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# Economic benefits of improved water quality in the Delaware River (USA)

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## Abstract

Water quality in the Delaware River, USA, has improved significantly since the Federal Water Pollution Control Act (1948), Clean Water Act of 1972, and authorization of the Delaware River Basin Commission Compact in 1961. Initial economic analysis by the Federal Water Pollution Administration in 1966 concluded the multimillion dollar pollution abatement programme would generate $350 million in annual benefits by improving dissolved oxygen levels to fishable standards in the Delaware River. Although water quality in the Delaware has improved substantially, scientists have called for raising the 1960s dissolved oxygen criteria from 3.5 mg/L to 5.0 mg/L to ensure year-round propagation of anadromous American shad and Atlantic sturgeon. This higher level would also mitigate atmospheric warming resulting in increased water temperatures and sea water incursion, both of which would lead to reductions in dissolved oxygen saturation in the river. Additional economic valuation of this water quality improvement shows direct use benefits in the Delaware River to range from $371 million to $1.1 billion per year. Other economic sectors benefiting from improved water quality include recreational boating ($46–$334 million), recreational fishing ($129–$202 million), agriculture ($8–$188 million), nonuse value ($76–$115 million), viewing/boating/fishing ($55–$68 million), bird watching ($15–$33 million), property value ($13–27 million), water supply ($12–$24 million), commercial fishing (up to $17 million), and navigation ($7–$16 million). Future economic research is needed in the Delaware River watershed to more precisely measure nonuse benefits by public willingness to pay for improved water quality.

KEYWORDS
economics, river basin, water policy, water quality

## 1 | INTRODUCTION

The concept of placing a dollar value on natural resources goes back a century to economists Arthur Pigou (1920) and John Hicks (1939) who outlined that individual preferences are based on individual willingness to pay (WTP) for benefits (Kramer, 2005). A half century ago, the Harvard Water Program (1971) advocated planning and design of water resources projects based on optimizing social, environmental, and economic costs/benefits (Dorfman, Jacoby, & Thomas, 1972; Maass et al., 1962). In environmental economics, WTP measures how much people are willing to pay for a given service regardless of whether or not they actually use the service (Goulder & Kennedy, 1997). Economic benefits can be measured as the dollar value of services that individuals are willing to pay (WTP) for improved water quality (Cech, 2005). Marginal benefits are defined as the incremental change in value of ecosystem services that improve with enhanced water quality (Dixon, Scura, Carpenter, & Sherman, 1994). The downward sloping demand curve traces marginal benefits (Figure 1) as the WTP for an additional unit of water quality (Hjalte, Lidgren, & Stahl, 1977; Koteen, Alexander, & Loomis, 2002).

The economic benefits of improved water quality in river systems are difficult to assess because of externalities, the free rider effect, and lack of property rights. If a river system is polluted by an upstream industrial discharge, for example, then downstream residents may be harmed by this negative externality because they are not compensated for impaired drinking water quality or reduced boating/fishing activity. A free rider is an individual such as a canoe livery that benefits from a public good such as improved water quality but does not pay to protect or conserve the watershed (Thurston, Heberling, & Schrecongost, 2009). In contrast to land where property is bought and sold in the real estate market, water rights are not as clearly defined, and water flow may be overused with no incentive to conserve it (Libecap, 2005).

Ecological valuation studies have found the benefits of improved water quality in the U.S. reaches up to $11 billion per year (Table 1). Water pollution programmes authorized through the Federal Water Pollution Control Act of 1948 and the Clean Water Act of 1972 improved water quality with national benefits to the U.S. economy of $11 billion per year (Bingham et al., 2000). A report by the Environmental Protection Agency (EPA, 2002) concluded that boatable, fishable, and swimmable benefits of improved water quality in the Willamette River in Oregon ranged from $120 to $260 million per year. In one of the earliest economic studies of its kind, the Federal Water Pollution Control Administration (FWPCA, 1966) estimated the benefits of improving water quality in the Delaware River at Philadelphia, from a dissolved oxygen (DO) level of 0.5 mg/L to 4.5 mg/L, would range from $120 to $350 million per year in 1964 dollars.

Except for the 1966 FWPCA and EPA 2002 economic analyses, little is known about the current economic benefits of pollution control

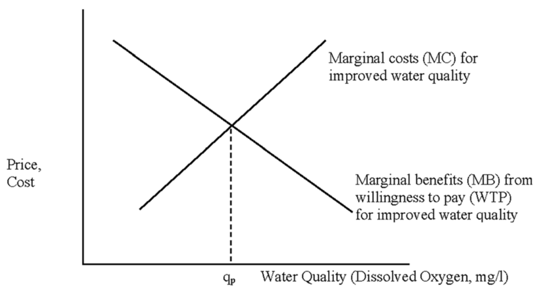


**FIGURE 1** Optimal water quality

efforts that have improved water quality in rivers across the United States. The objectives of this research are to estimate the economic benefits of pollution reduction strategies to raise DO levels from the current standard of 3.5 mg/L to a future year-round fishable criteria of 5.0 mg/L in the Delaware River, USA, that would boost the tourism, fishing/hunting, recreation, real estate, and water supply economies that rely on clean water. DO is considered in this economic analysis as the "fishable" water quality standard and an essential indicator of ecological health of the estuary system.

## 2 | THE DELAWARE RIVER

The Delaware River, which extends 300 miles (480 km) from the Catskill Mountains (NY) to its mouth at Cape May (NJ), is the longest unregulated river east of the Mississippi (Figure 2). The Delaware River Basin covers just 0.4% of the continental United States yet supplies drinking water to over 13 million people (4% of the nation's population). This includes New York City and Philadelphia, which are the nation's largest and seventh-ranked metropolitan economies, respectively (Kauffman, Homsey, Belden, & Sanchez, 2010). The Delaware River watershed supports $21 billion per year in ecosystem goods and services and over 500,000 jobs in Delaware, New Jersey, New York, and Pennsylvania (Kauffman, 2016).

When John F. Kennedy and the governors of Delaware, New Jersey, New York, and Pennsylvania signed the Delaware River Basin Commission Compact (DRBC) in 1961, it became one of the first models of intergovernmental river basin management in a shared approach between federal and state government (DRBC, 1961). The DRBC (2010) classifies the Delaware River/Bay in 10 water quality zones with designated uses such as (1) Water Supply, Agricultural, Industrial, Public, (2) Wildlife, Fish, Aquatic Life, (3) Recreation (Primary Swimming/Secondary Boating), (4) Navigation, and (5) Waste Assimilation. In the tidal section of the Delaware River, summer DO criteria ranges between 5 mg/L at Trenton, 3.5 mg/L at Philadelphia, 4.5 mg/L in the Delaware Bay, to 6 mg/L near the Atlantic Ocean. The DO criteria is 6.5 mg/L during spring and fall at Philadelphia for seasonal propagation of resident and anadromous fish.

An FWPCA (1966) study reported that the Delaware Basin was the only watershed in the United States empowered by federal/state law, the 1961 DRBC Compact, to implement regional, interstate water quality management. The 1966 FWPCA report described the Delaware River at Philadelphia as "a polluted waterway which depresses

**TABLE 1** Economic benefits of improved water quality in the United States

| Location | Reference | Benefits ($ billion per year) | Comments |
|---|---|---|---|
| U.S. | Freeman, 1990 | 5.2 | Water treatment/commercial fishing |
| Urban U.S. | EPA, 1994 | 0.8–6.0 | Pres. Clinton's Clean Water Initiative |
| U.S. | Bingham, 1995 | 11.0 | Clean Water Act of 1972/1977 |
| Oregon, Willamette R. | EPA, 2002 | 0.12–0.26 | Boatable, fishable, swimmable benefits |
| Delaware River at Phila. | FWPCA, 1966 | 0.12–0.35 | Improve DO from 0.5 mg/L to 4.5 mg/L |


**FIGURE 2** The Delaware River Basin [Colour figure can be viewed at wileyonlinelibrary.com]

aesthetic values, reduces recreational, sport and commercial fishing, and inhibits municipal and industrial water uses." This Delaware Estuary study was one of the first river basin economic analyses in the United States (Schaumburg, 1967; Kneese & Bower, 1984), and the report concluded through an evaluation of five objectives (I through V) that recreational benefits of swimming, boating, and fishing due to improved water quality in the Delaware Estuary ranged from $120–$350 million per year to raise DO from 0.5 mg/L during the 1960s to a future level of 4.5 mg/L (Table 2).

In the 1960s, a decade before Congress passed the 1972/1977 Clean Water Act amendments, the DRBC was among the first in the United States to establish water quality standards on a watershed basis (Albert, 1988). In 1967, a DRBC water advisory committee examined the 1966 FWPCA benefit–cost analysis to establish water quality criteria. Municipal/industrial interests endorsed Objective III (3.0 mg/L) with highest net benefits of $130 million (Figure 3). Conservationists recommended DRBC adopt Objective II (4.0 mg/) as more protective with the highest marginal benefits ($20–$30 million). The DRBC adopted a compromise between Objectives III (3 mg/L) and II (4 mg/L) and set a summer 24-hr DO criteria of 3.5 mg/L for the Delaware River at Philadelphia as a standard that still stands today.

The Delaware River has a history of nutrient pollution (Sharp, Culberson, & Church, 1982). However, water quality has improved considerably in the last few decades due to restoration by the DRBC, EPA, and the states (Bain, Walter, Steenhuis, Brutsaert, & Gaetano, 2010; Bricker et al., 2007 and Sharp et al., 2009). Reconstruction of a century-long DO record indicates water quality in the Delaware River has improved as much as any estuary in the world (Sharp,

**TABLE 2** Recreational benefits of improved water quality in the Delaware Estuary (1964 dollars; FWPCA, 1966; Thoman, 1972)

| Objective | DO summer (mg/L) | BOD/COD residual (lb/day) | Pollution removal (%) | Total benefits ($ million) | Marginal benefits ($ 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 |

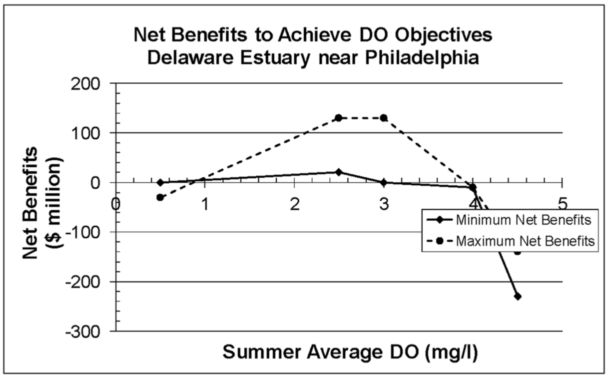


**FIGURE 3** Net benefits to achieve dissolved oxygen objectives in the Delaware Estuary near Philadelphia

2010). Although water quality has measurably improved in the Delaware River since the 1961 DRBC Compact, DO levels still do not fully meet DRBC criteria (3.5 mg/L) during the summer (Figure 4) when water temperatures rise close to 30°C (86°F) and DO saturation plunges below 50%. Scientists have concluded the DO criteria of 3.5 mg/L is not adequate to sustain the propagation of anadromous fish such as Atlantic sturgeon and American shad (Ad-Hoc Task Force, 1979; Campbell & Goodman, 2004; Delaware River Fish and Wildlife Management Cooperative, 1982; Secor & Gunderson, 1998). The DRBC has considered setting more protective DO criteria in the tidal Delaware River (to at least 5 mg/L) to sustain year-round propagation of anadromous fish and account for atmospheric warming and rising sea levels that in turn would increase water temperature and salinity in the estuary and further depress DO in the river. The following research estimates the economic benefits of improved water quality in the Delaware River with a future, more protective fishable DO standard.

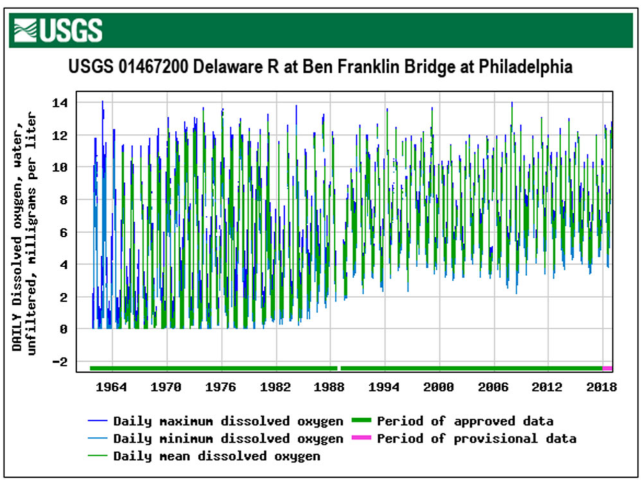


**FIGURE 4** Dissolved oxygen in the Delaware River near Philadelphia from 1960 to 2018 [Colour figure can be viewed at wileyonlinelibrary.com]

## 3 | METHODS

There are a variety of economic approaches to measure the ecosystem goods and services benefits of improved water quality in river systems. Benefits are summarized using available literature and data sources where noted on the basis of use value estimates for recreation (viewing, boating, fishing, bird/wildlife watching, swimming, beach going), commercial (fishing, agriculture, navigation), indirect use (property value), water supply (municipal and industrial), and nonuse (existence/bequest) value. Here, I review the methods to estimate use and nonuse value benefits as they pertain to the Delaware River and outline the process employed for the present study. Use and nonuse benefits (Lyon & Farrow, 1995; U.S. Water Resources Council, 1983) of improved water quality in the Delaware River are estimated on the basis of market and nonmarket valuation methods (Table 3 and Figure 5).

Markets do not adequately define economic benefits of improved water quality; therefore, environmental economists have defined nonmarket stated preference and revealed preference methods such as travel cost, hedonic pricing, and contingent valuation (CV; Wilson & Carpenter, 1999; World Business Council for Sustainable Development, 2011). The stated preference approach includes the CV method that asks people how much they would be willing to pay for improved water quality for viewing, boating, fishing, and swimming (Emerton & Bos, 2004; Kramer, 2005 and Thurston et al., 2009). Revealed preference methods estimate the increased sale or purchase of goods or reduced costs that result from improved water quality and include the market price, productivity, damage cost avoided, travel cost, and hedonic pricing methods. The travel cost method defines the higher costs that visitors are willing to pay for trip and equipment expenditures to participate in more frequent recreation tourism, boating, hunting, fishing, and birding trips due to improved water quality (Freeman, 2003; Smith & Desvousges, 1986). The hedonic pricing method indirectly measures benefits by recording the higher value of property

**TABLE 3** Benefits of improved water quality

| Benefit[a] | Category[b] | Examples | Method |
|---|---|---|---|
| Use | Recreation | Increased boating, fishing, swimming expenditures | Travel cost[c] |
| | Aesthetic/viewing | Commuting, hiking, picnicking, photography | Travel cost[c] |
| | Fishing | Commercial | Market price/productivity[c] |
| | Water Supply | Lowered municipal/industrial water treatment costs | Avoided cost[d] |
| | Property value | Increased river-side property value | Hedonic price[c,d] |
| | Ecosystem | Boating, fishing, bird watching, waterfowl hunting | Travel cost[c] |
| | Navigation | Reduced dredging costs | Avoided cost[d] |
| Nonuse | Existence | Relatives, friends, American public | Contingent valuation[c] |
| | Bequest | Family, future generations | Contingent valuation[c] |

[a]Hodge & Dunn, 1992.

[b]Carson & Mitchell, 1993.

[c]Kramer, 2005.

[d]EPA, 2012.

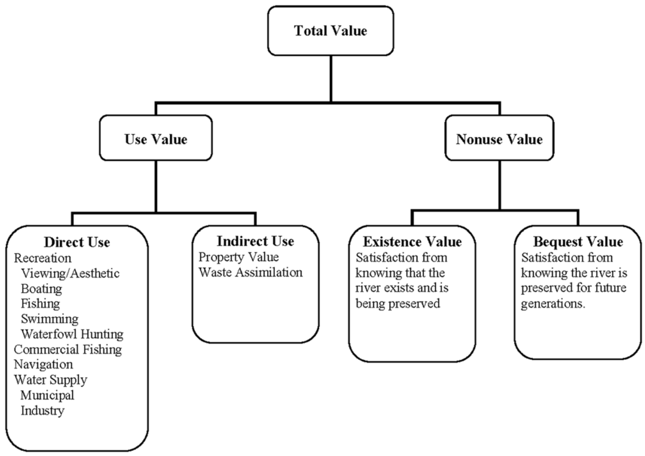


**FIGURE 5** Economic benefits of improved water quality in the Delaware Basin

close to rivers and bays with improved water quality (USDAzzzzz, 1995).

## 3.1 | Use values

Use values are defined for five activities, these being (a) boating, fishing, bird/wildlife watching recreation from net factor income, productivity, and travel cost methods (Bockstael, McConnell, & Strand, 1989; Cordell, Bergstrom, Ashley, & Karish, 1990; Leggett & Bockstael, 2000; Johnston, Grigalunas, Opaluch, Mazzotta, & Diamantedes, 2002; Leeworthy & Wiley, 2001; NOEP, 2010; Griffiths et al., 2012); (b) commercial fishing using market price method from National Marine Fisheries Service; (c) water supply (municipal/industrial) using market price and productivity methods due to decreased treatment costs; (d) viewing/aesthetics from WTP and CV methods; and (e) increased property value using hedonic pricing methods for riverside parcels (EPA, 1973). Market benefits are derived from the price of goods and services by the sale of fish by commercial fisheries or purchase of drinking water by the public. Travel cost methods reveal use benefits from increased recreational participation in outings, boating, fishing, swimming, and bird/wildlife viewing that result in trip and equipment expenditures (Freeman, 2003). Hedonic models indirectly reveal benefits by measuring increased waterfront property value due to improved water quality. Indirect use benefits may accrue from the increased value of properties along a restored river and waste treatment services by wetlands and forests (EPA, 2012).

## 3.2 | Benefits transfer

If primary valuation data collected from studies in the Delaware Basin were not available, then benefits transfer techniques were employed to translate data from other watersheds. Benefits transfer extrapolates benefits compiled from studies in other sites to the watershed in question with appropriate adjustments (EPA, 2010). Benefits transfer is relatively inexpensive to implement; however, it must be applied carefully to avoid double counting of benefits. Benefits transfer is most reliable when (a) the original site and watershed study site are similar in location and population characteristics, (b) water quality change is similar for the two sites, and (c) the original study used sound valuation techniques (WBCSD, 2011). EPA (2010) employs benefits transfer to estimate nonmarket benefits of proposed Federal Clean Water Act regulations. Although it has limitations, benefits transfer is employed here to estimate benefits of improved water quality in the Delaware River by applying WTP data from similar watersheds.

Due to uncertainty in the selection of parameters and transferring data to the Delaware River, lower and upper bound benefits are defined on the basis of 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 dollars per person). Benefits from the original base year were converted to 2010 dollars on the basis of the average annual change (2.6% rounded to 3%) in the Consumer Price Index (CPI) in the Northeast Region from 1991 to 2010 as reported by the Bureau of Labor Statistics.

Economic benefits of improved water quality are estimated for recreational boating, fishing, bird watching, waterfowl hunting, and beach going by determining the number of visitors who participated in recreational activities in the Delaware Basin. Next, statewide estimates of recreational participants were scaled to the watershed level by proportion of population and/or land area within each state. Then, the literature was reviewed to select appropriate unit day values per person for each recreation activity, and the existing value of each activity was selected by multiplying the unit day value by the number of recreation visits. Lastly, benefits were estimated by multiplying existing value by percentage change in value due to improved water quality.

### 3.3 | Travel cost models

Travel cost models were employed to estimate the benefits of improved water quality to go from nonsupport (impaired) to viewing, boatable (3.5 mg/), and fishable (5.0 mg/L) uses in the Delaware River. Annual recreation benefits were calculated to achieve boating and fishing water quality by selecting per person values from travel cost studies and multiplying by the U.S. Census (2010 adult population [>18 years old]). The value of recreation was estimated due to improved water quality using the unit day value method by multiplying the number of visitor days by the unit value (dollars per day) of a recreation day. Recreation benefits of improved water quality are measured by the increase in the number of activity days (Leeworthy & Wiley, 2001) by participants at the river.

### 3.4 | Nonuse values

Nonuse values are estimated from stated preference and CV surveys that are based on WTP for improved water quality for existing/future generations. Carson and Mitchell (1993) surveyed the public on WTP to achieve Clean Water Act goals based on a water quality ladder (Table 4). Nonuse values are defined as 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 the satisfaction that the river will be preserved for future generations (Ingraham & Foster, 2008).

**TABLE 4** Water Quality Ladder (Carson & Mitchell, 1993 from Resources for the Future)

| Water quality | Grade | Use | Dissolved oxygen |
|---|---|---|---|
| 10 | | | |
| 9 | | Potable (safe for drinking) | |
| 8 | | | |
| 7 | A | Swimmable (safe for swimming) | 5 mg/L |
| **6** | | | |
| 5 | B | Fishable (game fish such as bass can live in it) | 4 mg/L |
| 4 | | | |
| 3 | C | Boatable (OK for boating) | 3 mg/L |
| 2 | | | |
| 1 | | | |
| 0 | | Worst possible water quality | 1 mg/L |

Nonuse values include existence and bequest values from surveys that ask people how much they would be willing to pay for improved water quality for a river that they care about and may or may not visit (Krutilla, 1967). Existence value is the satisfaction that people have knowing that the river exists and is being preserved even if they will never see it or use it (Freeman, 2003). Bequest value is the value that people place on knowing the river is protected so future generations may enjoy it. Benefit–cost analyses that rely solely on use benefits may underestimate total benefits because nonuse values can be significant (Loomis, 2006). Nonuse values rely on individual opinions or stated preferences and not hard market data and therefore are hard to precisely quantify yet contribute to a large portion of total benefits (Brown, 2004). Nonuse values can be substantial because as University of Maryland economist Doug Lipton (2003) has observed, “If everyone in the watershed has a small value for the restoration of the Bay, it ends up being a big number.”

## 4 | RESULTS

Overall, the annual economic benefits associated with improving water quality (increased DO from 3.5 mg/L to a future DRBC year-round fishable standard of 5.0 mg/L in the Delaware River) range from a low bound of $370 million to an upper bound of $1.06 billion in 2010 dollars (Table 5 and Figure 6). Recreational boating provides the greatest benefits ($46–$334 million), followed by recreational fishing ($129–$202 million), agriculture ($8–$188 million), nonuse value ($76–$115 million), viewing/boating/fishing ($55–$68 million), bird watching ($15–$33 million), increased property value ($13–27 million), municipal water supply ($12–$24 million), commercial fishing ($0–$17 million), and navigation ($7–$16 million). Recreational boating, fishing, and viewing provide 45% of the high bound benefits, followed by agriculture (17%), nonuse (10%), wildlife/birdwatching, waterfowl hunting, and beach going recreation (6%), and water supply (4%), and commercial fishing, navigation, and property value each provide 2% of total benefits (Figure 7). Swimming benefits are not accrued in the Delaware River due to dangerous currents and high bacteria levels.

The following subsections consider the economic benefits of recreational use, boating activities (both commercial and recreational), and agriculture in more detail.

### 4.1 | Viewing/boating/fishing/swimming

Three Delaware Basin states (NJ, NY, and DE) ranked 4th, 7th, and 19th in coastal/estuary recreation activity with 6.2, 5.5, and 2.2 million annual participants, respectively (Leeworthy & Wiley, 2001). Travel cost values were transferred from a study in six north-eastern states

**TABLE 5** Benefits of improved water quality due to increased dissolved oxygen in the Delaware River in 2010 dollars

| Category | Sources | Economic benefits due to improved water quality (DO from 3.5 mg/L to 5.0 mg/L) | | Existing WQ (DO 3.5 mg/L; $M/year) | | WQ benefits (DO 5.0 mg/L; $M/year) | |
|---|---|---|---|---|---|---|---|
| | | Low bound | High bound | Low | High | Low | High |
| Use | | | | | | | |
| Recreation | | | | | | | |
| Viewing, boating, fishing | 1, 2 | 5,226,003 adults[1]; $10.62 per person[2] | 6,438,910 adults[1]; $10.62 per person[2] | 4 | 6 | 55 | 68 |
| Boating | 3, 4, 5 | 394,000 boaters[3]; $116 per boater[4] | 5.3 million boating days[3]; $63/trip[5] | 159 | 350 | 46 | 334 |
| Fishing | 6, 7, 8, 9 | 5.4 million fishing days[8]; $40/day[6] (60%[9]) | 4.5 million fishing days[8]; $75/day[7] (60%[9]) | 216 | 337 | 129 | 202 |
| Shad fishing | 9, 10 | – | 63,000 angler days[10]; $102/day[10] (60%[9]) | 0 | 6.5 | 0 | 3.9 |
| Bird/wildlife watching | 11, 12 | 864,000 watchers spent $307 million[11] (5%) | 923,000 watchers spent $325 million[12] (10%) | 307 | 325 | 15 | 33 |
| Waterfowl hunting | 11, 13 | 82,000 hunting days[11]; $17/day[11] (5%) | 229,000 hunting days[13]; $69/day[11] (10%) | 1.4 | 16 | 0.1 | 1.6 |
| Swimming | | Recreation swimming benefits not significant | Due to swift tidal currents, lack of beach access. | 0 | 0 | 0 | 0 |
| Beach going | 3, 14, 15 | 854,000 beach days[14]; $7.29/day[14] (32%[3]) | 854,000 beach days[14]; $58.81/day[15] (32%[3]) | 6 | 50 | 2 | 16 |
| Commercial | | | | | | 0 | |
| Fishing | 16, 17 | – | $34.1 million fish catch in 2010[16] (50%[17]) | 34 | 34 | 8 | 17 |
| Agriculture | 18, 19, 20 | $1,676/ac[18]; 5,600 ac erosion[19] (90%) | $110/ac[20]; 1.9 million ac farmland[18] (90%) | 0 | 0 | 7 | 188 |
| Navigation | 21 | 4 million $yd^3$ sediment[21]; $3.75 $yd^3$ (50%) | 4 million $yd^3$ sediment[21]; $8.09/$yd^3$ (50%) | 81 | 81 | 13 | 16 |
| indirect use | | | | | | 12 | |
| Property value | 22, 23, 24 | 34,800 shore acres[22]; $192,000/ac[23] (4%[24]) | 34,800 shore acres[22]; $192,000/ac[23] (8%[24]) | 333 | 333 | 8 | 27 |
| Water supply | | | | | | | |
| Municipal water supply | 25, 26, 27 | 538 mgd[25]; $1.00/1,000 gal[26] (6%[27]) | 538 mgd[25]; $1.00/1,000 gal[26] (12%[27]) | 196 | 196 | 12 | 24 |
| Industrial water supply | 28 | 630 mgd[25]; $0.61/1,000 gal[28] (6%[27]) | 630 mgd[21]; $0.61/1,000 gal[24] (12%[27]) | 140 | 140 | 8 | 17 |
| Nonuse (Existence/Bequest) | | | | | | | |
| WTP boatable to fishable WQ | 29, 30 | 5,226,003 adults[1]; $44.00 per person[29] (33%[30]) | 6,438,910 adults[1]; $54.00 per person[29] (33%[30]) | 102 | 151 | 76 | 115 |
| Total | | | | 1,580 | 2,025 | 371 | 1,063 |

*Note*. 1. Adult population >18 years old (U.S. Census Bureau, 2010) in Delaware Estuary and Delaware River watersheds. 2. Parsons, Helm, and Bondelid (2003) adjusted to 2010 dollar on the basis of 3% annual change in CPI. 3. Bockstael et al. (1989). 4. Smith and Desvousges (1986). 5. Leeworthy et al. (2001 and 2005) and NMMA (2010). 6. Rosenberger and Loomis (2000). 7. USFWS (2008). 8. USFWS (2013), and EPA (2002). 9. Lipton and Hicks (2003). 10. Pennsylvania Fish and Boat Commission (2011). 11. USFWS (2008). 12. Outdoor Industry Association (2006). 13. Leeworthy and Wiley (2001). 14. Kline and Swallow (1998). 15. Leeworthy and Wiley (2001). 16. NOEP (2010). 17. Weisberg, Himchak, Baum, Wilson, and Allen (1996). 18. USDA (2009). 19. USDA (2011). 20. Pimentel et al. (1995). 21. PDE (2012). 22. Area within 2,000 ft of Delaware Estuary shoreline of 757,000 linear feet. 23. Average real estate price of waterfront property. 24. EPA (1973), Leggett & Bockstael (2000), Poor, Pessagno, & Paul, 2007. 25. DRBC (2010). 26. UDWRA (2008). 27. Dearmont et al. (1998), Crockett (2007). 28. Frederick, VandenBerg, and Hansen (1996) adjusted to 2010 dollar at 3% annual change in CPI. 29. Carson and Mitchell (1993) adjusted to 2010 dollar at 3% annual change in CPI. 30. Johnston, Swallow, and Weaver (2003).

Abbreviations: DO, dissolved oxygen; WQ, water quality; WTP, willingness to pay.

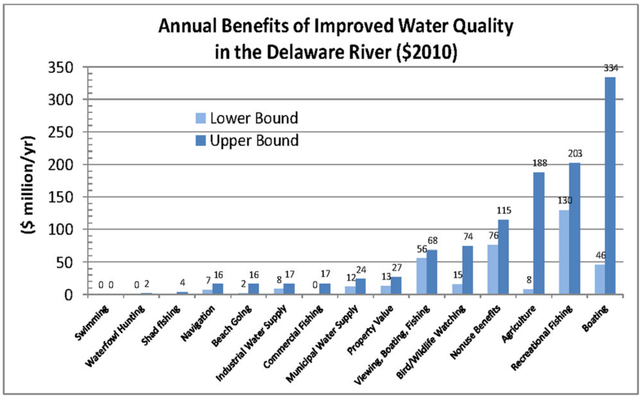


**FIGURE 6** Lower and upper bound benefits of improved water quality in the Delaware River in 2010 dollars [Colour figure can be viewed at wileyonlinelibrary.com]

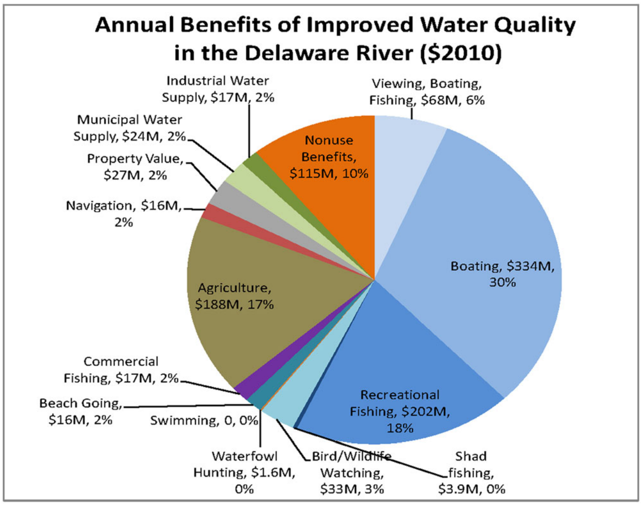


**FIGURE 7** High bound benefits of improved water quality in the Delaware River in 2010 dollars [Colour figure can be viewed at wileyonlinelibrary.com]

(Parsons et al., 2003). Converting to 2010 dollars, per person benefits to achieve high water quality are $3.61 for viewing, $4.03 for boating, and $2.98 for fishing. Low and high bound annual benefits due to improved water quality were estimated by multiplying per person benefits by the 2010 adult population (>18 years old) in the Delaware Estuary (pop. 5,226,003) and Delaware River (pop. 6,438,910) watersheds. Annual benefits of attaining high water quality in the Delaware River range from $55.5 to $68.1 million per year with $18.5–$23.2 million for viewing, $21.0–$25.9 million for boating, and $16.0–$19.2 million for fishing.

## 4.2 | Recreation and tourism

In 2009, the recreation/tourism industry contributed $379 billion to the U.S. economy or 2.7% of the total gross domestic product (Southwick Associates, 2008). In the mid-Atlantic census division (NY, NJ, and 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 Basin is home to 7,611,595 people in New Jersey, New York, and Pennsylvania or 18.5% of the mid-Atlantic population of 40,800,000; therefore, scaling by population, outdoor recreation in the basin supports $797 million in economic activity from fishing ($327 million), paddling ($145 million), and wildlife viewing ($325 million).

## 4.3 | Boating

The U.S. Forest Service estimated 89 million people (36% of the U.S. population) participate in recreational boating such as kayaking, canoeing, sailing, and motorboating (EPA, 2012). Although water quality standards for recreation boating are not as stringent as fishing and swimming, benefits are sizeable due to the many registered boats that cruise on estuaries (Cropper & Isaac, 2011). The National Marine Manufacturers Association (2010) announced Delaware, Pennsylvania, and New Jersey were ranked 7th, 17th, and 23rd in the United States in powerboat expenditures with a value within the Delaware Basin of $392 million per year. Low bound benefits by improving water quality from existing DO (3.5 mg/L) to a future DRBC standard (5.0 mg/L) is $46 million per year determined by multiplying 394,000 boaters (Leeworthy & Wiley, 2001) by $116 per year per boater in 2010 dollars transferred from Bockstael (1989). The high bound boating benefit is $334 million per year by multiplying 5.3 million activity days (Leeworthy & Wiley, 2001) by $63 per trip in 2010 dollars from Smith and Desvousges (1986).

## 4.4 | Fishing

The U.S. Fish and Wildlife Service (2008) reported 25 million anglers took 337 million trips and spent $26 billion on travel/equipment at $78 per trip. Recreational fishermen went on 4.5 million to 5.4 million trips per year to the Delaware Estuary (U.S. Fish and Wildlife Service [USFWS], 2008; EPA, 2002). Travel cost and CV models indicate the value of recreational fishing ranged from $40 to $75 per trip in 2010 dollars (EPA and NMFS, 2002; Johnston et al., 2002; Kaval & Loomis, 2003; McConnell & Strand, 1989; Rosenberger & Loomis, 2000; USFWS, 2008; and Walsh, Johnson, & McKean, 1992). Lipton and Hicks (2003) found a 2.4-mg/L increase in DO in Chesapeake Bay would increase recreational striped bass catch by 95%. By similarity, a 1.5-mg/L improvement in DO from 3.5 mg/L (existing) to a future standard of 5.0 mg/L would increase recreational fishing benefits by 60%. The existing recreational fishing value in the Delaware Estuary ranges from $216 to $337 million per year at a low bound value of $40/trip during 5.4 million trip days and upper bound value of $75/trip on 4.5 million trip days. If a 1.5-mg/L improvement in DO leads to a 60% increase in expenditures, then recreational fishing benefits range from $130 to $202 million per year.

## 4.5 | Shad fishing

The Pennsylvania Fish and Boat Commission (2011) referenced a 1986 study of shad fishing on the Delaware River that estimated anglers spent $1.6 million during 63,000 trips or $25.40 per trip on gasoline, food, lodging, and tackle. Anglers were willing to pay $50 per day for shad fishing or $102 per day adjusted to 2010 dollars. During 63,000 angler days, annual WTP for the Delaware River shad fishery was $3.2 million in 1986 or $6.5 million adjusted to 2010 dollars. If DO in the Delaware Estuary improves from 3.5 mg/L to a future standard of 5.0 mg/L, then shad fishing activity could increase by 60% with economic benefits of $3.9 million per year.

## 4.6 | Wildlife/bird watching

Over 90,000 bird watchers spent $5.5 million at Cape May National Wildlife Refuge in New Jersey along Delaware Bay and Bombay Hook NWR in Delaware was the nation's fourth most popular refuge with 271,000 recreational visits in 2006 and contributed $13.4 million to the economy from bird watching (Carver & Caudill, 2007; USFWS, 2008). Wildlife viewing participation in the Delaware Basin included 1.4 million people who took 5.1 million trips (EPA, 1994), 864,000 people or 3.3 million visitor days in 2006 (USFWS, 2008), and, scaling by basin population, and 923,000 people reported by the Outdoor Industry Association (2006). User day values for wildlife viewing range from $43.94 (Kaval & Loomis, 2003) to $92.00 (USFWS, 2008) in 2010 dollars. The existing recreational value of bird/wildlife watching ranges from $307 to $325 million on the basis of scaled data from the USFWS (2008) and the Outdoor Industry Association (2006). Bird/wildlife watching benefits due to improved water quality along the Delaware Estuary range from $15 to $33 million per year by multiplying existing recreation value by an estimated 5% and 10% increase in value due to improved water quality.

## 4.7 | Waterfowl hunting

Approximately 1.3 million people in the United States hunted for waterfowl on 13 million days and spent $900 million on trip/equipment expenditures in 2006 or $69 per trip (USFWS, 2008). Along the Delaware Estuary, waterfowl hunters participated in 82,000 activity days with annual trip/equipment expenditures of $1.4 million or $17/trip. The National Survey of Coastal Recreation (Leeworthy & Wiley, 2001) reported 16,347 people on 229,000 days hunted for waterfowl in Delaware and New Jersey along the Delaware Estuary. The existing value of waterfowl hunting ranges from $1.4 to $15.8 million on the basis of lower and upper bound estimates of consumer surplus. Waterfowl hunting benefits due to improved water quality range from $70,000 to $1.6 million per year at an estimated 5% and 10% increase in value due to improved water quality.

## 4.8 | Swimming

High pathogen and bacteria levels can infect swimmers and cause gastrointestinal upset and diseases such as cholera, hepatitis, and dysentery. The DRBC primary contact recreation (swimming) criteria is 100 colonies/100 ml of faecal coliform bacteria. Although public and private marinas operate 55 public access areas along 133 miles of the Delaware Estuary between the head of tide at Trenton and Cape Henlopen, recreational swimming benefits due to improved water quality are not expected to be significant due to swift tidal currents, high bacteria levels, and lack of sandy beach access that hinder this activity along the Delaware River between Trenton and Wilmington.

## 4.9 | Beach going

Tourists account for 6.4 million beach visits in Delaware and 9.7 beach visits in New Jersey in the Delaware Estuary watershed, and 5% of beach visits (854,000 in Delaware and New Jersey) occur on the upper Delaware River above the C&D Canal that benefits from improved water quality. The mean consumer surplus for a beach trip ranges from $5.36 to $31.45 per activity day or $7.29 to $58.81 per day in 2010 dollars (Kline & Swallow, 1998; Parsons et al., 2003). Bockstael et al. (1989) conducted a travel cost survey of visitors to beaches on the Chesapeake Bay and concluded that a 20% reduction in nitrogen plus phosphorus (TNP) results in a 20% increase in beachgoing activity or $19.86 per trip in 1987 dollars ($39.20 per trip in 2010 dollars). Krupnick (1988) used Bockstael et al. (1989) to estimate a 40% reduction in TNP resulted in 40% increase in beach going activity. Morgan and Owens (2001) used Bockstael et al. (1989) to estimate a 60% increase in beach benefits due to a 60% reduction in TNP to residents of Maryland, Virginia, and District of Columbia. The existing value of beach going along the Delaware Estuary above the C&D Canal ranges from $6 to $50 million on the basis of activity day estimates multiplied by low and high estimates of daily use value per person. Improved water quality is estimated to increase beach going activity by 32% in the Delaware Estuary; therefore, benefits range from $2 to $16 million per year transferred from Bockstael et al. (1989) where a 20% reduction in TNP resulted in a 20% increase in beach going activity.

## 4.10 | Commercial fishing

Improved water quality in estuaries can boost fish harvest, increase fishermen income, and reduce seafood prices (Cropper & Isaac, 2011). A 50% increase in DO in the Delaware Estuary between 1980 and 1993 (Figure 8) correlated with increased catch per haul of American shad, striped bass, and white perch (Weisberg et al., 1996). If water quality improves by 50% from the existing DO standard of 3.5 mg/L to the future criteria of 5.0 mg/L, fish catch for these species is estimated to increase by 50%. The annual value of commercial fish landings in the Delaware Estuary was $25 million in 2000 dollars or $34 million in 2010 dollars (NOEP, 2010). The most valuable Delaware Estuary commercial fisheries are blue crab ($14.4 million),

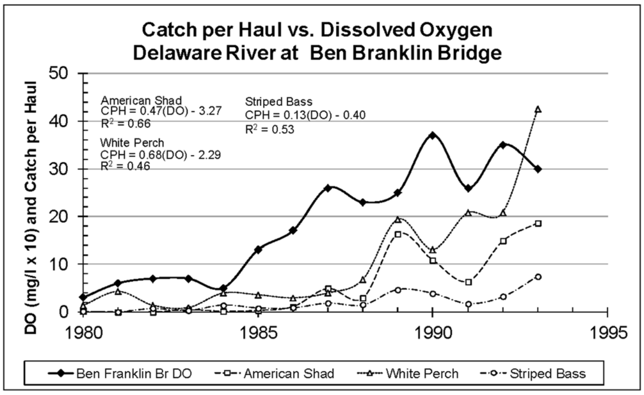


**FIGURE 8** Relationship between dissolved oxygen and fish catch in the Delaware Estuary

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 the future criteria (5.0 mg/L) in the Delaware Estuary, commercial fish landings are estimated to increase by 50% or $17 million per year.

## 4.11 | Agriculture

Soil erosion curtails agricultural production through reduced soil fertility and loss of crop production and sales. If soil erosion and sediment loss from cropland averages 1.2 ton/acre (2.7 tonne/ha) in the Chesapeake Bay watershed (USDA, 2011), then soil erosion from 1.9 million acres (770,000 hectares) of farmland in the Delaware Basin will deliver 2.3 million ton per year (2.1 million tonne per year) of sediment. In the Delaware Basin, with a soil thickness of 3 in. (7.7 cm) and soil density of 75 lb/ft$^3$ (1,130 kg/m$^3$), the erosion rate is eqivalent to removing 5,600 acres (2,700 hectares) of cropland from production in the watershed. Farm products sold for $1,676/acre or $4,138/ha (U.S. Department of Agriculture [USDA], 2009) on average in the Delaware Basin; therefore, the value of lost farm production from soil erosion is $9.4 million. If farm conservation best management practices (BMPs) reduce sediment loads by 90%, then the annual benefit of restoring cropland through soil erosion control programmes is $8.4 million. Nationally, 4 billion tons (3.6 billion tonne) of soil are lost at a cost of $7 billion per year ($110/ac or $272/ha) due to water erosion/siltation damages (Pimentel et al., 1995). At $110/ac or $272/ha, soil erosion damage due to sediment loss from 1.9 million acres (770,000 ha) of farmland in the Delaware Basin is $209 million per year. If farm conservation BMPs reduce sediment loads by 90%, then agricultural benefits from reduced soil erosion damages in the Delaware Basin amount to $188 million per year.

## 4.12 | Navigation

The Delaware River port at Wilmington, Camden, and Philadelphia (a) generates $81 million in tax revenues, (b) imports one half of the nation's cocoa beans, one third of the bananas, and one fourth of fruit and nuts, (c) ranks fifth among U.S. ports in import value and 20th in export value, and (d) handled 16% of U.S. container trade (Economic League of Greater Philadelphia, 2008). Soil erosion and sediment control programmes in the watershed can reduce need for navigation dredging costs in the Delaware River ship channel. From 1950 to 2009, sediment discharge to the Delaware Estuary averaged 2.2 million cubic yards or 1.3 metric tonnes (PDE, 2012). The U.S. Army Corps of Engineers operates a Delaware River navigation channel dredging programme that removes 4 million yd$^3$ (3.1 million m$^3$) at costs that range from $3.75/yd$^3$ in FY2005 to $8.09/yd$^3$ in FY2010. Without watershed BMPs to reduce sediment loads, the annual cost to dredge 4 million yd$^3$ from the Delaware River at costs of $3.75 to $8.09/yd$^3$ ranges from $15 to $32 million. If watershed BMPS reduce an annual 2.2 million yd$^3$ (1.7 million m$^3$) sediment discharge to the Delaware River by 90%, the savings from avoided dredging costs range from $7 to $16 million.

## 4.13 | Property value

Improved water quality produces amenity or indirect use benefits due to increased riverfront property value by enhancing aesthetic value to the owner (USDA, 1995). Along the Chesapeake Bay, Leggett and Bockstael (2000) concluded that improved water quality increases property values with economic benefits of $12.1 million within a range of $3.8 to $20.5 million. Property values within 2,000 ft (610 m) of the shoreline are estimated to increase by a low bound of 4% and high bound of 8% due to improved water quality along the tidal Delaware River between Wilmington and Trenton (EPA, 1973; Leggett & Bockstael, 2000; Poor et al., 2007). At an average property value of $192,000/ac ($474,074/ha), the value of 34,764 ac (14,070 ha) of property within 2,000 ft (610 m) of the Delaware River between the C&D Canal and Trenton is $334 million over a 20-year period. If property values along the shoreline are boosted by 4% to 8% due to improved water quality in the Delaware River, then the amenity value ranges from $13 to $27 million per year.

## 4.14 | Drinking water supply

Water treatment costs decline by 2% for every 1% increase in watershed forest area (Trust for Public Land and AWWA, 2004). Texas A&M University found a 4% decrease in turbidity can increase water treatment costs by 1% (Dearmont, McCarl, & Tolman, 1998). The lower Delaware River watershed supplies 538 million gallons per day (mgd) or 2 billion litres per day of drinking water to Delaware, New Jersey, and Pennsylvania. The value of untreated water in the Delaware Basin is estimated to be $1.00/1,000 gal or $0.26/1,000 L by water purveyors; therefore, the existing value of drinking water is $196 million per year. If a 50% increase in water quality from current criteria (3.5 mg/L) to a future DRBC DO standard (5.0 mg/L) reduces water treatment costs by 6% to 12% (Crockett, 2007; Dearmont et al., 1998), then drinking water supply benefits due to improved water quality range from $12 to $24 million per year.

## 4.15 | Industrial water supply

The median freshwater use value of industrial water supply is $0.40/1,000 gal (Frederick et al., 1996) or $0.61/1,000 gal in 2010 dollars. At $0.61/1,000 gal ($0.16/1,000 litres), the existing value of industrial water supply (804 mgd or 3 billion litre/day) in the Delaware Estuary watershed is $140 million. If improved water quality in the Delaware River reduces industrial water treatment costs by 6% to 12%, then benefits range from $8 to $16 million per year.

## 4.16 | Nonuse benefits

Nonuse benefits of actions to improve DO from the current 3.5 mg/L criteria to meet a future year-round fishable standard of 5 mg/L in the Delaware River are based on CV surveys that define public WTP to improve water quality from nonsupport (impaired) to boatable/fishable uses. Swimmable benefits are not estimated because severe tidal currents impede this recreational use along the tidal Delaware River. Johnston et al. (2003) reviewed the benefits of improved water quality and concluded that a $1.00 increase in use value correlated to a $0.50 increase in nonuse values; therefore, nonuse value is 33% of the total use plus nonuse value from WTP stated preference surveys.Carson and Mitchell (1993) surveyed the public on WTP to achieve Clean Water Act goals and found mean annual household WTP to improve water quality was $93 ($32 per person) to go from nonsupported to boatable use and $70 ($24 per person) to go from boatable to fishable uses in $1983. Adjusting for an annual 3% change in the CPI, annual WTP in 2010 dollars is $71 per person for boatable and $54 per person for fishable uses or a total of $125 per person. Annual nonuse benefits are estimated by multiplying individual WTP by the adult watershed population (78% of population >18 years old) to determine low bound benefits in the Delaware Estuary watershed (5.2 million) and high bound benefits in the Delaware Basin (6.5 million) then by 33%. Annual nonuse benefits from WTP to improve water quality from impaired to boatable use (DO 3.5 mg/L) in the Delaware River range from $102 to $151 million, to achieve fishable uses (DO 5.0 mg/L) range from $76 to $115 million, and to improve from impaired to fishable uses range from $178 to $266 million per year in 2010 dollars.

# 5 | DISCUSSION AND CONCLUSIONS

Ecological valuation studies have found that the benefits of improved river water quality in the United States reaches up to $42.3 billion per year. However, except for a 1966 FWPCA economic analysis for the Delaware River, little is known about the current economic benefits of pollution control efforts that have improved water quality in rivers across the United States.

Water quality in the Delaware River has improved considerably in the half-century since the authorization of Delaware River Basin Commission Compact in 1961, the EPA in 1970, and Federal Clean Water Act Amendments in 1972 and 1977. A first-of-its-kind 1966 benefit–cost analysis conducted by the FWPCA concluded that a multimillion-dollar per year waste load abatement programme to raise DO levels to boatable and fishable standards would generate up to $350 million in annual benefits in 1964 dollars. In 1967, the DRBC used this economic analysis to set DO criteria at 3.5 mg/L along the urban river from Philadelphia to Wilmington where this water quality standard has stood for five decades. With improved water quality, anadromous American shad and striped bass are returning to the Delaware along with a growing river tourism and recreation economy.

Scientists with the Delaware River Basin Commission have considered raising the 1967 DO standard of 3.5 mg/L to a higher level of protection to at least 5.0 mg/L to provide for year-round protection of anadromous fish such as the American shad and the nearly extirpated Atlantic sturgeon, a species on the Federal Endangered Species List. A more rigorous standard would also mitigate atmospheric warming that increases water temperatures, sea levels, and salt levels that, in turn, reduces DO saturation.

This analysis finds the estimated annual benefits of improved water quality by increasing DO criteria from 3.5 mg/L 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 $1.1 billion. Recreational viewing, fishing, and boating provide 45% of benefits, followed by agriculture (17%), nonuse (10%), birdwatching, waterfowl hunting, and beach recreation (6%), water supply (4%), and commercial fishing, navigation, and property value benefits (2%). Recreational boating provides the greatest benefits ($46–$334 million), followed by recreational fishing ($129–$202 million), agriculture ($8–$188 million), nonuse value ($76–$115 million), viewing/boating/fishing ($55–$68 million),bird watching ($15–$33 million), increased property value ($13–27 million), municipal water supply ($12–$24 million), commercial fishing ($0–$17 million), and navigation ($7–$16 million). Swimming benefits are naught as the urban Delaware River has dangerous currents and little public beach access.

Where available, use (market and nonmarket) and nonuse benefits were derived from primary data sources in the Delaware River watershed. If basin specific data were not available, then economic data for certain categories was derived from other watersheds (such as adjacent Chesapeake Bay) to the Delaware River by employing principles of benefits (or value) transfer. Benefits transfer is relatively inexpensive to implement and carefully applied to avoid double counting of benefits. In some cases, nonuse benefits may involve unrealistic projections because the public is asked what they would be willing to pay but do not actually make transactions in a market. However, the EPA and federal agencies include nonuse benefits in economic studies because if these methodologies were omitted, then the total benefits of improved water quality may be undercounted or even nil. Therefore, nonuse benefits are cautiously included in these projections of improved water quality in the Delaware River. Future economic research is needed along the Delaware River to gather more primary use and nonuse data including stated preference surveys of watershed residents to more precisely measure individual WTP for improved water quality in the river.

The research estimates the economic benefits of pollution reduction strategies to raise DO levels from the current standard of 3.5 mg/L to a future year-round fishable criteria of 5.0 mg/L in the Delaware River, USA, that would boost the tourism, fishing/hunting, recreation, real estate, and water supply economies that rely on clean water. Provided that attention is given to differences in scale, size, geography, and demographics between one basin, watershed, or catchment to the next, the use and nonuse economic valuation methods discussed herein may be applied with good measure to estimate the economic benefits of improved water quality in other river systems in the United States and globally.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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