

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

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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 (DWRP) 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 for 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)

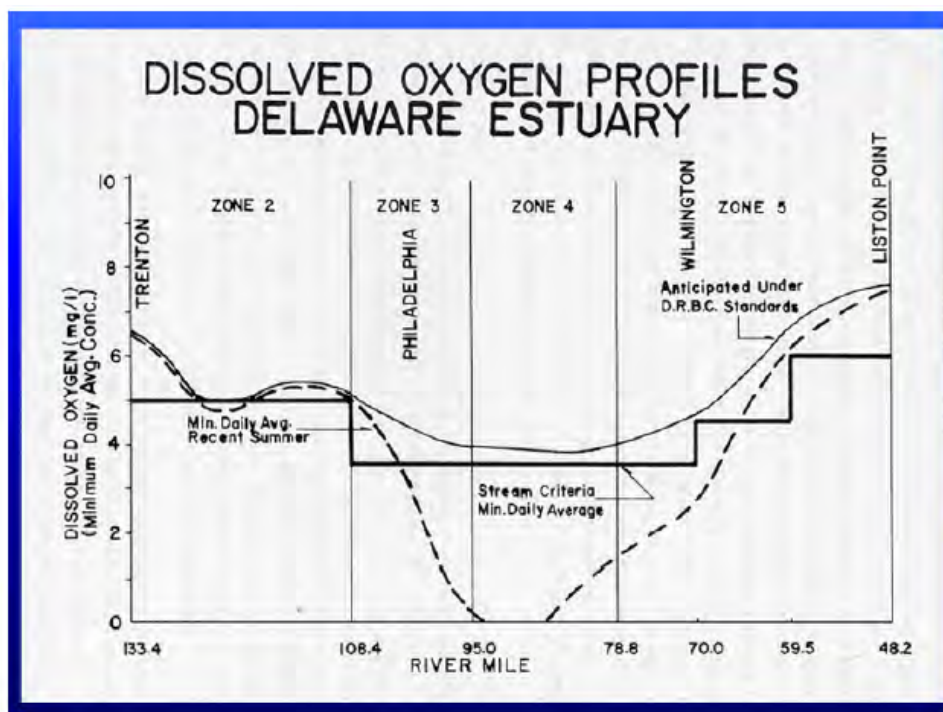


Figure 1.3 DRBC dissolved oxygen criteria along the Delaware Estuary in 1968

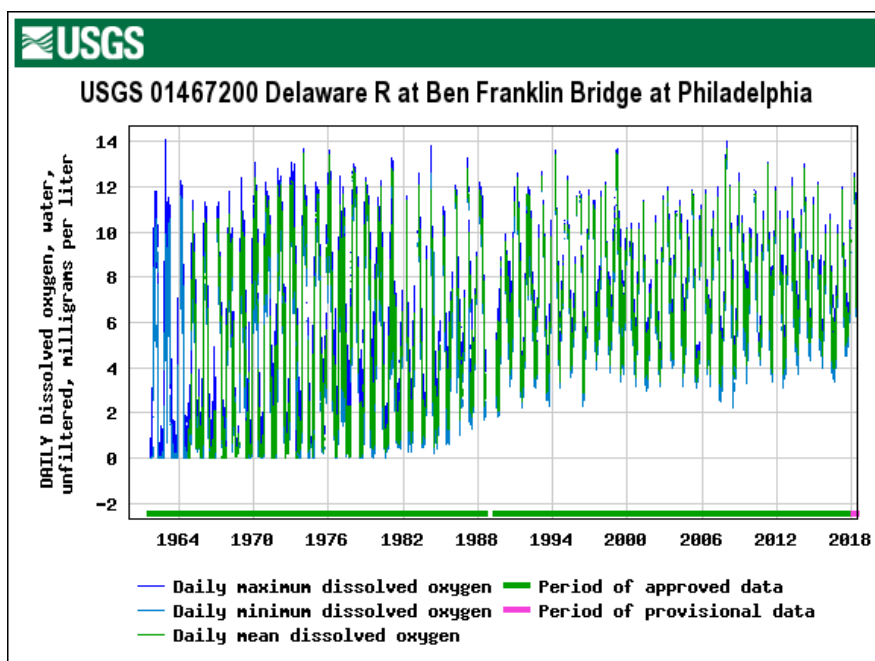


Figure 1.4 Dissolved oxygen along the Delaware River at Philadelphia

Since DO saturation and water temperature are inversely proportional, the maximum DO in the Delaware River at 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.

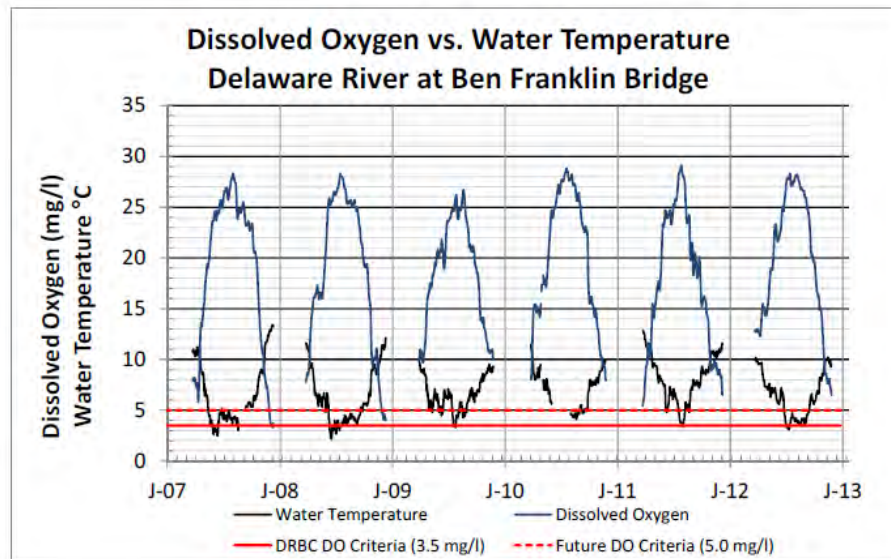


Figure 1.5 Dissolved oxygen and water temperature of the Delaware River at Philadelphia (2007-2013)

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 |

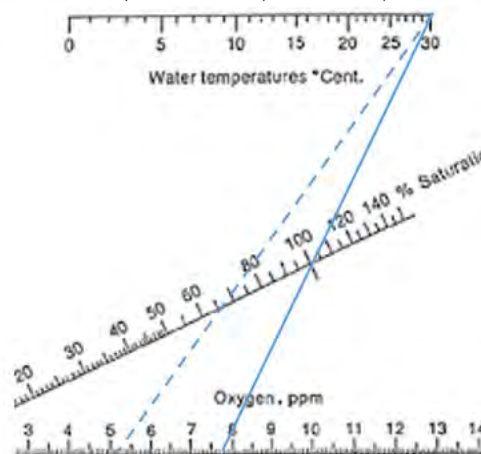


Figure 1.6 Dissolved oxygen saturation and water temperature relationship

Delaware River water chemistry is monitored as conductivity (salinity), water temperature, dissolved oxygen, and pH at Reedy Island, Chester, and Ben Franklin Bridge at Philadelphia (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.

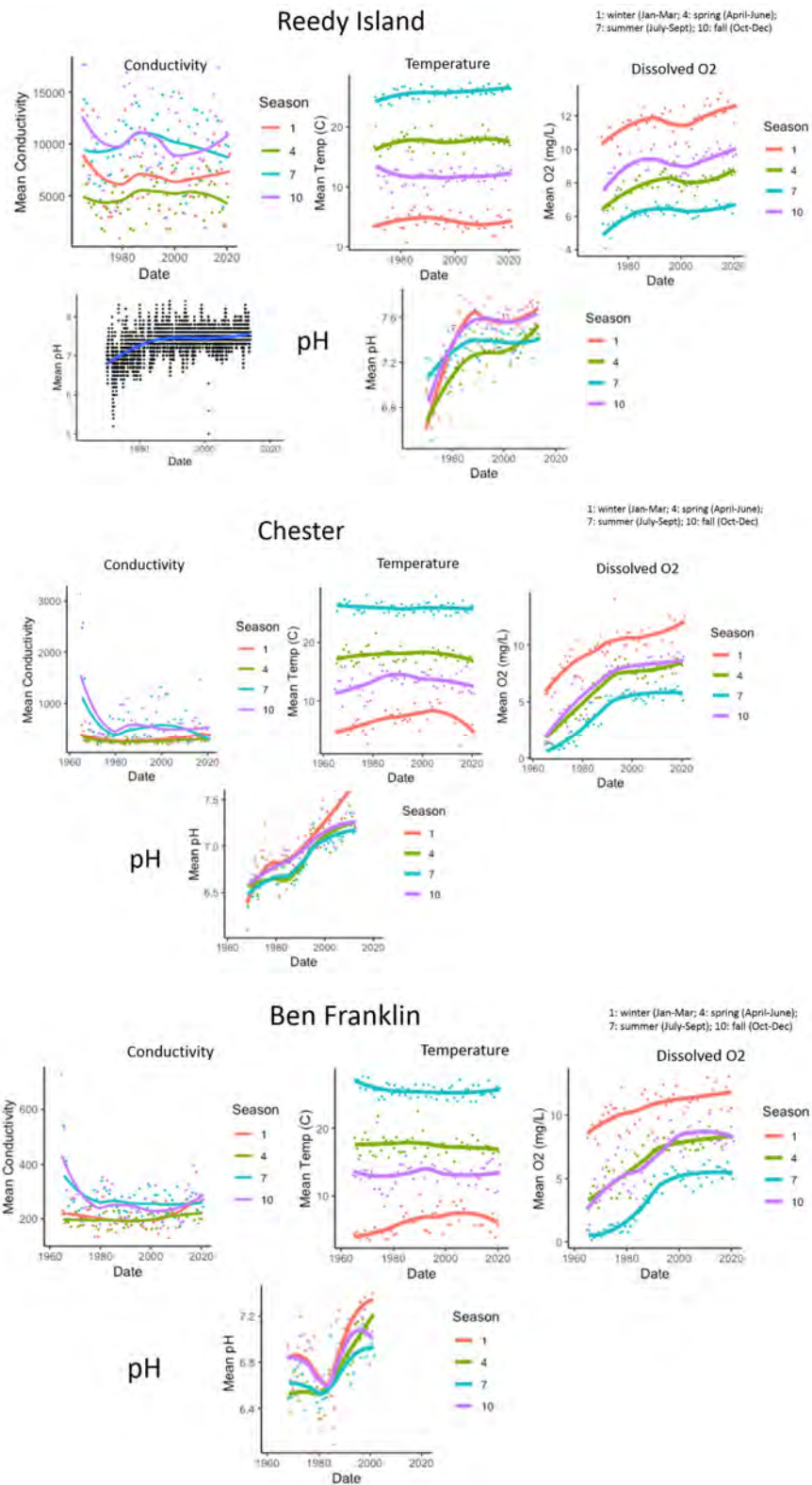


Figure 1.7 Water quality along the Delaware River at Reedy Island, Chester, and Philadelphia (USGS)

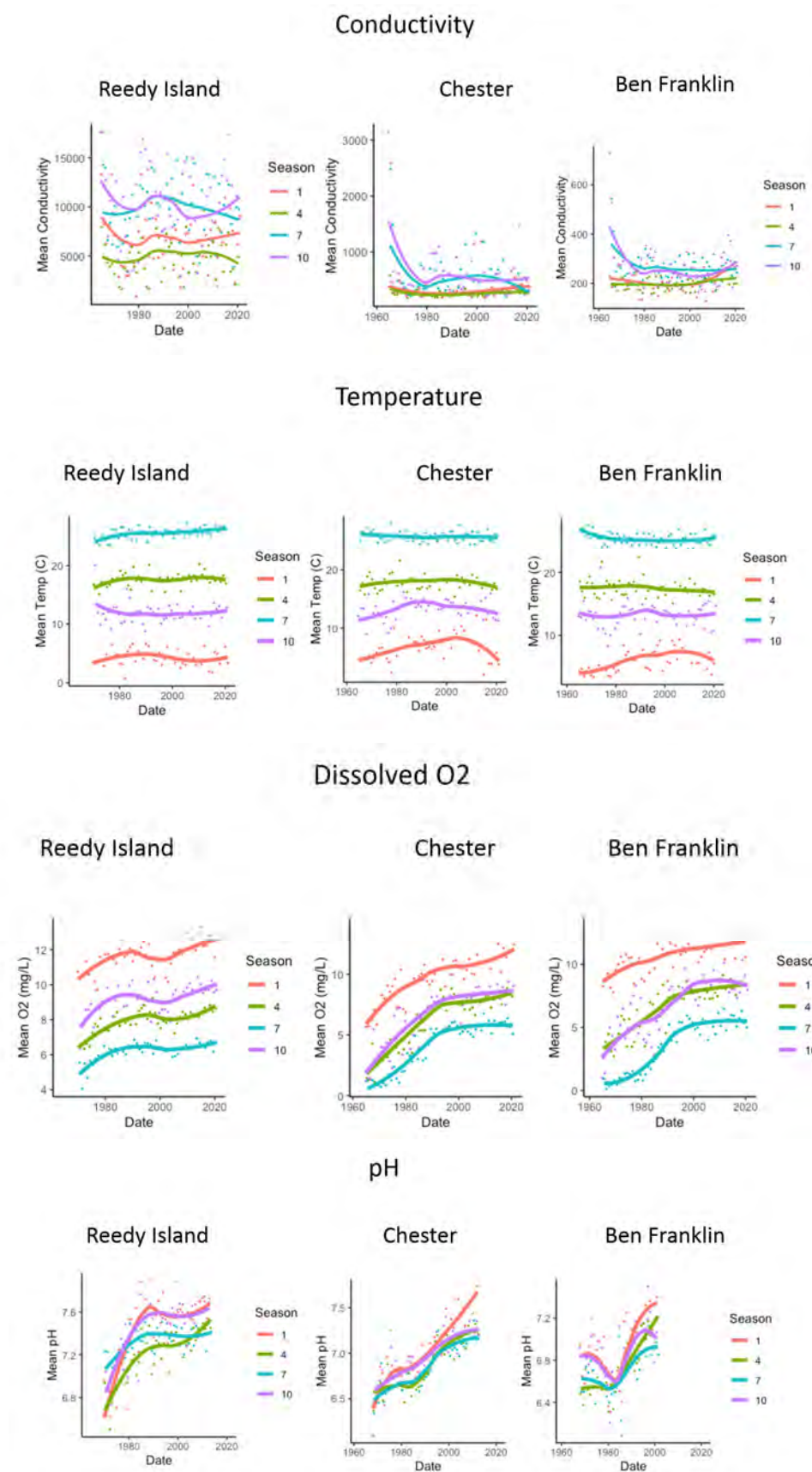


Figure 1.8 Water quality along the Delaware River for conductivity, water temperature, dissolved oxygen, and pH

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 Temp. Salinity | | | Description | Reference |
|-----------------------------------|----------------|-------------------|-------|----------------|--|---|
| | | (mg/l) | (°C) | (‰) | | |
| 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 | - | - | Survival 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. | Yargo and Sastry 1977 |
| Atlantic Rock Crab | Larval | 3.8 | 20 | 28-32 | LC10. | Miller, Foucher, and Coiro 2002 |
| Atlantic Rock Crab | Megalops | 4.7 | 30 | 30 | LC50. | Yargo and Sastry 1977 |
| Scud (<i>G. fasciatus</i>) | Adult | 4.3 | 20 | - | 24-hour LC50. | Sprague 1963 |
| Scud (<i>G. pseudolimnaeus</i>) | Adult, Female | 4.1 | 20 | 0 ^a | Lowest DO resulting in significant mortality. | Urbach 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: ^a 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).

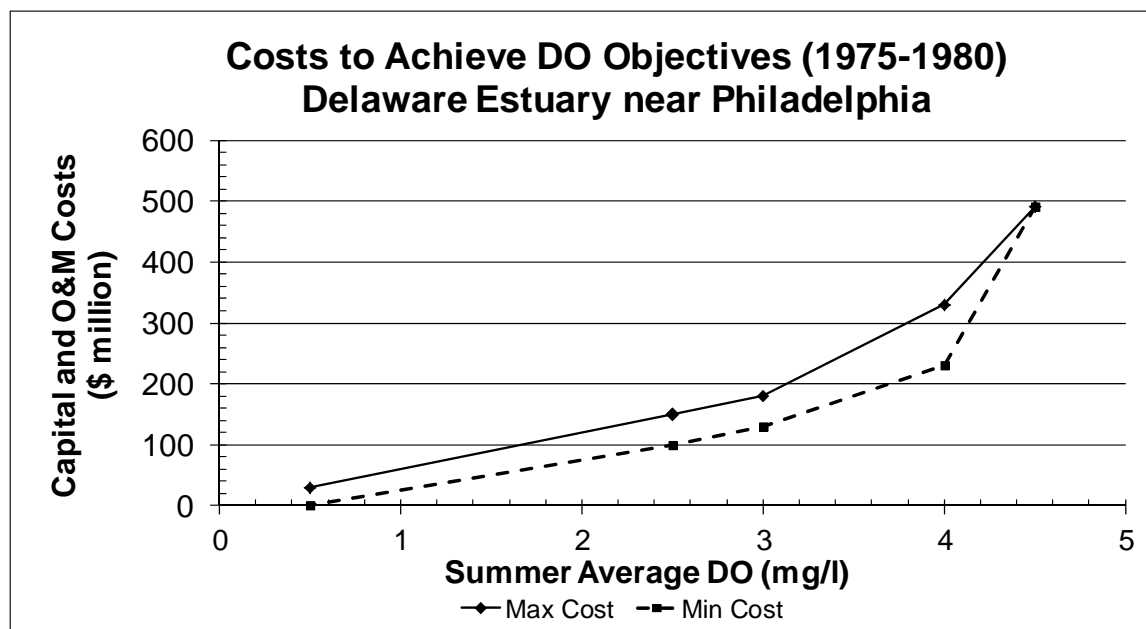


Figure 1.10 Costs to achieve DO objectives (1975-1980) in the Delaware Estuary near Philadelphia (FWPCA 1966)

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).

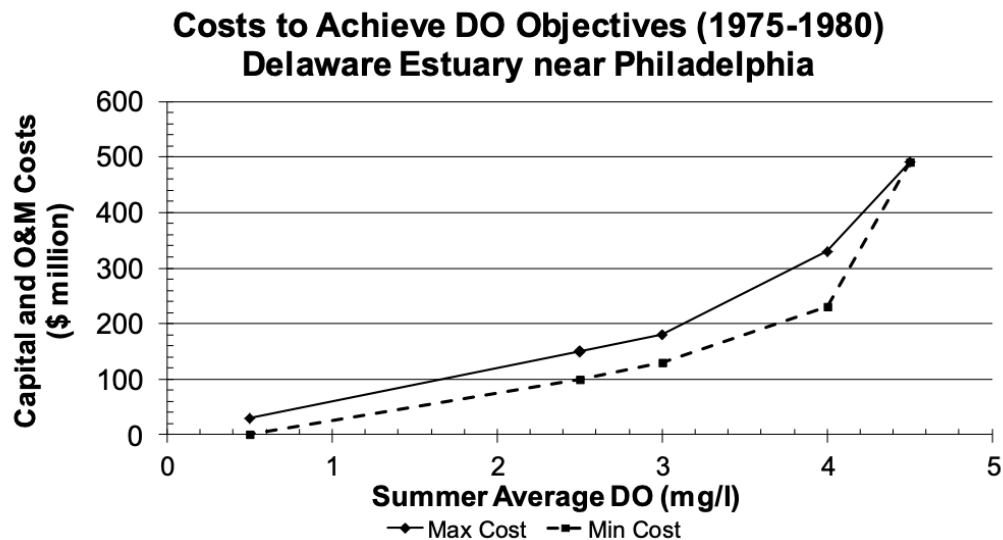


Figure 2.1 Costs to achieve DO objectives (1975-1980) in the Delaware Estuary near Philadelphia (FWPCA 1966)

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 ($\text{NH}_3\text{-N}$) 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).

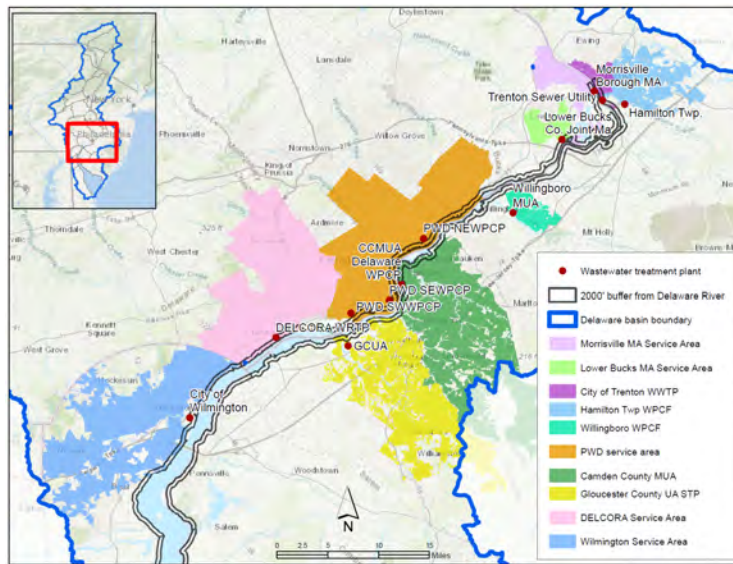


Figure 2.2 Largest wastewater treatment plant dischargers in the Upper Estuary

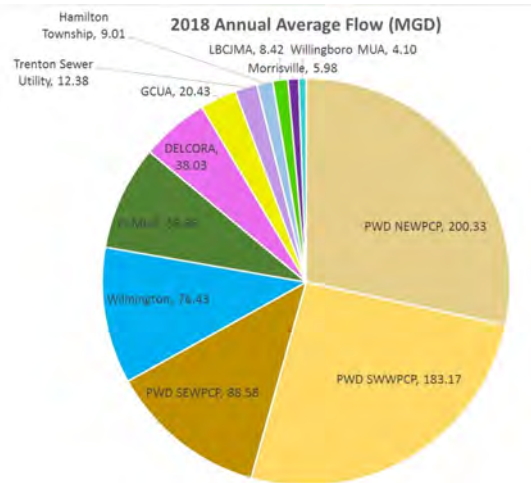


Figure 2.3 Annual average flow of wastewater dischargers in the Delaware Estuary

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 WRTF | 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.

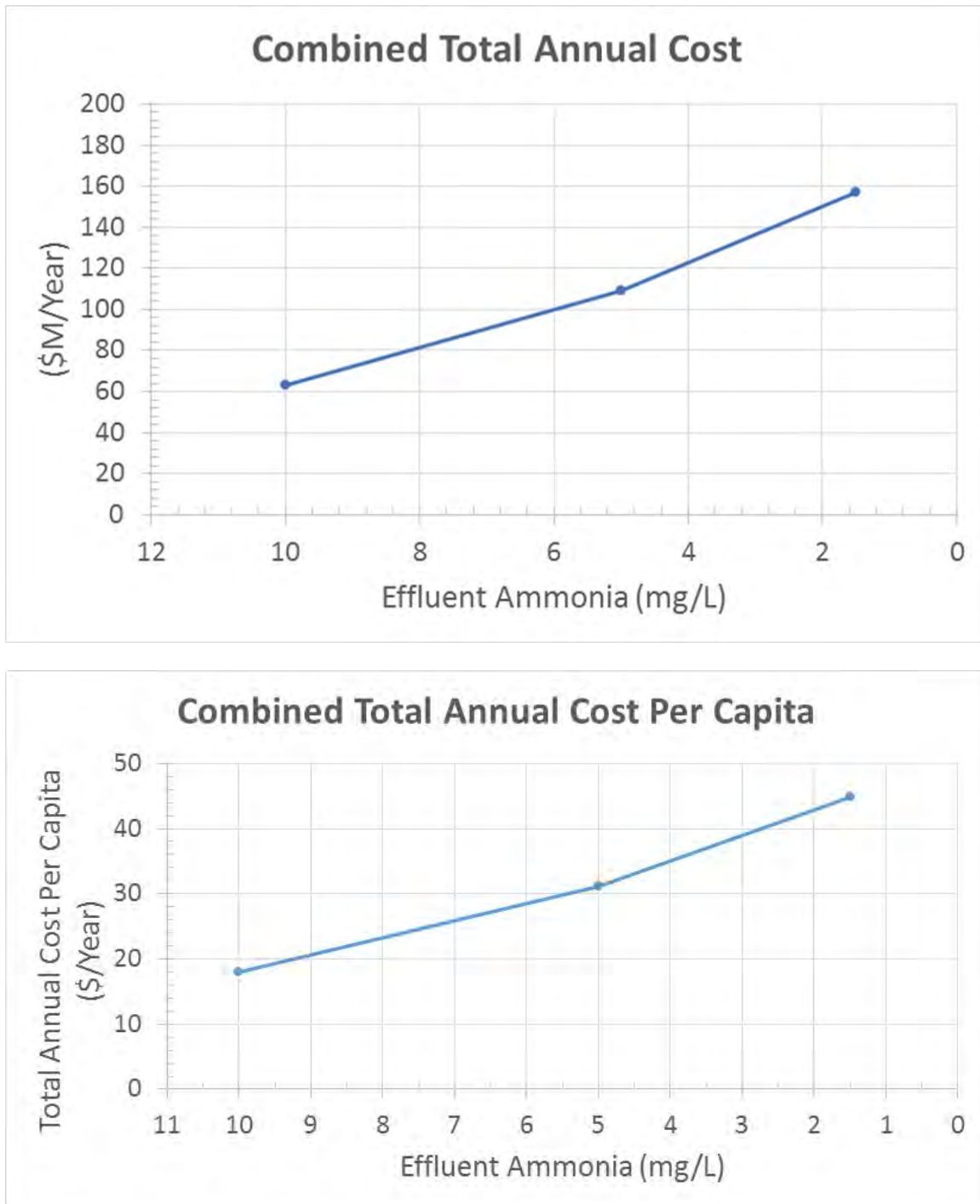


Figure 2.4 Annual and per capita cost of ammonia reduction at wastewater treatment plants in the Delaware Estuary

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

| Scenario NH ₃ -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 | | 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 |

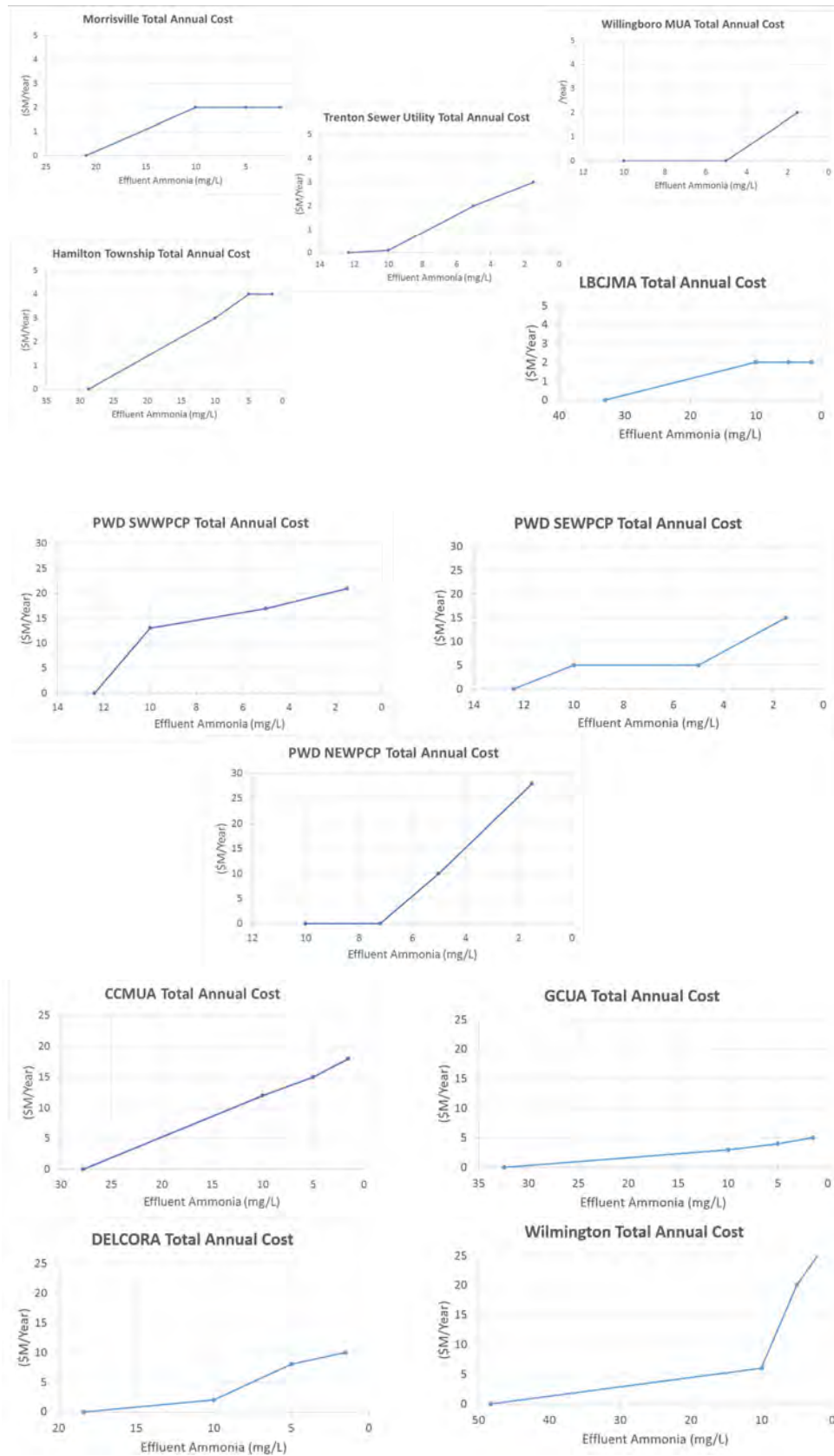


Figure 2.5 Annual cost of ammonia reduction at wastewater dischargers in the Delaware Estuary

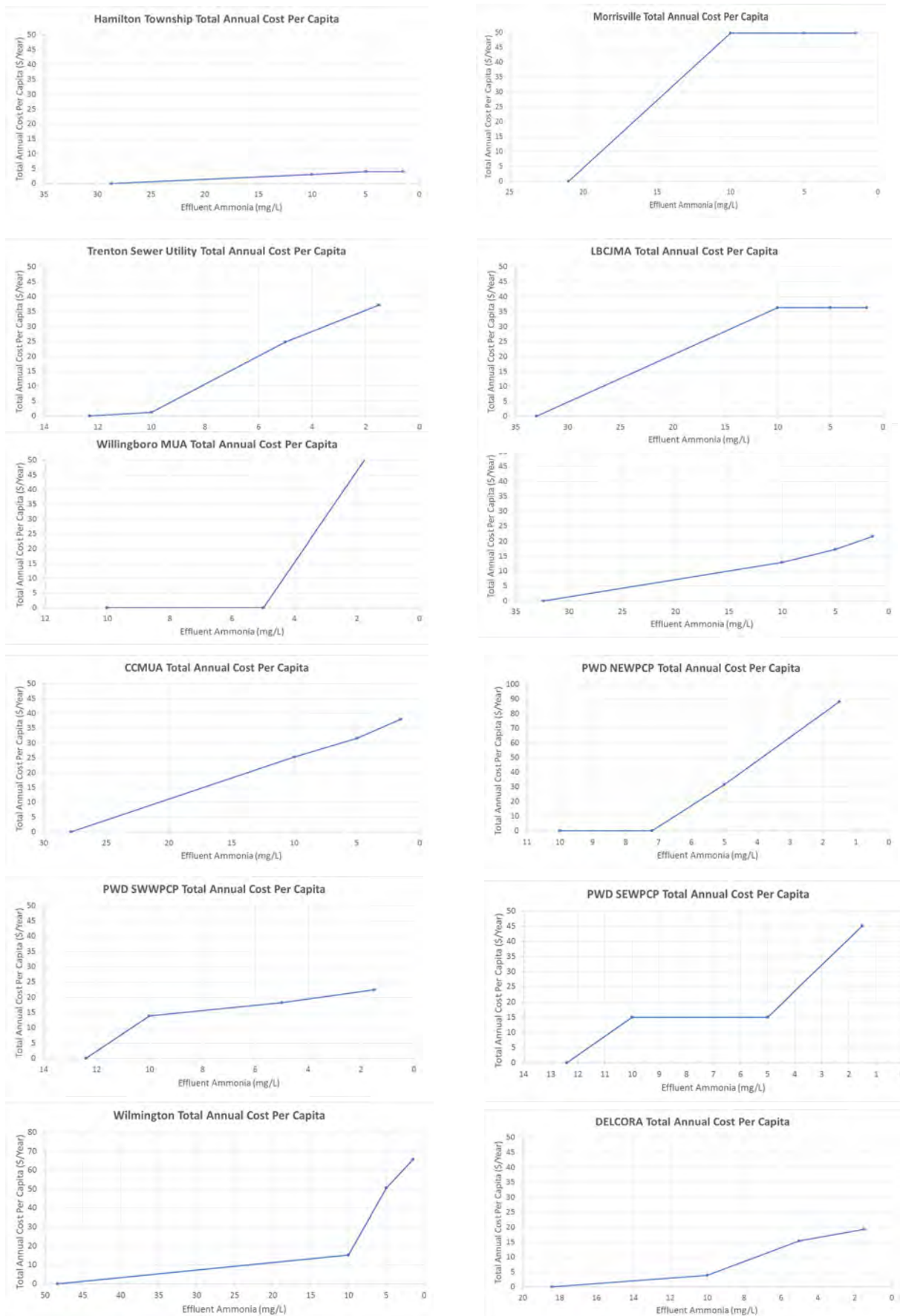


Figure 2.6 Annual cost of ammonia reduction at wastewater dischargers in the Delaware Estuary

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).

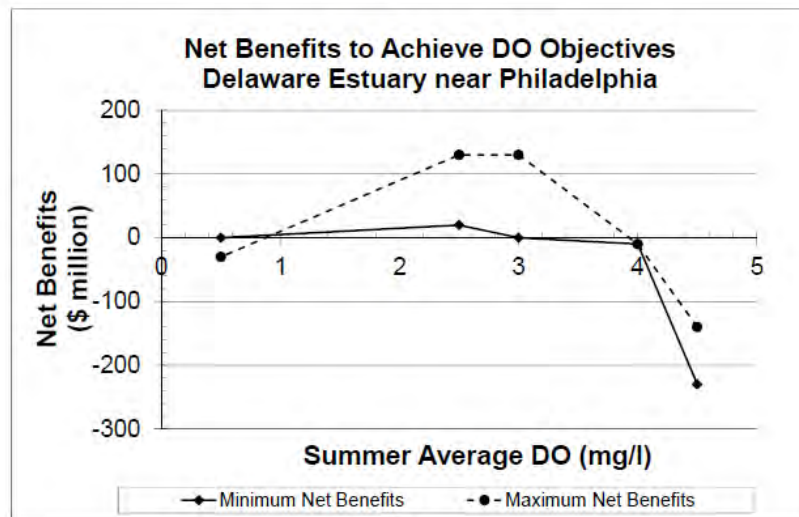


Figure 3.1 Net benefits to achieve DO objectives in Delaware Estuary near Philadelphia (FWPCA 1966)

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).

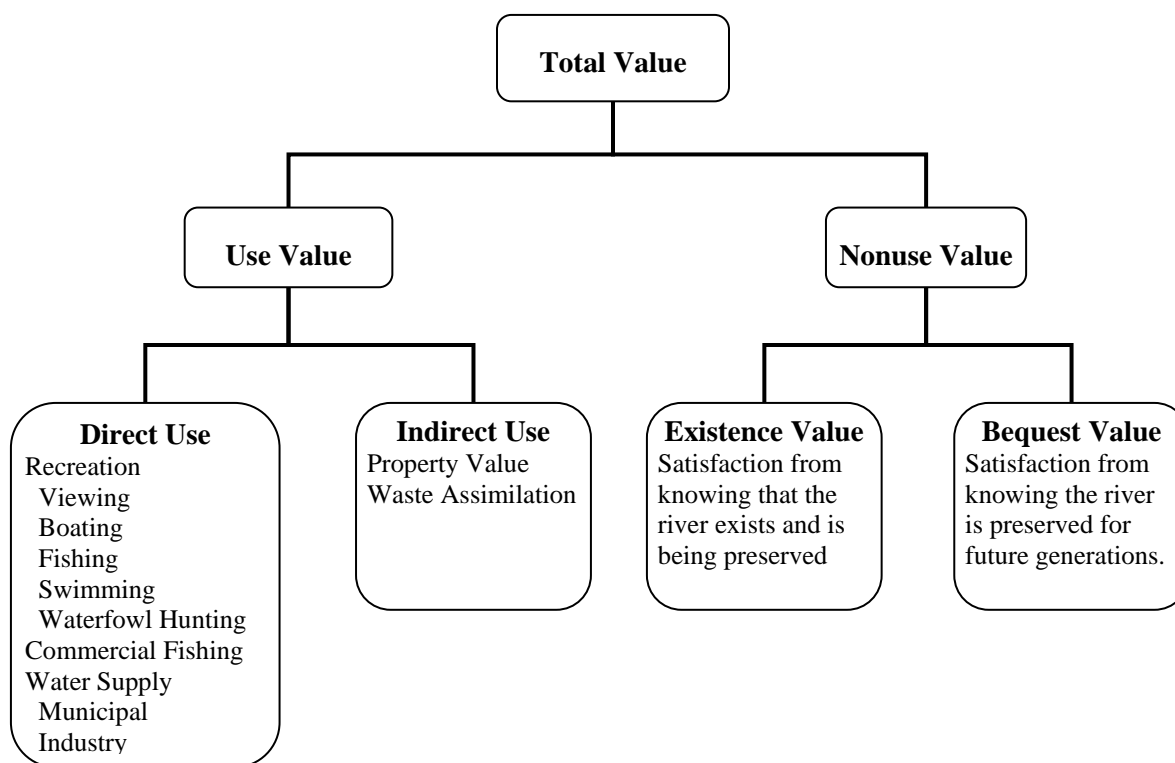


Figure 3.2 Economic benefits of improved water quality in the Delaware River

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 implement | 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.

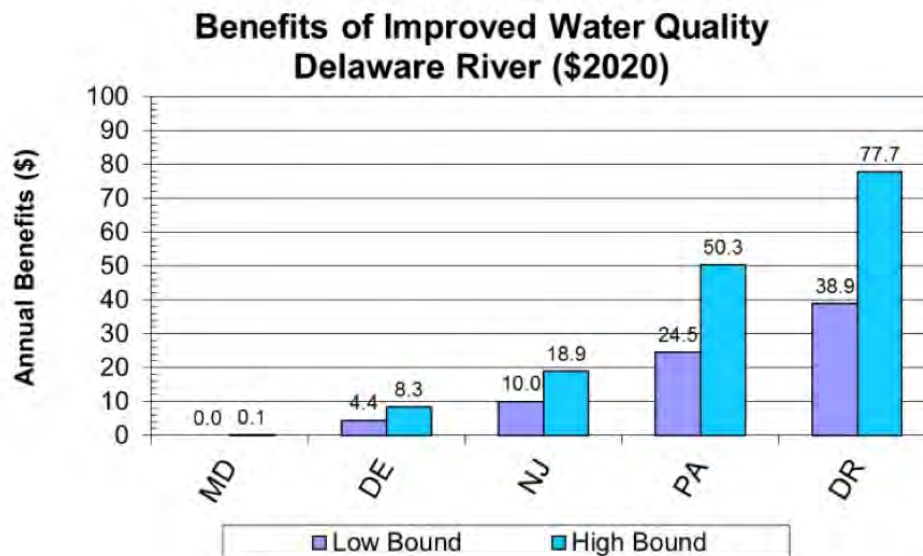
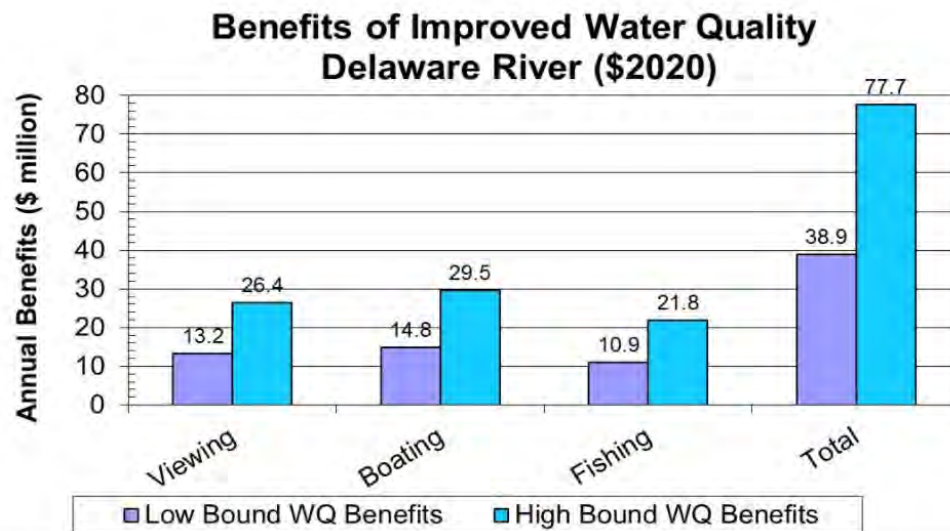


Figure 3.3 Annual recreation benefits due to improved water quality in Delaware River (Parsons et al. 2003 adjusted to \$2020 based on 3% annually.)

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 Desvougues (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 Desvougues (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

| Recreation Activity | Delaware | | New Jersey | |
|------------------------|---------------------|-------------------------------------|---------------------|-------------------------------------|
| | 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).

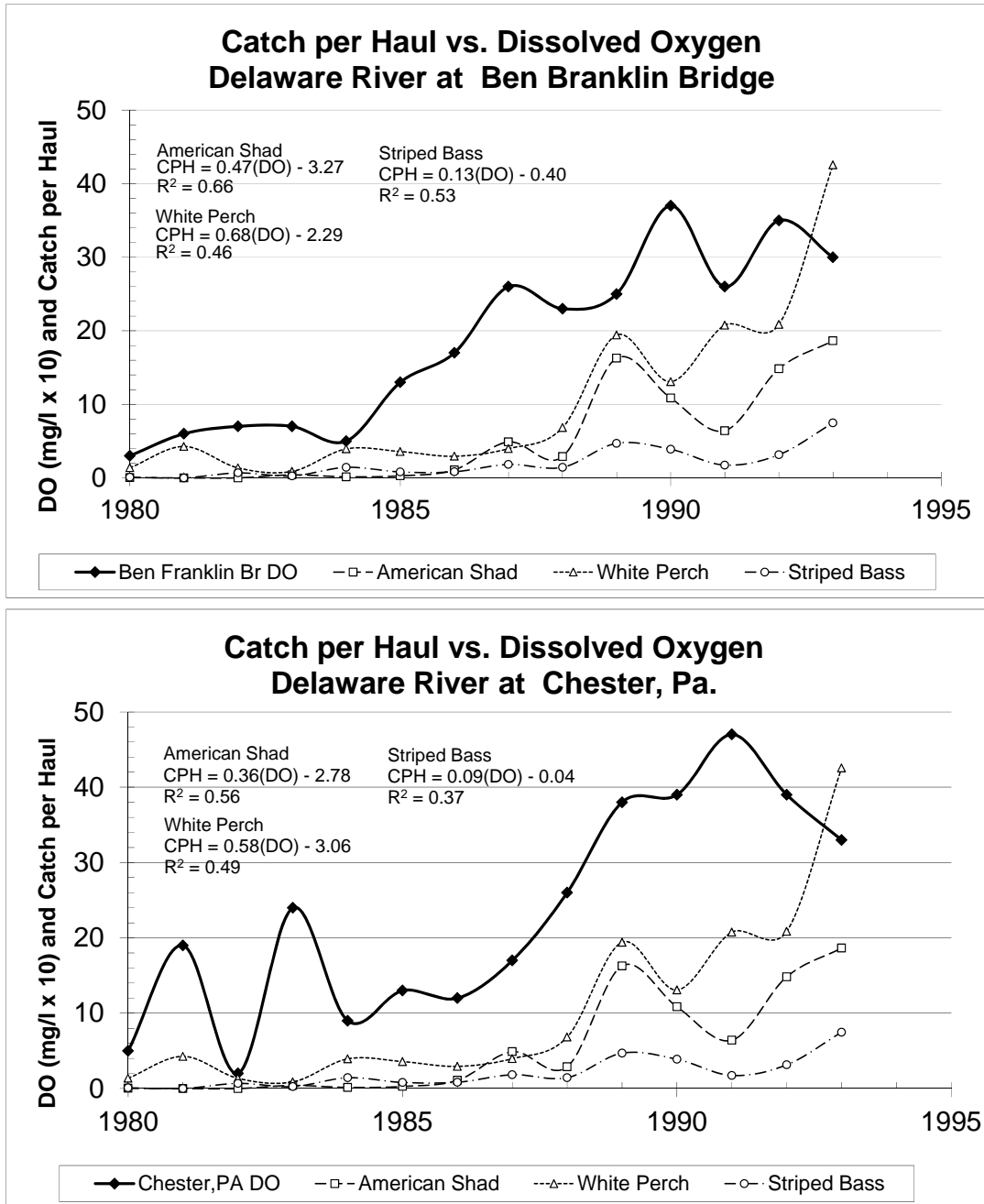


Figure 3.4 Relationship between dissolved oxygen and fish catch in the Delaware Estuary (Weisberg et al. 1996)

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% |

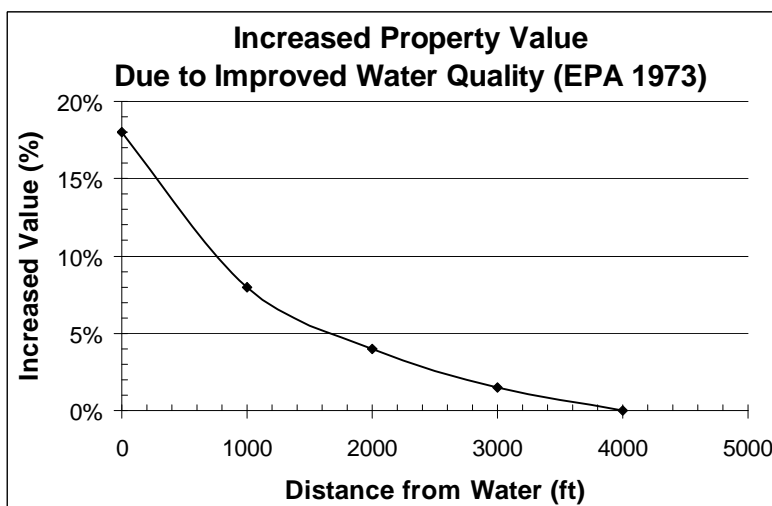


Figure 3.5 Increased property value due to improved water quality (EPA 1973)

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.

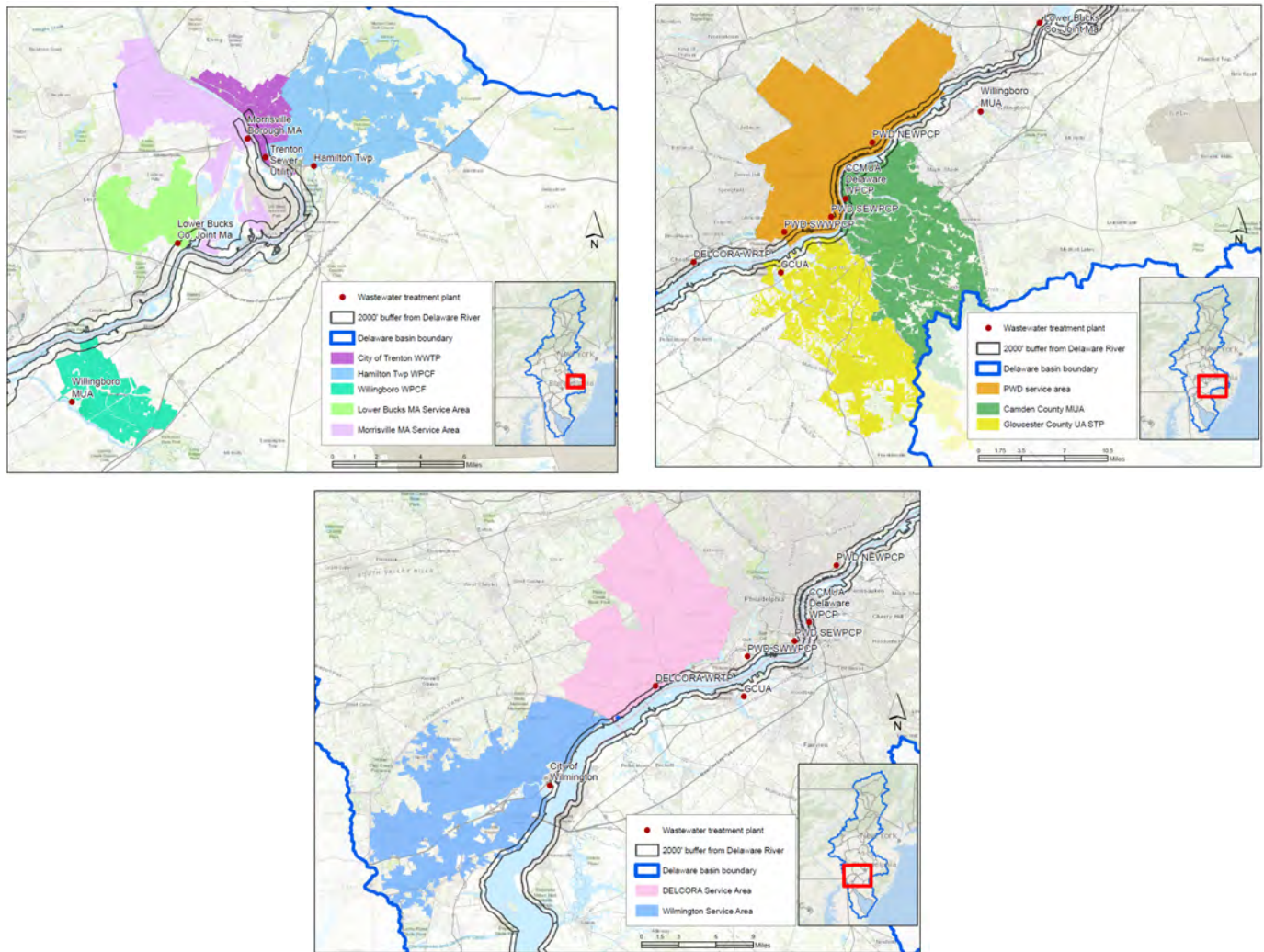


Figure 3.6 Property within 2000 feet of the Delaware River between Trenton and Wilmington

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 | 9,526,050 | 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) |
| Nonuse | Aesthetic | Near water recreation (hiking, picnicking, photography) |
| | | Viewing (commuting, office/home views) |
| | Ecosystem | Hunting/bird watching |
| | | Ecosystem support (food chain) |
| | 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.

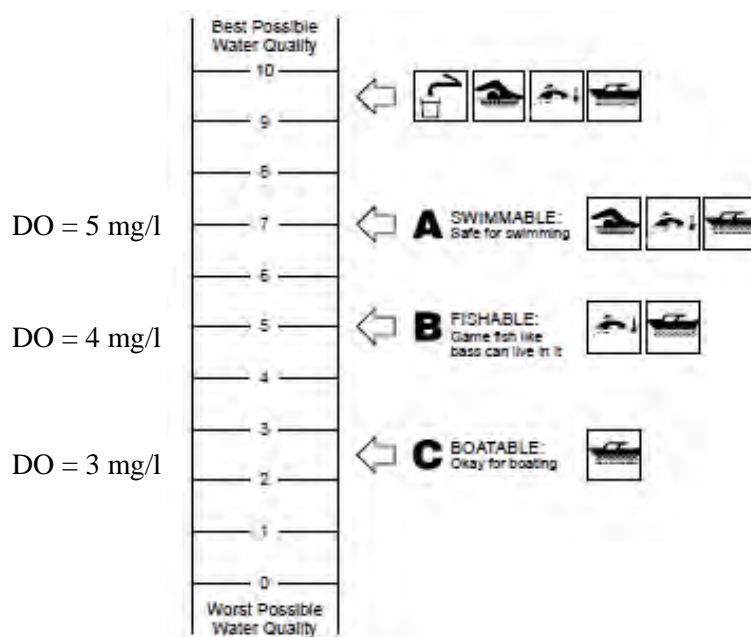


Figure 3.7 Water quality ladder
(Carson and Mitchell 1993 from Resources for the Future)

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 WTP¹ (\$/hhold) | 1983 Mean WTP (\$/person)² | 2020 Mean WTP³ (\$/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 WTP² (\$/person) | Low WTP (\$ mil/yr) | Low Nonuse³ (\$ 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 WTP² (\$/person) | High WTP (\$ mil/yr) | High Nonuse³ (\$ 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.

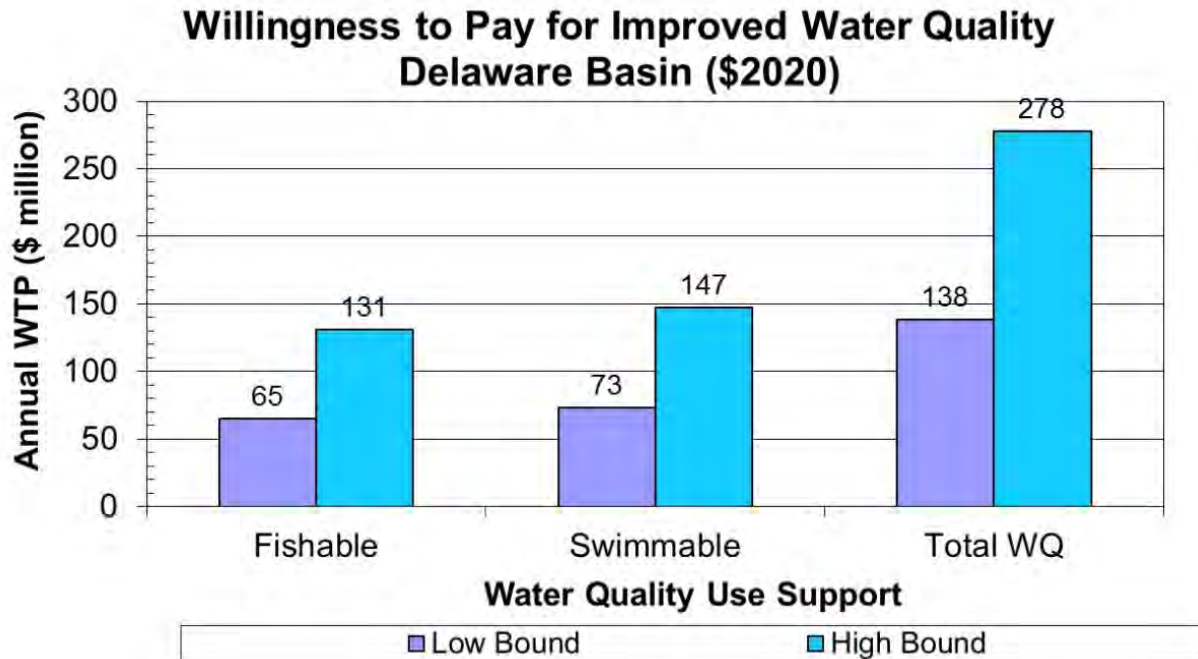


Figure 3.8 Nonuse benefits willingness to pay for improved water quality in Delaware Basin
(Carson and Mitchell 1993 adjusted to \$2020 at 3% annually. Nonuse benefits are 33% of WTP)

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 |

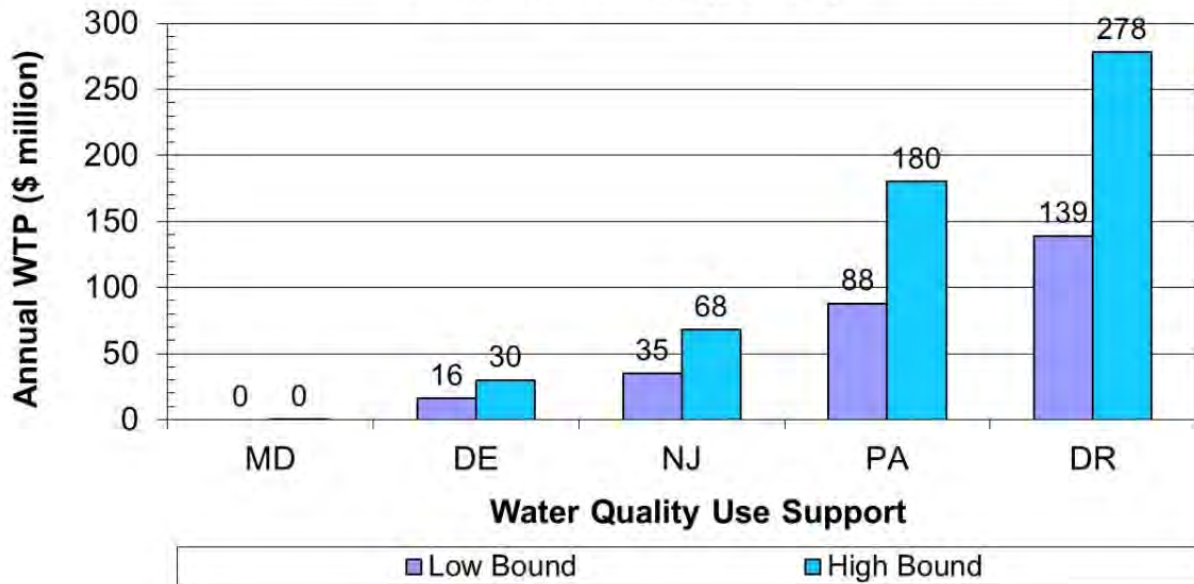
1. Adult pop. >18 yr. old. 2. Carson & Mitchell 1993 adjusted to \$2020 by CPI. 3. Nonuse benefits 33% of WTP.

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.

Willingness to Pay for Improved Water Quality Delaware Basin (\$2020)

**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).

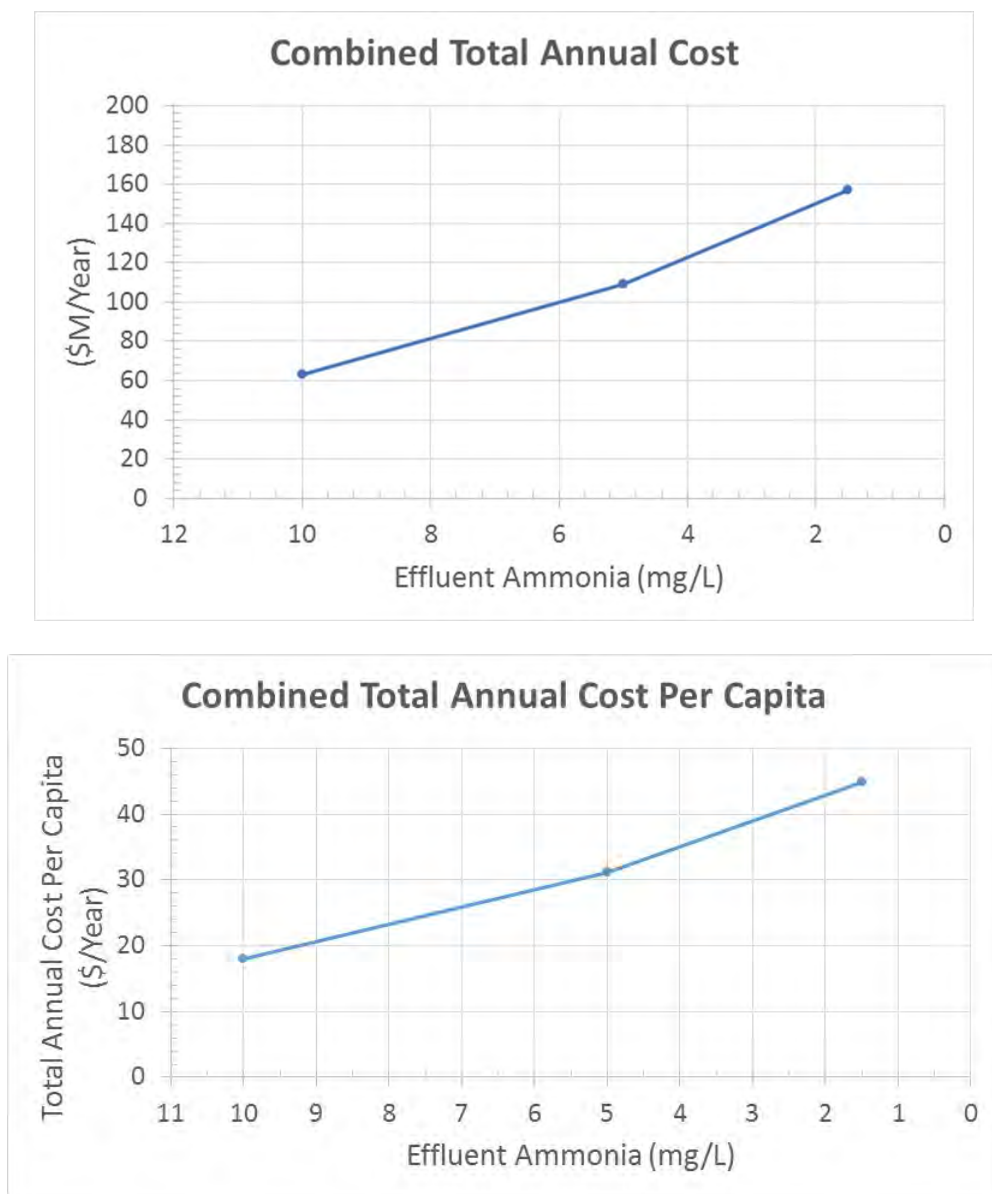


Figure 4.1 Annual and per capita cost of ammonia reduction at wastewater treatment plants in the Delaware Estuary

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

| Wastewater Service Area | Flow (mgd) | Pop. Served | Existing NH ₃ -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.

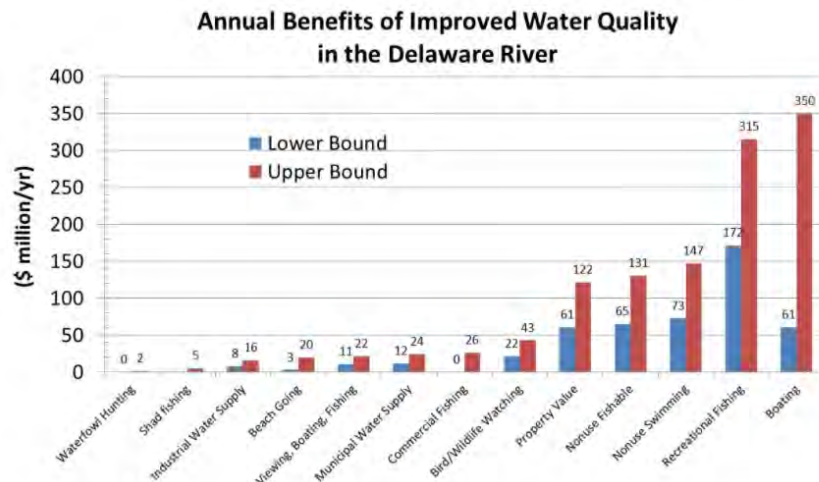
**Figure 4.2** Lower and upper bound benefits of improved water quality in the Delaware River

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 |

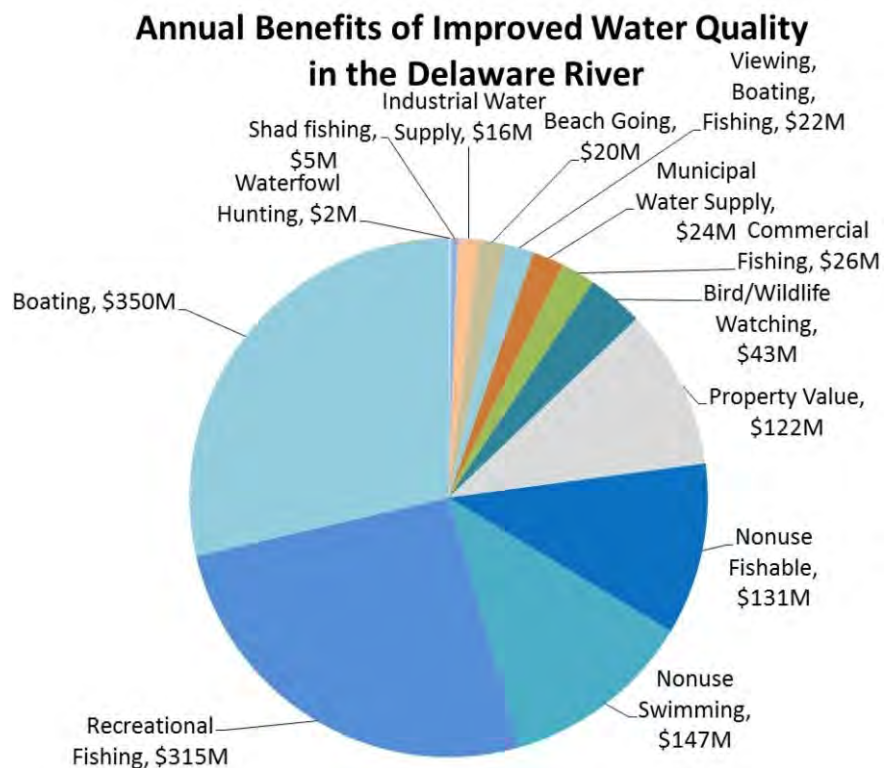


Figure 4.3 Upper bound benefits of improved water quality in the Delaware River

Net Benefits

Ammonia reductions at wastewater treatment infrastructure along the Delaware Estuary are cost effective as the benefits comfortably 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

| NH ₃ -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 |

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