. Risk and Exposure Assessment for Review of the Secondary National Ambient Air Quality Standards for Oxides of Nitrogen and Oxides of Sulfur. Washington, D.C.

Walsh, R. G., D. A. Greenley, R. A. Young, J. R. McKean, A. A. Prato, 1978. Option Values, Preservation Values and Recreational Water Quality: A Case Study of the South Platte River Basin, Colorado.

Walsh, R. G., D. M Johnson, and J. R. McKean, 1992. Benefit Transfer of Outdoor Recreation Demand Studies, 1968–1988. Water Resources Research. 28(3):707–713.

Weisberg, S. B, P. Himchak, T. Baum, H. T. Wilson, and R. Allen, 1996. Temporal Trends in Abundance of Fish in the Tidal Delaware River. Estuaries. 19(3):723-29.

Wey, K., 1990. A Social Welfare Analysis of Congestion and Water Quality of Great Salt Pond, Block Island, Rhode Island. Doctoral Dissertation. University of Rhode Island.

Wilson, M. A. and S. R. Carpenter, 1999. Economic Valuation of Freshwater Ecosystem Services in the United States: 1971–1997. Ecological Applications, 9(3):772-783.

World Business Council for Sustainable Development, 2011. Guide to Corporate Ecosystem Valuation, A framework for Improving Corporate Decision-Making. 73 pp.