GOVERNANCE, POLICY, AND ECONOMICS OF CLEAN WATER IN THE DELAWARE RIVER BASIN

by

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PREFACE

At dawn on June 16, 2011, I sped north to the headwaters to join the annual Delaware River sojourn organized by the American Canoe Association. My mission was to find out where the American shad go after they swim 200 miles from the Atlantic Ocean past Philadelphia and the 7th largest metropolitan economy in the United States to get to their ancestral spawning grounds in the Delaware Water Gap National Recreation Area. As our kayak flotilla floated past the mouth of the sparkling Flatbrook and rounded the bend on a blue sky Chamber of Commerce day, there they were - physical evidence of the river revival. Schools of two-feet long, aquamarine American shad were swimming like half-submerged submarines in lazy circles near the old Tocks Island dam site just north of the I-80 bridge. The fish were spent and their scales were sloughed after swimming against the current from the ocean and laying their eggs during the ancient spring ritual.

We were mesmerized. We were witnessing one of the beautiful synergies in the natural world. There up on the sycamore trees were flocks of bald eagles that swooped down from their perches on Kittatinny Mountain and grabbed the fat fish and feasted. The rocks in the middle of the river were covered with half-eaten carcasses as the eagles would take a few bites of the delicious belly and skin and move on to the next fish. Someone told me the eagles left the rest of the food on the rocks for other animals like the bears and crows and occasional cougar to feed on after a long, snowy winter.

Here at the foot of the Appalachian Trail was incontrovertible evidence of the river revival in the 50 years since the birth of JFK's 1961 DRBC Compact and Nixon's EPA and the Clean Water Act during the 1970s. Billions of dollars in watershed investments had paid off and rising dissolved oxygen levels way downstream in the old 1960s Philadelphia anoxic zone now allows the shad to swim upstream again at exactly the same time that the bald eagle, just off the Federal endangered species list due to the ban on DDT, is looking to fatten up on the fish in the spring. The Delaware River is recovering and so are the shad, bald eagles, and black bears. The word is out. People are traveling to camp, fish, and kayak by the river to see this spectacle of nature and the regional ecotourism economy can't help but be stimulated.

When you grew up playing hockey on the ice along the black and oily Delaware River in Pennsauken, N.J. while the Flyers were still winning Stanley Cups, it's a life-long dream come true to see the return of the shad and bald eagles with this river renaissance.

The question is…are the benefits of the Delaware River revival worth the current and future costs? This is what I wanted to find out.

ACKNOWLEDGEMENTS

I shall always be grateful to my committee – Chairman Dr. James J. Corbett, Dr. Thomas M. Church, Dr. Luc H. Claessens, and Dr. Katherine Bunting-Howarth – for their guidance in my quest for new knowledge at the University of Delaware.

Scientia sol mentis est.

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ABSTRACT

This dissertation evaluates the governance, policy, and economics of improved water quality in the Delaware Basin, an interstate watershed in Delaware, New Jersey, New York, and Pennsylvania. The watershed or river basin approach is examined as a means to manage the water resources of interstate river systems. The organization and budget structure of the Delaware River Basin Commission (DRBC) is compared to other prototypical institutional models of interstate river basin management in the United States. A benefit-cost analysis is applied that employs a watershed pollutant load model to estimate market and nonmarket benefits, marginal abatement cost curves, and net benefits to determine optimal costs of water quality improvements to meet a more protective year-round fishable standard in the Delaware River. Results show that the annual benefits of improved water quality to achieve a future dissolved oxygen standard of 5.0 mg/l in the Delaware River range from $370 million to $1.06 billion at an annual pollutant load reduction cost of $449 million. The most cost effective DO water quality standard is 4.5 mg/l defined by the intersection of the marginal benefits (MB) and marginal cost (MC) curves or the point where willingness to pay (WTP) for improved water quality equals the marginal costs of pollution reduction. This optimal criteria (4.5 mg/) can be achieved within a cost range of $150 to $350 million with benefits that range from $150 to $950 million per year. Market-based mechanisms such as user-polluter pays approaches and water quality trading are explored as alternatives to traditional Clean Water Act

regulations to incentivize and fund Delaware River water quality improvements. This research concludes that the DRBC has the requisite authority under a Federal/state compact to manage the Delaware River as a single entity and has the capability to tap beneficiary-pays revenue streams to fund water quality programs in an interstate basin that supplies drinking water to 5 percent of the population of the United States.

Chapter 1

RESEARCH GOALS AND POLICY CONTRIBUTIONS

1.1 Introduction

Water is a renewable resource that is the most essential chemical in society and one of the few substances in nature without an economic substitute. The nation's waters provide over 260 billion gallons per day of water supplies with annual market value of $21.4 billion (Kenny et al. 2009). The Gallup Poll (2009) revealed that the top four environmental problems among Americans concern water quality including 80% who care a great deal or fair amount about drinking water pollution, pollution of rivers, water contamination, and freshwater.

Water may be the most pressing environmental concern of the 21st century as government institutions are being transformed by society's changes that call for sound principles of transboundary watershed management (Delli Priscoli and Wolf 2009). In 1962, the Harvard Water Program recommended an economic approach that would balance the benefits and costs of improved water quality under the authority of a river basin organization (Maass et al. 1962). The watershed approach later evolved to balance institutional objectives at the Federal, state and local levels and to provide consensus building among multiple stakeholders to address the water resources challenges of society (National Academy of Sciences 1999).

Since watershed boundaries often do not align with political divisions, interstate compacts have been signed to share the flow of water and control water pollution (Cech 2005). In 1961, President John F. Kennedy and four governors signed the Delaware River Basin Commission (DRBC) Compact as one of the first models of Federalism or shared power in watershed management between the Federal government and states of Delaware, New Jersey, New York, and Pennsylvania (Mandarano, Featherstone, and Paulsen 2008). For over fifty years, the DRBC (1961) has been empowered by this compulsory Federal/state compact to enforce water quality standards and conduct water pollution control programs along the Delaware River.

The Interstate Commission on the Delaware River Basin (1940) once called the Delaware River near Philadelphia "one of the most grossly polluted areas in the United States". The tidal Delaware River has a long history of nutrient pollution (Sharp, Culberson, and Church 1982) but the upper estuary has recovered considerably in the last few decades largely due to restoration efforts by the DRBC, EPA, and the states (Bricker et al. 2007, Bain et al. 2010, and Sharp et al. 2009). Reconstruction of a century-long dissolved oxygen record indicates the tidal Delaware River has made one of the most extensive recoveries of any estuary in the world (Sharp 2010).

1.2 Delaware Basin

The 13,000 square mile, 300 mile-long Delaware River Basin (Figure 1.1) supplies drinking water to 16 million people (5% of the U.S. population) including New York City and Philadelphia, the first and seventh largest metropolitan economies in the United States (Kauffman 2011). After the Second World War, the river was severely polluted with dissolved oxygen levels near zero between Wilmington and Philadelphia due to unregulated dumping of untreated sewage, coal mine drainage, and agricultural and urban stormwater runoff. The polluted river prevented the spawning of American shad past the zero oxygen block upstream from Wilmington and threatened Philadelphia's drinking water supply. The river began to recover after passage of the DRBC Compact in 1961 and Federal Clean Water Act Amendments of 1972 and1977 and dissolved oxygen levels now exceed the water quality criteria of 3.5 mg/l most of the year except during hot summers. With improved water quality, the Delaware River now supports a growing drinking water, fishing, boating, and recreation economy.

In the late 1960s when the river was anoxic (DO levels at zero), the DRBC adopted the first interstate water quality standards and imposed waste load allocations on 80 dischargers, years before the Clean Water Act Amendments of 1972. At the same time, the Federal Water Pollution Control Administration (1966) conducted an economic study of the proposed waste load reductions and concluded the water supply and river recreation benefits from improved water quality would exceed the proposed wastewater treatment costs. In 1967, the DRBC considered this economic benefit-cost analysis and set a summer DO standard of 3.5 mg/l in the river between Philadelphia and Wilmington to provide for spring/fall migration (not year-round propagation) of anadromous fish. This 3.5 mg/l DO standard has stood for over four decades.

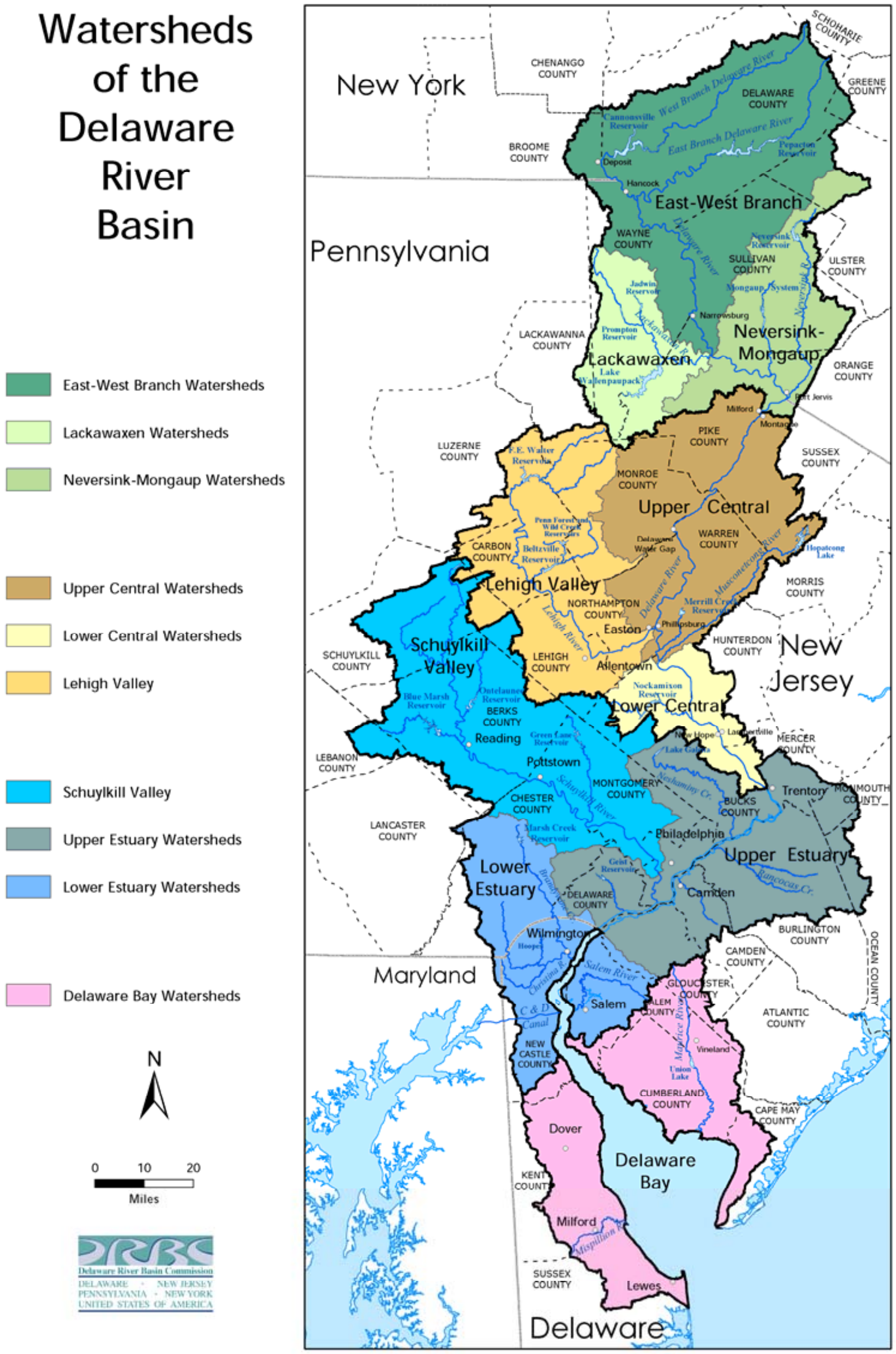


Figure 1.1: The Delaware River Basin (DRBC 2013)

While water quality has markedly improved in the tidal Delaware River between Wilmington and Philadelphia since the birth of the DRBC Compact, dissolved oxygen levels still do not fully meet the DRBC standard (3.5 mg/l) during the summer (Figure 1.2). Secor and Gunderson (1998) and others concluded that minimum DO criteria of 3.5 mg/l are not adequate to sustain anadromous fish such as Atlantic sturgeon and American shad in the river. The DRBC has discussed setting more protective DO criteria along the tidal Delaware River (to 4, 5, or 6 mg/l perhaps) to sustain year-round propagation of anadromous fish and plan for atmospheric warming that may increase water temperatures and boost salinity due to sea level rise which, in combination, would decrease DO saturation.

1.3 Primary Policy Contributions

Little is known about the cost-effectiveness of funding and achieving improved water quality in the Delaware River. This research is designed to determine the costs and benefits of reducing pollutant loads in the Delaware Basin to improve water quality and achieve a future, more protective dissolved oxygen standard in the river. This work examines the optimal or most cost-effective level of water quality (DO) in the Delaware River defined by the intersection of the marginal cost and marginal benefits curves. Once the costs and benefits of improved water quality are known, this dissertation explores various funding mechanisms available to pay for water pollution control programs under the umbrella of a Federal-state river basin organization.

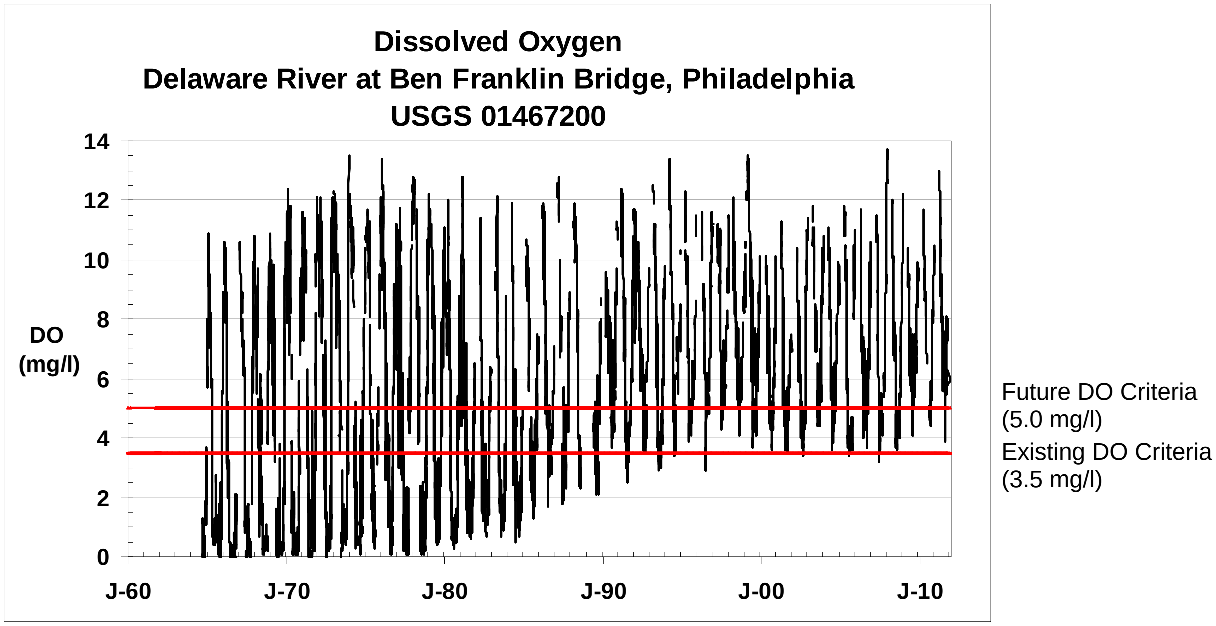


Figure 1.2: Dissolved oxygen at Ben Franklin Bridge along the Delaware River

1.4 Research Goals and Objectives

The objectives of this research are to examine watershed-based governance, policy, and economic strategies to cost-effectively restore the Delaware River to more protective year-round fishable DRBC and EPA Clean Water Act water quality criteria. This dissertation seeks to:

River Basin Governance Models: Review the evolution of the watershed approach and river basin management in the United States. Discuss the various institutional models of intergovernmental water management such as interstate compact commissions, watershed councils, and international models (Kauffman 2002, Cody and Carter 2009, Mehan 2010).

Overview of the Delaware River Basin: Describe the characteristics of the basin and watershed governance structures in the Delaware Basin in Delaware, New Jersey, New York, and Pennsylvania. Summarize basin population, climate, hydrology, land use, and geology. Describe the governmental structure of Federal, state, regional, and nonprofit water management agencies in the basin (Sherk 2005 and Abdalla et al. 2010). Review the enabling compact authority, organizational structure, and budget of the DRBC (Warren 2003 and DRBC 2004). Evaluate the performance of the DBRC as an interstate river basin governance organization (Wolff 2004, Hooper 2006, and GAO 2007).

Water Quality Trends: Examine water quality trends to determine how and why water pollution has changed spatially and temporally along the Delaware River and its major tributaries. Summarize existing DRBC (2008) water quality criteria along the river. Identify water quality trends for dissolved oxygen and total nitrogen. Review chronology, discussion, and policy background of proposals to adopt a future, more stringent DRBC DO water quality standard.

1960s Economic Study: Summarize conclusions of a 1966 Delaware Estuary economic study conducted by the Federal Water Pollution Control Administration (1966) and actions taken in 1967 by DRBC to adopt the current DO criteria of 3.5 mg/l (Johnson 1967, Schaumburg 1967, Thoman 1972, DeLorme and Wood 1976, Hjalte et al. 1977, Kneese and Bower 1984).

Costs of Pollution Reduction: Estimate costs of nitrogen load reductions needed to improve dissolved oxygen levels in the tidal Delaware River using a water quality model (Moore et al. 2011, Evans 2008, Cropper and Isaac 2011). Use total maximum daily load models to estimate pollutant load reductions needed to improve DO in the Delaware River from current 3.5 mg/l to future more protective standard. Identify measures to reduce pollutant loads from wastewater, airborne deposition, urban/suburban, and agriculture sources. Estimate unit N load reduction costs for the alternatives (Trowbridge 2010). Construct marginal abatement cost curves (Van Soesbergen et al. 2007) to define least costs to improve DO to more stringent fishable criteria.

Benefits of Improved Water Quality: Estimate benefits (Hodge and Dunn 1992) of improved water quality in the Delaware River based on market and nonmarket valuation methods for use and nonuse categories (Table 1.1). Use values are estimated for: (1) boating, fishing, bird/wildlife watching recreation using net factor income, productivity, and travel cost methods (Bockstael et al. 1989, Cordell et al. 1990, Leggett and Bockstael 2000, Johnston et al. 2002, EPA 2000, Leeworthy and Riley 2001, NOEP 2010, Griffiths et al. 2012), (2) commercial fishing using market price method from National Marine Fisheries Service, (3) water supply (municipal, agriculture, industrial/commercial) using market price and productivity methods to reflect decreased treatment costs, (4) viewing/aesthetics using willingness to pay and contingent valuation methods, and (5) increased property value using hedonic pricing methods involving the price of river-side parcels (EPA 1973). Estimate nonuse benefits of existence and bequest values from stated preference and contingent valuation surveys (Carson and Mitchell 1993).

Table 1.1: Benefits from improved water quality (Carson and Mitchell 1993)

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

Benefit-Cost Analysis: Conduct benefit-cost analysis (U.S. Water Resources Council 1983, Lyon and Farrow 1995) of pollutant load reductions needed to improve water quality and meet a more protective DRBC dissolved oxygen standard (up from existing 3.5 mg/l) to provide year-round propagation of diadromous fish in the tidal Delaware River. Using net benefits, marginal abatement cost curves (MAC), and marginal benefits (MB)/marginal cost (MC) curves (Daly and Farley 2011) determine cost-effective combinations of pollution reduction measures to achieve more stringent DO water quality criteria along the tidal Delaware River. Alternatively, identify a cost-effective DO standard or the optimal level where marginal benefits (willingness to pay) for improved water quality equal the marginal costs of pollution reduction (Figure 1.3).

Sustainable Watershed Funding: Explore market-based vehicles such as user-polluter pays approach and water quality trading banks to fund and incentivize water quality improvements in the Delaware River Basin. Compare economic water pollution control incentives such as fees, charges, and tradable permits to traditional EPA Clean Water Act command and control regulations. Discuss the policy and economic implications of the market-based water pollution control funding options for implementation in the Delaware Basin: (1), water use charge or user pays (Odum 1998), (2) effluent fee or polluter pays (Goldberg 2007), (3) water quality trading (Scatena et al. 2006, Jones et al. 2010, Kardos and Obropta 2011), and (4) watershed utility fee.

1.5 Organization of Dissertation

Chapter One: Describe research goals/objectives, policy contributions, and research design.

Chapter Two: Review river basin management models including the watershed approach, domestic/international basin agencies, and interstate river basin commissions.

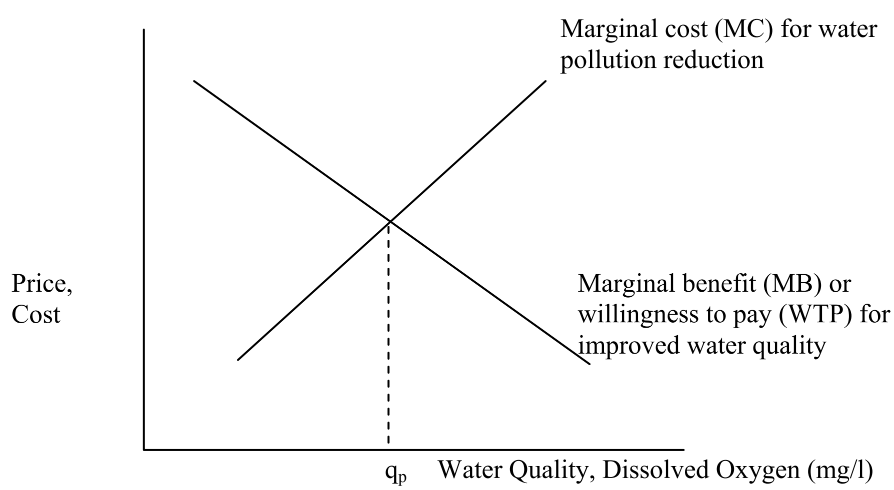


Figure 1.3: Optimal water quality

Chapter Three: Summarize the social and physical characteristics of the Delaware Basin, DRBC Compact of 1961, water governance and financial framework in the basin, and DRBC organizational and budget structure in relation to other river basin governance organizations.

Chapter Four: Examine water quality in the Delaware Basin including the function of the Delaware Estuary, DRBC water quality standards, the nutrient cycle, effect on dissolved oxygen levels, and discussions to adopt more stringent and protective DO criteria in the river.

Chapter Five: Review the 1966 Delaware River benefit-cost analysis by the Federal Water Pollution Control Administration as one of the first economic studies of its kind in the U.S.

Chapter Six: Estimate costs of improvements to reduce pollution to meet future DRBC water quality criteria in the Delaware River between Philadelphia and Wilmington. Construct nitrogen marginal abatement cost (MAC) curves to determine least cost approach to reduce pollutant loads.

Chapter Seven: Estimate use (market and nonmarket) and nonuse benefits for improved water quality in the Delaware River for recreation (boating, fishing, viewing), property value, water supply, navigation, and agriculture uses. Estimate marginal benefits or improved water quality.

Chapter Eight: Conduct a benefit-cost analysis to determine most cost-effective water quality criteria as measured by dissolved oxygen. Determine optimal water quality in the Delaware River at the intersection of the marginal benefits and marginal costs curves.

Chapter Nine: Analyze sustainable watershed funding models to finance water pollution control programs in the Delaware Basin. Compare the traditional command and control regulatory approach to user pays and polluter pays funding mechanisms.

Chapter Ten – Discuss the policy implications and limitations of the research and provide conclusions and recommendations for the analysis of the governance, policies, and economics of clean water in the Delaware Basin.

Chapter 2

RIVER BASIN GOVERNANCE MODELS

2.1 Introduction

This chapter reviews the river basin approach to water resources planning and management and (1) traces the evolution of watershed management, (2) examines the forms of river basin governance structures including basin commissions, agencies, associations and councils in the United States and overseas, and (3) compares and contrasts the types of river basin commissions in the U.S. along with their organizational and budget structures as related to DRBC.

2.2 The Watershed Approach

Water and federalism are a complicated mix as water flows through the hydrologic cycle without regard to political boundaries (Mandarano et al. 2008). Except for a few states such as Virginia and West Virginia and Idaho and Montana (Figure 2.1), watershed and political boundaries often do not coincide (Kauffman 2002). In the instances where political jurisdictions do not follow hydrologic lines, water managers face complex institutional and governance challenges and competition for water supplies (Sharpe 1999, Cody and Carter 2009). Watersheds in the U.S. include many state and local governments and this often results in inefficient and contentious use of the water resource. The Delaware River Basin presents unique challenges because each of its four states and dozens of counties and hundreds of cities and towns administers their own set of disparate water quality regulations, stormwater ordinances, and policies. Because the many governments have different agendas, it can put them in dispute with their upstream or downstream neighbors leading to conflicts that may be resolved by public managers through the principles of watershed management.

At "Drinking Water 2001", a public policy forum sponsored by the University of Delaware, keynote speaker and environmental journalist McKay Jenkins (2002) described this dilemma:

…What I would like to do today is try and expand our notion of the importance of watersheds to talk about borders and flow in a larger context. Ecologists and drinking water experts have long acknowledged the silliness - not to say utterly counterproductive, and potentially destabilizing notion - of political boundaries when it comes to the flow and distribution of water. What does a county line mean to an aquifer? What does a state line mean to a raincloud? What does a national border mean to a river? … The point I want to make here is that any effort to reject the permeability and flow of boundaries, be they natural or psychological, runs against the natural way of things. Water wants to flow - it's in the nature of water. People want to flow - it's in the nature of people. … Finally, at least in some places in the country, we are beginning to think in terms not of boundaries, but in terms of watersheds, and flow.

The word for watershed was derived from the 14th century German *wasser-scheide* or "water parting" (Reimold 1998). Also defined as a crucially important factor or event, the watershed is the region draining into a river or water body. As a scientific term, the English word for watershed did not become common until about 1800 (Oxford English Dictionary 1978). EPA (1999) described the watershed approach as "a coordinating framework for environmental management that focuses public and private sector efforts … within hydrologically defined geographic areas taking into consideration both ground and surface water flow."

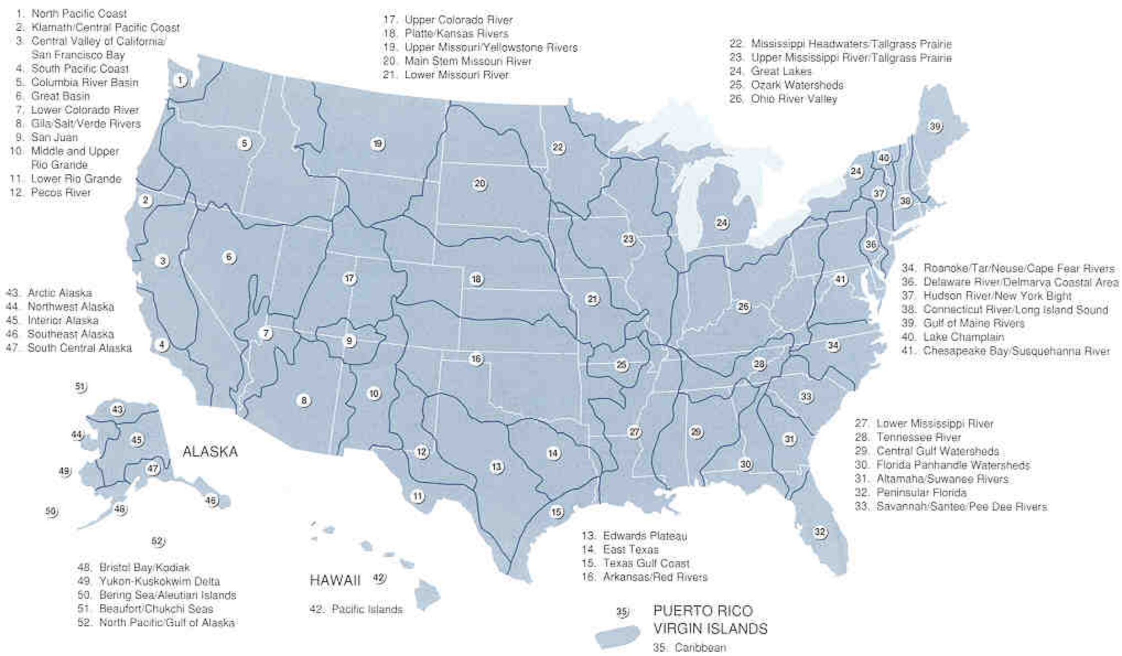


Figure 2.1: Watershed and political boundaries in the United States (Kauffman 2002)

The watershed approach is beneficial because it (NAS 1999 and Sherk 2005):

- Moderates competing uses between upstream and downstream stakeholders.
- Balances institutional objectives at the Federal, state, and local levels.
- Involves a consensus decision-making approach among stakeholders and citizens.
- Incorporates multidisciplinary thinking from the fields of science and policy.
- Provides for cost sharing among watershed stakeholders for cost-effective solutions.
- Relies on voluntary partnerships, not mandatory command and control regulations.

Watershed planning and management is challenging because:

- Diverse interest groups often cannot agree on a unified watershed master plan.
- Hydrologic and political boundaries often do not coincide leading to political conflicts.
- The process can be slow and complex as stakeholders often quit waiting for action.

- Fragmented authority leads to conflicts between insular Federal, State, local entities.

The watershed movement became more relevant in the United States after Congress passed the Clean Water Act amendments in 1972 and 1977. It advanced during the Reagan era (1980-1988) when political power decentralized from the Federal government to the states and a new “flexible federalism" ensued where the Federal and state governments shared more responsibilities through the watershed approach (National Academy of Sciences 1999). During the 1990s, the EPA (1995) unveiled the Watershed Protection Approach as a way for the states to meet the goals of the Clean Water Act. Congress commissioned a National Academy of Sciences (1999) study that concluded hydrologic basins provide a logical framework for regional water management by integrating water science (physical sciences) and policy (social sciences).

The watershed approach became more cogent at the turn of the century when EPA (2002) released a “Renewed Commitment to Watershed Management” as an environmental guiding principle. The U.S. Army Corps of Engineers developed a Civil Works Program Strategic Plan (FY2003-2008) that urged a comprehensive watershed approach to manage the nation’s water resources. The U.S. Commission on Ocean Policy (2004) recommended a regional watershed approach to manage the nation’s coastal, estuary, and ocean resources. A National Water Policy Dialogue sponsored by the American Water Resources Association in 2005 reinforced the need to embrace interstate watershed management. The Interstate Council on Water Policy (2006) announced a “rediscovery” of watershed planning and “renewed interest” in multistate river basin institutions to manage transboundary water resources. In 2009, the Congressional

Research Service called for reconsideration of an idea to form a nation-wide network of river basin commissions to resolve the challenges of watershed management (Cody and Carter 2009).

Tracy Meehan (2010), former EPA Administrator for Water, wrote that the problems of complying with the Clean Water Act are not those of science and technology but rather of governance and maintained that a new watershed approach was needed to address water resources problems in the United States. Meehan saw collaboration as a central theme of "symphonic watershed governance" to balance the interests of governments and stakeholders and concluded that river basin commissions are ideally suited to manage watersheds because they were formed by Congress and state legislatures as "sovereign entities unto themselves".

In 2010, a bill was introduced to establish an Office of Sustainable Watershed Management in the White House to fund ten regional watershed boards to cover the U.S. and coordinate public/private interests in water resources planning and management. The watershed boards would be co-chaired by federal and state representatives with membership from interstate agencies, tribes, local governments, and industries. The bill was tabled by the House of Representatives due to concerns about the Federal budget.

Water resources are managed by various governance institutions that overlap between the international, transnational, national, interstate, state, and local level (Goldfarb 1997). The DRBC is an example of an interstate watershed governance institution (Table 2.1).

Table 2.1: Types of watershed governance institutions (Goldfarb 1997)

Type	Example
International	United Nations
Transnational	International Joint Commission (U.S. and Canada)
National	Environmental Protection Agency
Interstate	Delaware Basin Commission
State	Delaware DNREC
Substate Regional	Chester County Water Resources Authority
Local	City of Newark Water Department

2.3 History of River Basin Management

While river basin management (RBM) is often practiced overseas, it is used in only a dozen or so river basins in the U.S. (Delli Priscoli and Wolf 2009). RBM has emerged as an efficient paradigm because the economies of scale provide benefits through compulsory water management (Wolff 2004). RBM is based on the principles of sound water law where water as a public good is essential to human survival and must be managed based on economic incentives (Dellapenna 2010). RBM is based on the principles of Integrated Water Resources Management (IWRM) that emerged from the 1992 U.N. Conference on Environment and Development in Rio de Janeiro as a multidisciplinary way to balance social, economic, and environmental river interests in a sustainable way (Hooper 2006 and Global Water Partnership and INBO 2009). The International Network of Basin Organizations found that transboundary RBM is most successful when: (1) political commitment is directed from the highest levels in government, (2) basin management is governed by national water policies and legislation, and (3) institutional roles and responsibilities are specifically defined. The Congressional Research Service (Cody and Carter 2009) concluded that water resource projects today are authorized in a piecemeal fashion and recommended reinvigorating the river basin approach originally adopted by the 1965 U.S. Water Resources Council to address 21st century water policy challenges.

River basin management reaches back over two centuries to the formative years of the United States (Hooper 2010, Cech 2005, Delli Priscoli 1976). In 1783 just after the American Revolution, New Jersey, and Pennsylvania signed the first interstate compact to resolve a conflict about navigation rights along the Delaware River. Colorado River explorer John Wesley Powell (1878) recommended delineating new states based on watershed boundaries and for this belief he lost his job as the second director of the USGS. In 1889, Powell spoke to an unsupportive audience at the Montana Constitutional Convention in Helena about mapping the new state's county boundaries "…which would be convenient with drainage basins" (Kemmis 2001).

At the turn of the 20th century, Congress passed the Rivers and Harbors Act of 1899 that authorized the U.S. Army Corps of Engineers to regulate dumping, dredging, and construction along navigable rivers. The Reclamation Act of 1902 authorized Theodore Roosevelt to create the Bureau of Reclamation under the Secretary of Interior to construct irrigation and reservoir projects in the arid lands west of the100th Meridian. To control water diversion along the U.S./Canada border in the Great Lakes, the U.S. and Great Britain signed the Boundary Waters Treaty of 1909 that established the International Joint Commission (Galloway and Clamen 2001).

After the First World War, the U.S. turned to domestic concerns during the "Roaring Twenties". President Warren G. Harding, Secretary of Commerce Herbert

Hoover, and seven governors signed the Colorado River Compact of 1922 that appointed the Secretary of Interior as the supreme Federal authority to apportion water between upper basin (Colorado, New Mexico, Utah, and Wyoming) and lower basin (Arizona, California, and Nevada) states (Gelt 2001). Congress passed the River Basin Study Act of 1925 authorizing the Corps to complete Section 308 studies that later led to the creation of river basin commissions such as the DRBC.

FDR's New Deal was designed to lift the nation from the Great Depression and it led to vigorous public works programs in many river basins. In 1933, Congress created the Tennessee Valley Authority to address poverty in Appalachia and produce hydroelectric power as the first river basin regional development organization in the U.S. (Feldman 2001). The economic success of TVA led to proposals after World War II to create ten more river authorities but Congress never acted as Federal and state interests feared losing their power to this "huge government bureaucracy". After the Dust Bowl, the Flood Control Act of 1936 for the first time required cost-benefit analysis and consideration of social benefits for federal river basin projects. In 1936, Congress approved a compact by New York, New Jersey, and Connecticut to form the Interstate Sanitary (now Environmental) Commission (IEC) to enforce water quality regulations in the Hudson River, East River, and Long Island Sound. In 1940, Maryland, Pennsylvania, Virginia, and West Virginia formed the Interstate Commission on the Potomac River Basin (ICPRB).

The nation returned to water resources management after World War II as populated rivers like the Delaware and Columbia were heavily polluted by industrial wastes discharges during the all-out war effort. In 1946, thirty people from West Chester, Pennsylvania and Wilmington, Delaware got together to form the Brandywine Valley Association as America's first small watershed organization (Kauffman 2002). In 1947, Congress consented to a compact between the six New England states plus New York State to create the New England Interstate Water Pollution Control Commission (NEIWPCC). With the first water quality legislation in fifty years, Congress passed the Federal Water Pollution Control Act of 1948 (amended in 1956) that funded states to improve water quality, prepare pollution control studies, and construct wastewater treatment plants. In 1948, Illinois, Indiana, Kentucky, New York, Ohio, Pennsylvania, Virginia, and West Virginia formed the Ohio River Valley Water Sanitation Commission (ORSANCO) to reduce water pollution in the largest river basin in the East.

With the turbulent '60s came the environmental movement. JFK was persuaded by Pennsylvania Governor David Lawrence to overrule Secretary of Interior Stewart Udall's concerns about unconstitutionality of treaties between the states and signed the 1961 Delaware River Basin Compact on the basis of comity between Delaware, New Jersey, Pennsylvania, and New York as the first shared Federal-state water accord (Albert 2009). In 1965 after years of consideration by JFK, Lyndon Baines Johnson signed the Water Resources Planning Act (WRPA) which formed the Water Resources Council in the White House to advise the President on water resources matters. In 1967, Congress amended the WRPA to establish Federal/state Title II interstate river basin commissions in the New England, Great Lakes, Ohio, Upper Mississippi, Missouri, and Pacific

Northwest basins. In 1968, LBJ signed the Wild and Scenic Rivers Act to protect "outstandingly remarkable" free flowing rivers as wild, scenic, and recreational.

In 1969, Richard Milhous Nixon assumed office and signed the National Environmental Policy Act (NEPA) that created the President's Council on Environmental Quality (CEQ), designated the Federal government as "Protector" of environmental resources, and required Environmental Impact Statements (EIS) for federally funded, owned, or permitted projects.

Earth Day was first observed in April 1970 and later that year Richard Nixon issued an Executive Order that created EPA while the states formed parallel agencies such as DNREC, NJDEP, PADNR, and NYSDEC. Based on the early success of the DRBC; the U.S., Maryland, New York, and Pennsylvania formed the Susquehanna River Basin Commission in 1970 as one of the last of the Federal-state basin compacts. Congress overrode Nixon's veto and passed the Federal Water Pollution Control Amendments (Clean Water Act) of 1972 that established water quality standards and pollution discharge permits. The 1977 CWA amendments required states to meet fishable and swimmable uses by 1983 and eliminate pollutant discharges by 1985. Section 208 of the CWA required that states form area-wide water pollution planning agencies such the Water Resources Agency for New Castle County, Delaware.

In 1981 Ronald Reagan terminated the Water Resources Council and defunded the Title II river basin commissions. In 1983, EPA and the District of Columbia, Maryland, Virginia, and Pennsylvania signed the voluntary Chesapeake Bay Agreement to clean up the nation's largest estuary and reduce water pollution in the vast 64,000 square mile watershed. The Safe Drinking Water Act of 1986 and amendments in 1996 set enforceable drinking water standards including a wellhead protection program and source water protection program. The Water Quality Act of 1987 was the first Federal law to control urban stormwater pollution and required states to submit a biannual Section 303d list of impaired streams to EPA and develop watershed Total Maximum Daily Loads (TMDLs) as a "pollution diet" to clean up polluted streams which do not meet water quality standards. The 1987 CWA amendments authorized EPA to establish the National Estuary Program where 28 partnerships such as the Delaware Estuary Program coordinate Federal, state, and estuary restoration activities on a watershed basis.

With the rise of the EPA watershed approach in the 1990s, hundreds of informal, grass roots watershed councils and associations (built on the 1946 BVA model) formed to provide a basin focus to water resources management. These watershed councils lack formal power but embrace a high level of collaboration by the public, stakeholders, and businesses. In 1997, New York City negotiated an agreement with EPA under the Safe Drinking Water Act to eventually spend $1.5 billion to reforest and restore farms on 105,000 acres of watershed land in 8 counties above the Catskill Reservoirs in the upper Delaware Basin instead of spending $10 billion on a microfiltration plant near the Bronx (Meehan 2010). Alabama, Florida, and Georgia signed the 1999 Alabama-Coosa accord as one of the last interstate river basin compacts in the U.S.

In 2003, the Christina Basin Clean Water Partnership between the DRBC, EPA, and Delaware and Pennsylvania was awarded a $1 million EPA Watershed Initiative Grant as the No. 1 ranked grant among over 200 applications received throughout the

United States (Ernst 2005). Watershed management has been assumed by the sharp rise in local environmental groups, at last count there were 132 of these organizations on the Delmarva Peninsula and over 16,000 local environmental groups in the U.S. (Kempton, Holland, Bunting-Howarth, Hannan, and Payne 2009). By 2010, the Milwaukee Metropolitan Sewerage District and Conservation Fund spent $13.4 million to create a Milwaukee Sweetwater Trust that promotes green watershed BMPs such as rain barrels, vegetated swales, cisterns, and green roofs to reduce stormwater flows (Meehan 2010). Alabama, Florida, and Georgia are negotiating a compact for the Apalachicola-Chattahoochee-Flint (ACF) river basin to address the after effects of the drought of 2010.

2.4 International Organizations

Various forms of river basin management (Table 2.2) have long been practiced around the world (GWP and INBO 2009). Since 1964, France has managed water through a network of six *Comites de Bassin* (Basin Committees) and *Agences de l'Eau* (Water Agencies) that collect user fees from polluters and dischargers and reinvest these revenues in watershed pollution control programs. The German Ruhr water associations (*Genossenschaften*) are authorized by Federal law and financed by user charges. The Dutch water boards (polders) are among the oldest democratic institutions in Europe and are composed of landowners (farmers) who vote and pay taxes to the board. In the 1980s, Portugal created 15 river basin authorities to regulate water use and collect funds based on user (water withdrawal) and polluter (discharger) pays principles. During the 1980s, the British National River Authority was formed to regulate catchment management under a 15 member board responsible for eight river basin regions. The Spanish Ministry of Public Works oversees nine *Confederaciones Hidrograficas* each with a secretariat of a water commissioner, technical staff, and Secretary General funded by water use charges and discharge fees. The Russian Ministry of Natural Resources coordinates five Volga River Basin agencies with funding by a user and polluter pays approach.

Table 2.2: River basin management organizations around the world (GWP and INBO 2009)

Country	Description	Funding
France	Six water basin agencies (*Agencies de L'eau*)	Users fees from polluters/dischargers
Germany	Ruhr water associations (*Genossenschaften*)	User charges
Netherlands	Dutch water boards (polders)	Water Board Tax
Portugal	15 river basin authorities	Water use and polluter (discharger) pays fees.
Great Britain	National River Authority, 15 member board with eight river basin regions	Privatized w/collection of user fees.
Spain	Nine basin authorities (*Confederaciones Hidrograficas*)	Polluter pays approach from water use charges, regulation fees, discharge fees.
Russia	Ministry of Natural Resources coordinates 17 river basin agencies	Funding generated by a user and polluter pays approach.
Mexico	National Water Commission oversees 25 river basin councils	User fees
Australia	Murray Darling Commission Murray Darling Basin Ministerial Council	
New Zealand	12 regional catchment councils based on watershed boundaries	

Mexico has 25 river basin councils, 6 basin commissions, and 2 basin committees including the Lerma Chapla River Basin Council created in 1993 from the National Water Law. In 1985, the Murray Darling Basin Ministerial Council in the provinces of New South Wales, Queensland, South Australia, and Victoria organized along the lines of the DRBC and is governed by two commissioners, 40 technical staff, and a 26 member

Community Advisory Council (Wolf 2005). In 1991, New Zealand replaced more than 800 governmental units with 12 regional water catchment councils to coordinate three central agencies and 74 district or city authorities.

2.5 Domestic River Basin Organizations

Under the Constitution, the United States has a Federal government that shares power with the sovereign states. The Federal government has long possessed central power over interstate waters and the states have maintained power over intrastate waters (Delli Priscolli and Wolf 2009). Since watersheds often do not coincide with political boundaries, river basin organizations have evolved for the Federal and state governments to share power over interstate waters. The challenge of interstate water management comes from lack of a national water resource planning policy, fragmented Federal and state regulation, squabbles over federal and state sovereignty, population growth, and extreme weather events (Mardarano et al. 2008). For a century, the Federal government has experimented with many forms of interstate river basin organizations such as single federal administrators, regional authorities, interstate watershed councils, Title II interstate basin commissions, and interstate compact commissions (Table 2.3).

Single Federal Administrator: Under the Colorado River Compact, Congress designated the Secretary of Interior as the sole Federal authority to allocate the waters of the six states in this vast western basin. This is a strict top-down, command and control approach to basin governance as the lines of authority are clear and definitive, decision-making is responsive, and a single leader provides the focal point for all planning, policymaking and implementation. However, the single administrator is usually focused on a single issue that leads to shortcomings in "intergovernmental collaboration and shared stewardship/ decision-making authority".

Table 2.3: River basin governance organizations in the United States ((ICWP 2006, Wolf 2004, Cody and Carter 2009)

Type	Description	Strength	Weakness	Example
Single Federal Administrator	Sole federal official (Sec. of Interior) has authority over single watershed.	Line of authority is clear. Decision making is responsive, single leader sets policy. More power to Federal government.	Single administrator focused on single issue. Shortcomings in interstate collaboration. Less power to states.	Colorado River Compact (1922)
Regional Authority	Centralized regional governmental agency.	Central authority minimizes inter-governmental coordination. Projects implemented efficiently by single agency.	Command and control approach with reluctance to employ checks and balances. Diminished consensus by public. Undue reliance on federal government.	Tennessee Valley Authority (1933)
Watershed Councils	Agreements between states through federal /state legislation, resolutions, or MOA.	Good collaboration with public. Consensus driven, and non- threatening to stakeholders and businesses.	Lack formal legal and enforcement power. Less power than a compact authority. States usually only members (little Federal role).	Chesapeake Bay Partnership (1983)
Title II Interstate-Basin Commissions	Organizations directed by commissions where each member had one vote.	Best way to manage water resources in an integrated basis. Permanent staff. Treated states as equals to the Federal government.	Seen as unnecessary layer of government and competing with Federal water agencies for turf and funding	New England, Great Lakes, Ohio, Upper Mississippi, Missouri Basins
Federal-State Interstate Basin Compact Commissions	Congressional consent needed to address Constitutional concerns about interstate treaties	Based on comity or collegiality, builds trust between states and minimizes disputes. Commissioners have equal, one state, one vote.	Time consuming process for Compact ratification. Hesitant to surrender Federal/state soverignty to third party and competition for Federal/state funding.	Delaware River Basin Commission

Regional Authority: To address crippling poverty in Appalachia, in FDR signed a 1933 law that created the Tennessee Valley Authority as the only true Federal river basin regional development organization in the U.S. The TVA's strengths as a strong centralized authority allow it to minimize intergovernmental coordination needs and allow projects to be implemented efficiently by a single agency. Weaknesses include a "command and control" approach with reluctance to employ checks and balances with little consensus by the public and too much reliance on the federal government.

Watershed Councils: Loosely organized informal groups such as the Christina Basin Clean Water Partnership are composed of elected officials, staff, nonprofit environmental groups, and the public to coordinate water management issues. These grass roots councils are run with "soft management authority" in planning, coordination, and advocacy with less power than a compact authority. With the rise of the EPA watershed approach in the 1990s, hundreds of grass roots watershed councils formed to be less formal than a commission and lack formal legal enforcement power but are able to collaborate with the public, are consensus driven, and are non-threatening to stakeholders and businesses. The strength of an informal interstate council is the flexibility to focus on emerging water issues without being encumbered by regulations.

Title II Interstate Basin Commissions: After years of pushing by JFK, Lyndon Johnson signed the Water Resources Planning Act of 1965 that recommended forming a network of interstate river basin commissions with the Federal government as chair and each Federal and state member with one vote (Mandarano, Featherstone, and Paulsen 2008). The WRPA amendments of 1967 funded new Federal/state commissions for the

New England, Great Lakes, Ohio, Upper Mississippi, Missouri, Pacific Northwest river basins (Table 2.4). In 1981, Ronald Reagan cut Federal funding for the Water Resources Council and in the following year terminated funding for the Title II river basin organizations which led to their demise. Water policy scientists have called for resurrecting the Water Resources Planning Act and reestablishing river basin commissions throughout the U.S. to address 21st century water resources problems.

Table 2.4: Structure of Title II river basin commissions (Mandarano et al. 2008)

River Basin Commission	Year	Chair	Commissioners	
			Federal	State
Pacific Northwest	1967	U.S.	8	5
Great Lakes	1967	U.S.	8	8
Sourin-Re-Rainey	1967	U.S.	8	3
New England	1970	U.S.	8	7
Ohio	1971	U.S.	10	10
Missouri	1972	U.S.	10	10
Upper Mississippi	1972	U.S.	10	5

2.6 Interstate River Basin Commissions

Since large rivers tend to flow through more than one state and watersheds do not usually align with political boundaries, interstate compacts have been signed to share the flow of water and control water pollution (Cech 2005). Established by treaties between the Federal government and the states, basin commissions are usually compulsory established by formal government legislation and have a permanent office and staff (secretariat) who manage the river system as a single entity (GWP and INBO 2009).

Interstate compacts are legal agreements between the states that provide a joint federal-state response to water resources problem to manage water resources (GAO 2007). Successful Federal-state compacts offer complimentary approaches to solving interstate water management issues and are based on comity or collegiality that builds equal trust between state partners and minimizes disputes (Mandarano et al. 2008). Commissioners have one state-one vote authorities, with members from each state and federal representatives appointed by the President. River basin commissions employ independent technical staff and are decentralized institutions that balance state autonomy with Federal supremacy in water resources management (Hooper 2006). Section 103 of the Clean Water Act requires the EPA to encourage cooperative activities by the states through compacts. Section 106 of the Clean Water Act provides EPA funding to river basin commissions for interstate water management (Meehan 2010). Many interstate compact commissions are funded by the Federal government and states. These compact commissions are neither the federal or state government and are often labeled as a third level of government. The Government Accountability Office (2007) reported to Congress that interstate compacts are effective in the areas of organization, authority, accountability, and conflict resolution.

Interstate compacts are a mix of Federal-and state law (Dellapenna 2010). Compacts are governed by a commission and require consent of Congress because Article 10 of the U.S. Constitution prohibits treaties between the states without Federal approval (Sherk 2005). The nondelegation principle of the Constitution holds that States are not permitted to sign treaties (compacts) without the consent of Congress. Congress can delegate authority for the compact to a Federal agency provided there is "an intelligible principle" for the agency's interest. A compact is federal law and cannot be amended without consent of Congress. Compacts do not violate the interstate commerce clause because Article I of the U.S. Constitution grants Congress the authority to regulate commerce among the states.

Over a dozen interstate river basin compacts (Table 2.5) have been signed in the United States (Cech 2005, U.S. Fish and Wildlife Service 2005 and GAO 2007). In 1783, Maryland and Virginia signed an accord to resolve fishing and navigation conflicts along the Potomac River President Warren G. Harding and seven governors signed the Colorado River Compact of 1922 as the first interstate water supply allocation agreement. Between 1923 and 1939, compacts were signed for the South Platte and Rio Grande river basins.

In the eastern United States, Federal and state governments have formed seven congressionally approved interstate basin compacts with roles in conflict resolution, regulation, water quality planning, flood mitigation, source water protection, and water supply regulation (Table 2.6). Congress established the Interstate Commission on the Potomac River Basin (ICPRB) in 1940 as the Mid-Atlantic's first basin compact to help the District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia and Federal government manage the Potomac through regional and interstate cooperation. The Interstate Environmental Commission (1936), New England Interstate Water Pollution Control Commission (1947), and Ohio River Valley Water Sanitation Commission (1948) are single purpose basin organizations that focus on water pollution. The success of the 1961 DRBC Compact led to signing of the 1970 Susquehanna River Basin Compact (SRBC) by the President and Governors of Pennsylvania, Maryland, and New York. The DRBC and SRBC compacts “were ahead of their time” in managing a river on a watershed basis without regard to political boundaries (Abdalla 2010). In 1999, the Alabama-Coosa accord was signed by Alabama, Florida, and Georgia. The Great Lakes Commission (2008) is a comprehensive multiple purpose agency with responsibilities in most areas of water management which is governed by the Council of Great Lakes Governors (CGLG) compact.

Table 2.5: Interstate river basin compacts in the United States
(ICWP 2002, Cech 2005, USFWS 2005, GAO 2007, and Abdalla 2010)

Adopted	River	States	Purpose
1783	Delaware	NJ, PA.	Navigation
1783	Potomac	MD, VA	Navigation/Fishing
1922	Colorado	WY, CO, UT, NM, AZ, NV, CA	Water Quantity
1923	South Platte	NE, CO	Water Quantity
1939	Rio Grande	CO, NM, TX	Water Quantity
1940	Potomac	MD, PA, VA, DC	Water Quality
1948	Ohio	IL, IN, KY, OH, NY, PA, VA, WV	Water Quality
1949	Connecticut	CN, MA, NH, VT	Flood Control
1961	Delaware	DE, NJ, NY, PA	Water Development
1970	Susquehanna	MD, NY,PA	Quantity/Flooding
1999	Alabama-Coosa	AL, FL, GA	Water Quantity
2008	Great Lakes	IL, IN, MI, MN, NY, OH, PA, WI, OT	Water Quality
2013	Apalachicola-Chaata-Flint	AL, FL, GA	Water Quantity

Table 2.6: Interstate basin compact responsibilities (ICWP 2002)

Basin Commission	Regulation	Water Quality	Flood Mitigation	Source Water Protection	Water Supply Regulation	Public Education Outreach
IEC		X				
ICPRB		X		X	X	X
NEIWPCC		X				
ORSANCO	X	X		X		X
DRBC	X	X	X	X	X	X
SRBC	X		X	X	X	X
GLC	X				X	X

Interstate Environmental Commission: The IEC was formed in 1936 as the Interstate Sanitation Commission by a congressionally approved compact between New York, New Jersey, and Connecticut to enforce water quality regulations in a 5,000 square-mile area around New York City with a population of 20 million people. IEC operates with a staff of 12 with a $1 million budget with 56% from Federal sources (EPA) and 44% from state appropriations. The IEC is governed by 12 commissioners with three commissioners from New Jersey, three from New York, and four from Connecticut.

Interstate Commission on the Potomac River Basin: The ICPRB was established by Congress in 1940 to protect, and conserve the Potomac River and its tributaries through regional and interstate cooperation. The Commissioners are from the District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia. The United States participates but never signed the compact. The ICPRB annual budget is $2.3 million with 43% from Federal sources and 57% from grants and fees. The ICPRB staff of 23 has limited regulatory authority over a 14,760 square-mile basin with 6.1 million people in the Washington, D.C., metropolitan area.

New England Interstate Water Pollution Control Commission: The NEIWPCC was created in 1947 to manage a 14,700 square-mile area with a population of 6 million in the six New England states plus New York State. The NEIWPPC has 13 staff with an annual budget of $10.8 million with 53% from Federal sources (mainly EPA), 19% from grants, and 11% from state funding. NEIWPCC is governed by 33 commissioners with five from each state except Rhode Island which has three commissioners.

Ohio River Valley Water Sanitation Commission: Illinois, Indiana, Kentucky, New York, Ohio, Pennsylvania, Virginia, and West Virginia formed ORSANCO in 1948 to control water pollution in the Ohio River basin. ORSANCO enforces water quality standards in a 154,000 square-mile basin with 21.7 million people. ORSANCO has 24 staff and an operating budget of $3.8 million with 61% from Federal (mostly EPA) sources and 35% from state appropriations. ORSANCO is governed by 25 commissioners from Illinois (3 commissioners), Indiana (3), Kentucky (3), New York (3), Ohio (2), Pennsylvania (3), Virginia (3), West Virginia (3), and the Federal government (2).

Delaware River Basin Commission: DRBC was created in 1961 with five commissioners representing a Presidential appointee and governors of Delaware, New Jersey, New York, and Pennsylvania. With a staff of 45 and a budget of $5.7 million, DRBC manages a 13,000 square-mile basin with 8.2 million people. Funding is provided by 46% state, 35% permit and fees, and 20% grants and contracts. DRBC has not received Federal funding since 1997.

Susquehanna River Basin Commission: The SRBC was created in 1970 by congressional approval of a compact between Maryland, Pennsylvania, and New York to manage water resources in a 27,510 square-mile watershed with 4 million people. The SRBC is governed by four commissioners representing the President and governors of the three states. The SRBC has 35 staff and an annual budget of $7.7 million with 19% from the states and 81% from permits/fees.

Great Lakes–St. Lawrence River Basin Water Resources Council: The Great Lakes states and Canada signed the Compact into law in 2008. The Council of Great Lakes Governors oversees economic development, interbasin water diversions, and water quality standards in a 375,000 square-mile area with 43 million people. The Great Lakes Commission has 31 staff with a $6.4 million budget including 92% from grants/contracts and 7% from state appropriations. The GLC is governed by 45 commissioners from Illinois (6), Indiana (5), Michigan (5), Minnesota (5), New York (4), Ohio (5), Pennsylvania (3), Wisconsin (3), Ontario (4), and Quebec (5).

Basin commission funding varies by size and scale with no discernible apportionment formula (Table 2.7). Seven eastern basin compacts cover all or parts of 20 states and 605,000 square miles or 19% of the contiguous U.S yet manage water resources for 109 million people or 1/3 of the nation’s population. Basin commissions range from the 5,000 square-mile IEC around New York City to the vast 375,000 square-mile Great Lakes Basin. The SRBC manages water supplies for 4 million people while the Great Lakes Commission manages a basin with 10 times as many residents.

Resource allocations for the interstate basin agencies range from 13 staff at the New England Interstate Water Pollution Control Commission with a $10.8 million annual budget to a staff of 35 for the SRBC with a $7.7 million budget and a staff of 45 for the DRBC with a $5.7 million budget. The Great Lakes and Ohio Basin commission budgets cover about $17/mi^2 to $25/mi^2 of basin area while the DRBC and New England commission budgets cost $418/mi^{2}to $734/mi^2. The IEC, ORSANCO, and Great Lakes budgets equate to $0.05 to $0.18 per capita while the NEIWPCC and SRBC budgets equate to $1.80 to $1.90 per capita (Figure 2.2).

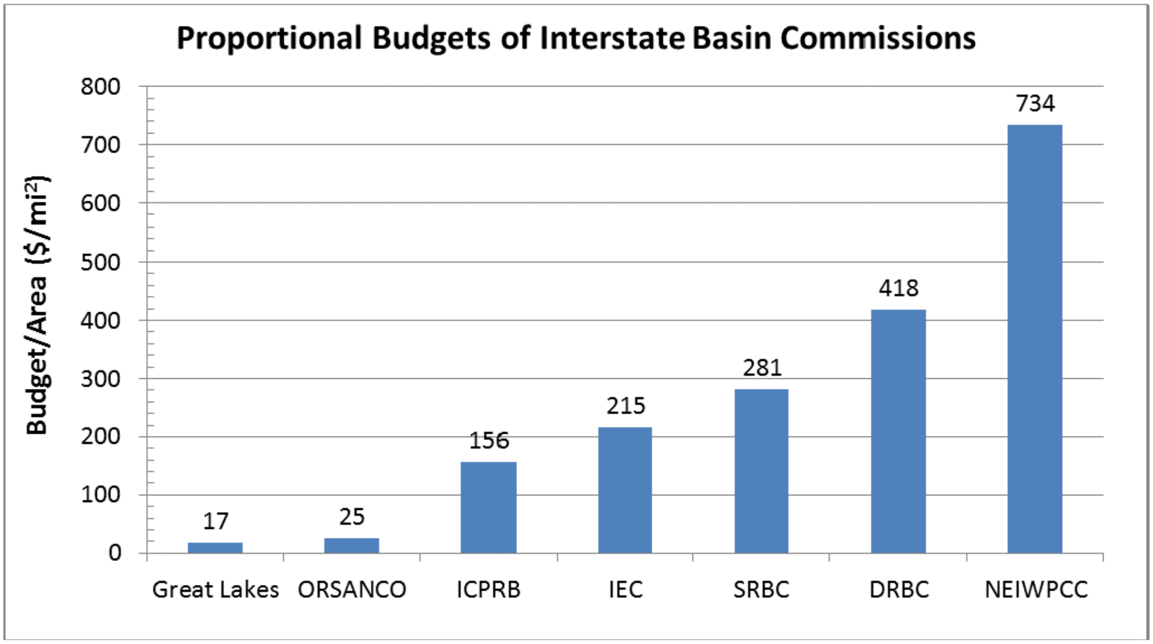
Annual revenues for the interstate basin commissions range from $1.1 million for the Interstate Environmental Commission to $10.8 million for the New England Interstate Water Pollution Control Commission (Table 2.8). Over 40% of the revenue for the IEC, Potomac, NEIWPCC, and ORSANCO commissions are mostly appropriated the annual EPA budget through the Clean Water Act while the DRBC, SRBC, and Great Lakes Commission lack these dedicated congressional line items and receive zero revenue from Federal budget appropriations (Figure 2.3). Over 55% of the Potomac and Great Lakes budgets come from grants and contracts that tend to ebb and flow for a few years and then sunset. Less volatile permit and user fees provide 80% of the SRBC budget. DRBC revenues are composed of 46% state funding, 35% permit/fees and 20% grants/contracts while Federal appropriations have been missing since 1997.

Table 2.7: Congressionally approved river basin compacts

Compact	Date	Commissioners	Basin (mi^2)	Pop.	Staff	Budget ($)
IEC	1936	CT, NJ, NY	5,000	20,000,000	12	1,076,236
ICPRB	1940	MD, PA, VA, WV	14,670	6,110,000	23	2,282,000
NEIWPCC	1947	CT, ME, MA, NH, NY, RI, VT	14,700	6,000,000	13	10,786,424
ORSANCO	1948	IL, IN, KY, NY, OH, PA, VA, WV, U.S.	154,185	21,698,691	25	3,855,407
DRBC	1961	U.S., DE, NJ, NY, PA	13,539	8,200,000	45	5,660,000
SRBC	1970	U.S., MD, NY, PA, US	27,510	4,000,000	35	7,737,902
Great Lakes	2008	IL, IN, MI, MN, NY, OH, PA, WI, OT	375,400	43,000,000	31	6,423,308

Table 2.8: Revenue sources of Federal interstate basin compact commissions

Compact	Federal ($)	State ($)	Permit/ Fees ($)	Grants/ Contracts ($)	Total ($)
IEC	598,989	471,173	0	6,074	1,076,236
ICPRB	983,000			1,299,000	2,282,000
NEIWPCC	5,666,003	1,187,000	577,000	3,356,421	10,786,424
ORSANCO	2,366,352	1,363,500	0	125,555	3,855,407
DRBC	0	2,588,000	1,958,000	1,114,000	5,660,000
SRBC	0	1,489,200	6,244,004	4,698	7,737,902
Great Lakes	0	480,000		5,943,308	6,423,308
	(%)	**(%)**	**(%)**	**(%)**	**(%)**
IEC	56%	44%	0%	1%	100%
ICPRB	43%	0%	0%	57%	100%
NEIWPCC	53%	11%	5%	31%	100%
ORSANCO	61%	35%	0%	3%	100%
DRBC	0%	46%	35%	20%	100%
SRBC	0%	19%	81%	0%	100%
Great Lakes	0%	7%	0%	93%	100%



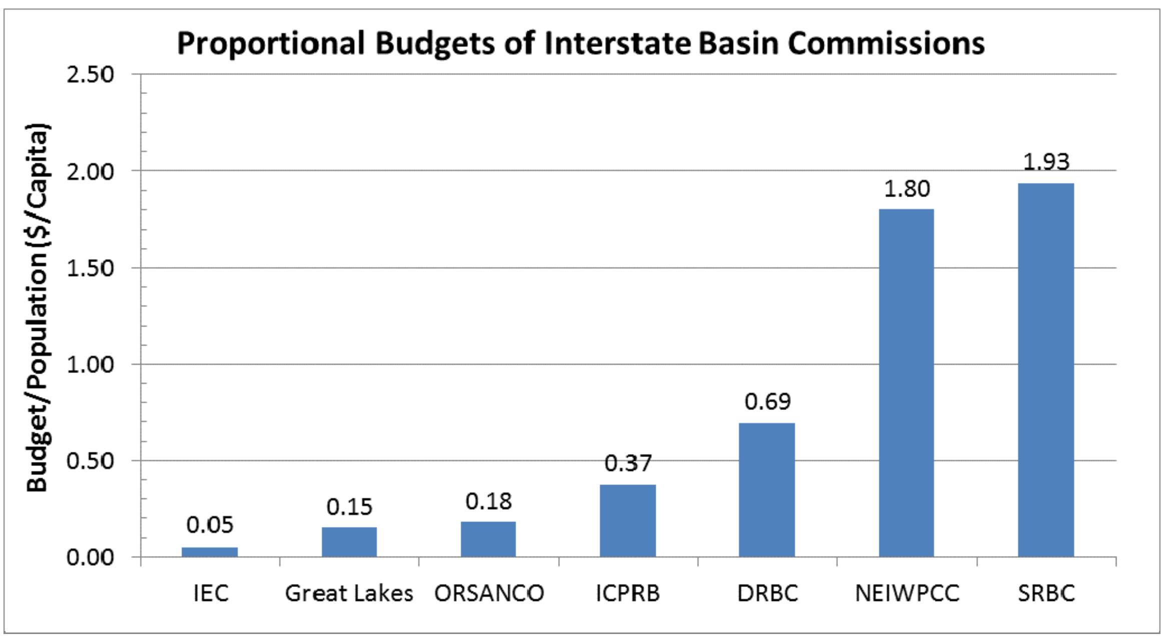


Figure 2.2: Proportional budgets of interstate basin commissions

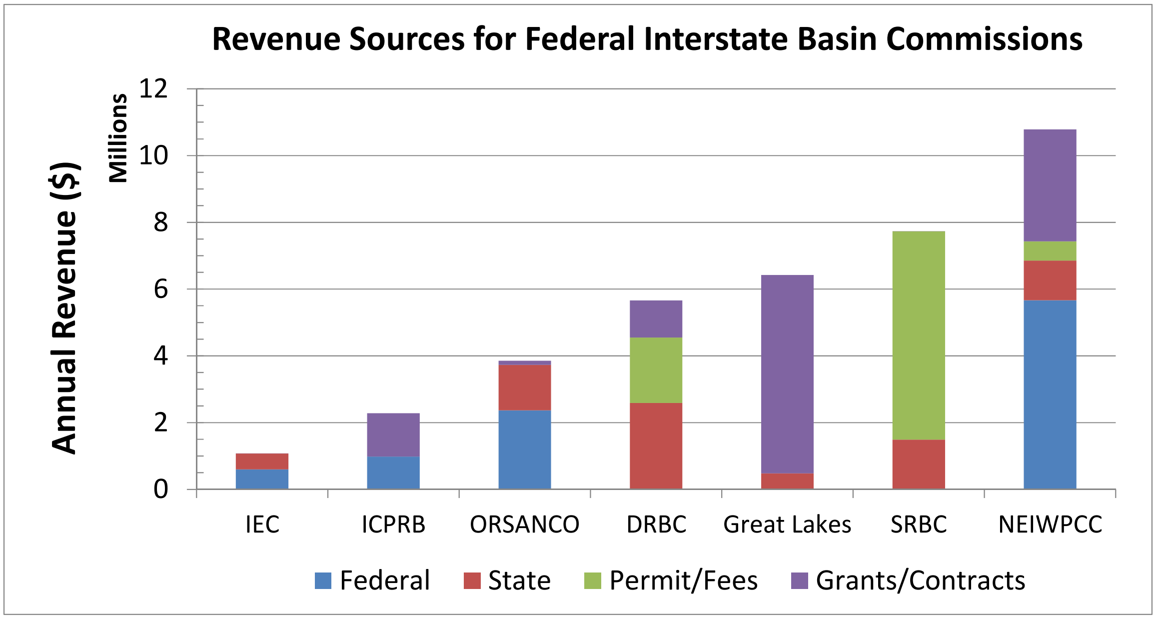


Figure 2.3: Revenue sources for Federal interstate basin commissions

2.7 Discussion and Conclusions

Since the Clean Water Act amendments were approved by Congress during the 1970s, the watershed approach has evolved to balance the economic, environmental, and social interests of the many governments and stakeholders that benefit from a river system. Because watershed and government boundaries often do not coincide, water managers face complex institutional and governance challenges and competition for scarce water supplies. The watershed approach is beneficial because it balances competing uses between upstream and downstream stakeholders, balances institutional objectives at the Federal, State and local levels, utilizes a multidisciplinary science and policy approach, and provides for cost sharing among watershed stakeholders. Watershed management remains challenging because it is difficult for a diverse group of people to agree on a unified course of action, hydrologic boundaries do not usually coincide with political boundaries, and because of the fragmented authority at Federal, state and local levels.

While river basin management (RBM) has long been practiced around the world, it is practiced in only about a dozen rivers in the United States, primarily in the east. River basin authorities financed through user charges and discharge fees are well established in France, Germany, Netherlands, Portugal, Great Britain, Spain, Russia, Mexico, Australia, and New Zealand.

The Federal government has experimented with many forms of interstate river basin management organizations such as single federal administrators, regional authorities, interstate watershed councils, basin interagency committees, and interstate compact commissions. Established by treaties between the Federal government and states, river basin commissions have the most authority of any of the organizations as they are granted compulsory powers through a compact between Federal and state governments, established by government legislation by law, and have permanent office staff (secretariat) available to oversee the basin in the long term.

In the eastern United States, Federal and state governments have formed seven congressionally approved interstate basin compacts. The Interstate Environmental Commission (1936) and New England Interstate Water Pollution Control Commission (1947) are single purpose basin organizations that focus on water pollution while the Interstate Commission for the Potomac River Basin (1940), Susquehanna River Basin Commission (1970), and Great Lakes Commission (2008) are comprehensive multiple purpose agencies with responsibilities in most areas of water management. The Delaware River Basin Commission (1961) is the only Federal-state basin compact with authority in all areas of water supply, water quality, flood mitigation, and watershed management.

The seven eastern basin compacts touch 20 states and cover 19% of the contiguous United States and manage water resources for 109 million people or 1/3 of the nation's population. The DRBC, SRBC, and Great Lakes Commission receive no Federal appropriations whereas the IEC, New England Interstate Commission, and ORSANCO receive over half their funding from Federal sources. The DRBC, ISC, and ORSANCO rely on the states for over a third of funding while the GLC relies on grants and contracts for over 90% of its funding and SRBC relies on permit fees for 80% of its funding. DRBC revenues are spread between 46% state, 35% permit/fees and 20% grants/contracts. It is a noticeable omission that the DRBC as one of the more successful interstate river basin organizations with the most authority has not received a Federal appropriation since 1997.

Chapter 3

GOVERNANCE OF THE DELAWARE RIVER BASIN

3.1 Introduction

This chapter reviews the governance and funding framework in the Delaware Basin in Delaware, New Jersey, New York, and Pennsylvania including the: (1) physical characteristics of the basin such as population, land use, physiography, and hydrology, (2) organization and budget structure of the Delaware River Basin Commission, (3) numerous interstate, Federal, state, local, and nonprofit organizations, (4) water resources appropriations in the basin, and (5) an evaluation of the DRBC budget model and performance as an interstate watershed governance organization.

3.2 Geography of the Basin

The Delaware River is the longest undammed river east of the Mississippi, extending 390 miles from the 2,000 feet high Catskill Mountains in New York to the mouth of the Delaware Bay at Cape May, New Jersey (Figure 3.1). The Delaware Estuary extends 130 miles from the ocean to the head of tide at Trenton. The river is fed by 216 tributaries including the Schuylkill and Lehigh rivers in Pennsylvania and drains 13,539 square miles in Pennsylvania (51% of the basin), New Jersey (23%), New York (18%), and Delaware (8%) and a small sliver of Maryland.

Figure 3.1: The Delaware River Basin

The Delaware Basin covers just 0.4% of the coterminous U.S. yet supplies drinking water to 5% of the population and the first (New York City) and seventh largest (Philadelphia) metropolitan economies in the nation. Over 8.2 million people live in the Delaware Basin and over 16 million people rely on the basin for drinking water including 8 million people in New York City and central New Jersey who live outside the basin. New York City draws half of its drinking water through an 85-mile long aqueduct that flows eastward from three reservoirs in the Catskill headwaters of the Delaware River.

The Delaware Basin contributes over $20 billion in annual economic activity and is responsible for over 500,000 jobs in Delaware, New Jersey, New York, and Pennsylvania (Kauffman 2011). The ecosystem goods and services value in the four basin states exceeds $20 billion annually.

With improved water quality, American shad and striped bass have returned to the Delaware River in numbers not recorded in 100 years (Kauffman et al. 2008). Blue crabs, a multimillion dollar shellfishery, are increasingly abundant in the Delaware Bay as harvests in Delaware have increased from less than a million pounds during the 1960s to about 4 million pounds by 2005. In September 2009 for the first time in fifty years, Delaware fisheries biologists caught a seven-inch juvenile Atlantic sturgeon in the river off Wilmington, evidence that spawning of these prehistoric fish may be occurring in the cleaner river. Over fifty bald eagle pairs returned to the cleaner Delaware Basin, even nesting in South Philadelphia in 2007. Congress has designated 400 river miles in the basin to the national wild and scenic river system.

While the health of the Delaware River has improved, the health of some indicators remains poor. Industrial pollutant impacts from PCBs have declined over twenty five years but are still detected in 84% of fish samples in the basin. Fish consumption advisories due to mercury from power plant emissions remain along 1,000 stream miles. Annual oyster catches have dropped to 100,000 bushels in the bay, down from 700,000 bushels harvested twenty years earlier. The Atlantic sturgeon is endangered, just three fish were caught during a DNREC haul survey in 2011 and one in 2010, down from over 15 fish in 1991 and 1992. The habitat of the native brook trout, the state fish of New Jersey, New York, and Pennsylvania, is eradicated in 15% of the basin. In 2010, American Rivers named the Upper Delaware River as America's Most Endangered River due to proposed Marcellus shale gas drilling in Pennsylvania and New York headwaters.

Physiography: The Delaware Basin is formed by five physiographic provinces, the mountainous Appalachian Plateau north of the Delaware Water Gap, the Valley and Ridge north of Easton, and New England and Piedmont provinces north of the fall line (head of navigation) which runs through Trenton, Philadelphia, and Wilmington (USGS 2004). The flat, sandy Coastal Plain sits south of the fall line along the estuary in South Jersey and Delaware (Figure 3.2).

Land Use: According to the NOAA Coastal Service Center (2006), the Delaware Basin is covered by 14% urban/suburban land, 26% agriculture, 54% forest, and 4% water/wetlands (Table 3.1). Developed land gained 180 mi^2 from 1996 to 2006. Agricultural land declined by 61 mi^2. Forests decreased by 118 mi^2 between 1996 and

2006. Wetlands have lost 8 mi^2 between 1996 and 2006. Land use ranges between 70% forested in the mountainous headwaters of the Catskill and Pocono Mountains to over 20% urban near Philadelphia to over 10% wetlands and over 25% agriculture along Delaware Bay.

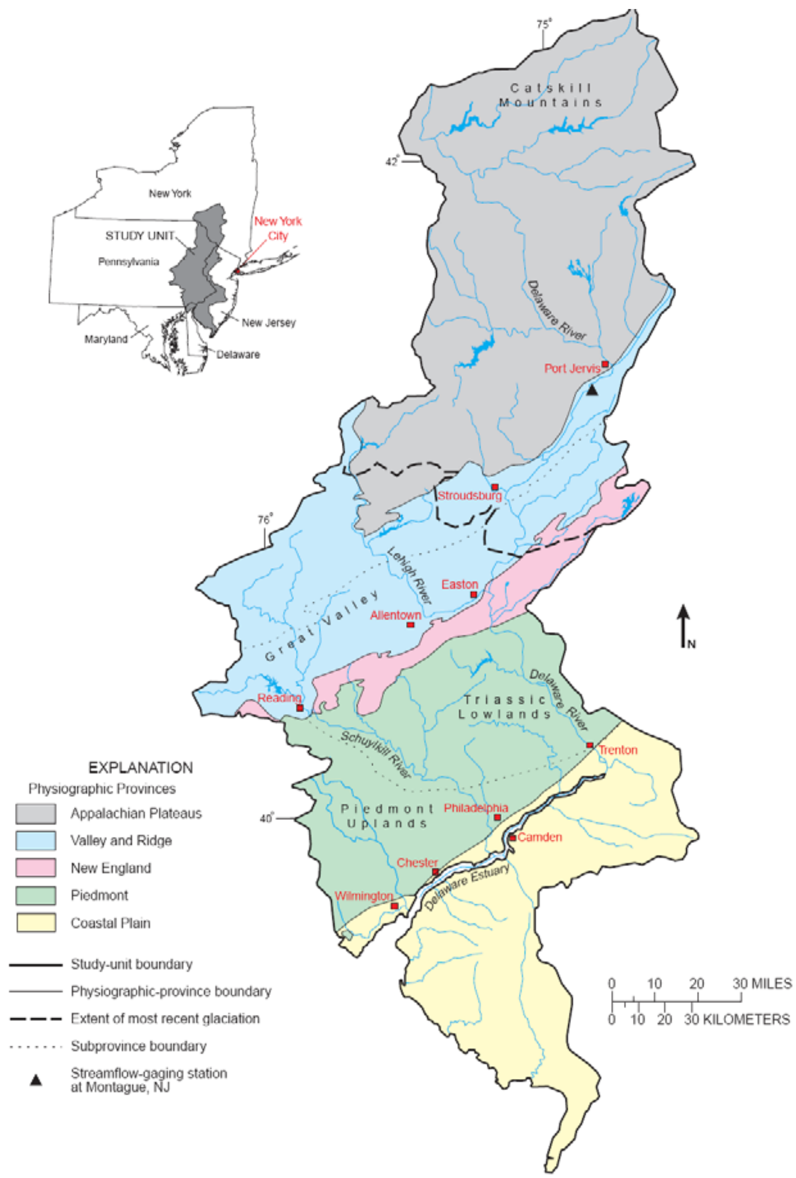


Figure 3.2: Physiographic provinces in the Delaware Basin (USGS 2004)

Table 3.1: Land use in the Delaware Basin

Land Use	1996 NOAA CSC (mi^2)	2006 NOAA CSC (mi^2)
Urban/Suburban	1790	1975
Agriculture	3361	3300
Forest	7093	6975
Water/Wetlands	572	564
	%	**%**
Urban/Suburban	14%	15%
Agriculture	26%	26%
Forest	55%	54%
Water/Wetlands	4%	4%

Population: The U.S. Census (2010) recorded the Delaware Basin population exceeds 8.2 million (Table 3.2 and Figure 3.3) including 704,000 in Delaware (9% of the basin population), 6,000 in Maryland, 1,946,000 in New Jersey (24%), 121,000 in New York (2%), and 5,479,000 in Pennsylvania (66%). If considered as a single jurisdiction, the basin would be the 11th most populous state after North Carolina and New Jersey but ahead of Virginia and Massachusetts. In Delaware, the basin covers 50% of the state yet includes 74% of the First State's population. In New Jersey, the basin covers 40% of the state and includes 22% of the Garden State's population. In New York, the basin covers 5% of the state and includes 0.7% of the Empire State population. The basin in Pennsylvania covers just 14% of the state yet includes 43% of the Keystone State's population. Almost 3.5 million people are employed in the Delaware Basin.

Table 3.2: Land area, population, and employment in the Delaware Basin

State	Area (mi^2)	Population[1] 2010	Employment[2] 2010
Delaware	965	703,963	316,014
Maryland	8	6,339	1,172
New Jersey	2,961	1,945,966	823,294
New York	2,555	121,160	69,858
Pennsylvania	6,280	5,478,577	2,271,317
Total	**12,769**	**8,256,005**	**3,481,655**

1. U.S. Census Bureau 2010. 2. U.S. Bureau of Labor Statistics

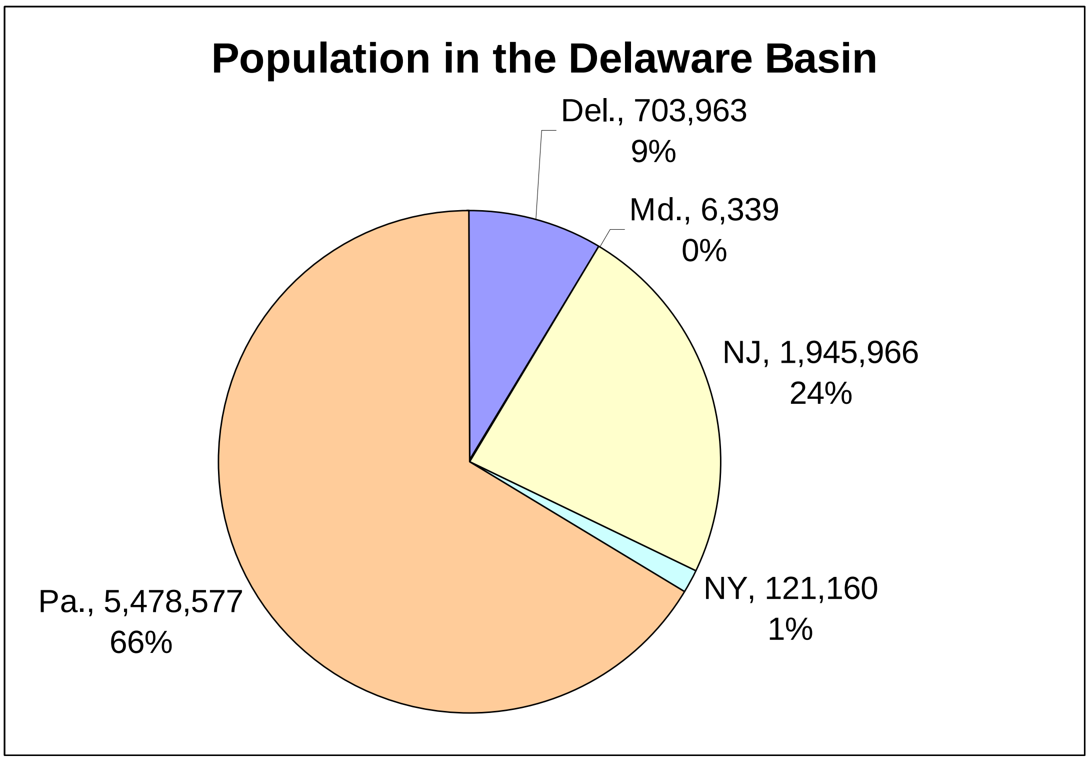


Figure 3.3: Population in the Delaware Basin (U.S. Census Bureau)

Between 2000 and 2010, the basin population increased by almost a half million people or equal to adding the cities of Camden, Easton, Trenton, and Wilmington to the

Delaware Basin (Figure 3.4). Over ten years, the population increased by over 30% in Kent County and Sussex County, Delaware and over 20% in Pike County and Monroe County, Pennsylvania. Philadelphia gained population for the first time in a half century. Eight counties gained over 30,000 people including New Castle and Kent counties, Delaware and Berks, Chester, Montgomery, Monroe, Northampton, and Lehigh counties, Pennsylvania. Several basin counties lost population including Cape May, New Jersey; Ulster and Broome counties, New York; and Schuylkill County, Pennsylvania.

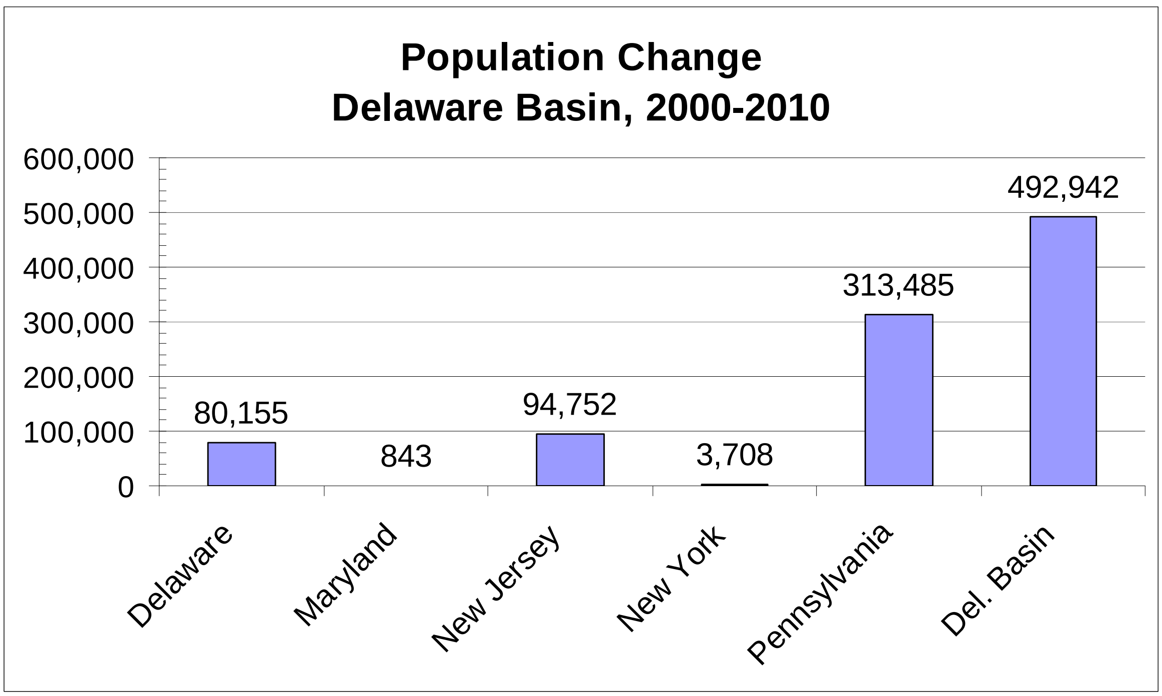


Figure 3.4: Population change in the Delaware Basin, 2000-2010
(U.S. Census Bureau)

Hydrology: The Delaware River flows for 390 miles from its headwaters and is the 56th longest river in the continental U.S. and 17th longest east of the Mississippi River (Table 3.3).

Table 3.3: Longest rivers in the continental United States

Rank	River	Length (mi)	Drainage Area (1,000 mi^2)
1	Missouri-Red Rock	2,540	529.0
2	Mississippi	2,348	1,150.0
3	Rio Grande	1,900	336.0
4	Arkansas	1,459	161.0
5	Colorado	1,450	246.0
43	Susquehanna	444	27.2
56	Delaware	390	13.5
57	Potomac	383	14.7
76	Hudson	317	13.1

The Delaware is a river defined as "a fairly large, flowing body of water whose characteristics are largely determined by the geology, topography, soils, and land use of the watershed" (Patrick 1972). By nutrient classification, the thickly forested Delaware River before settlement by the Europeans over 400 years ago was close to an oligotrophic stream, low in dissolved solids and nutrients and relatively cool. By the 20th century, the tidal Delaware became nearly eutrophic, excessively polluted by organic wastes and rich in dissolved nutrients such as nitrogen. With improved water quality, the Delaware is progressing toward but has not quite become a mesotrophic stream, moderate in nutrients. The Delaware is a soft water river, relatively low in cations such as calcium, magnesium, sodium and potassium. Mean annual flow at the Delaware River at Trenton is 11,901 cfs from the 6,780 mi^2 watershed or 1.75 cfs/mi^2 (Figure 3.5).

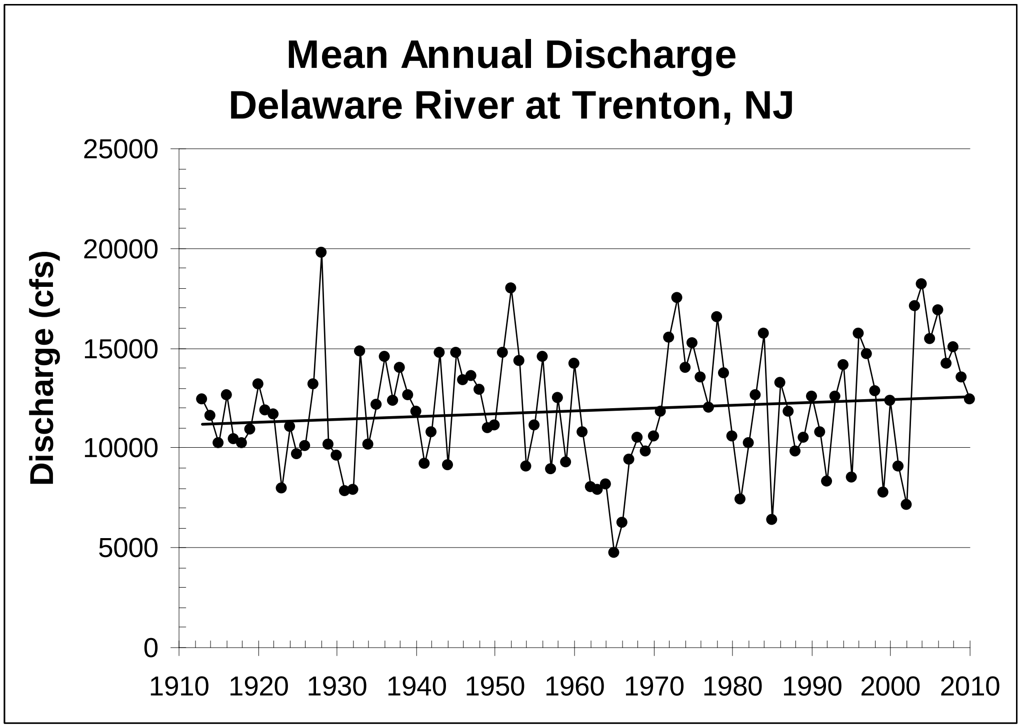


Figure 3.5: Annual discharge along the Delaware River at Trenton, New Jersey

The Delaware River below Trenton is influenced by a diurnal M2 lunar tide (twice per day) with a period of oscillation between high tides of 12 hours, 25 minutes. Due to the Coriolis force from the spinning of the Earth, incoming tides in the Northern Hemisphere flow up and to left or counter clockwise up the New Jersey bayshore and push saltier water to the Delaware bayshore. This counter clockwise motion also pushes pollutant loads from the lower bay rivers in Delaware out toward the ocean and washes pollutants from New Jersey rivers up into the interior of the bay. Tidal flows decrease from 500,000 cfs at the Delaware Memorial Bridge to 50,000 cfs just south of Trenton. According to NOAA, the mean tidal height increases upstream from 5.34 feet near the C&D Canal to 5.99 feet at Philadelphia and 8.18 feet at Trenton.

The freshwater Delaware Estuary extends 45 miles from the head of tide at Trenton to the Schuylkill below Philadelphia (Sharp 2006). The saltwater river and bay stretches 96 miles from Wilmington to the Atlantic Ocean with a salinity range from 0.2 to 30 parts per thousand (Table 3.4). The wide middle and lower bay with salinity from 10 to 30 ppt occupies most of the volume of the estuary. High nutrient loads that flow from urban tributaries near Philadelphia, and rural agricultural streams along the bay are diluted by the large volume of saltwater as the bay widens and salinity increases toward the mouth of the Delaware Bay. Recirculation in the Delaware Estuary occurs once every 8 days with half mixing from freshwater inputs at Trenton, the Schuylkill River, and other tributaries and half from the waters of the Atlantic Ocean through the 11 mile wide bay mouth (Bricker et al. 2007). The estuary is relatively turbid with a light extinction coefficient from 0.3 to 7.0 (Roman et al. 2000).

Table 3.4: Characteristics of the Delaware River Basin
((Roman et al. 2000 and Bricker et al. 2007)

Characteristic	Value
Drainage Area (mi^2)	13,600
Population (2010)	8,200,000
Total River Length (mi)	390
Nontidal River Length (mi)	294
Tidal River Length (mi)	96
Mean Annual Discharge (cfs)	11,901
Bay Mouth Width (mi)	11
Watershed/Estuary Ratio	18
Estuary Recirculation (days)	8
Light Extinction Coefficient	0.3-7.0

3.3 Delaware River Basin Compact Authority

The Delaware River Basin Compact (1961) was signed on November 2, 1961 by President John F. Kennedy, Delaware Governor Elbert Carvel, New Jersey Governor Robert Meyner, New York Governor Nelson Rockefeller, and Pennsylvania Governor David Lawrence. The Compact was approved by Congress as Public Law 87-328 on September 27, 1961. The U.S. House of Representatives passed the pact on June 29, 1961. The U.S. Senate approved the Compact on September 15, 1961. The Compact was signed by the legislatures of New York (March 17, 1961), New Jersey (May 1, 1961), Delaware (May 26, 1961), and Pennsylvania (July 7, 1961).

The DRBC Compact recognized that efficient management of the interstate Delaware Basin rested with authority in a single institution with legal power to collectively allocate water supplies, reduce pollution, and raise funding. The DRBC Compact states:

> Whereas, the President and Congress of the United States and Governors of Delaware, New Jersey, New York, and Pennsylvania signed the Delaware River Basin Compact on November 2, 1961. The water resources of the basin are functionally interrelated, and the uses of these resources are interdependent. A single administrative agency is therefore essential for effective and economical direction, supervision, and coordination of efforts and programs of federal, state, and local governments and of private enterprise. The DRBC shall promote sound practices of watershed management in the basin. Each of the signatory parties to the DRBC reserves the right to levy, assess, and collect fees (i.e. revenue) measured by the withdrawal or diversion of water from the basin for use within the jurisdiction of the respective signatory parties.

The 100-year DRBC Compact oversees water interests of 14 federal, 14 interstate, and 43 state agencies in the watershed. The DRBC Compact is based on watershed boundaries rather than political subdivisions and allows for water management on a cumulative rather than piece-meal basis along the river. With the DRBC Compact came a shift in managing water resources - the creation of a single collaborative agency where each state shares equal responsibility for managing the river and its watershed without regard for political boundaries (Abdalla 2010). The DRBC was the first Federal/state regional water agency united to manage a river basin without regard to political boundaries (Gore 2012). The DRBC Compact creates opportunities for coordination not available in other basins without a regional compact (Warren 2003).

JFK signed the DRBC compact with the Governors in the White House and declared:

Today's formal signing of the Delaware River Basin Compact is a significant event. Its significance lies in the unique character of the Compact and the great hope for comprehensive plans for full and effective development of the Delaware River Valley. The highly industrialized character of the Basin and the heavy population concentrated in the region presents a real challenge to the Commission in its efforts to devise a water resource program suited to the area's needs. We are glad to join with Delaware, New Jersey, New York, and Pennsylvania in this bold venture...

Later in 1969, New York Governor Nelson Rockefeller remarked:

As one of the five signators of the compact creating the commission and the only charter member still surviving, I am deeply mindful of what we set out to achieve originally. We wanted a genuine partnership among the four states that contain the Delaware River Basin and the federal government - a partnership that could carry out true regional development of the basin. We viewed our efforts as a pioneering experiment in creative federalism. Time and time again since its creation, we have seen the commission act as a single, unified agent of the states in successfully handling a variety of water problems…

The DRBC Compact grew from unsuccessful attempts to coordinate river management on an interstate watershed basis (Dellapenna 2010). The Interstate Commission on the Delaware River Basin of 1936 adopted the basin approach but did not make much progress due to limited power. The DRBC evolved from a 1931 legal debate over rights to divert 440 mgd of water to New York City from the Catskill headwaters in the Delaware Basin. The Supreme Court decreed in 1954 that New York had the right to divert 800 mgd of water from the basin provided the City released water from reservoirs to maintain minimum river flows downstream at Montague (1,750 cfs) and Trenton (3,000 cfs) to protect Delaware, New Jersey, and Pennsylvania water rights.

The DRBC governs the basin by equity (one state, one vote) through five commissioners representing the Governors of Delaware, New Jersey, New York, and Pennsylvania and the President of the United States. Each commissioner has one vote of equal power and a majority vote is needed to decide most issues. The DRBC annual budget is approximately $6 million funded by (1) appropriations by the signatory parties (federal government and four states), (2) project review fees, (3) water use charges, and (4) grants. The commission holds public bimonthly meetings, hearings, and advisory committee meetings to discuss and resolve basin project, regulatory, and budget matters.

By signing the DRBC Compact, the Federal government for the first time incorporated the tenets of Federalism to share interstate water management power with the states (Hooper 2010). Federalism, the basis for governance in the U.S. Constitution, is a system where sovereignty is shared between a central authority (Federal government) and political divisions (states). The DRBC utilizes this shared Federal-state power structure to govern the four basin states under the principle of comity. Comity is a model of legal reciprocity where the Federal and state governments extend certain courtesies to each other without demeaning the sovereign laws of each jurisdiction. Comity posits that Federal and state governments will reciprocate the courtesy shown to each other for the common good of the Delaware Basin.

The unique legal structure of the Compact allows the DRBC to coordinate between Federal and state governments and strive to achieve a balance between self-governing by the jurisdictions and shared power to manage the basin. When interstate waters issues are considered, the Federal government or the states may not choose to exert their authority power and leave it up to the DRBC to exercise its regulatory authority at the behest of the commissioners (Warren 2003). Using the watershed approach, the DRBC tries to manage water quality/quantity and ground/surface water issues in an integrated manner which is in contrast to federal and state agencies that may view programs separately within their jurisdiction boundaries from a narrow perspective. The DRBC has long convened stakeholder groups and bimonthly Commission meetings to provide the public with a forum to communicate with high level policymakers who report directly to the President and four governors.

Of the federal-interstate compacts, the DRBC compact grants the most extensive powers with broad authority to engage in comprehensive, basin-wide water resources planning and management and most fully binds the federal government as a party. The DRBC is effective in meeting its compact, such as interstate coordination, settling water allocation disputes, and addressing severe pollution problems in the Delaware Estuary (Featherstone 1999).

However, in federal-state and federal interagency coordination, the DRBC is only partly successful. The DRBC Compact specifies the need for a single representative to coordinate Federal action in the basin. The Federal representative has evolved into an ambassador like role reporting the various and conflicting positions of Federal agencies without resolving them (Featherstone 1999). One of the criticisms of DRBC is that it prefers to operate by consensus which often leads to a “least common denominator solution” (Mandarano et al. 2008).

3.4 Basin Governance

The Delaware River Basin is politically fragmented as the river is the boundary between Delaware, New Jersey, New York, and Pennsylvania (USACOE undated). The DRBC executive director and deputy director manage 48 staff and five divisions at headquarters in West Trenton, New Jersey (Figure 3.6). By Federal/state law, the DRBC Compact formally links the water resources interests of 8.2 million people governed by 4 states, 38 counties, 838 municipalities, eight U.S. Senators, 24 Congressmen, 14 federal agencies, and many basin nonprofits (Table 3.5 and Figures 3.7 and 3.8).

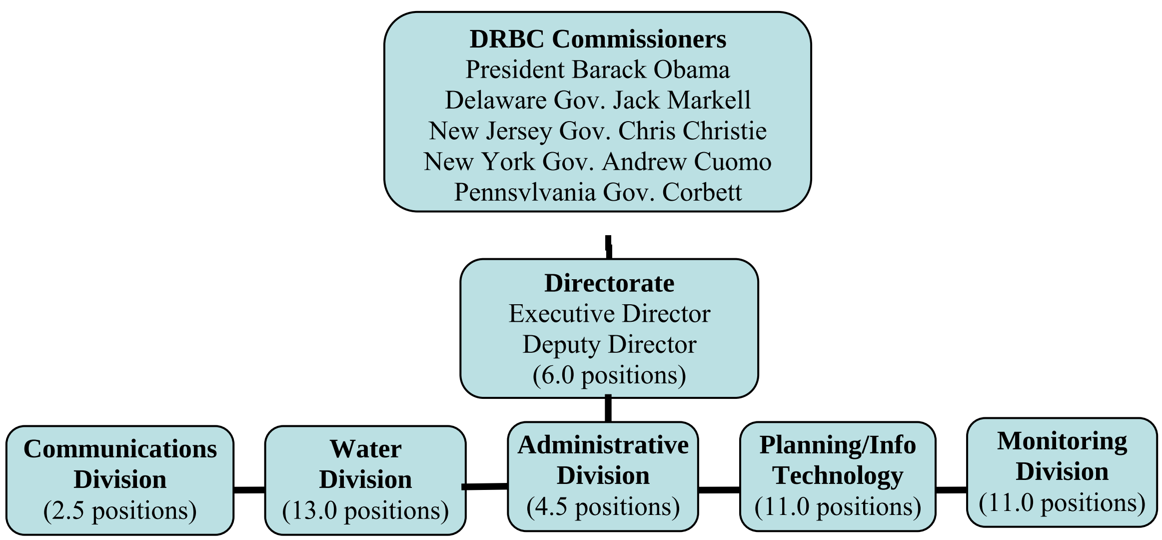


Figure 3.6: Administrative organization of the Delaware River Basin Commission

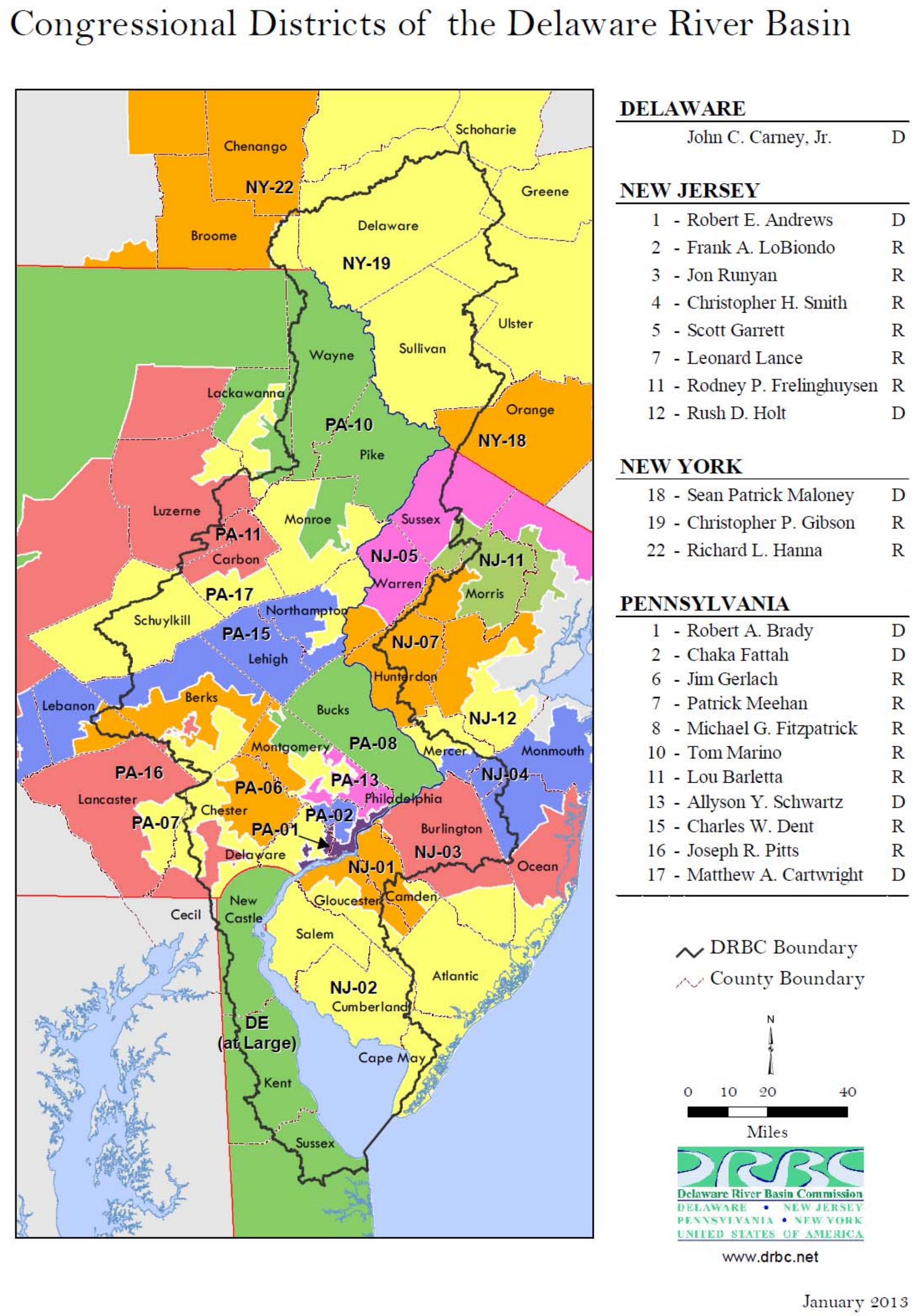


Figure 3.7: Congressional districts within the Delaware Basin (DRBC 2013)

Table 3.5: Water resources governance in the Delaware Basin

Regional	Federal		State/County/Local				Nonprofit
	Executive	**113th Congress**	**Delaware**	**New Jersey**	**New York**	**Pennsylvania**	
DRBC	President Obama	U.S. Senate	Gov. Markell	Gov. Christie	Gov. Cuomo	Gov. Corbett	Delaware Riverkeeper
PDE	Cabinet	Carper (DE)	DNREC	NJDEP	NYSDEC	PADEP	FUDR (Upper Delaware)
DRBA	Agriculture	Coons (DE)				PADCNR	Natural Lands Trust
DVRPC	Forest Service	Lautenberg (NJ)	Counties (3)	Counties (12)	Counties (6)	Counties (17)	Nature Conservancy
WILMAPCO	NRCS	Menendez (NJ)	Kent	Burlington	Broome	Berks	Pinchot Foundation
Pinelands Comm.	FSA	Clinton (NY)	New Castle	Camden	Delaware	Bucks	WRADRB
	Commerce	Schumer (NY)	Sussex	Cape May	Greene	Carbon	
	NMFS	Casey (PA)		Cumberland	Orange	Chester	
	NOAA	Toomey (PA)		Gloucester	Sullivan	Delaware	
	NWS	House		Hunterdon	Ulster	Lackawanna	
	Defense	Carney (DE)		Mercer		Lancaster	
	USACOE	Andrews (NJ-1)		Monmouth		Lebanon	
	Energy	LoBiondo (NJ-2)		Ocean		Lehigh	
	FERC	Runyan (NJ-3)		Salem		Luzerne	
	EPA	Smith (NJ-4)		Sussex		Monroe	
	Homeland Security	Garrett (NJ-5)		Warren		Montgomery	
	Coast Guard	Lance (NJ-7)				Northampton	
	FEMA	Frelinghuysen (NJ-11)				Philadelphia	
	Interior	Holt (NJ-12)				Pike	
	NPS	Maloney (NY-18)				Schuylkill	
	USFWS	Gibson (NY-19)				Wayne	
	USGS	Tonka (NY-20)					
		Hanna (NY-22)	Municipal	Municipal	Municipal	Municipal	
		Brady (PA-1)	Dover	Bridgeton	Callicoon	Allentown	
		Fattah (PA-2)	Newark	Camden	Hancock	Bethlehem	
		Gerlach (PA-6)	Wilmington	Phillipsburg	Port Jervis	Chester	
		Meehan(PA-7)	39 Towns	Trenton	Roscoe	Easton	
		Fitzpatrick (PA-8)		Salem	65 Towns	Philadelphia	
		Marino (PA-10)		183 Towns		Reading	
		Barletta (PA-11)				Stroudsburg	
		Schwartz (PA-13)				360 Towns	
		Dent (PA-15)					
		Pitts (PA-16)	Conservation	Conservation	Conservation	Conservation	
		Cartright (PA-17)	Districts	Districts	Districts	Districts	

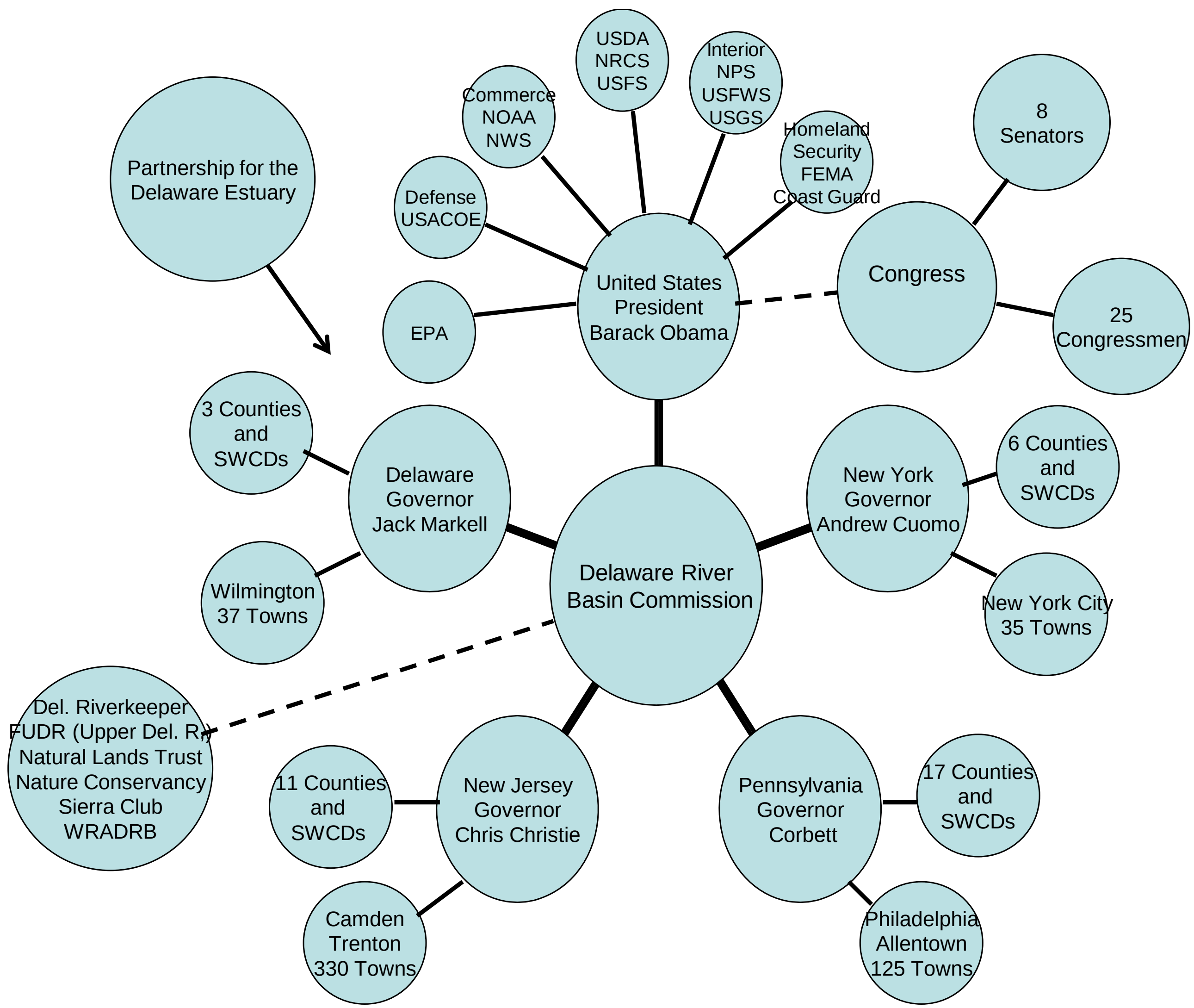


Figure 3.8: Water resources governance in the Delaware Basin

Regional Agencies

The following regional agencies exercise their interests across state and county boundaries within the Delaware Basin.

Partnership for the Delaware Estuary: The mission of the PDE is to implement a 1996 Comprehensive Conservation and Management Plan (CCMP) and collaboratively protect the Delaware Estuary through the Board of Directors and Steering, Executive Implementation, and Science and Technical Advisory Committees (Figure 3.9). In 1988, the Governors of Delaware, New Jersey, and Pennsylvania requested that Congress designate the Delaware Estuary as one of 28 National Estuary Programs under Section 320 of the Clean Water Act. The PDE formed in 1996 and is managed by an executive director with 16 staff at headquarters at Wilmington. The PDE annual budget is $1.8 million including a $714,000 EPA NEP appropriation, state/local funding, grants, and contributions (Table 3.6).

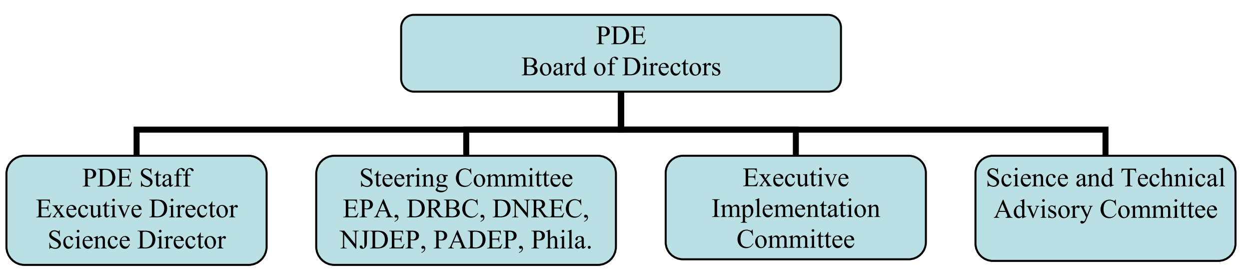


Figure 3.9: Organization of the Partnership for the Delaware Estuary

Table 3.6: Partnership for the Delaware Estuary FY12 Budget

Revenue Source	Budget ($)	%
EPA NEP Sec. 320	714,229	39%
EPA Grants	167,701	9%
DNREC	115,718	6%
NJDEP	28,201	2%
PADEP	172,545	9%
Philadelphia Water Dept.	216,639	12%
Grants/Contributions	422,014	23%
Total	**1,837,047**	**100%**

Delaware River Basin Authority: Created by Compact in 1962 and directed by six commissioners from New Jersey and six from Delaware to provide transportation between the two states and economic development in Delaware and the four southern counties of New Jersey. The DRBA operates the Delaware Memorial Bridge, Cape May-Lewes Ferry and five airports.

Delaware Valley Regional Planning Commission: Funded by USDOT as a Metropolitan Planning Organization responsible for land use, environmental, and transportation planning in Bucks, Chester, Delaware, Montgomery, Philadelphia counties in Pennsylvania and Burlington, Camden, Gloucester and Mercer counties in New Jersey.

Wilmington Area Planning Council: Funded by the USDOT as a Federal Metropolitan Planning Organization (MPO) and is responsible for land use, environmental, and transportation planning in New Castle County, Delaware and Cecil County, Maryland.

New Jersey Pinelands Commission: Protects the natural resources of the Congressionally-designated Pinelands National Reserve on 1.1 million acres in seven counties in South Jersey.

Federal Agencies

In the Delaware Basin, Federal water resources responsibilities are administered by 14 agencies in seven cabinet departments (Figure 3.10) through budgets that exceed $300 million annually.

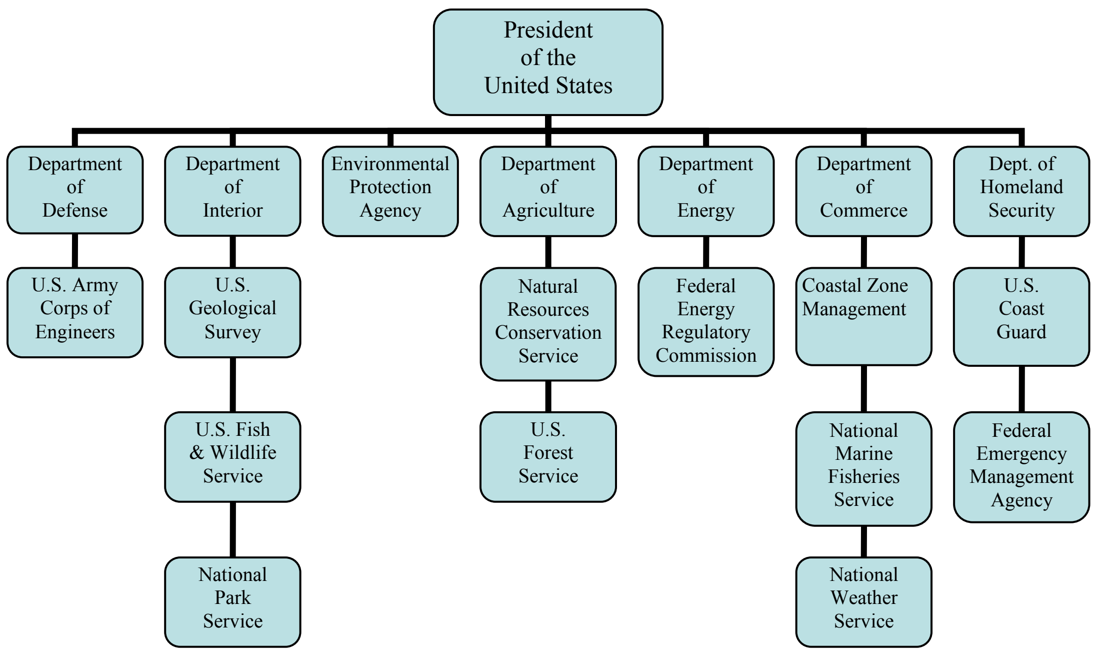


Figure 3.10: Federal water agencies with responsibilities in the Delaware Basin

USDA Natural Resources Conservation Service: Administers a $3 billion annual budget in the U.S. with $33 million spent in the Delaware Basin to reduce nutrient/sediment loads through the Environmental Quality Incentives (EQIP) program, Conservation Technical Assistance (CTA), Wetland Reserve Program (WRP), Conservation Stewardship Program (CSP), Wildlife Habitat Incentive Program (WHIP), Wildlife Restoration Program (WRTP), and Forest Legacy Program (FLP).

USDA Farm Services Agency: The Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP) provides payments to farmers to decrease erosion, restore wildlife habitat, and protect ground and surface water

U.S. Forest Service: The State and Private Forestry Office in Newtown Square, Pennsylvania funds $4 million in Forest Stewardship Program Grants for managing nonfederal forest lands and $2 million in Urban and Community Forestry Program awards. There are no National Forests in the Delaware Basin.

NOAA National Marine Fisheries Service: The Northeast region is responsible for protection of marine and anadromous fish species that inhabit the Delaware Estuary.

NOAA Coastal Zone Management: The Coastal Services Center provides funding to the the coastal management community. In 2010, NOAA issued Federal CZM grants of $1.3 million to Delaware for 381 coastal miles and $2.5 million to New Jersey for 1,792 coastal miles. NOAA designated the Jacques Cousteau National Estuarine Reserve along the Mullica River and Great Bay near Atlantic City and Delaware National Estuarine Reserve along Blackbird Creek in Townsend (1,180 ac) and the St. Jones River in Dover (3,750 ac).

NOAA National Weather Service: The NWS operates a network of meteorological stations from a regional office in Mt. Holly, New Jersey. The Mid-

Atlantic River Forecasting Center in State College, Pennsylvania provides flood warning alerts along Delaware Basin streams and rivers.

U.S. Army Corps of Engineers: The Philadelphia District maintains over 200 miles of navigable waters in the Delaware Basin and is overseeing a $300 million project to deepen the Delaware River ship channel from 40 feet to 45 feet to accommodate super tankers after the widening of the Panama Canal. The Corps of Engineers operates Blue Marsh Reservoir along the Schuylkill River above Reading and F. E. Walter Reservoir in the Lehigh River basin

Federal Energy Regulatory Commission: FERC regulates thermoelectric and hydropower power projects within the Delaware Basin.

Environmental Protection Agency: EPA Region 3 covers Delaware, Pennsylvania, Maryland, Virginia, West Virginia, and the District of Columbia and awards funds to states and local governments through the Clean Water State Revolving Fund under Title VI of the 1987 Clean Water Act ($43 million), Section 319 Nonpoint Source Program ($3.6 million), and Office of Wastewater Management Pollution Control (Section 106) through the Clean Water Act. The 1996 Safe Drinking Water Act Amendments fund Drinking Water State Revolving Fund (DWSRF) loans to public water systems and source water protection programs ($38 million).

U.S. Coast Guard: Oversees the National Pollution Funds Center to pay for remediation costs including $50 million for the 2004 Athos I oil spill clean-up on the Delaware River.

Federal Emergency Management Agency: FEMA oversees flood management, flood insurance mapping, and disaster response. By 2011, the National Flood Insurance Program paid out $235 million in flood loss claims to 2,266 properties in the basin.

U.S. Fish and Wildlife Service: USFWS protects fish and wildlife through the 1973 Endangered Species Act and operates National Wildlife Refuges at Prime Hook and Bombay Hook, Delaware; Cape May, New Jersey; and Forsythe NWR at Philadelphia.

United State Geological Survey: USGS operates over 150 stream gages in the Delaware Basin that monitor water supplies, water quality, droughts, and floods. USGS conducts a national water quality assessment (NAWQA) for the basin. Congress awarded funding to conduct a Delaware Basin Water Use Census as one of just three watersheds in the nation.

National Park Service: The NPS operates the Delaware Water Gap National Recreation Area that protects 5,000 square miles of land and administers over 300 miles of national wild and scenic rivers along the Upper Delaware River in New York and Pennsylvania, White Clay Creek in Delaware and Pennsylvania, and Maurice River in New Jersey. The NPS also awards Federal Land and Water Conservation Funds to preserve state and local park land in the Delaware Basin.

State Agencies

Each of the basin states formed environmental agencies in 1970 during the same year that the President authorized the EPA at the Federal level.

Delaware Department of Natural Resources and Environmental Control: The DNREC was created in 1970 to manage the state's natural resources, protect public health and safety, and provide outdoor recreation. From Dover, DNREC administers an annual budget of $126 million with $63 million funded in the Delaware Basin. In 1971 Delaware Governor Russell Peterson signed the Delaware Coastal Zone Act to protect Delaware's coastal area from heavy industrialization and offshore bulk product transfer facilities.

New Jersey Department of Environmental Protection: Water resources are managed through the Division of Water Quality, Division of Watershed Management, Water Supply Administration, and Office of Water Quality Monitoring and New Jersey Water Quality Planning Act and Water Pollution Control Act. NJDEP has a staff of 2,800 with headquarters in Trenton and a $380 million budget which funds $152 million toward the Delaware Basin.

New York State Department of Environmental Conservation: Founded in 1970, the NYSDEC employs 3,378 people and is responsible for the conservation of natural resources in the State of New York. From Albany, the NYSDEC oversee an annual water resources budget of $186 million with $9 million dedicated toward the Delaware Basin.

Pennsylvania Department of Environmental Protection: With headquarters in Harrisburg, PADEP was established in 1995 to succeed the Department of Natural Resources. The Southeast (Norristown) and Northeast (Wilkes Barre) Regions cover the Delaware Basin. The PADEP budget is $145 million with $20 million allocated to the Delaware Basin

Pennsylvania Department of Conservation and Natural Resources: The PADCNR split from PADEP in 1995 and manages 117 state parks and 20 state forests including Ridley Creek, Marsh Creek, Neshaminy, and Big Pocono State Park in the Delaware Basin. The budget of DCNR is $82 million with $11 million dedicated to the Delaware Basin.

Pennsylvania Fish and Boat Commission: The PAFBC was founded in 1866 to protect, conserve, and enhance the Commonwealth's aquatic resources and provide fishing and boating opportunities. The Commission is an independent Commonwealth agency led by ten Commissioners appointed by the Governor and the Legislature. Annual funding from licenses, fees, fines, and penalties is $54.5 million with $8 million apportioned to the Delaware Basin.

Local Governments

The Delaware Basin includes 838 municipal governments and 38 counties and supplies drinking water to the first and seventh largest cities in the United States.

City of Philadelphia: The City draws up to 180 mgd of drinking water at the Baxter Water Treatment Plant along the Delaware River upstream from the Tacony Palmyra Bridge and the Belmont Plant along the Schuylkill near the Philadelphia Art Museum (Crockett 2007). The PWD operates the 200 mgd Southeast wastewater plant that discharges treated effluent into the Delaware River near the Schuylkill. PWD funds upstream source water protection projects along the Schuylkill and Pennypack Creek. Philadelphia administers a $406 million annual budget with $81 million for water pollution control and water quality monitoring in the Delaware Basin.

City of New York: The NYCDEP draws up to 50% of the City's water supply (800 mgd) from three reservoirs in the Catskill mountain headwaters of the upper Delaware Basin. The City has invested $1.5 billion in reforestation, watershed restoration, and agricultural conservation to improve water quality in the Catskill reservoir watersheds. NYCDEP operates the water supply/wastewater system with an annual budget of $1 billion with about 10% of that applied to watershed projects in the Catskill/Delaware reservoir system.

Counties and Municipalities: In the Delaware Basin, local governments have water resources planning powers granted by state law (Delaware Estuary Program 1996). In Delaware, county governments have land use planning and zoning authority under the 1995 Quality of Life Act. In New Jersey, the county and regional planning enabling act provide for county planning boards that review land use plans for consistency with comprehensive plans. In Pennsylvania, county comprehensive plans are advisory as local rule is applied by towns and boroughs. Towns govern land use through the Municipalities Planning Code in Pennsylvania, Municipal Land Use Law in New Jersey, and Municipal Zoning Regulation Act in Delaware.

Soil and Water Conservation Districts: Local organizations formed by state law to work with USDA to administer agricultural conservation programs under the Federal Farm Bill. Each of the 38 basin counties is served by a county conservation district.

Nonprofit Organizations

Many nonprofit environmental organizations are involved in the Delaware Basin including:

Delaware Riverkeeper: Part of the Delaware Riverkeeper Network. Champions rights of local communities to a free-flowing, clean, and healthy Delaware River and tributary streams.

Friends of the Upper Delaware River: Its mission is to protect, preserve, and enhance the ecosystem and cold-water fishery of the Upper Delaware River System above the Delaware Water Gap for the benefit of local communities, residents, and visitors to the region.

Natural Lands Trust: The Delaware Valley's largest conservation organization manages 40 nature preserves in eastern Pennsylvania and southern New Jersey totaling more than 21,000 acres and holds conservation easements on nearly 20,000 acres.

The Nature Conservancy: The TNC works throughout the Delaware Bayshores Initiatives to protect 16,310 acres at 18 nature preserves. The Delaware River Basin Conservation Initiative is funded by the National Fish and Wildlife Foundation, PDE, and Natural Lands Trust.

Pinchot Foundation: The Common Waters Fund provides financial incentives to owners from a $1 million fund to implement forest stewardship plans, forest practices, and conservation easements to protect the excellent water quality in the upper Delaware River.

Water Resources Association for the Delaware River Basin: The WRADRB was formed in 1959 as a non-partisan advocacy and public information organization to represent industry and public/private utilities to promote sound water resources management within the Delaware Basin.

3.5 Basin Appropriations

Water resources appropriations to the Delaware Basin totaled $740 million in FY12 with $8 million from interstate sources (1%), $285 million in Federal funds (38%), $264 million from the states (36%), and $183 million (25%) from New York City and Philadelphia (Table 3.7 and Figure 3.11). The funding equates to $7.50/capita/month for a basin population of 8.2 million or $3.75/capita/month for the 16 million people who draw drinking water from the basin.

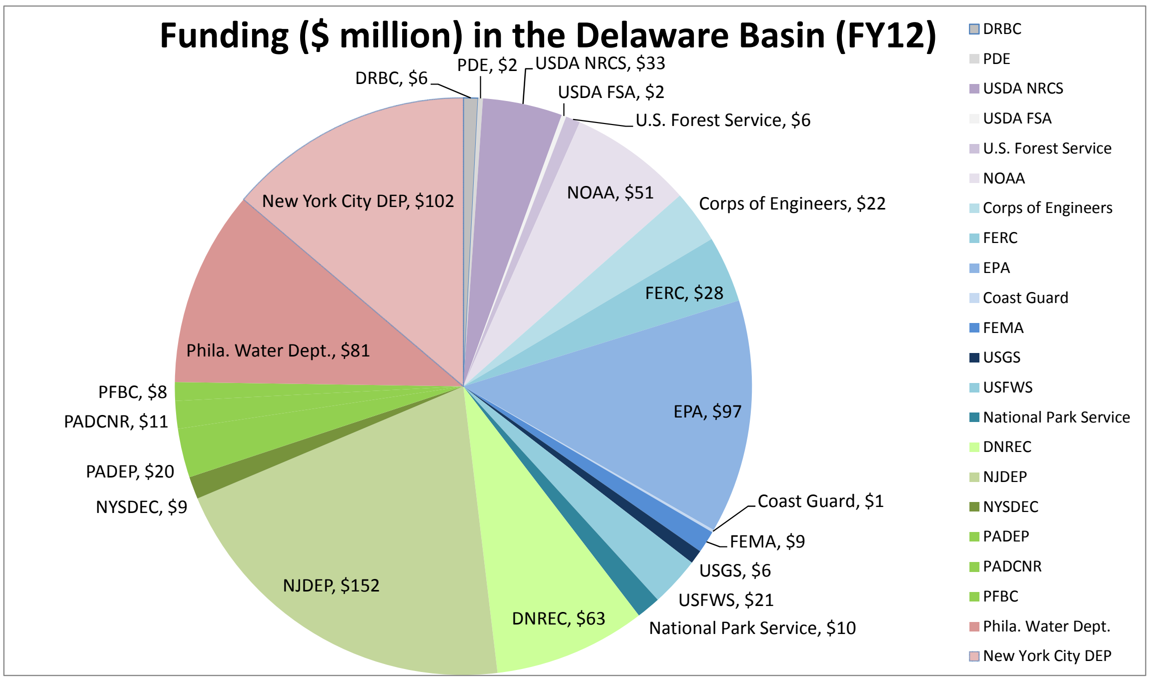


Figure 3.11: Funding apportioned to the Delaware Basin (FY12)

Table 3.7: Water resources funding in the Delaware Basin (FY12)

Jurisdiction	Funding ($ million	Funding (%)
Interstate	**8**	**1%**
Delaware River Basin Commission	6	
Partnership for the Delaware Estuary	2	
Federal	**285**	**38%**
USDA Natural Resources Conservation Service	33	
USDA Farm Services Agency	2	
USDA. Forest Service	6	
NOAA Coastal Zone Management	3	
NOAA National Marine Fisheries Service	27	
NOAA National Weather Service	21	
U.S. Army Corps of Engineers	22	
Federal Energy Regulatory Commission	28	
Environmental Protection Agency	97	
Coast Guard	1	
FEMA	9	
U.S. Geological Survey	6	
Fish and Wildlife Service[1]	21	
National Park Service	10	
State	**264**	**36%**
DNREC	63	
NJDEP	152	
NYSDEC	9	
PADEP	20	
PADCNR	11	
PFBC	8	
Municipal	**183**	**25%**
Philadelphia Water Department[3]	81	
New York City DEP Water Supply System[4]	102	
Total Delaware Basin	**740**	**100%**

3.6 DRBC Budget Structure

The DRBC Compact (1961) specifies that the five Commissioners share in funding the DRBC budget. The FY12 signatory party budget request was $3,303,000 including $893,000 from Pennsylvania (27%), $893,000 from New Jersey (27%), $715,000 from the Federal government (22%), $626,000 from New York (11%), and $447,000 from Delaware (14%). In 1997, Congress passed the Emergency Supplemental Appropriations Act that deleted funding for the Federal commissioner for the DRBC (and SRBC) and appointed the U.S. Army Corps of Engineers as the Federal Commissioner (Gore 2012). Congress moved that river basin management was largely a state concern and compact commissions served states more than the Federal government.

Since Congress has not appropriated funding to DRBC since 1997, actual signatory party funds received were $2,588,000 with 17% from Delaware, 35% from New Jersey, 14 % from New York, and 35% from Pennsylvania (Table 3.8). The DRBC FY12 budget received was $5,787,900 with $2,588,000 from signatory party appropriations (45%), $127,000 from the Southeastern Pennsylvania Groundwater Protected Area fund (2%), $704,000 from grants/permit application fees (12%), $1,958,000 from the water supply use charge fund (34%), and $410,000 from interest bearing accounts (6%).

The 1961 DRBC Compact (Section 13.3) requires that the annual budget "shall be apportioned equitably among the signatory parties by unanimous vote of the commission" but does not include a formula for cost sharing (Gore 2012). At the DRBC's first-ever Commission meeting on December 13, 1961, the Commissioners unanimously adopted Resolution 61-2 that apportioned the signatory party budget between Delaware (4%), New Jersey (24%), New York (24%), Pennsylvania (24%) and the United States (24%).

In 1973, Delaware recommended raising its share (8%) and reallocating the budget for other states and the U.S. at (23%). In 1974, New York reduced its share to 20.7%. Public Administrative Services (1976) outlined alternative cost sharing formulas based on basin area, population, base payment, and fiscal capacity. The PAS report raised the issue of equity including how the signatory parties should balance their appropriations to DRBC while protecting their sovereign interests. In 1977, the DRBC considered the PAS report and approved the cost-share at 8-23-23-23-23 which remains today as the officially approved formula.

Table 3.8: Delaware River Basin Commission FY 2012 Budget

Entity	Budget Requested ($)	%	Budget Received ($)	%	% of Total Budget
Delaware	447,000	14%	447,000	17%	
New Jersey	893,000	27%	893,000	35%	
New York	355,000	11%	355,000	14%	
Pennsylvania	893,000	27%	893,000	35%	
Federal	715,000	22%			
Signatory Parties	**3,303,000**	**100%**	**2,588,000**		**45%**
Groundwater Area	127,000		127,000		2%
Grants and Fees	704,000		704,000		12%
Water Use Fund	1,958,000		1,958,000		34%
Equity Interest	410,900		410,900		7%
Total	**6,502,900**		**5,787,900**		**100%**

In 1981, the Government Accountability Office (GAO) recommended to Congress that each of the DRBC signatory parties contribute 23% of the budget with Delaware contributing 8%. In 1981, New York State sought to reduce its funding asserting that DRBC duplicated State regulatory duties, infringed on intrastate water rights, and was controlled by downstream states that receive most of the benefits. At that time Congress fully funded the Federal share of 40% of the DRBC signatory party budget. In 1988, the DRBC Executive Director sent a letter to the Commissioners that summarized an agreement to revise the allocation as Delaware (12.5%), New Jersey (25%), New York (17.5%), Pennsylvania (25%), and United States (20%). Table 3.9 traces the DRBC appropriations from signatory parties over the last 50 years.

Table 3.9: Proportion of DRBC appropriations from signatory parties

Signatory Party	**1961**	**1973**	**1988**	**2012**
Delaware	4%	8%	12.5%	17%
New Jersey	24%	23%	25%	35%
New York	24%	23%	17.5%	14%
Pennsylvania	24%	23%	25%	35%
Federal	24%	23%	20%	0%
Total				**$2,588,000**

Funding based on equitable apportionment is based on policy decisions by the signatory parties and/or formulas that account for benefits that the river basin commission provides to the governments based on population, land area, property value, personal income, and/or shoreline length. Cost sharing formulas from other river basin commissions provide a basis for comparison and benchmarking (Table 3.10). The Interstate Commission on the Potomac River Basin (ICPRB) budget is set by a base contribution from each state plus a share based on state population in the basin with the Federal contribution equal to the largest state appropriation. The Interstate

Environmental Commission (IEC) budget prorates expenses among New Jersey, New York, and Connecticut on a 45-45-10 basis which is based on the length of shoreline in the IEC jurisdiction. The New England Interstate Water Pollution Control Compact (NEIWPC) budget is based on 50% population and 50% value of real property in each state. The Ohio River Valley Water Sanitation Compact (ORSANCO) budget is based on 50% state area and 50% state population in the basin. Like DRBC, the SRBC compact specifies the budget should be "apportioned equitably among the signatory parties by unanimous vote of the Commission" which the SRBC interprets that each party should pay an equal share.

Table 3.10: River basin commission funding formulas

Basin Commission	Parties	Apportionment
DRBC	US, DE, NJ, NY, PA	Population, Area
ICPRB	PA, WV, VA, MD, DC	Base Rate, Population, Federal = largest state
IEC	NY, MJ, CT	Length of Shoreline
NEIWPCC	ME, NH, VT, MA, RI, CT, NY	50% Population and 50% Property Value
ORSANCO	IL, IN, KY, NY, OH, PA, TN, WV	50% Population and 50% Area
SRBC	US, MD, NY, PA	Equal share by jurisdiction
GLC	IL, ID, MI, MN,NY, OH, PA, WI	Base Rate, Population, Area, 50% Federal

Table 3.11 summarizes the apportionment of funding for river basin organizations in the eastern United States. Like the DRBC, the Great Lakes Commission (GLC) and SRBC received no Federal appropriation whereas the Interstate Environmental Commission (IEC), New England Interstate Water Pollution Control Commission, and Ohio River Valley Sanitary Commission receive over half their funding from Federal

sources. The DRBC, IEC, and ORSANCO rely on the states for over a third of their funding while the Great Lakes Commission relies on grants and contracts for 92% of its funding and the SRBC relies on permit fees for 81% of its funding

Table 3.11: Funding apportionment for river basin organizations

Revenue Sources (FY10)	DRBC ($)	IEC ($)	GLC ($)	NEIWPCC ($)	ORSANCO ($)	SRBC ($)
Federal	0	598,989	0	5,666,003	2,366,352	0
State	2,588,000	471,173	480,000	1,187,000	1,363,500	1,489,200
Permit Fees	1,958,000			577,000		6,244,004
Grants/Contracts	704,000		5,895,108	2,028,421	125,555	4,698
Other	410,000	6,074	48,200	1,328,000		
Total	5,660,000	1,076,236	6,423,308	10,786,424	3,855,407	7,737,902
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Federal	0%	56%	0%	53%	61%	0%
State	46%	44%	7%	11%	35%	19%
Permit Fees	35%	0%	0%	5%	0%	81%
Grants/Contracts	12%	0%	92%	19%	3%	0%
Other	7%	1%	1%	12%	0%	0%
Total	100%	100%	100%	100%	100%	100%

Annual appropriations to the DRBC could be based on equitable formulas that account for land area, population, public water supply, wastewater discharges, and/or pollutant loads in each of the states in the basin (Table 3.12). Based on these criteria, equitable signatory state contributions to the DRBC budget would be Delaware (4-9%), New Jersey (16-24%), New York (4-20%), and Pennsylvania (38-66%). Delaware seems to be contributing more than their fair share as the FY12 appropriation was 17% which is at least double the formula based on area, population, water supply, wastewater, and pollutant load criteria. New Jersey's FY12 appropriation of 35% is higher than the formula based on these factors. New York's FY12 appropriation of 14% is significantly higher than the criteria suggested by population, wastewater, and nitrogen load but less than the amount suggested by land area criteria and far less than calculated based on water supply withdrawals. However, New York State's shortfall based on water supply criteria is more than made up by the contributions from New York City DEP for the Catskill reservoir system. Pennsylvania just about contributes its equitable share based on the water supply criteria (38%) but the Commonwealth's FY12 funding of 35% is less than the criteria based on land area, population, wastewater discharge, and pollutant loads.

Table 3.12: Cost share formulas for signatory state appropriations to DRBC

State	**1973 Authorized**	**2012 Received**	**Land Area (mi^2)**	**Population**	**Water Supply (mgd**	**Wastewater Discharges (mgd)**	**Nitrogen Load (ton/yr)**
Delaware			965	703,963	40	106	1,613
New Jersey			2,961	1,945,966	284	218	10,404
New York			2,555	121,160	800	7	1,944
Pennsylvania			6,280	5,478,577	679	849	36,531
Total			12,769	8,256,005	1,803	1,180	50,525
State	**1973 Authorized (%)**	**2012 Received (%)**	**Land Area (%)**	**Population**	**Water Supply (%)**	**Wastewater Discharges (%)**	**Nitrogen Load (%)**
Delaware	10%	17%	8%	9%	2%	9%	4%
New Jersey	30%	35%	23%	24%	16%	18%	21%
New York	30%	14%	20%	1%	44%	1%	4%
Pennsylvania	30%	35%	49%	66%	38%	72%	72%
Total	100%	100%	100%	100%	100%	100%	100%
State	**1973 Authorized ($)**	**2012 Received ($)**	**Land Area ($)**	**Population[1] ($)**	**Water Supply ($)**	**Wastewater Discharges ($)**	**Nitrogen Load ($)**
Delaware	258,800	439,960	207,040	232,920	51,760	232,920	103,520
New Jersey	776,400	905,800	595,240	621,120	414,080	465,840	543,480
New York	776,400	362,320	517,600	25,880	1,138,720	25,880	103,520
Pennsylvania	776,400	905,800	1,268,120	1,708,080	983,440	1,863,360	1,863,360
Total	2,588,000	2,588,000	2,588,000	2,588,000	2,588,000	2,588,000	2,588,000

Water Code Resolution No. 71-4 authorized DRBC to collect annual revenue to meet project, operation, maintenance, replacement, and administrative costs. The DRBC (2009) utilizes a user pays approach that imposes a minimum charge on water withdrawals of $80/mg for consumptive uses (water lost through evaporation or otherwise not returned to the river) and $0.80/mg for nonconsumptive uses such as power plant intakes where the flow is immediately returned to the river (2010). The advantages of the water use charge are that it: (1) equitably spreads out the costs basin-wide to those who benefit from the water supply, (2) helps to diversify the DRBC budget while government appropriations are falling, and (3) provides a less volatile revenue base for a more financially secure DRBC which is necessary for efficient management of drinking water supplies for16 million people in the four-states.

The DRBC (1961) Compact authorizes the water supply charge by equitable apportionment under a "pooled water concept" which means that the waters of the basin operate as a unit, that ground and surface waters are inter-related, and that water depleted in the basin diminishes the quantity and may affect the quality of freshwater of use at other locations in the basin (DRBC 1978). In 1964, the DRBC passed a resolution that authorized collection of water use revenue to repay the Federal government for reservoir water supply costs in the basin. In 1974, the DRBC adopted a resolution to amend the basin regulations and impose water use charges on diversions or withdrawals of $60 per million gallons for consumptive use and $0.60 per million gallons for nonconsumptive use. The DRBC granted exemptions for agriculture, groundwater, withdrawals in place before the 1961 Compact (entitlements), withdrawals above Montague in the upper basin, and withdrawals below river mile 38 in the Delaware Bay. In 2010 the Commissioners voted to adjust the water supply use charge to $80/mg for consumptive use and $0.80/mg for nonconsumptive use (DRBC 2010).

Water use charge revenue increased from zero in 1975 to $2.92 million by 2011 or 3% per year (Figure 3.12). The fund receives revenues from 366 water users that range from the Mermaid Swim and Golf Club (0.06 mg/yr) to the PSE&G Salem nuclear power plant (1,058,000 mg/yr). In 2011, the power sector (72%) provided the largest contribution followed by industrial (15%) and public water (11%) withdrawals then golf, ski, and irrigation uses (Figure 3.13).

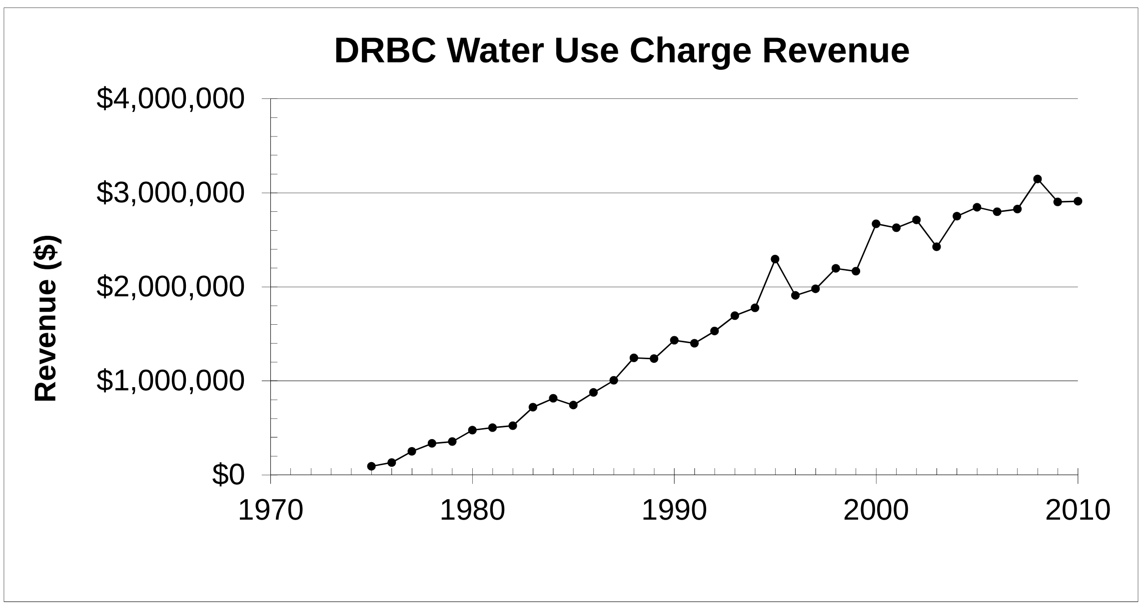


Figure 3.12: DRBC water use charge revenue

The top twenty consumptive water users in the Delaware Basin provide $1.9 million or 65% of the total water use charges (Table 3.13). Five of the largest users (Philadelphia, Trenton, PSE&G Mercer, U.S. Steel Fairless Works, and Aqua Pennsylvania Perkiomen) are exempt from water use charges as these withdrawals were in place prior to the 1961 DRBC Compact and retain an entitlement. If the pre-Compact water users were included in the program, for instance if the firm was sold to another owner, the additional revenue would exceed a half million dollars.

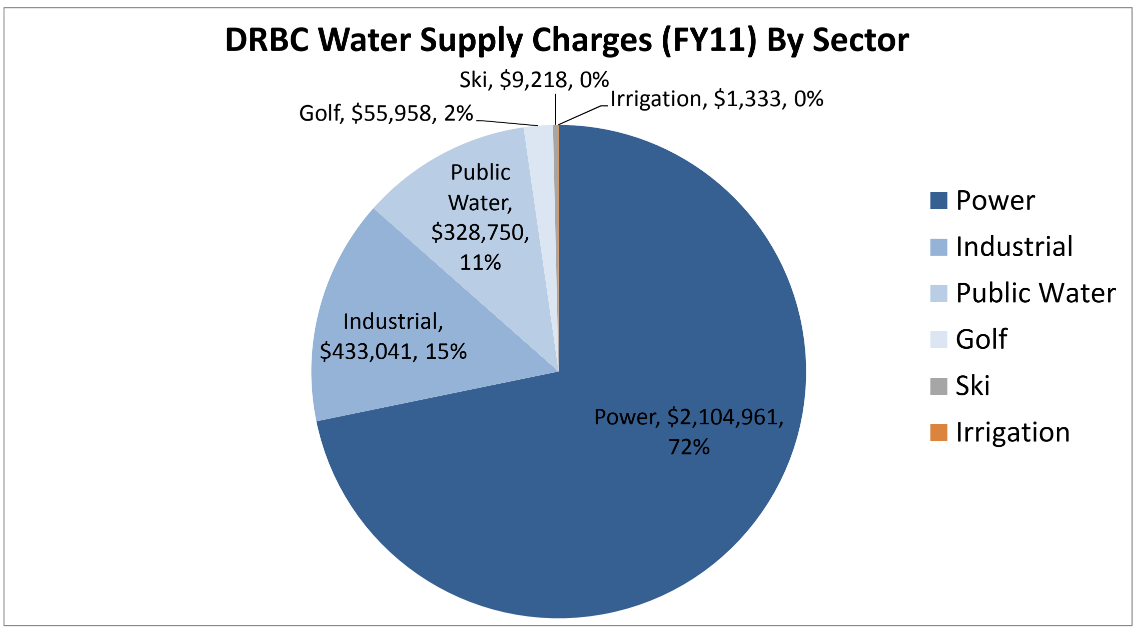


Figure 3.13: DRBC water use charge revenue by sector

Water use charges authorized by SRBC are over three times higher than the DRBC's charges (Table 3.14). In 1985, SRBC authorized a $60/mg consumptive use fee, equal to DRBC at the time, for a water management fund to plan, design, and construct water supply projects. In 1993, SRBC raised the fee to $140/mg. In 2005, using data from a Gannett Fleming study, SRBC adopted a water use charge of $280/mg. In 2010, SRBC raised the fee to $290/mg. The fee is adjusted annually based on the USACOE Civil Works Construction Cost Index. In FY2011, SRBC water use revenues were $3.2 million with $589,000 from Marcellus shale gas drilling fees (Table 3.15).

Table 3.13: Top twenty consumptive water users in the Delaware Basin

Sector	Water User	Withdrawal (mg)	Consumptive (mg)	Nonconsumptive (mg)	Charge ($)
EL	EXELON Limerick	13,734	11,044	2,690	822,211
EL	PSEG Salem	1,058,450	7,351	1,051,099	223,870
PU	Philadelphia Torresdale	55,668	5,567	50,101	
EL	PSEG Hope Creek	20,158	5,395	14,763	70,243
PU	Philadelphia Queen Lane	26,701	2,670	24,031	
IN	SUNOCO Girard Point	5,077	2,315	2,762	161,594
PU	Hazelton City Authority	1,978	1,791	187	46,609
PU	Philadelphia Belmont	17,300	1,730	15,570	
EL	FPL Energy Marcus Hook	1,898	1,521	377	76,624
EL	Fairless Energy	1,546	1,279	267	89,374
PU	NJ American Water	9,577	958	8,619	72,255
PU	Trenton Water	9,352	935	8,417	
EL	PSEG Mercer Gen.	156,624	908	155,716	
PU	United Water Delaware	5,807	871	4,936	1,205
EL	Calpine Corp. Hay Road	863	863	0	35,891
EL	Calpine Corp Bethlehem	975	766	209	52,701
PU	AQUA Pennsylvania Crum	7,248	724	6,524	126
IN	US Steel Fairless	14,030	694	13,336	
EL	PPL Mount Bethel	975	692	283	47,237
EL	EXELON Eddystone	234,184	685	233,499	200,212
	Total	**1,642,145**	**48,759**	**1,593,386**	**1,900,152**

Table 3.14: Water use charges authorized by the DRBC and SRBC in 2013

Water Use	DRBC ($/mil. gal)	SRBC ($/mil gal)
Consumptive Use	80.00	290.00
Nonconsumptive Use	0.80	2.90

Table 3.15: SRBC consumptive water use revenues for FY2011

Project	FY2011
Natural Gas Projects	$588,971
Non-gas Projects	$2,683,089
Total	$3,272,060

3.7 Basin Organization Performance

River basin commissions like the DRBC are effective at interstate watershed management (Abdalla 2010, Mandarano et al. 2008, Wolf 2005, Delli Priscoli and Wolf 2009) because they:

- Provide statutory basis by compact to address problems through consensus building.
- Advocate Federal/state cost sharing to maximize economic/social benefits at least cost.
- Allow sovereign states to manage a common river through goodwill and comity.
- Align decisions by the President and Governors from the highest offices in the land.
- Resolve Federal water disputes in a nonlitigious way outside the Supreme Court.
- Provide forum for dispute resolution with the Commission's neutral, professional staff.
- Hold meetings as systematic monthly forums for stakeholders to address conflicts.

While they have lasted over a half century, interstate river basin commissions remain constrained by inefficiencies that limit the management of water resources due to

(Abdalla 2010, Hooper 2006, Mandarano et al. 2008, Sherk 2005, Delli Priscoli 1976, and Muys 2001):

- Chronic competition for funding with declining Federal/state budget appropriations.
- Potential duplication of the Federal and state government water resources bureaucracy.
- Interstate compacts that operate within fragmented U.S. federalist government system.
- Hesitancy to surrender Federal/state sovereignty to a third party.
- Compacts requiring unanimous agreement among members that often result in watered down decisions.

Hooper (2010) developed a set of basin organization metrics that can be used to evaluate the efficiency of the DRBC based on the following performance indicators.

Decision-making: The use of consensus-based coordination mechanisms between/within basin agencies. Does decision-making occur within a consensual national framework that coordinates across sectors in the basin and is linked vertically to governments with stakeholder access?

The DRBC operates under a national framework established by the 1961 Compact that allows vertical communication by the five Commissioners between the Federal government, the states, and local governments. The DRBC Commissioners meet every other month to consistently and incrementally discuss and approve the business of the basin. Horizontal communication by stakeholders between the public, industry, and nonprofit environmental groups is provided by formal science and technical advisory committees appointed by the DRBC including the Water Use, Drought Management, and Flood Management Committees.

Goals/Objectives: Evidence of integrated water resources management (IWRM) practiced by the river basin commission. Are objectives specified in a river basin management plan?

The five DRBC Commissioners including the Federal representative (Colonel of the U.S. Army Corps of Engineers, Philadelphia District) and Governors of Delaware, New Jersey, New York, and Pennsylvania approved the Water Resources Plan for the Delaware River Basin (DRBC 2004) that outlined goals and objectives for IWRM including Key Result Area 1(Sustainable Use and Supply), Key Result Area 3 (Linking Land and Water Resource Management), and Key Result Area 4 (Institutional Coordination and Cooperation).

Financing: Evidence of financial support, cost sharing, and transparency. Is river basin management financed through cost sharing and linked to national and state priorities?

DRBC revenues are provided by cost sharing between the five signatory governments, project permit fees, and water uses charges. The DRBC budget is approved only after public hearing and public review and by unanimous vote of the Commissioners at the annual budget meeting.

Organizational Design: Use of democratic processes; stable agreements, and organizational structures that fit basin needs and avoid fragmentation. Do stable democratic conventions exist?

The compulsory DRBC Compact adopted a Federalist democratic process for basin management that shares power between the five Commissioners from the executive branch of the Federal government (The President) and states (The Governors).

Role of laws: Do laws protect natural resources relevant to basin management and do laws specify river basin commission functions?

The DRBC operates by force of Federal and state law under a 1961 Compact adopted by Congress and the State legislatures. DRBC water quality regulations are integrated with the Federal Clean Water Act and State water quality regulations.

3.8 Discussion and Conclusions

The Delaware Basin covers just 0.4% of the continental U.S. yet supplies drinking water to over 16 million people (5% of the U.S.) population and the first (New York City) and seventh (Philadelphia) largest metropolitan economies in the nation. The DRBC Compact of 1961 is a novel governance instrument that formed the first Federal/state regional water agency united to manage a river basin without regard to political boundaries. The DRBC compact links together dozens of federal, state, and interstate water agencies and a politically fragmented basin governed by four Governors, eight U.S. Senators, 25 Congressmen, 38 counties, and 838 municipalities.

By signing the DRBC Compact, the Federal government was willing for the first time to employ Federalism principles to share interstate water resources management power with the states. Federalism is a system where sovereignty is shared between a central governing authority (Federal government) and political units (states). The DRBC utilizes a shared power structure under the principle of comity or legal reciprocity where the Federal government and four states extend certain courtesies to each other without demeaning the sovereign laws of each jurisdiction.

DRBC coordinates dozens of regional, Federal, state, local, and nonprofit agencies that fund at least $740 million per year in water resources programs in the Delaware Basin including FY12 appropriations of $8 million from interstate sources (1%), $285 million in Federal funds (38%), $264 million from the four states (36%), and $183 million (25%) from New York City and Philadelphia. The funding amounts to $3.76/capita/month for the 16 million people who draw drinking water from the basin to $7.52/capita/month for the basin population of 8.2 million.

The DRBC manages the basin by equity (one state, one vote) through five commissioners representing the highest offices in the land by the President of the United States and Governors of Delaware, New Jersey, New York, and Pennsylvania. The DRBC executive director and deputy director manage 48 staff organized in five divisions at headquarters in West Trenton, New Jersey. The DRBC annual budget is about $6 million funded by signatory party appropriations by the federal (0%) and state governments (46%), permit and water use fees (35%), and grants/contracts (20%).

The DRBC compact specifies that the five Commissioners (the U.S. and four states) share in funding the Commission's annual budget. The DRBC FY12 budget received was $5,787,900 including signatory party appropriations of $2,588,000 (45%), permit review and water use fees $1,958,000 (35%), and income from grants and contracts of $1,114,000 (20%). The signatory funding of $2,588,000 was appropriated by Delaware (17%), New Jersey (35%), New York (14%), and Pennsylvania (35%).

Based on basin area, population, water supply, wastewater, and pollutant load criteria, equitable formulas for signatory state contributions to the DRBC budget are Delaware (4-9%), New Jersey (16-24%), New York (4-20%), and Pennsylvania (38-66%). Delaware is contributing more than its fair share as the FY12 appropriation was 17% or double the amount suggested by the criteria. New Jersey's appropriation of 35% is higher than the formula based on these factors. New York's appropriation of 14% is higher than the criteria suggested by population, wastewater, and nitrogen load but is less than the level suggested by land area and far less than calculated based on water supplies. However, New York State's shortfall based on water supply criteria is more than made up by the millions of dollars of contributions from New York City DEP to protect the Catskill-Delaware reservoir watersheds. Pennsylvania covers over half the Delaware Basin and its funding of 35% is less than the equitable level suggested by the criteria (38-66%). While low, the Commonwealth's contribution to DRBC is supplemented somewhat by over a hundred million dollars in funding apportioned to the basin by the Philadelphia Water Department.

Among the largest challenges facing the DRBC are the declining government appropriations to fund the administration and operation of this acclaimed river basin governance organization. The DRBC has not received its Federal appropriation of $750,000 since 1997 when Congress zeroed out the funding during decentralization of Federal functions. In recent years, the states of New Jersey, New York, and Pennsylvania have reduced or withheld their contributions to the DRBC.

Answers to these financial challenges may lie in the economic approach to river basin management where the users who benefit from the river bear some of the costs of restoring the basin. Since JFK formed the DRBC in 1961; the Harvard Water Program, National Academy of Sciences, and Interstate Council on Water Policy have touted the Commission as an ideal river basin governance organization with unique authority by Federal/state compact to reduce water pollution using an economic benefit-cost approach.

The DRBC already employs this user pays approach to some degree and since the 1970s has used the authority of the Compact to levy water supply use charges (now at $0.08/1000 gallons) to fund about a quarter to a third of the annual budget. The advantages of the water use charge are that it: (1) equitably spreads out the costs basin-wide to those who consume or benefit from the water supply, (2) helps to diversify the DRBC budget while government appropriations are falling due to the recession, and (3) taps a less volatile revenue base for a more financially secure DRBC which is necessary for optimal management of drinking water supplies for over 16 million people in the four-states.

The top twenty water withdrawals in the Delaware Basin provide about $1.9 million annually or 70% of the total water use charges. Five of the largest water users (Philadelphia, Trenton, PSE&G Mercer, US Steel Fairless Works, and Aqua Pennsylvania) do not pay water supply charges as these withdrawals were in place prior to the DRBC Compact of 1961 and therefore retain an entitlement or exemption from the program. If the pre-Compact entitlement water users were included in the program, for instance if the water utility was sold to another owner, the additional revenue would exceed a half million dollars. In comparison, the DRBC water use charge ($0.08/1000 gal) is less than the fees assessed by the Rhode Island Water Board ($0.10/1000 gal), Susquehanna River Basin Commission ($0.28/1000 gal), and New Jersey Water Supply Authority ($0.97/1000 gal). The DRBC could raise additional revenue by expanding the program to include the exempt water supply user and/or increasing the charge commensurate to the rates set by other basin agencies such as the SRBC and NJWSA.

A more successful Delaware River Basin Commission would adopt the following three changes in the area of budget and finance to more effectively manage the watershed. One, the DRBC should petition the Administration to appoint a different cabinet department such as the EPA or Department of Interior (instead of the U.S. Army Corps of Engineers) as the Federal Commissioner and restore the Federal signatory share of the DRBC budget through a line item appropriation in that Department's annual budget. Two, given that the annual appropriations from New York and Pennsylvania seem to waver from year to year, the DRBC should seek a more formal funding relationship with the two largest local governments and water users that benefit from the basin (New York City and Philadelphia) as their collective budgets in the basin exceed $180 million. And three, since annual signatory member contributions from some states are unpredictable and Federal water funding is in decline, the DRBC should work toward making up the gap through less volatile beneficiary pays approaches such as perhaps an expansion of the existing water supply use charge program that has been in place since the 1970s.

Chapter 4

WATER QUALITY

4.1 Objectives

This chapter reviews the state of water quality along the Delaware River and tributaries including the (1) characteristics of the Delaware River and Estuary system, (2) nutrient cycle and effects on dissolved oxygen in the Delaware Estuary, (3) existing DRBC water quality standards, (4) temporal and spatial water quality trends for dissolved oxygen and nitrogen, and (5) proposed more rigorous DO criteria to sustain year-round anadromous fisheries along the river.

4.2 Introduction

After three decades since the 1970s Clean Water Act amendments, EPA (2004) reported to Congress that 44% of assessed streams and 30% of estuaries in the U.S. were still not clean enough to support fishable and swimmable uses. Approximately 16% of assessed stream miles remain impaired in the Delaware Basin according to biannual surveys conducted by the states for EPA in accordance with Section 305b of the Clean Water Act. The Total Maximum Daily Load (TMDL) amendments authorized by the 1992 Clean Water Act were intended to cap the maximum amount of pollutants that a stream can receive and still meet water quality standards. Top causes of water pollution include bacteria, nitrogen/phosphorus, and organic enrichment/low DO. Largest pollutant sources are agriculture, urban runoff, wastewater, and airborne deposition.

Over the last half century, improved water quality in the Delaware River and its tributaries has coincided with a recovering anadromous fishery. In 1967, the DRBC set a minimum dissolved oxygen water standard of 3.5 mg/l in the tidal river near Philadelphia for spring/fall passage but not year-round propagation of diadromous fish. The 3.5 mg/l DO criteria is occasionally violated during the summer when water temperatures rise close to 30°C (86°C) and DO saturation plunges to less than 50%. The DRBC is considering setting a more protective DO standard along the tidal Delaware River (to 4, 5, or 6 mg/l perhaps) to sustain year-round propagation of anadromous fish such as American shad and Atlantic sturgeon. More stringent DO criteria would also account for atmospheric warming and rising sea levels that could increase water temperatures and salinity in the estuary which in combination would further depress DO saturation.

4.3 The Delaware Estuary

An estuary is a "semi-enclosed coastal waterbody with restricted circulation or coastal marine waters influenced by significant freshwater inflow during part of the year" (Gilbert et al. 2010). Estuaries are classified into four categories (riverine, coastal lagoon, coastal embayment, and fjord) based on tidal, freshwater flow, hydromorphological, and other properties. The tidal Delaware is a riverine estuary which is linear and seasonally turbid except near the C&D Canal and experiences high currents partially mixed with variable salinity. The Delaware is typical of riverine estuaries with a V-shaped channel and salt wedge, moderate surface to volume ratio, high watershed to water area ratio, and high wetland to water area ratio.

Tributary inflow contributes nitrogen from point sources (primarily wastewater discharges) and nonpoint sources (stormwater, agriculture, and airborne). Nitrogen is usually the limiting nutrient in coastal waters like the Delaware Estuary. Nutrient loads and chlorophyll concentrations are high in the Delaware Estuary yet eutrophication susceptibility is moderate because high turbidity inhibits the light that would otherwise stimulate algae blooms. Other factors that affect eutrophication include residence time, stratification, local climate variability, and freshwater input (Gilbert et al. 2010).

Water quality in the Delaware Estuary can be improved by reducing point and nonpoint source nutrient loads and utilizing the assimilative capacity of the river, bay, tributaries, and coastal wetlands. Nutrient loads could be reduced by implementing best management practices (BMP) to control point sources such as wastewater treatment plants and nonpoint sources such as atmospheric deposition, urban/suburban stormwater, and agriculture. Nitrogen in wastewater is composed of nitrate (NO_3^-), nitrite (NO_2^-), and ammonia (NH_3) which may not be effectively removed by conventional secondary treatment. Biological nitrogen removal requires advanced (tertiary) treatment such as nitrification and denitrification (USACE 2001).

Nutrient and dissolved oxygen levels are influenced by the freshwater flow balance in the Delaware Estuary. According to USGS stream gage data, the four largest rivers in the basin (the Delaware, Schuylkill, Lehigh, and Christina) supply 93% of the freshwater flow to the Delaware Estuary (Table 4.1). Over 87% of the freshwater flows into the estuary from above Wilmington which is normally at or just downstream from the freshwater/saltwater interface. Nitrogen loads can be reduced most effectively by prioritizing pollutant control programs in the four large watersheds that contribute most of the freshwater flow to the Delaware Estuary.

Table 4.1: Freshwater inputs to the Delaware Estuary

River/Stream	Gaged Watershed (mi^2)	% of Watershed
Delaware River at Trenton, NJ	5,421	54.4%
Schuylkill River, Pa.	1,893	19.0%
Lehigh River, Pa.	1,359	13.6%
Christina River, Del	565	5.7%
Neshaminy Creek,Pa.	210	2.1%
Rancocas Creek, NJ	140	1.4%
Murderkill River, Del.	104	1.0%
Other	273	2.8%
Total	**9,965**	**100%**

Groundwater can contribute significant nitrogen and phosphorus loads to estuaries. For instance, half of the nonpoint source N load to the Chesapeake Bay flows through groundwater and the other half flows via surface runoff (Phillips and Lindsey 2003). Depending on soil permeability, it could take years for nutrients such as N and P in groundwater to reach the estuary from the source. Since subsurface flow is diffuse, groundwater flow paths to the estuary are often difficult to identify and remediate. Slow travel times and the diffuse nature of groundwater make it expensive to clean up subsurface sources of nitrogen to the estuary.

The Delaware Estuary has estuarine characteristics that differ from the adjacent Chesapeake Bay (Gilbert et al. 2010). While mean depths are comparable, the surface area and volume of the Delaware Estuary are 3 to 4 times smaller than the Chesapeake (Table 4.2). The Delaware Estuary is well flushed by freshwater flow and the ocean as the mean residence time is about 1/10 the recirculation rate of the Chesapeake Bay. The watershed area of the Delaware is more than four times smaller than the Chesapeake while the watershed to surface area ratio is about 50% lower. Nitrogen loads are high in both estuaries, however, the susceptibility of eutrophication is moderate in the Delaware Bay and less severe than the high susceptibility in the Chesapeake Bay.

Table 4.2: Characteristics of the Delaware and Chesapeake estuaries (Gilbert et al. 2010).

Characteristic	Delaware Estuary	Chesapeake Bay
Classification	Riverine	Riverine
Surface Area (mi^2)	796	2,681
Mean Depth (ft)	20	24
Volume (trillion gal)	3.4	13.4
Residence Time (days)	8	90
Watershed (mi^2)	12,783	64,000
Watershed/Surface Area	16	24
Nitrogen Load	High	High
Eutrophic Susceptibility	Moderate	High
Eutrophic Condition	Moderate	High
Future Outlook	Little change	Improved

4.4 Water Quality Standards

The DRBC (2010) classifies the Delaware River and Bay according to five non-tidal and five tidal water quality zones (Figure 4.1) based on these designated uses:

- Water Supply (Agricultural, Industrial, and Public)
- Wildlife, Fish and Aquatic Life
- Recreation (Primary contact swimming/secondary contact boating, fishing, wading)
- Navigation
- Waste Assimilation

Dissolved oxygen criteria vary according to the DRBC water quality zone (Table 4.3). In the freshwater river above Trenton, 24 hour DO criteria vary from 6 mg/l from Narrowsburg to Hancock, New York (7 mg/l for trout production), and 5 mg/l between Narrowsburg and Trenton. In the tidal Delaware below Trenton, 24-hour DO criteria are 5 mg/l from Trenton to RM 108 below Rancocas Creek, 3.5 mg/l down through RM 70 near the Delaware Memorial Bridge, 4.5 mg/l at Liston Point below the C&D Canal (RM 59.5) and then 6 mg/l down to the Atlantic Ocean. For seasonal propagation of resident and anadromous fish, the minimum DO criterion is 6.5 mg/l during the spring and fall in the river from Trenton down to Liston Point.

DRBC (2008, 2010) water quality assessments reported that aquatic life uses (the fishable standard) were supported most of the year but there were seasonal DO excursions below the criteria during the hot summer months in tidal water quality Zones 2, 3, 4, and 5 from Trenton to below Wilmington. In Zone 2 (Trenton to Philadelphia), the DO criteria (5 mg/l) was not met on 12 of 590 days (2% of the time). In Zones 3 and 4 (Philadelphia to DE/PA line), the DO criteria (3.5 mg/l) was not met in 6 of 1,199 days (0.5% of time). In Zone 5 (Wilmington to Liston Point), the DO criteria (3.5 to 5.0 mg/l) was not met in 143 of 1,622 days (8.8% of time). In Zone 6 (Liston Point to Atlantic Ocean, just 6 of 404 observations (1.5%) were below the DO criteria of 5 mg/l.

Table 4.3: Water quality criteria for the Delaware River and Bay (DRBC 2008 and 2010)

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.

Every two years, the states assess water quality of streams and submit to Congress and EPA a list of impaired streams in accordance with Sections 305(b) and 303(d) of the 1977 Clean Water Act, amended 1981 and 1987. The four states assessed 13,855 stream miles in the Delaware Basin and reported to EPA that 2,240 miles (16%) were impaired and did not meet criteria for nutrients, low DO, and bacteria (Table 4.4). Impaired streams were detected along 7% of stream miles in New York, 14% in Pennsylvania, 17% in New Jersey, and 35% in Delaware (Figures 4.2 and 4.3). Note that some non-assessed waters may not attain water quality standards for certain designated uses.

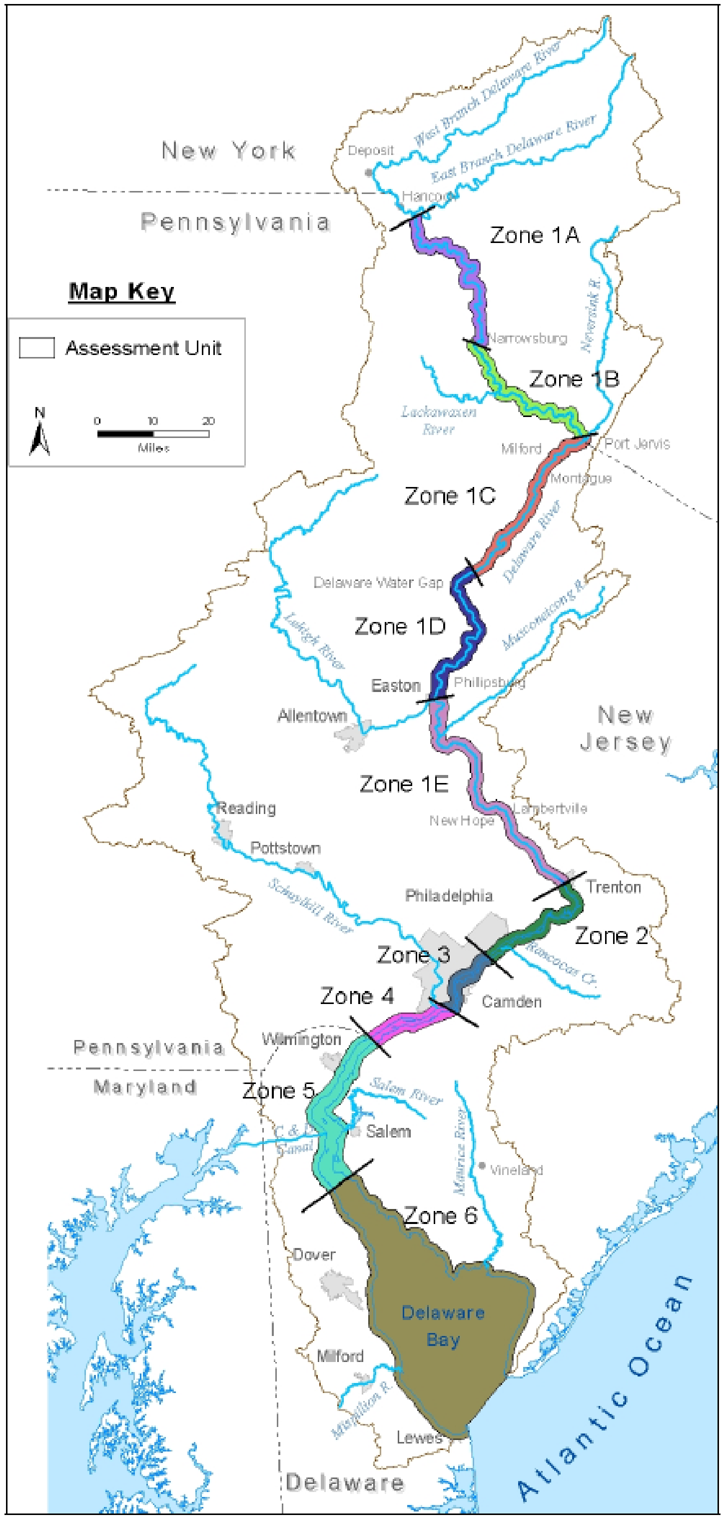


Figure 4.1: Delaware River water quality management zones (DRBC 2010)

Table 4.4: Impaired stream miles in the Delaware Basin

State	Attaining (mi)	Impaired (mi)	Total (mi)
New York	2,454	173	2,627
New Jersey	3,092	618	3,710
Delaware	1,179	642	1,821
Pennsylvania	4,890	807	5,697
Delaware Basin	11,615	2,240	13,855
State	**Attaining (%)**	**Impaired (%)**	**Total (%)**
New York	93%	7%	100%
Pennsylvania	86%	14%	100%
New Jersey	83%	17%	100%
Delaware	65%	35%	100%
Delaware Basin	84%	16%	100%

Sources: DNREC 2006, NJDEP 2006, PADEP 2006, NYSDEC 2004

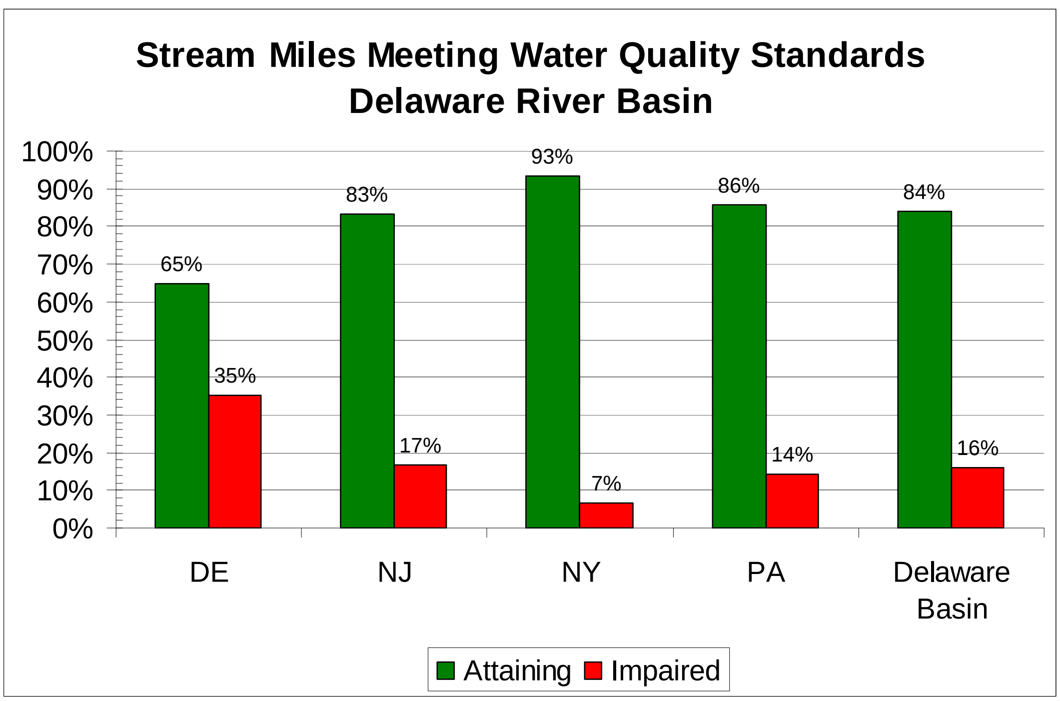


Figure 4.2: Stream miles meeting water quality standards in the Delaware River Basin

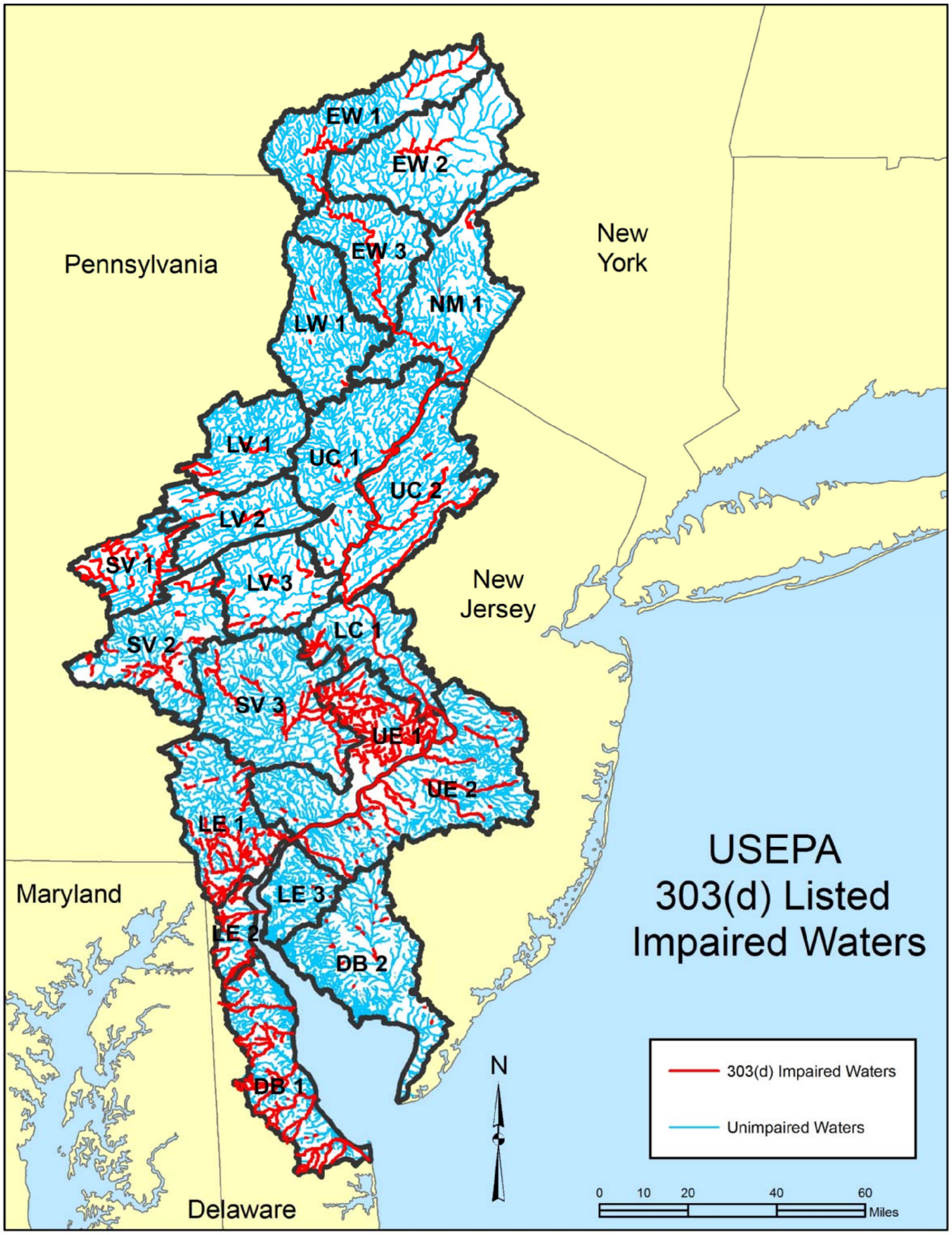


Figure 4.3: Impaired streams in the Delaware Basin (EPA 2008)

4.5 Nitrogen Cycle

Over 65% of U.S. estuaries have moderate to high eutrophic conditions from high nutrient loads that exceed the water body's flushing capacity (Bricker et al. 2007). Eutrophication is often caused by high nitrogen and phosphorus loads that stimulate algae blooms and lead to low DO and loss of aquatic vegetation. The nitrogen/dissolved oxygen cycle includes reaeration from the atmosphere, deoxygenation by carbonaceous substances (CBOD), conversion of ammonia to nitrite and nitrate by nitrification, and nutrient uptake to form chlorophyll-a and algae.

Over the last 30 years, University of Delaware researchers have conducted influential research on the nitrogen cycle and impacts on dissolved oxygen in the Delaware Estuary. Sharp, Culberson, and Church (1982) observed the upper Delaware Estuary above Wilmington had very high nutrient levels while DO was above 35% saturation, yet algal blooms were not prevalent because high suspended sediment caused light limitation and nutrient utilization sustained moderate productivity. Sharp et al. (1984) concluded that nitrates downstream from tributary inputs were impacted by river discharge variability and that nitrates increase with decreasing salinity especially in late summer and fall when river flows are low. Scudlark and Church (1993) concluded 15% of annual dissolved inorganic nitrogen (DIN) deposition to Mid-Atlantic coastal waters were from upwind industrial and urban atmospheric emissions and 40% of the DIN loads were from municipal and industrial wastewater dischargers. Sharp (2006) recorded nitrate and ammonia levels peaked near Philadelphia (120 to 150 km) and declined to low levels downstream near the mouth of the bay (Figure 4.4). Church et al. (2006) sampled

Delaware Estuary marsh sediments in New Jersey and found dissolved nitrogen (nitrate) spiked in the 1960s due to population growth with more fertilizer use and increased wastewater discharges. Successful watershed restoration efforts depend on an understanding of nitrogen uptake, cycling, and processing patterns that vary temporally and spatially based on seasonality, hydrology, the size of the stream network, and level of urbanization in a river system (Claessens et al. 2010).

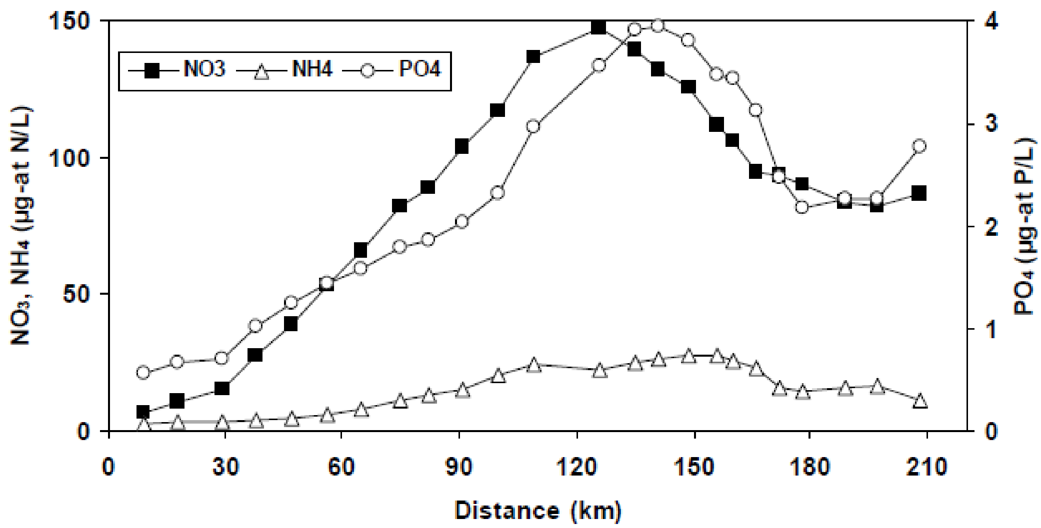


Figure 4.4: Monthly nutrient concentrations in the Delaware Estuary.
(Sharp 2006)

Sharp (2010) reported that ammonium levels declined near Philadelphia since the 1960s but dissolved inorganic nitrogen and nitrate levels remained elevated in the urban estuary between Wilmington and Philadelphia at 100-150 km upstream from the ocean (Figure 4.5).

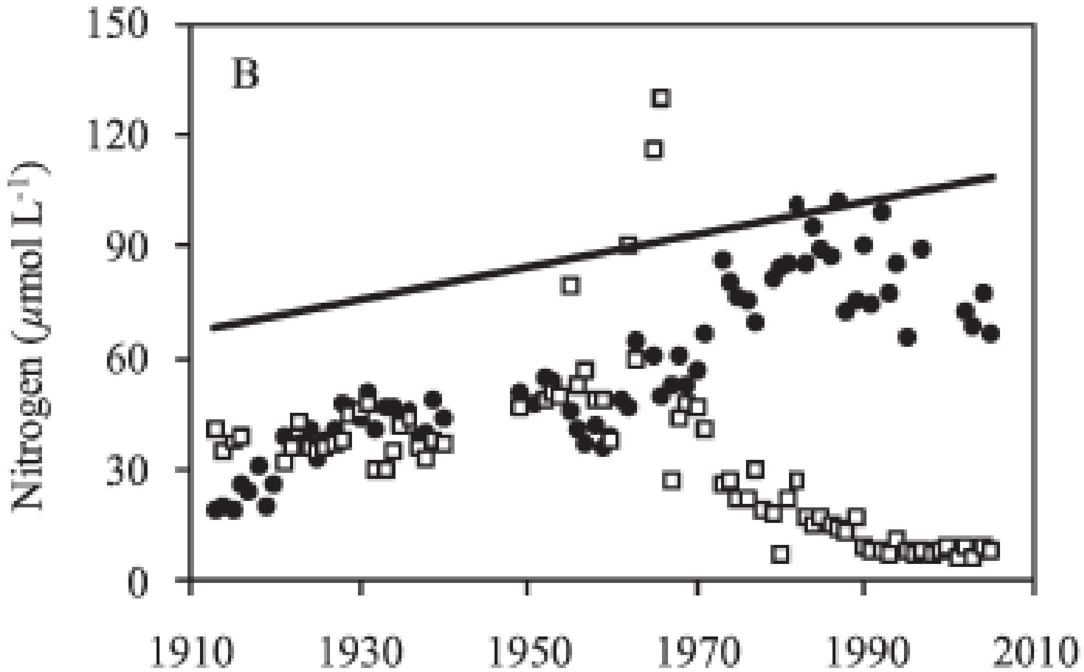


Figure 4.5: Nitrogen concentration in the Delaware River from 1913 through 2005 (Sharp 2010). Nitrate (circles), ammonium (squares), and total dissolved inorganic nitrogen (solid line)

Median nitrogen concentrations were low in the Delaware River at Port Jervis and Callicoon and the Lackawaxen (LW1), Pocono tributaries (UC1), and Musconetcong River (UC2) near the Delaware Water Gap but exceeded 1 mg/l along the Delaware River at Ben Franklin Bridge and tributaries like the Lehigh (LV3), Schuylkill (SV3), and Christina (LE1) rivers (Figure 4.6).

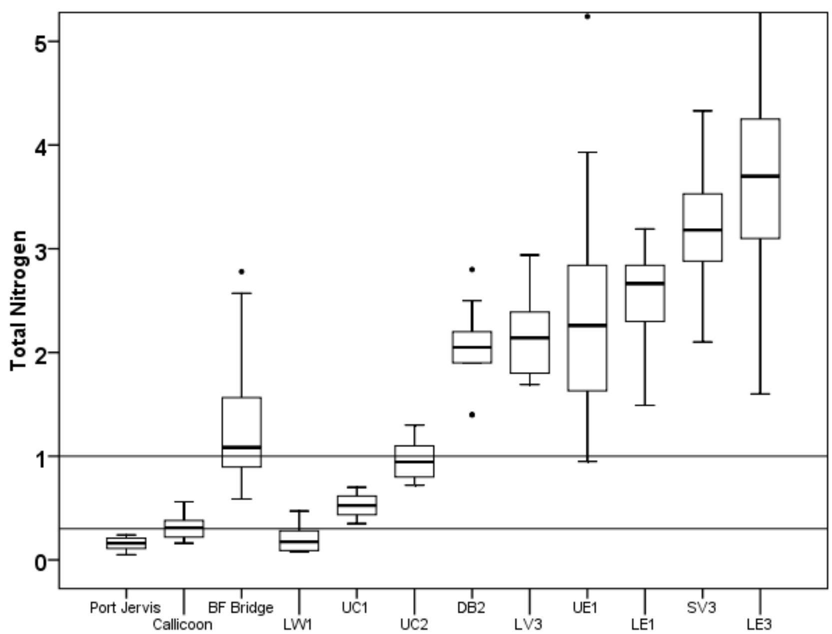


Figure 4.6: Median nitrogen levels in the Delaware Basin from 1990-2005 (Kauffman et al. 2010)

The dissolved oxygen sag along the Delaware between Wilmington and Philadelphia is mostly due to BOD from high nutrient (nitrogen) loads from atmospheric sources such as NOX emissions from marine shipping (Corbett and Koehler 2003) and wastewater, stormwater, and agriculture sources that flow from the Delaware River at Trenton and tributaries such as the Schuylkill, Brandywine/Christina, Piedmont watersheds in Pennsylvania, and inner Coastal Plain streams in New Jersey and Delaware. Excess nitrogen and phosphorus can cause excess algae growth or an algae bloom. The overgrowth of algae consumes oxygen and blocks sunlight from underwater plants. When the algae die, the oxygen in the water is consumed making it difficult for aquatic life to survive.

Despite very high nutrient loading, the Delaware Estuary does not exhibit classic eutrophication symptoms of hypoxia or algal blooms as observed in the Chesapeake Bay. Algal blooms are inhibited by the assimilative capacity of wetlands and the high turbidity and low light in the well-flushed Delaware Estuary. Wetlands that rim the estuary help to assimilate nutrient loads from agriculture along the Delaware and New Jersey bayshore. The Delaware Estuary is one of the more turbid estuaries in the U.S. mainly due to resuspension of clay bottom sediments by tidal currents that blocks about 9/10 of the light, thus limiting photosynthesis and eutrophication that usually occurs with the high nutrient loads. The estuary is recirculated every 8 days by a combination of freshwater tributary inflows from the 13,000 square mile watershed and the replenishing waters of the ocean through the 11 mile wide mouth of the bay. Since the mouth of the Delaware Bay and 25-mile throat from Prime Hook, Del. to Dividing Creek, NJ are wide compared to other estuaries, the Atlantic Ocean contributes to a large tidally induced flushing action that mixes and reoxygenates the estuary, thus limiting algae blooms and fish kills. The only major bloom observed in the Delaware Estuary is the spring bloom, which occurs primarily in the mid estuary. Table 4.5 shows that while the eutrophic condition is moderate and stable and chlorophyll is high and getting worse, algae, toxic blooms, and submerged aquatic vegetation are of low concern in the Delaware Bay (Bricker et al. 2007).

In addition to eutrophication, high nitrogen causes other water quality problems. Dissolved ammonia at levels above 0.2 mg/l may be toxic to fish, especially trout. Nitrates in drinking water above 10 mg/l can reduce the oxygen carrying capacity of blood and cause blue baby syndrome in infants, a potentially dangerous situation. Delaware has not yet set nutrient criteria but sets targets of 0.05 mg/l for total phosphorus and 1 mg/l for total nitrogen.

Table 4.5: Eutrophic condition and symptoms of the Delaware Bay (Bricker et al. 2007)

Parameter	Condition
Overall Eutrophic Condition	● (yellow)
Chlorophyll a	▼ (red)
Macroalgae	● (blue)
Nuisance/Toxic Blooms	● (blue)
Submerged Aquatic Vegetation	

▼ (red) Low, no change ● (blue) Moderate, no change ● (yellow) High, worsened

The most severe impact of high nitrogen loads to the Delaware Estuary is the 50% saturation DO sag that occurs near Philadelphia with high water temperatures during late spring, summer, and early fall that can limit propagation and spawning of anadromous fish such as the American shad, striped bass, and Atlantic and shortnose sturgeon. Biological oxygen demand (BOD) from waste discharges reduces DO in two phases. In the first phase after wastes flow into a nearly fully saturated river, DO levels decline briefly and then recover as organic material is degraded by bacteria. Then in the second phase as wastes move downstream for 5 days (about 15 miles for a river flowing at 0.2 ft/sec), DO declines for a second time as nitrogen converts to nitrite and nitrate by nitrifying bacteria (Thoman 1972).

Nitrogen in municipal wastewater is generally composed of ammonia and organic nitrogen that is not usually removed by conventional secondary treatment. Nitrogen removal involves an advanced or tertiary treatment process through biochemical reactions that convert nitrate to nitrogen gas using bacteria through denitrification.

Nutrient pollution hurts the economy with negative impacts on tourism, commercial fishing, recreation, hunting, real estate, and water treatment which depend on clean water (Stoner 2011). Federal, state and local governments spend billions of dollars per year to prevent and reduce nutrient pollution. The tourism industry loses near a billion dollars annually through losses in fishing and boating activities near waterways with nutrient pollution. Waterfront property values decline near excessive algal blooms. Annual commercial fishing industry losses from nutrient pollution and low DO exceed tens of millions of dollars. Algal blooms at drinking water supplies can increase treatment costs to remove taste and odor problems and disinfection by-products. Algal blooms impacts clear water, recreation, businesses and property values.

In 2011, EPA urged the states to adopt numeric nutrient criteria and make greater progress in reducing nitrogen and phosphorus loads to U.S. waters (Stoner 2010). EPA cited that 50% of U.S. streams have medium to high levels of nitrogen and phosphorus and 78% of coastal waters experience eutrophication. The EPA recommended that states adopt nutrient criteria based on the 25th percentile of ambient water quality data or 75th percentile in reference areas.

Based on 17 years of boat run monitoring studies, the DRBC is considering setting nutrient (nitrogen and ammonia) criteria along the Delaware/River and Bay. The

DRBC is moving towards using existing (ambient) water quality as the nitrogen criteria in the Delaware Estuary. For the Delaware Estuary the approach would be to develop criteria using physical characteristics and natural trophic conditions. If eutrophication emerges even though existing water quality at the 95th percentile is maintained, lower nutrient criteria will be established based on empirical thresholds between nutrient levels and biological responses in the Delaware Estuary.

4.6 Dissolved Oxygen Criteria

Dissolved oxygen is the concentration of oxygen gas in water absorbed from the atmosphere and increased by turbulent wave action plus plant photosynthesis. Waters with DO concentrations of 5.0 mg/l or higher tend to support a well-balanced, healthy biological community. As dissolved oxygen drops below 5.0 mg/l, aquatic life is put under stress. Oxygen levels that remain below 1 to 2 mg/l for a few hours can kill many fish. Minimum DO levels needed for fish spawning and propagation range from 4 to 5 mg/l for warm water species (smallmouth bass, white perch) to 6 mg/l for anadromous species (American shad) and 7 mg/l for cold water species (brook trout).

Dissolved oxygen levels in the Delaware Estuary vary daily and seasonally depending on water temperature, sunlight, wind conditions, and pollutant loads (Gilbert et al. 2010). During fall through spring, the estuary is cold and DO saturation is high. During hot summers, DO may decline below 3.5 mg/l (50% saturation) between Wilmington and Philadelphia as water temperatures approach 30° C. In the mid-bay below the C&D Canal, the water is often supersaturated with DO, even during the summer, by reaeration from winds and current mixing. DO levels are diurnal, peaking during the day in late afternoon and declining during the night just before dawn. DO levels are depleted by biochemical oxygen demand (CBOD) by wastewater discharges, anoxia caused by decaying algae from over nitrification from agriculture and urban sources, and oxidation of ammonia.

During the 1960s, a few years before the birth of EPA in 1970 and Congress passed the 1970s Clean Water Act amendments, the DRBC was one of the first organizations in the U.S. to establish water quality standards on a watershed basis (Albert 1988). In 1967 after the Federal Water Pollution Control Administration completed a benefit-cost analysis of waste load abatement options, the DRBC set minimum DO criteria at 3.5 mg/l during the summer in tidal river Zones 3, 4, and 5 between Philadelphia and Wilmington to allow for year-round maintenance, but not propagation, of resident fish and aquatic life and 6.5 mg/l during the spring/fall for seasonal passage of anadromous fish such as shad. In 1968, the DRBC set waste load allocations for municipal and industrial dischargers that: (1) delineated water quality zones based on river reach, (2) required 85% to 90% removal of biochemical oxygen demand (BOD), and (3) allocated millions of dollars of Federal Clean Water Act grants for secondary wastewater treatment plant upgrades. Years later, the Delaware River Fish and Wildlife Cooperative (1982) recommended that the DRBC adopt DO criteria higher than 3.5 mg/l in Zones 3 and 4 as fisheries biologists considered this standard inadequate for year-round propagation and spawning of American shad.

In 1968, the DRBC conducted an analysis (Figure 4.7) for the Delaware Estuary between Trenton and Liston Point that compared the summer minimum daily average DO profile (dashed line) with proposed minimum daily average stream criteria (thick black line) and future DO levels anticipated by DRBC water quality standards and waste load allocations (thin black line). During the summer of 1968, the Delaware River between Philadelphia (mile 100) and Wilmington (mile 75) varied from anoxic to hypoxic as DO levels were at or near zero. In 1968, the DRBC anticipated (successfully as it turns out now) that if proposed minimum daily average criteria were implemented (thick line), the waste load abatement plan would remove 85% to 90% of carbonaceous BOD and eventually boost DO from near zero (dashed line) to 4 mg/l in the future at Philadelphia (thin line). Based on this modeling analysis and an economic study, the DRBC set minimum DO criteria at 3.5 mg/l (24 hour mean) as the fishable water quality standard which is less than 50% saturation when July water temperatures reach 30° C. The 1968 DRBC waste load allocations coupled with cleanup actions prompted later by EPA and the states under the 1972/1977 Clean Water Act amendments were indeed successful. By 2010, DO levels in the Delaware River at Ben Franklin Bridge mostly exceed 3.5 mg/l year round except excursions below the criteria during the hot summer months of June through August.

While the upper Delaware Estuary is a highly urbanized waterway, it has experienced remarkable water quality improvements from recent municipal sewage treatment upgrades (Sharp et al. 2009). After reconstructing a century-long DO record, Sharp (2010) concluded the Delaware Estuary has experienced one of the most dramatic improvements in water quality of any river in the world (Figure 4.8).

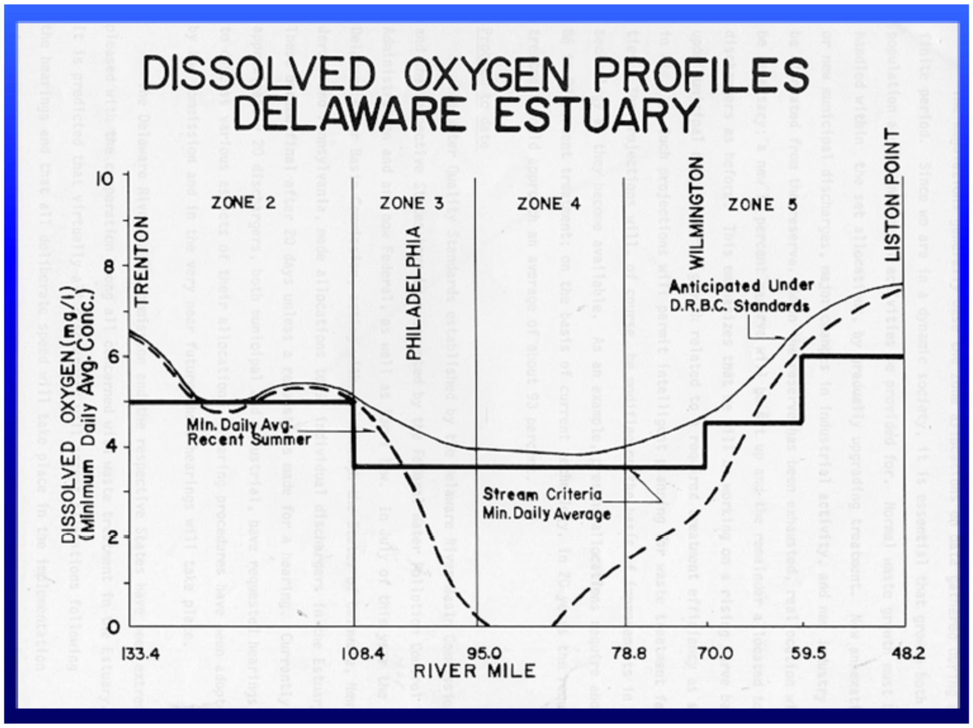


Figure 4.7: DRBC dissolved oxygen criteria along the Delaware Estuary in 1968.

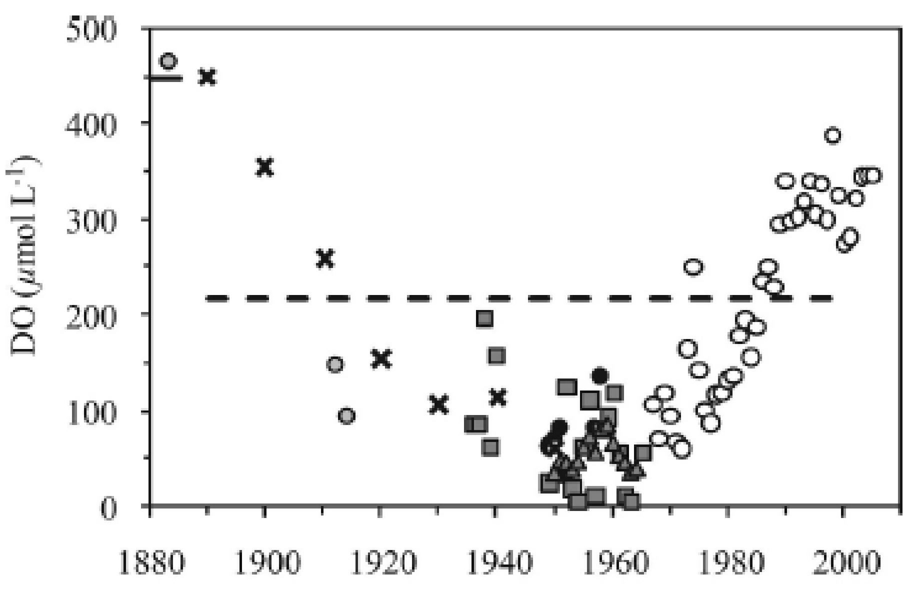


Figure 4.8: Dissolved oxygen in the Delaware River near Philadelphia, 1880-present (Sharp 2010)

The Delaware has a long history of nutrient pollution but DO levels in the river and upper bay have recovered considerably in the last two decades (Bain et al. 2010). Since 1970, the DRBC and DNREC have conducted monthly boat run surveys from Cape Henlopen to Trenton that indicate summer DO levels have improved since the 1960s along the Delaware Estuary between Wilmington (RM 70) and Philadelphia (RM 100). Box and whisker plots show improvement at Philadelphia during July, typically the warmest month when DO levels are at seasonal lows (Figure 4.9). Most readings now exceed the 3.5 mg/l standard, however, a noticeable decline in DO has occurred since the turn of the 21st century (a convex effect), which may indicate a troubling reversal from early successes of the 1970s, 1980s, and 1990s.

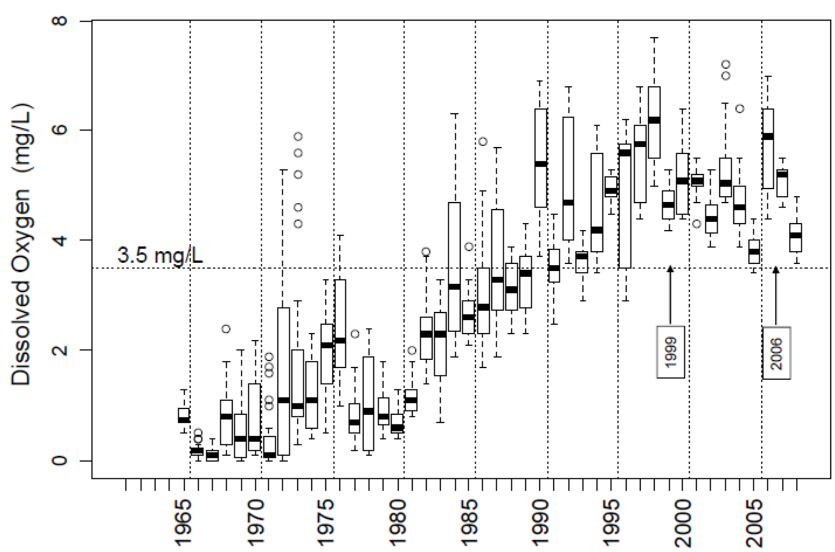


Figure 4.9: July dissolved oxygen levels along Delaware River at Ben Franklin Bridge (USGS and DRBC)

Since the 1960s, the USGS has operated continuous, 30 minute interval water quality monitoring gages at the Ben Franklin Bridge in Philadelphia that indicate the river was anoxic to hypoxic during the 1960s (Figure 4.10). By 2010, summer DO levels have improved markedly from near zero during the 1960s to mostly above the 3.5 mg/l water quality standard. Except for occasional violations during the summer, DO mostly meet the DRBC 24-hour criteria of 3.5 mg/l at Ben Franklin Bridge. At Ben Franklin Bridge, less than 0.5% of readings since 2000 did not meet the 3.5 mg/l criteria, primarily during June through August with warm water temperatures.

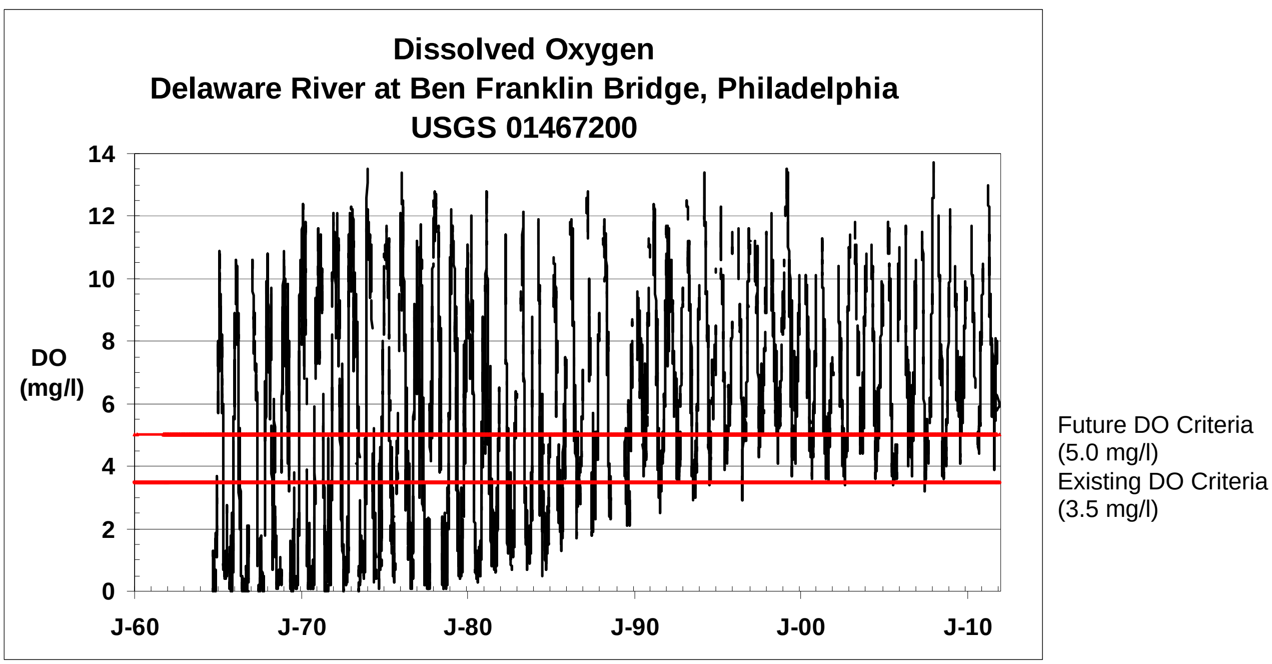


Figure 4.10: Daily dissolved oxygen at Ben Franklin Bridge along Delaware River

Low oxygen saturation in the river is due to pollution and oxygen demanding constituents from wastewater (point source) and stormwater (nonpoint) discharges

(Sildorf and Fikslin 2010). Since 1970, the DRBC has conducted monthly boat run surveys from March through November along 130 miles of the Delaware Estuary from Cape Henlopen to Trenton. Figure 4.11 depicts improved summer dissolved oxygen levels since the 1960s along the Delaware Estuary (DRBC 2004). Summer DO saturation levels in the tidal Delaware are high (near 100%) throughout the year at Trenton and decline to 80% during the late summer at Delran, NJ. A noticeable DO saturation sag (near 50%) occurs between Philadelphia and Chester during July through September. DO saturation returns to 80% at Reedy Island which is downstream from the urban centers and closer to the tidal mixing of the Atlantic Ocean.

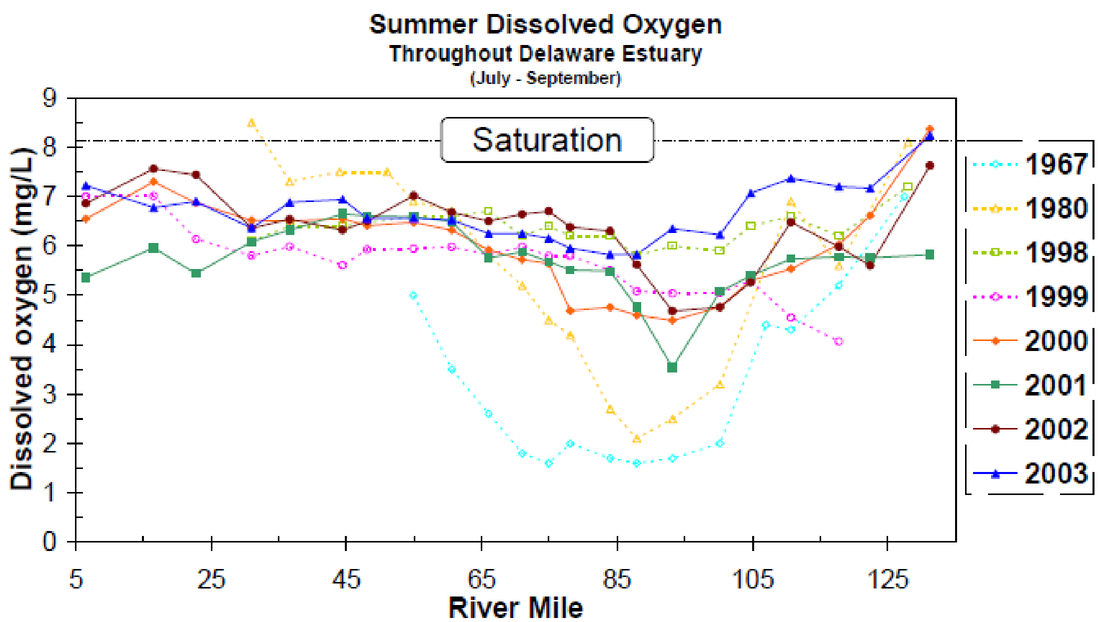


Figure 4.11: Summer dissolved oxygen in the Delaware Estuary (DRBC 2004). Wilmington = RM 70. Philadelphia = RM 100

Median dissolved oxygen levels are high in the Delaware River and tributaries above Trenton and low in the tidal river below Trenton (Figure 4.12). Stations that comfortably exceed a DO standard of 6 mg/l include the main stem at Trenton, Port Jervis and Callicoon and large tributaries such as the Lehigh (LV) and Schuylkill (SV) rivers. Stations along the Delaware River at Ben Franklin Bridge and Delaware Coastal Plain tributaries to the Delaware Bay (DB1) have low DO levels that approach or decline below the standard (Kauffman et al. 2010).

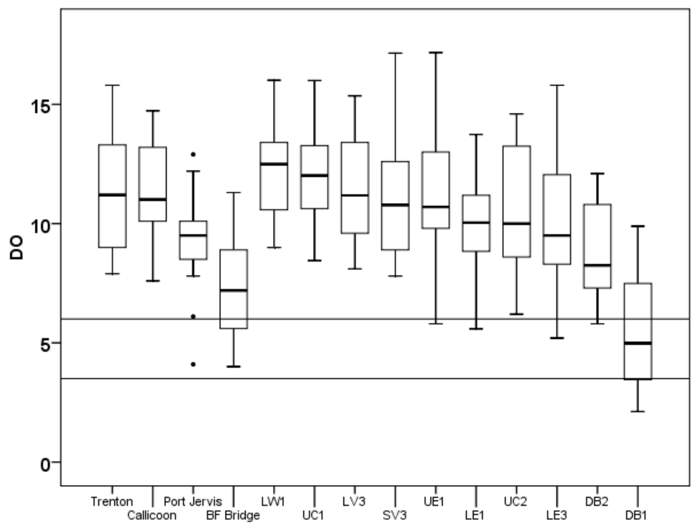


Figure 4.12: Median dissolved oxygen levels in the Delaware Basin from 1990-2005. (Kauffman et al. 2010)

4.7 Future DO Criteria

The DRBC is considering setting more stringent DO standards in Zones 3, 4, and 5 along the tidal Delaware River from Philadelphia to Wilmington to at least 4, 5, or 6 mg/l to provide for year-round propagation of anadromous fish because the existing DO standard of 3.5 mg/l does not yet protect the "highest attainable use". The DNREC has discussed the need to consider more stringent DO criteria in the tidal Delaware to support year-round (not just seasonal spawning and migration) propagation of domestic and anadromous fish (Schneider 2007). A more stringent dissolved oxygen standard may be necessary as the DRBC and scientists from the Partnership from the Delaware Estuary are concerned that continued atmospheric warming may increase river temperatures and accelerate upstream movement of the salt front due to sea level rise as warmer, saltier water reduces DO saturation (Silldorf and Fikslin 2010).

Fish abundance surveys indicate anadromous fish have returned to spawn in the Delaware River. With improved water quality, striped bass are again spawning in the Delaware and the American shad run is recovering (Figure 4.13). A juvenile 7-inch Atlantic sturgeon was caught off Wilmington in 2009 by DNREC fisheries biologists, the first evidence of spawning by the giant fish in 50 years. On February 1, 2012, the NOAA Fisheries Service listed the Atlantic sturgeon as a Federally Endangered Species in the New York Bight which includes the Delaware River.

The literature indicates the existing DO standard of 3.5 mg/l is not adequate to sustain year-round abundance of anadromous fish such as the sturgeon in the Delaware River. Secor and Gunderson (1998) found juvenile Atlantic sturgeon may suffer 50% to 100% mortality at 25° C (77° F) when DO is 3.5 mg/l. Campbell and Goodman (2004) concluded that juvenile shortnose sturgeon are prone to 50% mortality when DO declines below 3.0 mg/l at 25° C.

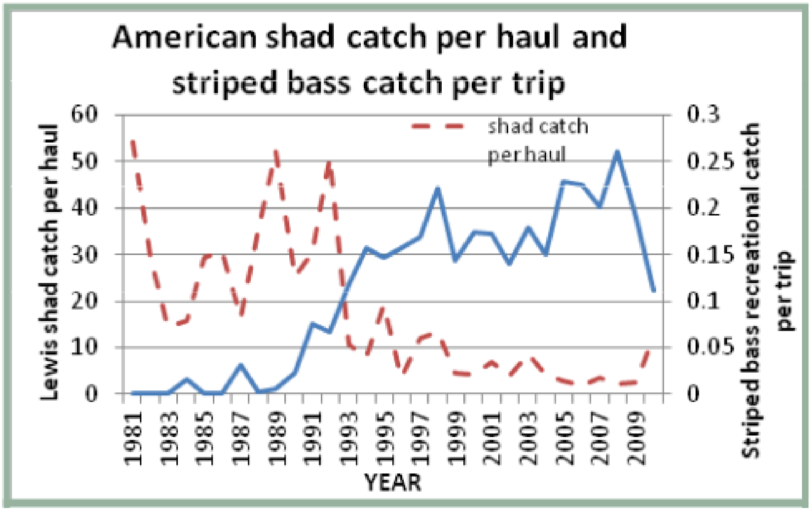


Figure 4.13: American shad and striped bass catch along the Delaware River (DNREC 2012)

Dissolved oxygen saturation decreases with rising water temperature (Table 4.6). DO saturation is 9.07 mg/l at 20°C and 7.54 mg/l at 30°C. In July, DO in the Delaware River at Philadelphia declines below the criteria of 3.5 mg/l (46% saturation) when water temperature nears 30° C (Figure 4.14). If DRBC raises the DO criteria to 4, 5, or 6 mg/l, DO saturation at 30°C would be 53%, 66%, or 80%, respectively. At 30°C, just a bit of BOD loading will depress DO from 100% saturation at 7.54 mg/l to 80% saturation at 6 mg/l, therefore it may not be very feasible to achieve a future DO criteria much higher than 5 mg/l (66% saturation) due to the very warm summer water temperatures.

Table 4.6: 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

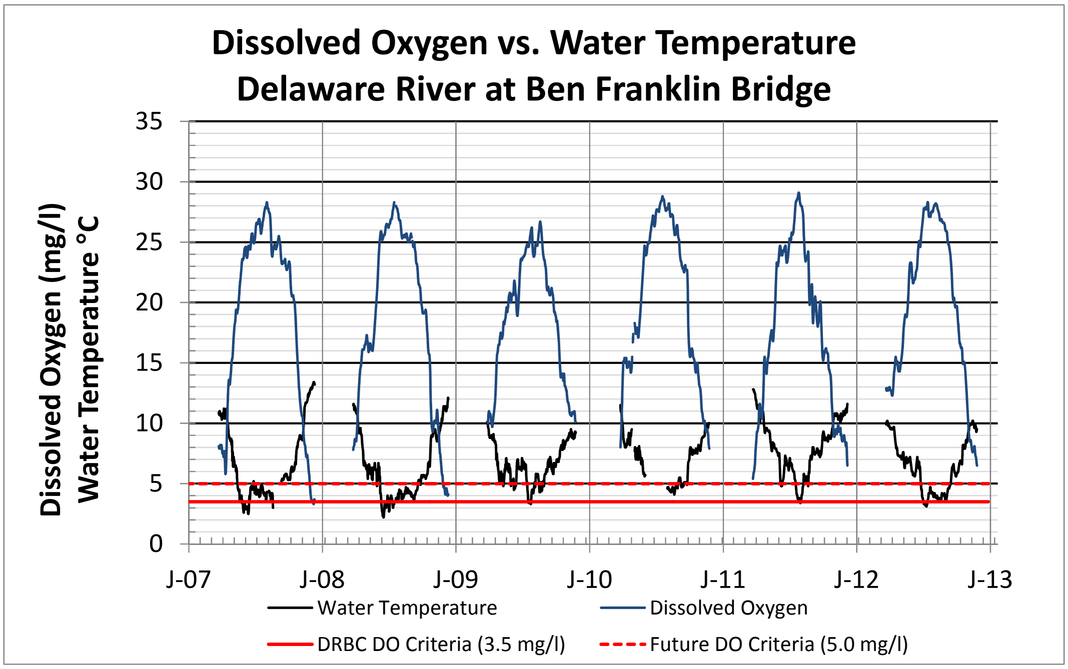


Figure 4.14: Water temperature and dissolved oxygen at the Delaware River (www.usgs.gov)

Two studies prepared for the Delaware River Basin Commission concluded that the fishable standard for dissolved oxygen should be defined by a minimum of 4.0-4.5 mg/l in Zone 3 at Philadelphia, 4.0-5.0 mg/l in Zone 4 from the Schuylkill to the DE/PA line, and 4.5-5.0 mg/l in Zone 5 from the DE/PA line to below Wilmington near Liston Point (Ad-Hoc Task Force 1979 and Delaware Estuary Use Attainment Project 1989). The Partnership for the Delaware Estuary's Science and Technical Advisory Committee has recommended that the DRBC consider these fishable criteria as a starting point when considering a more rigorous DO standard in the Delaware River

The focus of a proposed increase in DO criteria is on the Delaware River in Water Quality Zones 2, 3, and 4 from above Philadelphia to below Wilmington where the current DRBC summer criteria 3.5 mg/l. The consensus of the Partnership for the

Delaware Estuary Science and Technical Advisory Committee (STAC) is the standard should be raised to at least 4.5 mg/l to be consistent with the criteria in DRBC Zone 5 below Wilmington or perhaps 5.0 mg/l, the 24-hr criteria in Zone 2 above Philadelphia. The STAC has advised the DRBC that the current DO criteria of 3.5 mg/l is too low to support year-round survival and growth of anadromous fish such as the American shad and juvenile sturgeon and the standard should be raised to a more protective level.

4.8 Discussion and Conclusions

While nitrogen loads from the Delaware Basin are the largest of any estuary along the Atlantic seaboard, eutrophic susceptibility is moderate in the Delaware Estuary. Despite very high nutrient loading and concentrations, the Delaware Estuary does not show classic eutrophication symptoms of hypoxia or Chesapeake Bay-like algal blooms. The algal blooms may be tempered by high turbidity and low light in the well-flushed Delaware Estuary. Wetlands that rim the estuary assimilate nutrient loads along the Delaware and New Jersey bayshore.

The most severe impact of over nitrification in the Delaware Estuary is the 50% saturation DO sag between Philadelphia and Wilmington with warm water temperatures during late spring and summer that can limit propagation and spawning of anadromous fish like the American shad, striped bass, and Atlantic and shortnose sturgeon.

Approximately 16% of assessed stream miles are impaired in the Delaware Basin according to biannual surveys conducted by the four states for the EPA in accordance with Section 305b of the Clean Water Act. Over the last half century, water quality improvements in the Delaware River and its tributaries have coincided with a recovering anadromous fishery. In 1967, the DRBC set a minimum DO standard of 3.5 mg/l in the tidal river near Philadelphia for spring/fall passage but not year-round propagation of diadromous fish. The 3.5 mg/l DO standard is increasingly violated during the summer when water temperatures approach 30° C (86° F) and DO saturation plunges below 50%.

The DRBC is considering setting a more protective DO standard along the tidal Delaware River (to 4, 5, or 6 mg/l) to sustain year-round propagation of anadromous fish such as American shad and Atlantic sturgeon. At 30°C, just a little BOD loading will depress DO from full saturation at 7.54 mg/l to 80% saturation at 6 mg/l, therefore it may not be very feasible to achieve a future standard much greater than 5 mg/l (66% saturation) due to the hot water temperatures that occur in the river during the summer. A higher, more stringent DO criteria would serve as a hedge against atmospheric warming and rising sea levels that may increase water temperatures and salinity in the tidal river which in combination would further depress DO saturation.

This proposed policy change has economic implications. A watershed restoration program that reduces nutrient pollution could improve water quality and boost the economies of tourism, commercial fishing, recreation, hunting, real estate, and water treatment that depend on clean water. How much will it cost to reduce pollutant loads and improve water quality to a higher, more protective DRBC DO standard and what are the benefits? Will the benefits exceed the costs? What is the efficient level of water quality in the river where the costs of pollutant reductions equal the benefits of improved water quality? The next chapter begins to answers these questions with the review of a 1960s economic study of the Delaware River.

Chapter 5

1960s Benefit-Cost Analysis

5.1 Introduction

To understand the state of economics as applied to water pollution control a half century ago, this chapter re-examines a first-of-its-kind benefit-cost analysis conducted for the Delaware Estuary by the Federal Water Pollution Control Administration (FWPCA) during the 1960s. This Delaware River study was completed just a few years after JFK created the DRBC in 1961 and before Richard Nixon formed the EPA in 1970 and is cited as one of the first water pollution control efforts in the U.S. to employ the "economic" approach to cost-effectively achieve water quality in a river system.

The health of the Delaware River began to improve after World War II with resurging prosperity and a renewed understanding of the societal benefits of improved water quality on human well-being (Thoman 1972). During the early 1960s, the Federal Water Pollution Control Administration (1966) described the Delaware River near Philadelphia as "a polluted waterway which depresses aesthetic values, reduces recreational, sport and commercial fishing, and inhibits municipal and industrial water uses." National concern about the river surfaced earlier when the Federal Water Pollution Control Act of 1956 directed the government to reduce pollution in the interstate waters of the Delaware River (Kneese and Bower 1984). In 1957, the Corps of Engineers requested that the U.S. Public Health Service conduct a comprehensive technical and economic study of water quality in the Delaware Estuary. The study began in 1961 while the White House, Congress, and the states adopted the DRBC Compact. In 1965, Lyndon B. Johnson signed the Water Quality Act that required states to set interstate water quality standards and created the FWPCA in the Department of Interior to replace the U.S. Public Health Service as the guardian of water resources in the U.S.

In 1966 the newly formed FWPCA, replaced by the EPA just four years later, issued the "Delaware Estuary Comprehensive Study: Preliminary Report and Findings" that noted the Delaware Basin was the only watershed in the U.S. empowered by Federal and state law (the DRBC Compact) to implement regional, interstate water quality management. This 1960s FWPCA study of the Delaware Estuary was one of the first economic analyses in the U.S. that evaluated the costs and benefits of achieving water quality goals (Johnson 1967). A mathematical steady state computer model simulated the Delaware Estuary effluent and waste system based on mass balance equations for BOD, DO, and organic waste (Thomann 1972). The carbonaceous oxygen demand (COD) waste load to the Delaware Estuary was 1 million lb/day with 65% from municipal discharges and 35% from industrial discharges (DeLorme and Wood 1976). This analysis solely examined point source loads from municipal and industrial wastewater treatment plants and noticeably omitted the effects of airborne, urban/suburban, and agricultural sources as these nonpoint source pollutant loads were little understood then.

5.2 Costs

The 1966 FWPCA study estimated costs of municipal and industrial wastewater controls to achieve minimum DO levels based on Objective Sets I (4.5 mg/l), II (4.0

mg/l), III (3.0 mg/l), IV (2.5 mg/l), and V (0.5 mg/l, status quo) for 1975-1980 drought conditions. Benefits and costs were in calculated in 1964 dollars.

Objective Set I: Achieve summer average DO of 4.5 mg/l in the Delaware River at Philadelphia to sustain anadromous fishery. Provide highest water quality, maximum water contact recreation, and expanded sport/commercial fishing. Remove 92% to 98% of carbonaceous waste sources. Allow residual of 100,000 lbs/day of biological oxygen demand (BOD) wastes. Construct large scale, advanced wastewater treatment plants. The estimated capital and operation and maintenance cost was $490 million for 1975-1980 drought conditions.

Objective Set II: Achieve summer average DO of 4.0 mg/l. Remove 90% of carbonaceous waste sources. Allow residual of 200,000 lbs/day of BOD wastes. Required uniform waste treatment processes. Estimated capital and O & M cost ranged from $230-330 million.

Objective Set III: Achieve summer average DO of 3.0 mg/l. Spring/fall DO criteria for anadromous fish passage not imposed. Decrease in sport/commercial fishing may occur with lowered DO criteria. Water quality benefits for municipal water supply are reduced. Remove 75% of carbonaceous waste. Allow BOD residual of 500,000 lbs/day. Required uniform waste treatment and reduction processes. Estimated capital and O & M cost was $130-180 million.

Objective Set IV: Achieve summer average DO of 2.5 mg/l that would result in just a slight increase in water contact recreation and fishing in the lower estuary. Water quality slightly enhanced over 1964 conditions. Remove 50% of carbonaceous waste.

Allow BOD residual of 500,000 lb/day. Estimated capital and O & M cost was $100-150 million.

Objective Set V: Maintain 1964 summer average DO of 0.5 mg/l (status quo) at an estimated capital and O & M cost of $30 million.

The 1966 FWPCA study estimated pollutant load reduction costs ranged from $100-$150 million to meet summer DO criteria of 2.5 mg/l to $490 million to meet summer DO criteria of 4.5 mg/l to sustain the diadromous fishery (Table 5.1). Objective III appeared to be most cost-effective as the marginal costs are lowest ($30 million) to achieve DO of 3 mg/l whereas the marginal costs rise to achieve Objective I (4.5 mg/l) and Objective II (4.0 mg/l). The break point where marginal costs become significantly higher occurs when DO exceeds 3.0 mg/l on the cost curve (Figure 5.1). Marginal costs are the change in cost as water quality (DO) improves by one objective set.

Table 5.1: Cost to meet water quality goals in the Delaware Estuary (1975-1980) (FWPCA 1966)

Objective Set	DO Criteria (mg/l)	BOD/COD Residual (lb/day)	% Pollution Removal	Total Costs ($1964) ($ million)	Marginal Costs ($1964) ($ million)	% Survival Shad Passage
I.	4.5	100,000	92%-98%	490	160-260	
II.	4.0	200,000	90%	230-330	100-150	90%
III.	3.0	500,000	75%	130-180	30-30	80%
IV.	2.5	500,000	50%	100-150	70-120	
V.	0.5	status quo		30	0	20%

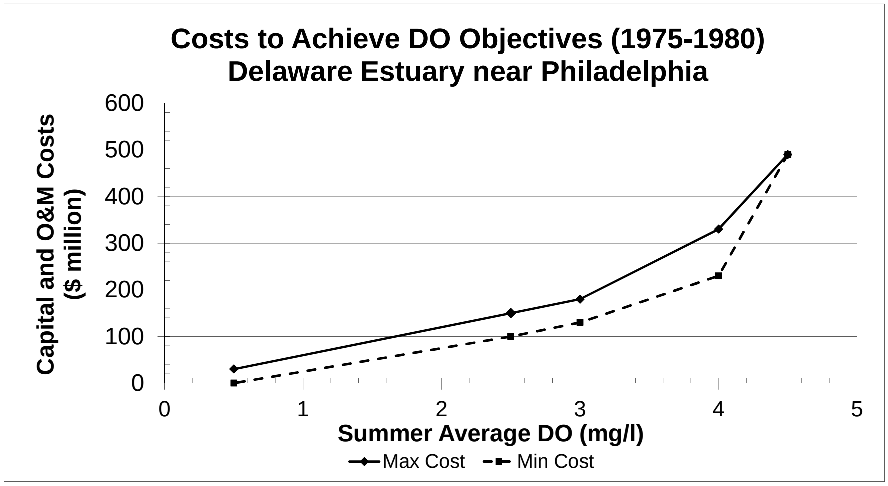


Figure 5.1: Costs to meet dissolved oxygen goals in the Delaware Estuary (FWPCA 1966, Kneese and Bower 1984)

Note the relationship between modeled percent pollutant load removal and DO criteria (Figure 5.2) is nearly linear since the coefficient of determination for the linear regression ($r^2 = 0.92$) is almost identical to the curvilinear line of best fit ($r^2 = 0.95$).

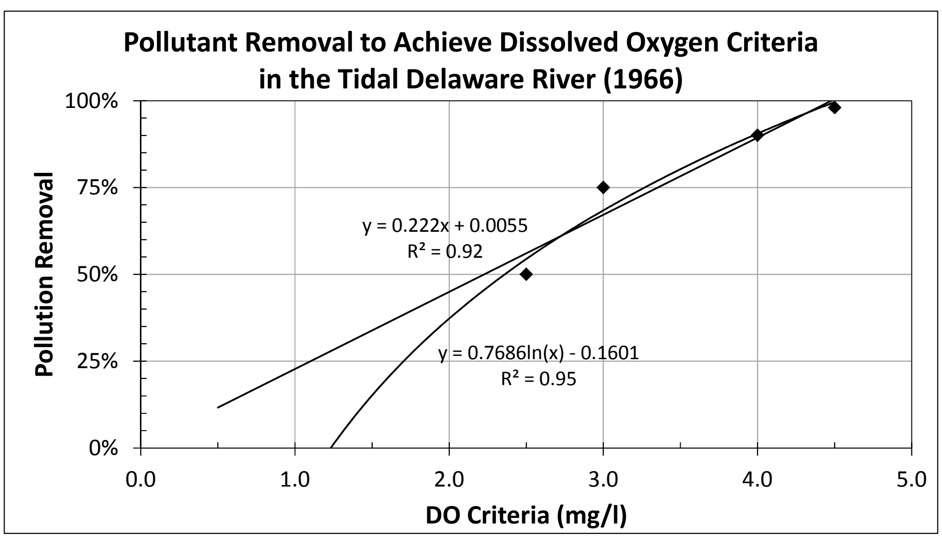


Figure 5.2: Pollutant removal to meet DO criteria in the Delaware River (FWPCA 1966)

Four decades ago, Thoman (1972) estimated that if dissolved oxygen levels were improved from the 1964 conditions of 0.5 mg/l (Objective V) during a 25-year drought to a future level of 3.0 mg/l (Objective III) in Zones 3 and 4 near Philadelphia, then survival of upstream shad passage would rise from 20% to 80%. Improving DO to 4.0 mg/l (Objective II) would achieve 90% survival of shad passage.

By 1976 the DRBC reported that BOD had been reduced by 90% due to construction of secondary wastewater treatment plants and with continued progress DO levels in the tidal Delaware River could increase to 4.5 mg/l. Delorme and Wood (1976) predicted that if water quality improved, then the economic value of water-based recreation like boating, fishing, swimming, and fish/wildlife would return to the estuary and drinking water and industrial water supplies and riverside property values would benefit from the river recovery.

5.3. Benefits

The Delaware River study by the FWPCA (1966) estimated water quality benefits for direct instream uses (recreational fishing, boating, commercial fishing) and withdrawal uses (drinking water) and indirect uses of potential use (option value) and nonuse (existence value). The highest benefits resulted from improved recreational fishing, commercial fishing, boating, and direct water quality benefits (Morgenstern 1997).

Improved water quality at the Torresdale Water Treatment Plant along the Delaware River at Philadelphia was predicted to reduce water treatment coats and reduce "taste and odor problems that greatly increased the ability of the plant to produce a more palatable drinking water." However, improved DO provided little benefits to industrial water suppliers as some firms were concerned about possible increased corrosion costs from reduced pH in the oxygenated water.

The study considered the economic benefits of wastewater treatment plants at Wilmington, Trenton, Camden, Chester, Philadelphia, and Delaware County Authority in Ridley Park, Pennsylvania. During 1964, about 26,000 employees worked at 18 industrial firms that discharged waste to the Delaware Estuary with an economic output over $2 million.

Recreational value was obtained from: (1) direct estimates of willingness to pay such as the market price of fish landings coupled with interviews and (2) indirect estimates based on actual behavior of recreation users willing to pay for trips and expenses. During 1975-1980, the study estimated annual swimming, boating, and fishing recreation demand in the Delaware Estuary would increase by 43 million activity days due to improved water quality and by 2010 annual recreation would increase to 100 million activity days. Boating benefits were derived from more than 80 marinas that berthed 10,000 boats and were based on 2 to 4 activity days per boat which was worth $295,000/yr. Hunting for waterfowl, ducks, teal, and Canadian geese on 39,000 acres of tidal marsh was worth millions of dollars. Water quality was suitable for recreational fishing only far upstream near Trenton or downstream from Delaware City. Swimming was absent along the estuary since municipal/industrial waste discharges caused high bacteria levels that made water contact unhealthy (Kneese and Bower 1984). Due to poor water quality in the Delaware Estuary, recreational uses were limited in 1964 but did include some water skiing, boating, sport fishing, and unsanctioned swimming. Just 23% of boating capacity and 8% of fishing capacity were utilized due to concerns about the polluted water (Table 5.2).

Table 5.2: Recreational activity in the Delaware Estuary from 1964-1965

Recreation	Activity Days	Utilization
Boating	8,120,000	23%
Fishing	1,620,000	8%
Swimming	0	0%

With improved water quality under Objective Sets I, II, and III, commercial fishing was expected to increase due to a rise in the number of anadromous fish and the catch of menhaden and other finfish such as striped bass, weakfish, and bluefish. The commercial fish harvest of shad, sturgeon, striped bass, weakfish, and white perch landed 80,000 pounds which at $0.17/lb was worth $14,000. The commercial menhaden harvest in the lower bay was worth $1.4 million.

The marginal cost to remove 90% to 100% of BOD was $95 million/year in $1976 (DeLorme and Wood 1976). The natural recycling capacity of wetlands was capable of removing 3.5 lb/day of BOD to treat the remaining 10%. The 463,000 acres of wetlands in the Delaware Estuary watershed could treat 1.6 million pounds of waste per day or 590 million pounds per year. At $2.00/lb of BOD removed, Delaware Estuary wetlands had an annual economic replacement value of $1.18 billion or $255 per acre.

The 1966 FWPCA study concluded the recreational benefits of swimming, boating, and sportfishing due to improved water quality in the Delaware Estuary would be "substantial". Municipal and industrial water supply and wastewater treatment benefits due to improved DO water quality were small. Recreational benefits due to increased swimming, boating, and fishing activity ranged from \$120-\$280 million to meet DO criteria of 2.5 mg/l to \$160-\$350 million to meet DO criteria of 4.5 mg/l (Table 5.3). Net marginal benefits were greatest for Objective Set II (4.0 DO mg/l) ranging from \$20 to \$30 million. The 1975-1980 recreation benefits, in 1964 dollars, are calculated with an interest rate of 3% and a time horizon of 20 years.

Table 5.3: Recreational benefits in the Delaware Estuary (1975-1980) (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

5.4 Benefit-Cost Analysis

The 1966 study estimated wastewater load reduction costs ranged between \$100-\$150 million to meet a summer DO goal of 2.5 mg/l and \$490 million to meet a summer DO goal of \$4.5 mg/l (Table 5.4). Benefits ranged from \$120-280 million to meet DO of

2.5 mg/l to $160-$350 million to meet a DO goal of 4.5 mg/l in the Delaware River (Kneese and Bower 1984).

Table 5.4: Costs/benefits to meet water quality objectives in the Delaware Estuary (FWPCA 1966 and Thoman 1972))

Objective	**DO Summer (mg/l)**	**BOD/COD Residual (lb/day)**	**% Pollution Removal**	**Costs ($1964) ($ million)**	**Benefits[1] ($1964) ($ million)**	**Net Benefits ($1964) ($ million)**	**% Shad Survival Passage**
I	4.5	100,000	98%	490	160-350	-230 to -140	
II	4.0	200,000	90%	230-330	140-320	-90 to -10	90%
III	3.0	500,000	75%	130-180	130-310	0 to 130	80%
IV	2.5	500,000	50%	100-150	120-280	20 to 130	
V	0.5	status quo		30	0	-30	20%

In January 1967, the DRBC water use advisory committee composed of the public, industry, government, recreation, conservation, and fish and wildlife stakeholders examined the FWPCA benefit-cost analysis to establish a water quality standard. Municipal and industrial interests recommended that DRBC adopt Objective III (3.0 mg/l) with the highest net benefits of $130 million (Table 5.5 and Figure 5.3). Conservation interests and local elected officials recommended that DRBC adopt Objective II (4.0 mg/) as a more protective option with the highest marginal benefits ($20-$30 million). Over 50 people testified at the hearings and the public format for debate and discussion was hailed as unique and progressive for the time. In 1967, the DRBC adopted a combination of Objective Sets III (3 mg/l) and II (4 mg/l) as the most cost-effective option and as a compromise established the summer 24 hour DO standard at 3.5 mg/l for the Delaware Estuary water quality zones near Philadelphia.

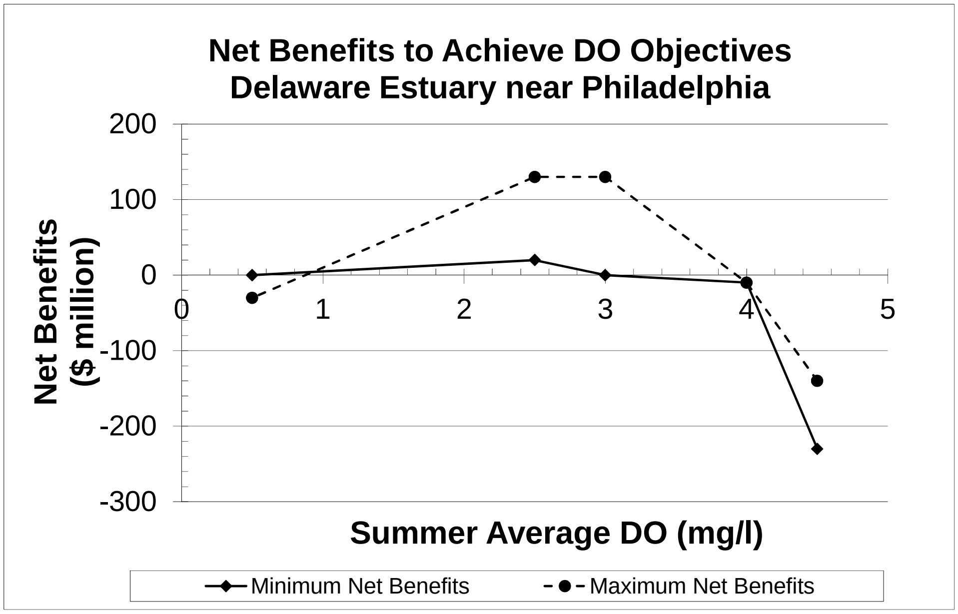


Figure 5.3: Net benefits to achieve DO objectives in Delaware Estuary near Philadelphia (FWPCA 1966)

The 1966 Delaware Estuary study concluded the costs to attain improved water quality would be justified mainly on aesthetic and recreational grounds since the benefits for municipal/industrial water users were small. If a value of $2.50 a day were placed on boating, then user pay revenue of $4.8 million could be raised reduce pollutant loads and maintain DO above 3 mg/l even if no other benefits were considered.

To fund the water pollution control effort, the FWPCA recommended that the DRBC adopt an effluent charge of $0.08 to $0.10 per pound of biochemical oxygen demand (BOD) substances (nitrogen) discharged to produce the largest DO increase in the Delaware Estuary. This FWPCA study concluded that a user charge would raise $7 million annually for the DRBC waste load abatement effort, a modest amount that was unlikely to disrupt the regional economy.

5.5 Discussion and Conclusions

A 1966 study of the Delaware Estuary by the Federal Water Pollution Control Administration (FWPCA) was one of the first economic analyses in the U.S. that evaluated the costs and benefits of achieving water quality goals. The 1966 FWPCA study noted the Delaware Basin was the only watershed in the U.S. empowered by Federal and state law (the DRBC Compact) to conduct regional, interstate water quality management using an economic approach and estimated costs of municipal/industrial wastewater controls to achieve minimum DO levels that ranged from 0.5 mg/l to 4.5 mg/l for 1975-1980 drought conditions. While the economic study was notable for its time, the analysis did not evaluate the costs of nonpoint atmospheric, urban/suburban, and agricultural runoff controls as little was known about these diffuse sources water pollution then. Nonuse benefits from the modern willingness to pay concepts available today were not incorporated either.

In January 1967, the DRBC water use advisory committee composed of the public, industry, government, recreation, conservation, and fish and wildlife stakeholders examined the FWPCA benefit-cost analysis to recommend establishing a water quality standard. Over 50 people testified at the hearings and the public format for debate and discussion was hailed as unique and progressive for the time. In 1967, the DRBC Commissioners adopted a combination of Objective Sets III (3 mg/l) and II (4 mg/l) as the most cost-effective option and established the summer 24 hour DO standard at 3.5 mg/l for the Delaware Estuary between Philadelphia and Wilmington.

The 1960s Delaware Estuary study concluded that higher water quality could be justified almost entirely on aesthetic and recreational grounds since the benefits for municipal and industrial water users were very small. If a value of $2.50 a day were placed on boating, then it would have been justified to maintain 3 mg/l DO even if no other benefits were considered. To fund the water pollution control effort, the FWPCA recommended that the DRBC adopt an effluent charge of $0.08 to $0.10 per pound of biochemical oxygen demand (BOD) substances discharged to produce the largest DO increase in the Delaware Estuary. This FWPCA study concluded that a user charge would raise $7 million annually for the DRBC waste load abatement effort, a modest amount that was unlikely to disrupt the regional economy.

Adjusting to 2010 dollars (Table 5.5), annual costs from the 1966 Delaware Estuary economic study range from $133-$191 million to achieve summer DO of 4.0 mg/l to $284 million to reach 4.5 mg/l versus benefits of $81-$186 million (DO 4.0 mg/l) to $93-203 million (DO of 4.5 mg/l).

Table 5.5: Annual costs/benefits to meet Delaware Estuary water quality goals (FWPCA 1966 and Thoman 1972)

Objective Set	**DO Summer (mg/l)**	**% Pollution Removal**	**Annual Costs ($ million)**		**Annual Benefits ($ million)**	
			$1964	**$2010[1]**	**$1964**	**$2010[1]**
I	4.5	98%	98	284	32-70	93-203
II	4.0	90%	46-66	133-191	28-64	81-186
III	3.0	75%	26-36	75-104	26-62	75-180
IV	2.5	50%	20-30	58-87	24-56	70-162
V	0.5		6	17	0	0

1. Adjusted from $1964 to $2010 by 3% annually based on change in CPI.

Chapter 6

COSTS

6.1 Introduction

This chapter defines the 2010 costs of nitrogen pollutant load reductions to achieve improved water quality as measured by increased dissolved oxygen in the Delaware Basin. The most cost-effective N reduction options are identified by the minimum costs to obtain the desired water quality goal assuming marginal costs of all possible measures are equal. To estimate the most cost-effective combination of nitrogen load reductions, it is necessary to: (1) quantify N loads from the Delaware Basin for atmospheric, urban/suburban, wastewater, and agricultural sources, (2) estimate N load reductions to increase dissolved oxygen levels to meet a more stringent water quality standard, (3) define best management practices to reduce nitrogen loads from point and nonpoint sources and estimate unit N load reduction costs ($/lb N/yr), (4) compute N reduction costs (lb/yr) for each of the options, and (5) estimate cost effective N load reduction practices from marginal abatement cost curves.

6.2 Literature Review

Based on a review of previous studies, the annual costs of nutrient load reductions that improve water quality range from millions of dollars in a single watershed to billions of dollars on a national basis (Table 6.1). The costs to reduce phosphorus loads by 50%

in the Fox-Wolf River Basin in northern Wisconsin ranged from $8 to $35 million (Schleich et al. (1996). Trowbridge (2010) calculated the annualized costs of upgrading 18 wastewater treatment plants in New Hampshire and Maine to meet nitrogen effluent limits ranged from $200 to $365 million or $63-$79/lb N removed. Lyon and Farrow (1995) reported to EPA that annual stormwater control costs to comply with the Clean Water Act would range from $9.9 to $14 billion.

Table 6.1: Nitrogen load reduction costs

Location	**Source**	**N Load Reduction (mil lb/yr)**	**Cost ($ million/yr)**	**Unit Cost ($/lb N)**
Fox-Wolf River Basin, WI	Schleich et al. 1996	50%	8-35	
Connecticut River Basin	Evans 2008	5.7	203	35
New Hampshire, Maine	Trowbridge 2010		200-236	63-79
Chesapeake Bay Watershed	Chesapeake Bay Comm. 2004	103	1,000	10
Upper Mississippi Basin	Rabotyagov et al. 2010	30%	800-1,800	
Netherlands	Van Soesbergen et al. 2007		2,326	
United States	Lyon and Farrow 1995		9,900-14,000	

Evans (2008) from Penn State estimated it would cost $203 million/yr to reduce nitrogen loads by 5.7 million lb/yr from the Connecticut River Basin to Long Island Sound (Table 6.2). A GIS-watershed model (AVGWLF) estimated 1999-2004 N loads from the basin were 28.7 million/lb/yr. An EPA Long Island Sound TMDL called for reducing N loads by 20% or 5.7 million lb/yr. Annual unit nitrogen reduction costs at Long Island Sound ranged from $4.93/lb N for agricultural BMPs such as nutrient management, cover crops, and buffers, to $17.31/lb N for wastewater treatment, and $133.01/lb N for urban stormwater best management practices.

Table 6.2: Costs of nitrogen load reductions in the Connecticut River Basin (Evans 2008)

Control	Nitrogen Load (mil lb/yr)	Nitrogen Reduction (mil lb/yr)	N Load Reduction (%)	Annual Cost ($ million)	Annual Cost ($/lb N)
Agriculture	3.9	1.3	33%	6.5	4.93
Point Source	10.1	3.4	33%	58.6	17.31
Urban	3.0	1.0	33%	137.7	133.01
Other Nonpoint	11.6				
Total	**28.7**	**5.7**	**20%**	**202.8**	**35.36**

The Chesapeake Bay Commission (2004) reported the total cost to clean up the Chesapeake Bay was $19 billion or about $1 billion/yr based on 2000 goals to reduce nitrogen by 103 million lb/yr, phosphorus by 6.7 million lb/yr, and sediment by 900,000 ton/yr. The most cost effective nitrogen removal options for bay restoration ranged from $1.57/ lb N for conservation tillage (no till) to $53.00/lb N for urban forest buffers (Table 6.3). Agricultural nutrient management ($1.66/lb N) reduces nutrients in manure or fertilizer with no loss of crop yield. Early ($2.33/lb N) and late ($3.50/lb N) cover crops of winter grains such as rye, wheat or barley are planted in the fall to capture excess nitrogen from manure and fertilizer. Wastewater treatment plant upgrades ($8.56/lb N) include denitrification with capital and operating costs amortized over 20 years. Forest buffer replacement ($53/lb N) retain up to 88% of the nitrogen from the air as the most cost-effective urban stormwater retrofit option.

Table 6.3: Annual Chesapeake Bay nitrogen reduction costs (Chesapeake Bay Commission 2004)

Measures	Nitrogen Reduction (million lb)	Cost of N Removed ($/lb N)
Conservation Tillage	12.0	1.57
Traditional Nutrient Management	13.6	1.66
Cover Crops	23.3	3.50
Enhanced Nutrient Mgmt.	23.7	4.41
Wastewater Treatment	35.0	8.56
Urban Forest Buffers		53.00

The estimated costs to reduce agricultural nitrogen and phosphorus loads by 30% from the Upper Mississippi River Basin to the Gulf of Mexico ranged from $0.8 to $1.8 billion per year (Rabotyagov et al. 2010). Agricultural conservation practices include reduced crop fertilization, conservation tillage, contour farming, grassed waterways, terraces, crop retirement, and conversion to perennial cover.

The European Union Water Framework Directive (EUWFD) requires that river basin management plans include cost-effective analysis to achieve good water quality (Van Soesbergen et al. 2007). The steps of the EUWFD cost-effectiveness analysis are (1) define the water quality objective, (2) identify sources of pollution, (3) identify measures to achieve target water quality, (4) assess the costs of measures, (5) rank measures according to increasing unit costs, and (6) assess the least cost option to reach the environmental objective.

A study in the Netherlands calculated pollution abatement costs that reduced nitrogen loads by 5% to 50% in 2002 dollars (Table 6.4). The most cost-effective measures with lowest cost per unit N reduction would be implemented first starting on the left hand side of the abatement cost curve (Figure 6.1). In the Netherlands, a 25% reduction in nitrogen from agriculture could be achieved at a cost five times less ($403 million) than the $2.3 billion cost to reduce N by 50%.

Table 6.4: Agricultural nitrogen emission reduction scenarios in Netherlands (Van Soesbergen et al. 2007)

Nitrogen Reduction (%)	Emission Level (kg N/ha/yr)	Cumulative Abatement Cost ($M/yr)
0	21	0
5	20	121
10	19	147
20	16	302
30	14	547
40	12	1,053
50	10	2,326

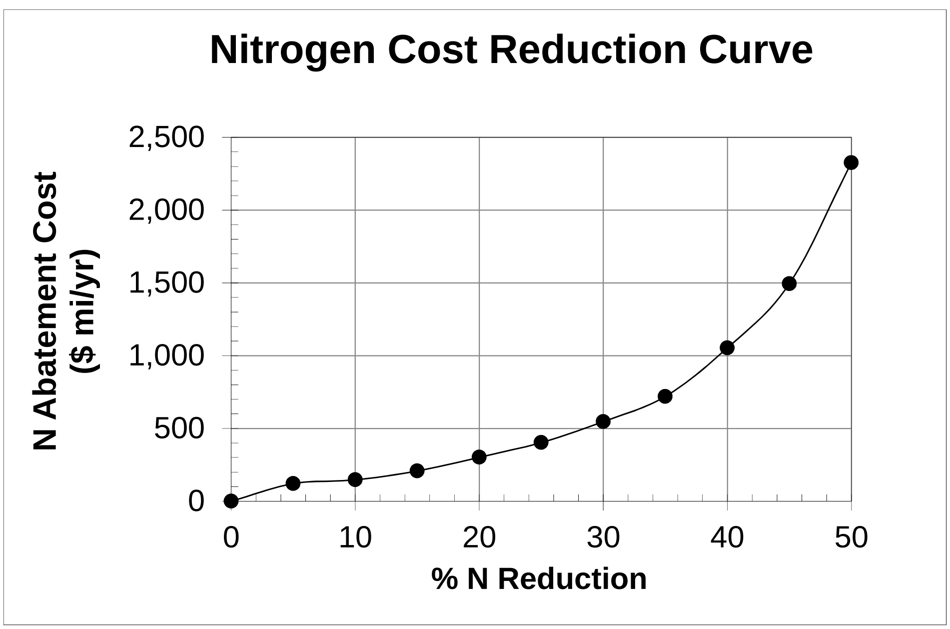


Figure 6.1: Agricultural nitrogen emission reduction scenarios in Netherlands (Van Soesbergen et al. 2007)

6.3 Methods

This research employs the following methods to estimate the costs of nitrogen load reductions to improve dissolved oxygen from current criteria (3.5 mg/l) to a future, more stringent standard in the Delaware River.

Nitrogen Loads: Estimate existing annual nitrogen loads (lb/yr) from the Delaware Basin in Delaware, New Jersey, New York, and Pennsylvania to the estuary using a watershed-based pollutant load model. Moore et al. (2011) from the USGS computed nitrogen loads from the Delaware Basin using the SPAtially Referenced Regressions on Watershed attributes (SPARROW) nutrient model. The SPARROW model estimates nitrogen loads to the Delaware Estuary for base year 2002 from point sources (municipal and industrial wastewater discharges) and nonpoint sources (atmospheric deposition, agriculture and urban/suburban land).

N Load Reductions: Determine nitrogen load reductions (lb/yr) needed to improve water quality to meet a future DRBC 5.0 mg/l dissolved oxygen standard in the tidal Delaware River in Zones 3, 4, and 5 between Philadelphia and Wilmington. A survey of fifteen Total Maximum Daily Load (TMDL) models by Scatena et al. (2006) in the lower Delaware River Basin suggests that to achieve a DO target of 5.0 mg/l, it would require a 32% (median) reduction in total nitrogen, within a range from 20% (25^{th} percentile) to 48% (75^{th} percentile) reduction.

BMP Unit N Load Reduction Costs: Determine alternative best management practices to reduce nitrogen loads. From the literature, establish unit costs of N load reductions ($/lb N reduced) for point source and nonpoint source BMPs including:

- Atmospheric (motor vehicle exhaust controls & power/industrial plant scrubbers)
- Urban/suburban retrofitting (stream restoration, wet ponds, stormwater wetlands)
- Wastewater treatment (point source control nutrient reduction technology)
- Agricultural practices (no till, cover crops, forest buffers, animal waste management)

Total N Reduction Costs: Calculate total costs to reduce nitrogen loads by 20% (25^{th} percentile), 32% (median), and 48% (75^{th} percentile) by multiplying N load reduction (lb/yr) by the unit cost ($/lb N reduced) for atmospheric emission, wastewater, agriculture, and urban/suburban BMPs. Plot costs versus percent nitrogen load reductions in the Delaware Basin.

Marginal Abatement Cost: Construct nitrogen marginal abatement cost (MAC) curves to determine cost effective N load reductions to improve water quality (DO) in the Delaware River. Marginal cost curves show the change in cost compared with the change in reduced pollutant loads (Brown 1999). If no pollution reduction is implemented, the marginal cost of control is $0. Initial reductions in pollutant load may be relatively inexpensive for agricultural BMPs such as cover crops. However, further reducing pollutant loads would become exceedingly expensive without corresponding increase in benefits. MAC curves depict the increasing costs of reducing pollutants on the horizontal axis and pollutant load reductions for each abatement measure on the vertical axis. The MAC curve illustrates how measures become more expensive with increasing amounts of pollutant load reductions. The MAC curve is constructed by calculating the pollutant load reductions (lb/yr) for each of the practices and the annual costs of these measures. The least expensive practices are plotted first on the curve and then adding more expensive pollutant reduction practices. A plot of the measures will form a curve with the least expensive measures on the left and the most expensive measures to the right. The MAC curves are constructed by plotting N load reduction costs ($/yr) on the horizontal axis and 25th, 50th (median), and 75th percentile N load reductions (lb/yr) on the vertical axis along with various options.

6.4. Results

Nitrogen Loads: Moore et al. (2011) computed nitrogen loads to the Delaware River and other estuaries along the Atlantic seaboard using the USGS SPAtially Referenced Regressions on Watershed attributes (SPARROW) nutrient model. Nitrogen loads were estimated from point (municipal/industrial wastewater discharges) and nonpoint sources (atmospheric deposition, agriculture and urban/suburban runoff) for base year 2002. SPARROW is a nonlinear least squares regression model where mean annual N load as the dependent variable is weighted by land to water movement, instream transport, and assimilation of nitrogen as the explanatory variable (Table 6.5).

SPARROW accounts for watershed characteristics such as precipitation, temperature, soil permeability and stream density and river/stream delivery attributes such as flow rate, velocity and lake/reservoir hydraulic loading (Alam and Goodall 2012). Nitrogen loads are computed from data from atmospheric deposition, agricultural fertilizer applications, animal manure, point source wastewater discharges, population density, and land cover (urban, agriculture, forest). Nitrogen loads from wastewater discharges are estimated from an EPA NPDES permit dataset. The model hydrologic framework is constructed from the EPA and USGS NHD Plus (1:100,000) stream network, National Elevation Dataset (NED), and USDA Watershed Boundary Dataset (WBD) and USGS National Land Cover Database (NLCD).

The SPARROW model nitrogen load estimates are calibrated against Federal and state stream water quality monitoring data bases such as EPA STORET. Predicted nitrogen loads from SPARROW are well correlated to observed loads from stream monitoring data as the coefficients of determination (r^2) are 0.83 for yield and 0.97 for load which accounts for 83% to 97% of the variance between the predictive model and observed water quality data. The SPARROW model suggests that tributary streams and rivers provide significant instream nitrogen attenuation and reduction benefits before flows enter the Delaware Estuary.

However, the SPARROW model has limitations. One, the model estimates mean annual nitrogen loads for flow and land use conditions for a 2002 base year and does not model loads in a more frequent daily or monthly simulation format (Alam and Goodall 2012). Since this research utilizes annual cost estimates, relying on mean annual loads from the SPARROW model is adequate here. Future work should be conducted to update the SPARROW nitrogen load model to more current flow and land use conditions. Two, SPARROW only models nitrogen loading from streams and does not account for contributions from groundwater directly to the estuary. It is likely that nitrogen loads from groundwater to the Delaware Estuary are underestimated in this analysis. And three, there is a question about whether the first-order process parameterization of in-stream N removal is valid in streams with high nitrogen loads (Claessens et al. 2009). A higher order process model would be required to address this concern.

Table 6.5: Mid-Atlantic SPARROW model coefficients (Moore et al. 2011)

Parameter	Coefficient Unit	Model Coefficient
Nitrogen Sources		
Developed land (km^2)	$kg/km^2/yr$	1422
Wastewater discharge (kg/yr)		1.16
Fertilizer and fixation from agriculture in corn, soybeans, alfalfa. (kg/yr)		0.310
Fertilizer to agriculture in other crops (kg/yr)		0.186
Manure from livestock (kg/yr)		0.090
Land to Water Delivery		
Mean annual temperature	ln deg C	-0.864
Average overland flow distance to stream (km)	km^{-1}	-0.190
ln ratio of nitrate to inorganic N wet deposition		2.56
Aquatic Decay		
Time of travel in stream reach where mean discharge <2.83 m^3/s (days)	per day	0.224
Statistics		
Root Mean Square Error (RSME)		0.35
r^2 load		0.97
r^2 yield		0.83

SPARROW utilizes land cover data to predict nitrogen loads from nonpoint source urban/suburban and agricultural runoff. Pennsylvania occupies 51% of the Delaware Basin followed by New Jersey and New York that each cover 21% of the basin and Delaware and Maryland that cover 8% of the basin (Figure 6.2).

In 2006, 62% of the Delaware Basin was covered by forest or wetlands, 20% by agriculture, and 17% by urban/suburban land (Table 6.6). Most of the forested land lies in the northern half of the basin in the hills above Trenton and mountains above the Delaware Water Gap (Figure 6.3). Agricultural land lies in the valleys in upstate New York and then mostly south of the Delaware Water Gap in the headwaters of the Lehigh, Schuylkill, and Brandywine watersheds in Pennsylvania and on the South Jersey and Delaware Coastal Plain along Delaware Bay. Urban areas are centered along the

Reading-Allentown-Easton axis in the Lehigh Valley of Pennsylvania and along the Trenton-Camden-Philadelphia-Wilmington I-95 metropolitan corridor. Developed urban and agricultural land covers 23% of the basin in Pennsylvania, 17% in New Jersey, 2% in New York, and 25% in Delaware. Pollutant loads from developed lands are buffered somewhat by large tracts of forests and wetlands that cover 87%, 57%, 54%, and 46% of the Delaware Basin in New York, Pennsylvania, New Jersey, and Delaware, respectively.

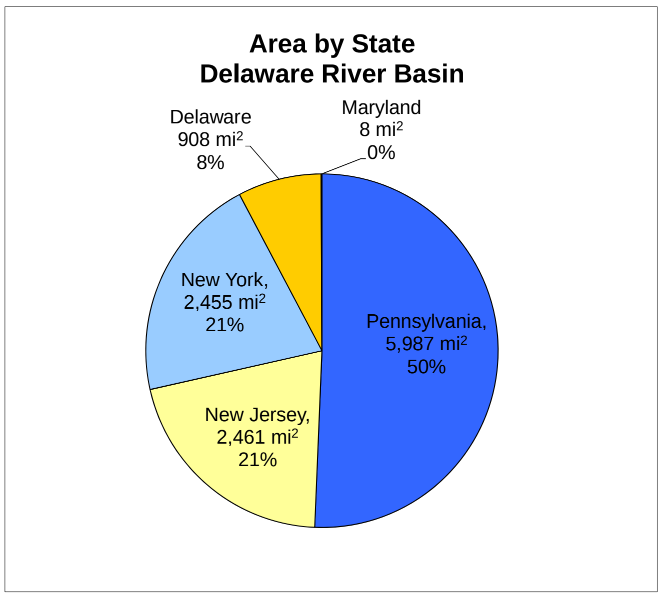


Figure 6.2: Land area by state in the Delaware Basin

Table 6.6: Land use/land cover in the Delaware Basin (NOAA CSC 2006)

State	Urban/ Suburban (%)	Agriculture (%)	Forest/ Wetlands (%)	Total (%)
Delaware	25%	28%	46%	100%
New Jersey	17%	29%	54%	100%
New York	2%	11%	87%	100%
Pennsylvania	23%	20%	57%	100%
Delaware Basin	17%	20%	62%	100%

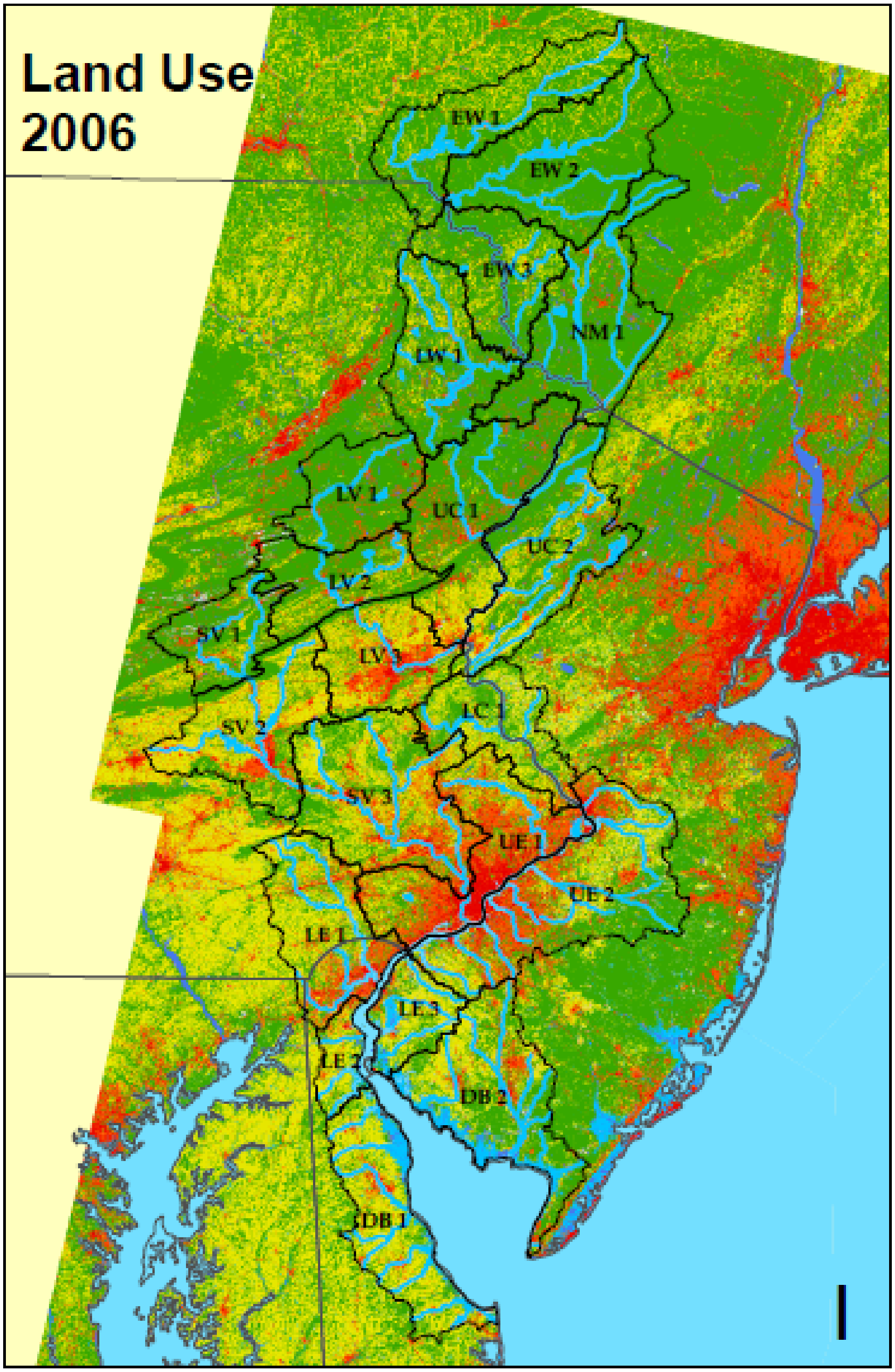


Figure 6.3: Land use in the Delaware Basin, 2006 (NOAA CSC)

The SPARROW model determines that the Delaware River receives the highest unit nitrogen load (4.3 ton/ mi^2/yr) and the 2nd highest nitrogen load (50,525 ton/yr), after the Susquehanna River, of any basin in the northeastern and mid-Atlantic U.S (Table 6.7).

Table 6.7: Nitrogen loads from SPARROW by river basin
(Moore et al. 2011)

River Basin	Drainage Area (mi^2)	Nitrogen Load (ton/yr)	Unit N Load (ton/mi^2/yr)
Susquehanna	27,490	73,040	2.7
Delaware	11,819	50,525	4.3
Potomac	14,658	44,707	3.0
Hudson	13,363	28,711	2.1
James	10,339	17,482	1.7
Connecticut	11,261	17,236	1.5
Merrimack	5,000	9,068	1.8
Kennebec	9,564	7,539	0.8
Penobscot	8,458	5,413	0.6

In the Delaware Basin, almost half (46%) of the nitrogen load flows from point source wastewater discharges and almost a third (29%) comes from fertilizer and animal manure-laden runoff from agriculture (Table 6.8 and Figure 6.4). Just over a tenth of N loads are from urban/suburban stormwater (14%) from the cities and suburbs. The Delaware River airshed is 10 times larger than the river basin and atmospheric deposition contributes 12% of the nitrogen to the estuary. Over 90% of the nitrogen loads to the Delaware Basin are discharged by the states of Pennsylvania (72% of N load) and New Jersey (21%) with about half from wastewater discharges and a quarter to a third from agriculture in both states. New York and Delaware contribute just 4% and 3% of the nitrogen loads to the basin, respectively.

Table 6.8: Nitrogen loads by state in the Delaware Basin (Moore et al. 2011)

Basin/State	Drainage Area (mi^2)	Nitrogen Load (ton/yr)	Atmospheric Deposition (ton/yr)	Wastewater Discharge (ton/yr)	Urban/ Suburban (ton/yr)	Agriculture (ton/yr)
Delaware Basin	11,819	50,525	6,063	23,242	7,074	14,652
Pennsylvania	5,987	36,531	3,653	16,804	5,114	10,959
New Jersey	2,461	10,404	1,040	5,514	1,248	2,601
New York	2,455	1,944	1,069	117	311	467
Delaware	908	1,613	145	565	323	581
Maryland	8	33	3	0	4	26
Basin/State	**Drainage Area (mi^2)**	**Nitrogen Load (%)**	**Atmospheric Deposition (%)**	**Wastewater Discharge (%)**	**Urban/ Suburban (%)**	**Agriculture (%)**
Delaware Basin	11,819	100%	12	46	14	29
Pennsylvania	5,987	72%	10	46	14	30
New Jersey	2,461	21%	10	53	12	25
New York	2,455	4%	55	6	16	24
Delaware	908	3%	9	35	20	36
Maryland	8	0%	8	0	12	80

Mean annual total nitrogen loads measured at stream gages in the Delaware Basin compare favorably with estimated loads from the USGS SPARROW model (Trench et al. 2012). The mean annual N load measured at the Delaware River at Port Jervis was 4.3 million pounds compared to 6.1 million pounds estimated by the SPARROW model. The measured N load at the Delaware River at Trenton was 31.2 million pounds compared to 25.1 million pounds estimated by the SPARROW model. At the mouth of the Schuylkill, the measured annual N load was 20.8 million pounds versus 28.9 million pounds from the SPARROW model.

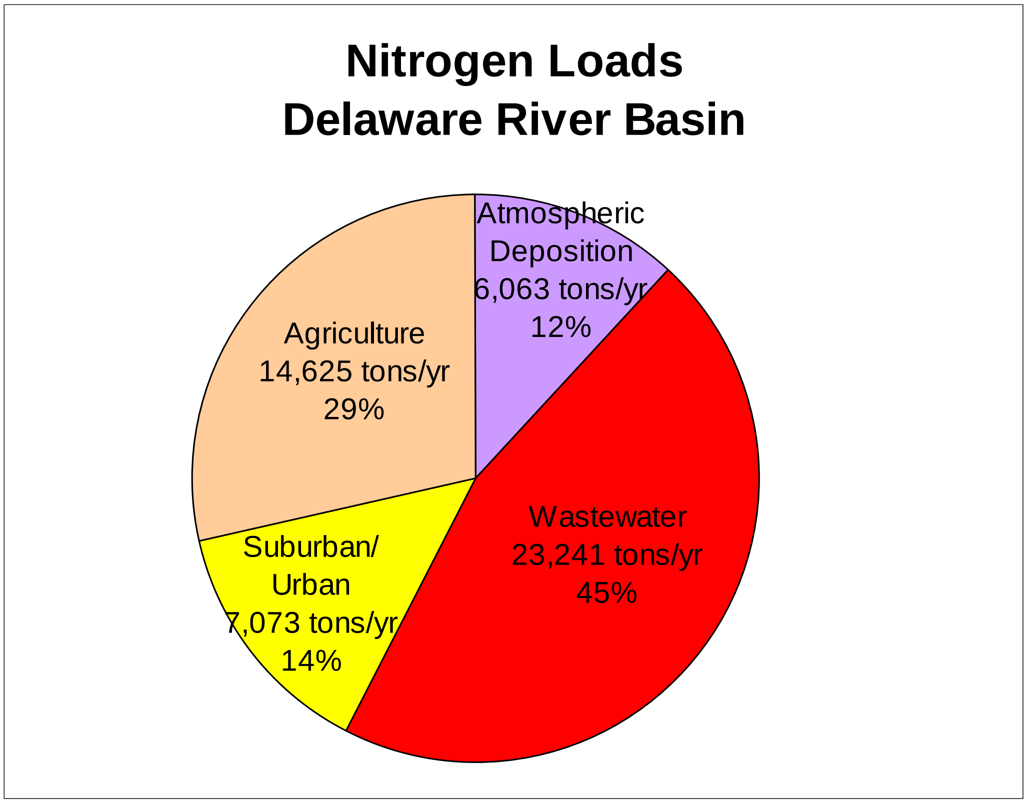


Figure 6.4: Annual nitrogen loads delivered in the Delaware Basin (Moore et al. 2011)

In the Delaware Basin, over 80% of the nitrogen load to the estuary is delivered by three watersheds as a quarter (25%) of the N load flows from the Delaware River at Trenton and almost a third (29%) each is delivered from the Schuylkill River and the watersheds that flow into the river between Philadelphia and Trenton (Table 6.9 and Figure 6.5). In the upper Delaware Basin, 9% of the N load flows from the Lehigh River.

Below Philadelphia; the Brandywine/Christina, Delaware River above Wilmington, and Delaware Estuary above Prime Hook watersheds contribute 7%, 8%, and 3% of the nitrogen loads, respectively

Wastewater discharges are the predominant nitrogen sources in the Delaware River above Philadelphia (82%), Schuylkill (46%), and Delaware River above Wilmington (68%) watersheds. Agriculture is a primary N source in the Delaware River at Trenton (34%), Brandywine/Christina (77%), and Delaware Bay above Prime Hook (72%) watersheds and the second highest N source in the Schuylkill watershed (35%).

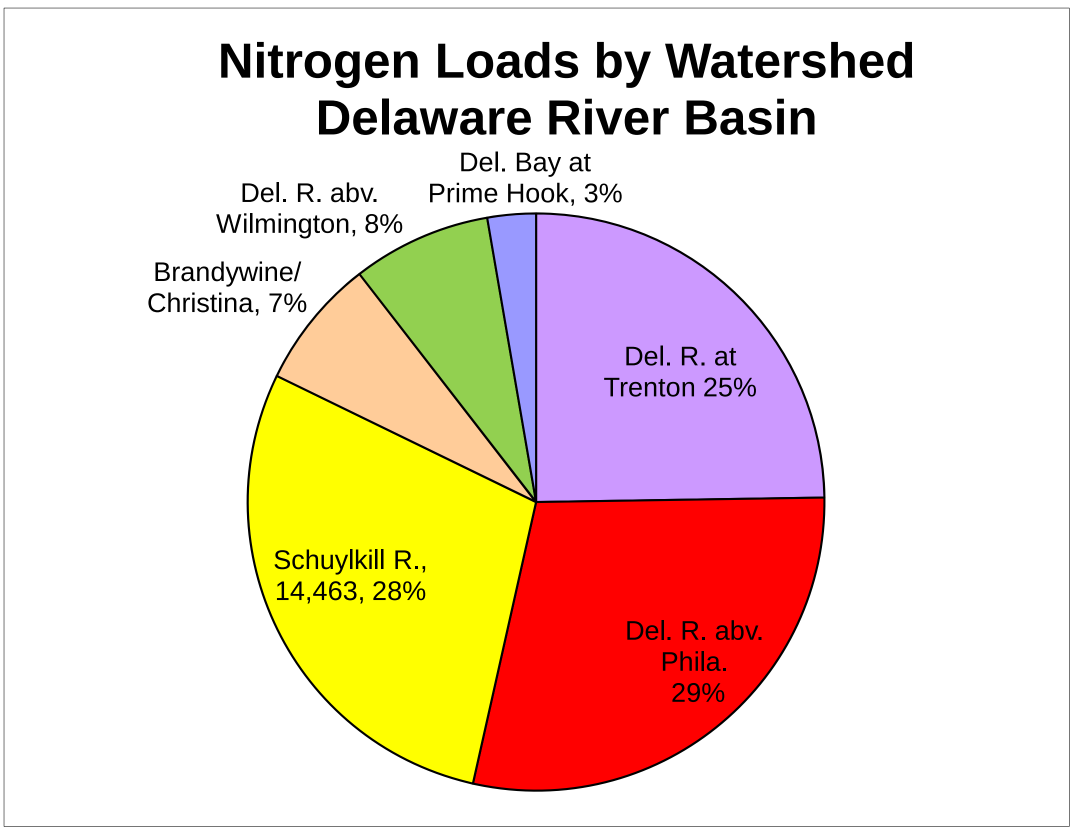


Figure 6.5: Nitrogen loads delivered by watersheds in the Delaware Basin (Moore et al. 2011)

Table 6.9: Nitrogen loads by watershed in the Delaware Basin
(Moore et al. 2011)

Watershed	**Drainage Area (mi^2)**	**Nitrogen Load (ton/yr)**	**Atmospheric Deposition (ton/yr)**	**Wastewater Discharge (ton/yr)**	**Urban/ Suburban (ton/yr)**	**Agriculture (ton/yr)**
Del. R. at Pt. Jervis, NY	3,408	3,051	1,668	134	582	667
Del. R. abv. Easton, Pa.	1,293	2,833	809	178	752	1,093
Lehigh R.	1,357	4,457	877	938	1,102	1,540
Del. R. abv. Trenton	789	2,141	399	400	416	926
Del. R. at Trenton	6,846	12,483	3,753	1,651	2,852	4,227
Del. R. abv. Phila.	1,246	14,510	453	11,930	1,355	772
Schuylkill R.	1,894	14,463	1,085	6,625	1,628	5,124
Brandywine/Christina R.	561	3,684	254	168	408	2,853
Del. R. abv. Wilmington	488	3,925	180	2,650	569	525
Del. Bay at Prime Hook	732	1,370	177	104	103	986
Delaware Basin	**11,767**	**50,434**	**5,903**	**23,129**	**6,915**	**14,487**
Basin/State	**Drainage Area (mi^2)**	**Nitrogen Load (%)**	**Atmospheric Deposition (%)**	**Wastewater Discharge (%)**	**Urban/ Suburban (%)**	**Agriculture (%)**
Del. R. at Port Jervis, NY	3,408	6%	55%	4%	19%	22%
Del. R. abv. Easton, Pa.	1,293	6%	29%	6%	27%	39%
Lehigh R.	1,357	9%	20%	21%	25%	35%
Del. R. abv. Trenton	789	4%	19%	19%	19%	43%
Del. R. at Trenton	6,846	25%	30%	13%	23%	34%
Del. R. abv. Phila.	1,246	29%	3%	82%	9%	5%
Schuylkill R.	1,894	29%	8%	46%	11%	35%
Brandywine/Christina R.	561	7%	7%	5%	11%	77%
Del. R. abv. Wilmington	488	8%	5%	68%	15%	13%
Del. Bay abv. Prime Hook	732	3%	13%	8%	7%	72%
Delaware Basin	**11,767**	**100%**	**12%**	**46%**	**14%**	**29%**

The USGS SPARROW model simulates nitrogen removal rates based on hydrological and biogeochemical processes such as denitrification, particulate settling, water velocity, and depth (Preston et al. 2011). Instream fractional nitrogen removal declines with increased water depth and stream size. The climate influences nutrient delivery to streams as watersheds with lower temperatures and higher precipitation deliver greater nitrogen loads to streams.

The SPARROW model calculates delivery factors such as climate, distance from the estuary, and land use that impact the flow of nitrogen from streams and watersheds to the Delaware Estuary Based on the delivery fraction of nitrogen (i.e. proportion of nitrogen load delivered to the outlet) implementation of best management practices in watersheds closest to the Delaware Estuary would provide the most immediate improvements in water quality (Figure 6.6). The SPARROW model indicates that the delivered yield of nitrogen from watersheds far from the estuary such as the headwaters of the Delaware River in New York State and the upper Lehigh and Schuylkill watersheds are less likely to influence water quality in the Delaware Estuary.

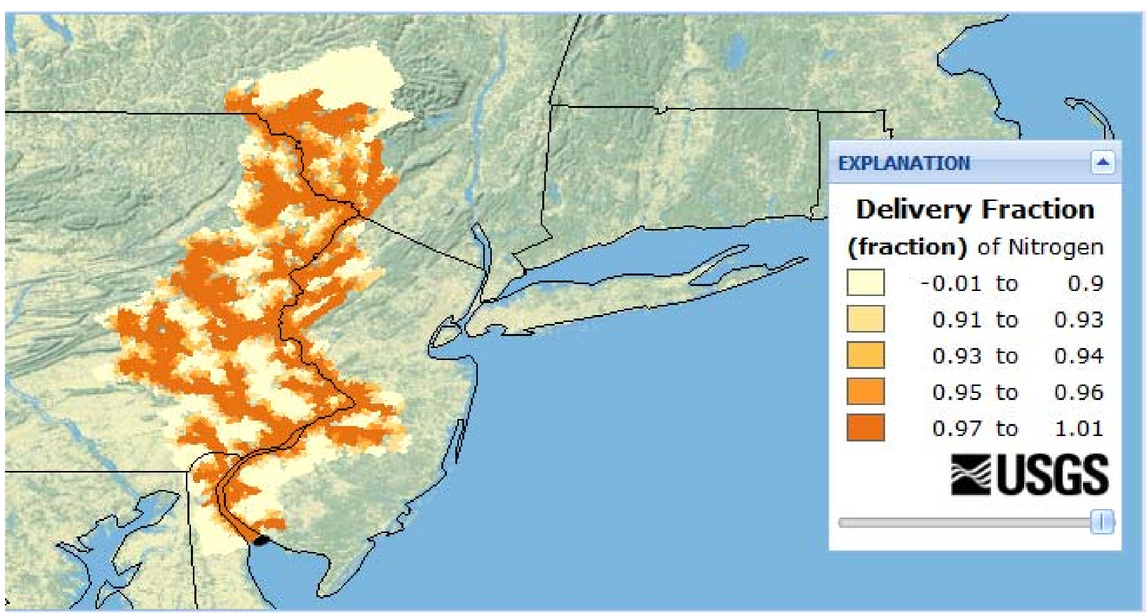


Figure 6.6: Nitrogen delivery fraction to the Delaware River from SPARROW

N Load Reductions: Nutrient load reductions to improve dissolved oxygen in receiving waters are often promulgated by watershed-based Total Maximum Daily Loads (TMDL). The TMDL is the maximum amount of a pollutant that can be discharged to a stream without violating water quality standards. Section 303(d) of the Federal Clean Water Act requires states to develop an impaired streams list every two years as a prioritized list for restoration of water quality during implementation of TMDLs. Section 305(b) of the Federal Clean Water Act requires states to develop TMDLs if a stream or river is listed as impaired (does not meet water quality standards) for a particular pollutant (such as nutrients). The TMDL (lb/yr) is defined as:

TMDL = PS + NPS + FS

Where:

TMDL = Maximum pollutant load without violating stream water quality standards.

PS = Sum of point source pollutant loads from wastewater discharges.

NPS = Nonpoint source loads from atmospheric, agriculture, stormwater sources.

FS = Factor of safety (10% to 25%) to account for monitoring and modeling variance.

Over the last 50 years, a series of water quality models have been developed to simulate the effects of nutrient loads on dissolved oxygen and eutrophication levels in the Delaware Estuary (EPA 2000). During the 1960s, the DRBC utilized one-dimensional estuary models of DO and carbonaceous and nitrogenous BOD. During the 1970s, the Dynamic Estuary Model (DEM) simulated the nitrogen cycle by incorporating variables such as organic nitrogen, ammonia, and nitrate plus nitrite. During the 1980s, DRBC consultants developed a two-dimensional hydrodynamic model (DEM-2D) that built on the earlier one-dimensional model with kinetic coefficients and update waste load allocations. The model was then updated during the 1990s to include eutrophication and nitrogen and phosphorus cycles. This model determined that "better-than-secondary" treatment was necessary to meet a DO standard of 5 mg/l in the Delaware River below Philadelphia. The DRBC is preparing to develop an advanced hydrodynamic model to consider freshwater input, nutrient load, temperature, salinity, and tidal effects on DO in the Delaware Estuary but this effort is years away from completion.

In the lower Delaware Basin, Scatena et al. (2006) surveyed 15 TMDLs issued by EPA that indicated nitrogen loads should be reduced by a median 32% to improve water quality and boost dissolved oxygen in the Delaware River to 5.0 mg/l (Figure 6.7) within confidence intervals of 20% (25^{th} percentile) to 48% N load reduction (75^{th} percentile). For instance, the Brandywine-Christina watershed TMDL model requires a 38% reduction in nitrogen loads to meet a dissolved oxygen water quality standard of 5 mg/l (EPA 2006). Water quality models such as the EPA Water Quality Analysis Simulation Program (WASP), USGS Hydrological Simulation Program-Fortran (HSPF), and Generalized Watershed Loading Function (GWLF) were used to estimate TMDL pollutant load reductions in the lower Delaware Basin.

Unit N Load Reduction Costs: Unit N load reduction costs are transferred from a synthesis of existing reported studies. Nitrogen reduction BMPs available for implementation in the Delaware Basin include point source (PS) controls such as wastewater treatment plants and nonpoint source (NPS) controls for atmospheric deposition, agricultural conservation, and urban/suburban retrofitting (Table 6.10).

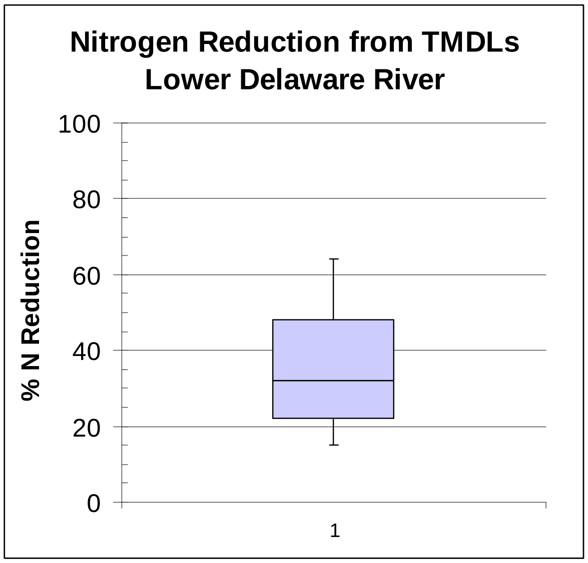


Figure 6.7: Nitrogen reduction from TMDL models in the lower Delaware Basin (Scatena et al. 2006)

Table 6.10: Nitrogen reduction best management practices (EPA 1993)

Nitrogen Source	Best Management Practice
Point Source	
Wastewater Treatment Plant	Nutrient Reduction Technology
Nonpoint Sources	
Atmospheric Deposition	Motor vehicle exhaust controls
	Power/industrial plant scrubbers
Agricultural Conservation	Ag Nutrient Management Plans
	Conservation Tillage
	Cover Crops
	Diversions
	Forest Buffers
	Grass Buffers
	Terraces
Urban/Suburban Stormwater	Extended Detention Pond
	Grass Swale
	Infiltration Basin
	Porous Pavement
	Septic System Replacement
	Stormwater Wetland
	Vegetated Filter Strip
	Wet Detention Pond

Wastewater treatment plants contribute 46% of the nitrogen load to the Delaware Basin. Nitrogen in municipal wastewater is generally composed of ammonia and organic nitrogen that is not often removed by conventional secondary treatment. Nitrogen removal involves biochemical reactions that transform nitrogen from one form to another through nitrification and denitrification. At the tertiary level, nitrifying bacteria biologically convert ammonia to nitrate through nitrification. Nitrate is converted to nitrogen gas using bacteria through denitrification. Wastewater treatment plant upgrades are designed to reduce nitrogen to permitted effluent targets that range between 8 mg/l (least expensive), 5 mg/l (moderately expensive), and 3 mg/l (most expensive). Biological nitrogen removal processes include trickling filter, rotating biological contactor, denitrification filter, and fluidized bed reactor. Reported wastewater treatment nitrogen load reduction costs vary between $8.56 to $27.65/lb N in the Chesapeake Bay watershed, $17.30/lb N in the Connecticut River Basin, and $63.00 to $79.00/lb N in Maine and New Hampshire (Chesapeake Bay Commission 2004, Evans 2008, Jones et al. 2010, Trowbridge 2010).

Airborne sources of nitrous oxide (NOX) contribute 12% of the nitrogen to the Delaware Basin. Airborne nitrogen controls include motor vehicle exhaust controls and power/industrial plant emissions scrubbers required under the 1990 Clean Air Act and its amendments. EPA requires cars and light trucks to meet Tier 2 low emission vehicle (LEV) exhaust standards that allow less than 1% of the tailpipe pollution emitted in the 1960s. In 2005, EPA announced the Clean Air Interstate Rule that incentivized power plants to reduce emissions of SO_2 and NOX through a cap and trade program that built on the success of the U.S. acid rain program. NOX levels have declined due to outfitting coal plants with flue-gas desulfurization scrubbers (FGD), switching to low sulfur coal, installing noncatalytic reduction (SNCR), and more recently converting from coal to cheap, plentiful, and cleaner natural gas from nearby Marcellus shale fields. Airborne deposition nitrogen load reduction costs in the Chesapeake Bay (Table 6.11) range from $75/lb N for Clean Air Act programs (Jones et al. 2010) to $132/lb N for low emission vehicle programs (EPA 1996 and Jones et al. 2010).

Table 6.11 Costs of air pollution controls to reduce nitrogen to the Chesapeake Bay (EPA 1996 and Jones et al. 2010)

Scenario	**Cost ($/lb N)**
Clean Air Act	$75
Sector CZ	$75
Scenario E	$77
Highway Vehicle (LEV)	$132

Agriculture contributes 29% of the nitrogen load to the Delaware Basin. Main agricultural NPS pollutants are nutrients, sediment, animal wastes, salts, and pesticides (EPA 1993). Nutrients include nitrogen and phosphorus loads from crop fertilizers and farm animal manure. Previous studies (EPA 2000, Weiland 2009, Evans 2008, Chesapeake Bay Commission 2004, and Jones et al. 2010) indicate agricultural conservation practices can reduce nitrogen loads by 40% for grass buffers to 90% for cover crops at unit costs that range from $1.20/lb N for forest buffers to $10.11/lb N reduced for cover crops (Table 6.12). Agricultural nutrient management plans can reduce nitrogen by 20% at a cost of $1.66 to $4.41/lb N reduced. Conservation tillage such as no-till cropping can reduce N by 55% at a cost of $1.57 to $3.20/lb N reduced. Winter cover crops such as rye, barley, and wheat reduce N by 90% at a cost of $4.39 to $10.11/lb N. Water diversions are swales that convey stormwater around farm fields that reduce N by 75% at $7.00/lb N. Forest buffers remove 50% of nitrogen at $1.20 to $6.79/lb N. Grass buffers remove 40% of N at $1.67 to 6.76/lb N. Terraces reduce the grade and velocity of runoff and can reduce N loads by 70% at $7.00/lb N reduced.

Table 6.12: Nitrogen reduction best management practices (BMPs) for agriculture (EPA 2000, CBC 2004, Evans 2008, Weiland 2009, and Jones et al. 2010)

Agriculture BMP	**N Load Reduction (%)**	**N Reduction Costs ($/lb N)**
Agricultural Nutrient Management	20%	1.66-4.41
Conservation Tillage	55%	1.57-3.20
Cover Crops (Rye, Barley, Wheat)	90%	2.33-10.11
Water Diversions	75%	7.00
Forest Buffers	50%	1.20-6.79
Grass Buffers	40%	1.67-6.76
Terraces	70%	7.00

Urban/suburban stormwater runoff contributes 14% of the nitrogen load to the Delaware Basin from lawn fertilizers, septic systems, and pet waste. Previous studies indicate that urban/suburban stormwater best management practices have N removal efficiencies that range from 10% for grass swales to 82% for infiltration basins (EPA 1999, EPA 2000, CWP 2000, and USDA undated). BMPs such as wetlands remove significant nitrogen (67%) and also remove up to 78% of bacteria, and 76% of TSS

(Table 6.13 and 6.14). N load reductions in the Delaware Basin that improve dissolved oxygen levels will also reduce bacteria and sediment loads to meet water quality goals for swimmable and water supply uses. Based on the literature, urban/suburban stormwater retrofitting is an expensive option with costs that range from $90 to $500/lb N reduced (EPA 1999, EPA 2000, CBC 2004, Evans 2008, Weiland 2009, USDA, Jones et al. 2010).

Table 6.13: Pollutant removal efficiencies of urban stormwater BMPs (EPA 1999 and CWP 2000)

Pollutant	Dry Pond (%)	Wet Pond (%)	Wetlands (%)	Filter/Bioswale (%)	Infiltration (%)
Bacteria	78	70	78	37	5
Phosphorus	19	51	49	59	70
Nitrate Nitrogen	4	43	67	14	82
Total Susp. Sediment	47	80	76	86	95

Table 6.14: Nitrogen reduction BMPS for urban/suburban stormwater retrofitting (EPA 1999, 2000, CBC 2004, Evans 2008, Weiland 2009, USDA, Jones et al. 2010)

Stormwater BMP	N Load Reduction (%)	N Reduction Costs ($/lb N)
Extended Detention Pond	65%-67%	210
Grass Swale	10%	
Infiltration Basin	60%-82%	
Porous Pavement	65%	
Stormwater Retrofit		90, 137, 200, 500
Stormwater Wetland	20%	
Vegetated Filter Strip	14%-40%	
Wet Detention Pond	35%-43%	104

Nitrogen reduction costs vary from $1.20 to $11.00/lb N for agricultural conservation measures, $8.56 to $79.00 for wastewater treatment, $75.00 to $132.00 for airborne emissions controls, and \$90.00 to \$500.00/lb N for urban/suburban stormwater retrofitting BMPs (Table 6.15).

Table 6.15: Nitrogen reduction costs by source

Location	Source	Atmospheric Deposition (\$/lb N)	Wastewater Treatment (\$/lb N)	Urban/Sub. Retrofit (\$/lb N)	Agriculture BMPs (\$/lb N)
Chesapeake Bay	Jones et al. 2010	75	27.65	200-500	1.20-4.70
New Hampshire	Trowbridge 2010		63.00-79.00		
Connecticut R.	Evans 2008		17.30	137	4.93
Iowa	USDA NRCS			90	2.00-11.00
Chesapeake Bay	Chesap. Bay Comm. 2004		8.56	>100	1.57-4.41
United States	EPA 1996	75-132			
Maryland	Weiland NOAA 2009			104-210	1.57-10.11

Nitrogen Load Reduction Costs: The costs of nitrogen pollution abatement to meet a more stringent DRBC dissolved oxygen standard in the Delaware River are determined by multiplying the required nitrogen load reduction (lb/yr) by per pound N reduction cost in \$2010 for atmospheric NOX reduction (\$75.00/lb), wastewater treatment upgrades (\$28.00/lb), urban/suburban stormwater retrofits (\$200/lb), and agriculture conservation (\$5.00/lb) as shown in Figure 6.8. These values are within the range of the reported unit costs from other watersheds and are utilized in this analysis.

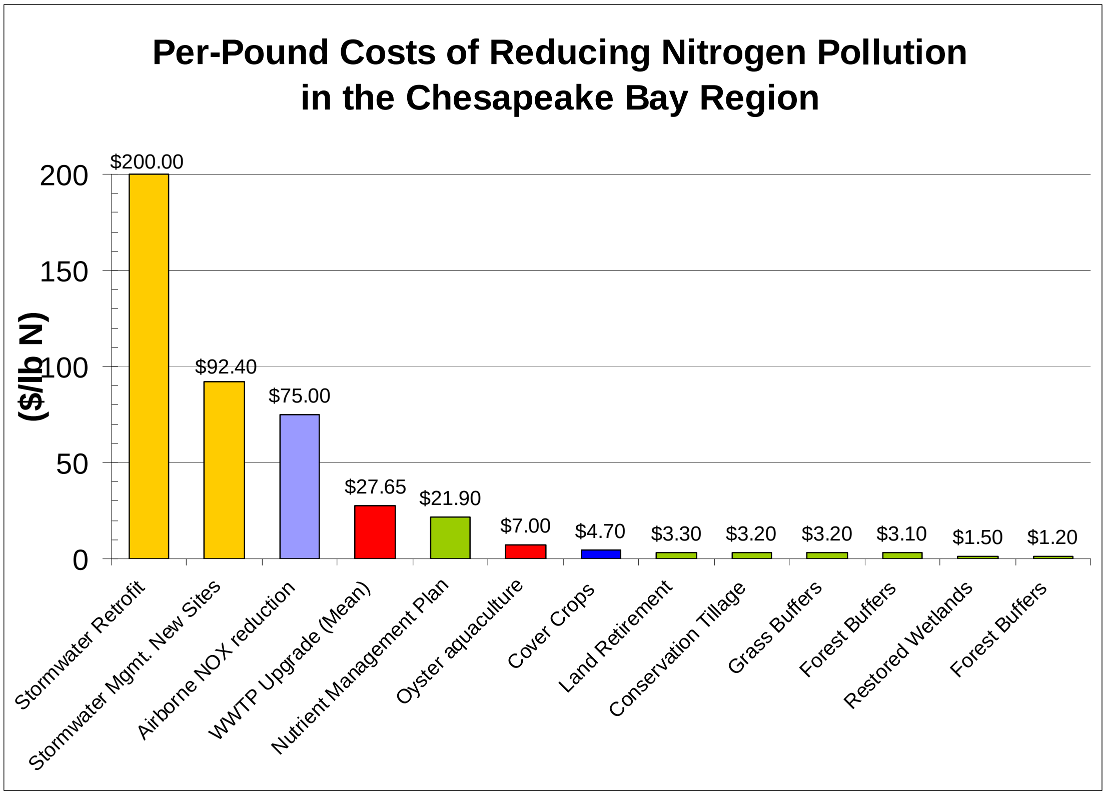


Figure 6.8: Per-pound costs to reduce nitrogen in the Chesapeake Bay Region (Chesapeake Bay Foundation 2010 and World Resources Institute)

Costs are determined to reduce nitrogen loads by a median 32% within a range of 20% (25^{th} percentile) to 48% (75^{th} percentile) from SPARROW model and survey of lower Delaware Basin TMDL models. Costs to reduce nitrogen loads by a median 32% are estimated by maximizing the proportion of N load reductions from the least cost agriculture and wastewater sources according to the following options which range from highest cost (Option 1) to least cost (Option 5).

Option 1 - Reduce nitrogen loads equally from all sources by median 32%.

Option 2 - Reduce agriculture N loads by 32%, wastewater by 47%, atmospheric deposition by 5%, and urban/suburban stormwater by 5%.

Option 3 - Reduce agriculture N loads by 60%, wastewater by 29%, atmospheric deposition by 5%, and urban/suburban stormwater by 5%.

Option 4 - Reduce agriculture N loads by 75%, wastewater by 20%, atmospheric deposition by 5%, and urban/suburban stormwater by 5%.

Option 5 - Reduce agriculture N loads by 90%, wastewater by 10%, atmospheric deposition by 5%, and urban/suburban stormwater by 5%.

Under Option 1, nitrogen loads in the Delaware Basin must be reduced by 16,168 tons/yr (32.3 million lb/yr) to achieve reductions of 32% applied equally to all sources (Table 6.16). Under this uniform load reduction scenario, wastewater N loads must be reduced by 7,437 tons/yr followed by agriculture (4,689 tons/yr), urban/suburban (2,264 tons/yr), and atmospheric reduction (1,940 tons/yr). The estimated cost to reduce N loads evenly by 32% for each source in the Delaware Basin is $1.66 billion/yr with the largest costs borne by urban/suburban stormwater retrofitting ($905 million/yr) which has the highest unit cost $200/lb N followed by wastewater discharge ($416 million/yr, atmospheric NOX reduction ($291 million/yr), and agriculture conservation ($47 million) which has the lowest unit cost of $5/lb N reduced.

To reduce nitrogen equally by 32% from all sources, loads are reduced by 11,690 ton/yr in Pennsylvania, 3,329 ton/yr in New Jersey, 622 ton/yr in New York, 516 ton/yr in Delaware, and 12 ton/yr in Maryland. Annual N reduction costs are $1.2 billion in

Pennsylvania, $317 million in New Jersey, $95 million in New York, $60 million in Delaware, and $700,000 in Maryland.

Table 6.16: Costs to reduce N by 32% from all sources in the Delaware Basin

Basin/State	Area (mi^2)	Nitrogen Reduction (32%) (ton/yr)	Atmospheric Deposition (32%) (ton/yr)	Wastewater Discharge (32%) (ton/yr)	Urban/ Suburban (32%) (ton/yr)	Agriculture Sources (32%) (ton/yr)
Del. Basin	11,819	16,168	1,940	7,437	2,264	4,689
Penna.	5,987	11,690	1,169	5,377	1,637	3,507
New Jersey	2,461	3,329	333	1,765	400	832
New York	2,455	622	342	37	100	149
Delaware	908	516	46	181	103	186
Maryland	8	11	1	0	1	8
Basin/State	**Area (mi^2)**	**Nitrogen Reduction ($ mil/yr)**	**Atmospheric Deposition ($75/lb N/yr) ($ mil/yr)**	**Wastewater Discharge ($28/lb N/yr) ($ mil/yr)**	**Urban/ Suburban ($200/lb N/yr) ($ mil/yr)**	**Agriculture Sources ($5/lb N/yr) ($ mil/yr)**
Del. Basin	11,819	1,660	291	416	905	47
Penna.	5,987	1,166	175	301	655	35
New Jersey	2,461	317	50	99	160	8
New York	2,455	95	51	2	40	1.5
Delaware	908	60	7	10	41	1.8
Maryland	8	0.7	0.1	0	0.5	0.1

By maximizing least cost agricultural and wastewater BMPs and minimizing higher cost airborne emissions and urban stormwater retrofitting BMPs, annual costs to reduce N loads by 32% in the Delaware Basin are cut by more than 300%, from $1.66 billion for Option 1, to $845 million for Option 2 (reduce Ag N by 32%, $652 million for Option 3 (reduce Ag N by 60%), $552 million for Option 4 (reduce Ag N by 75%), to $449 million for Option 5 to reduce Ag N by 90% (Figure 6.9).

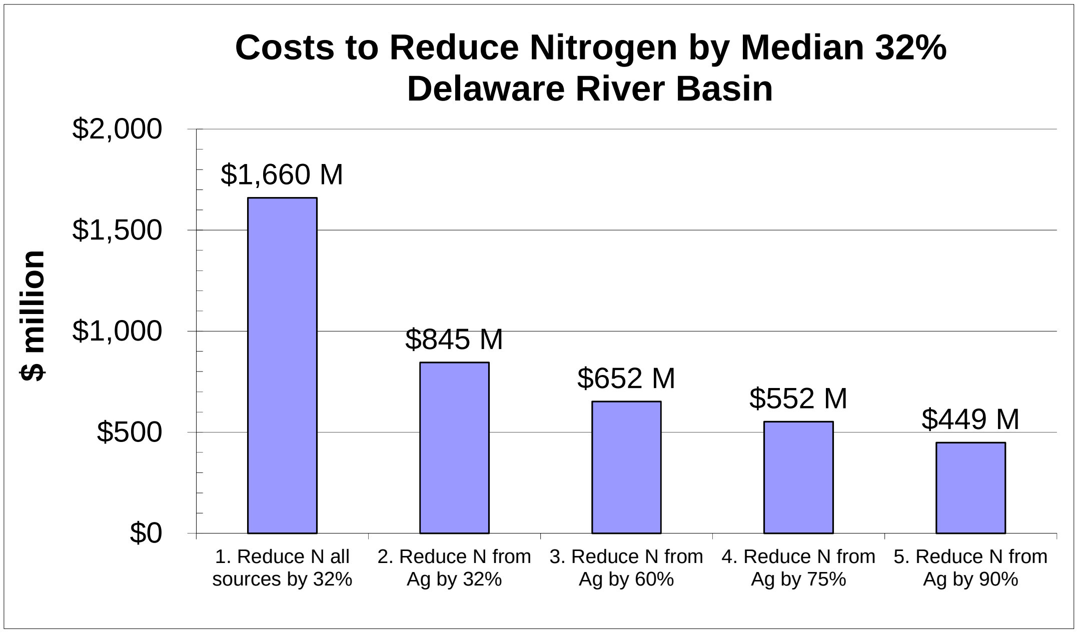


Figure 6.9: Costs to reduce nitrogen loads by 32% in the Delaware Basin

The least cost Option 5 reduces nitrogen loads by a median 32% or 16,168 ton/yr in the Delaware Basin and is achieved by reducing atmospheric NOX by 5%, wastewater by 10%, urban/surburban by 5%, and agricultural loads by 90%. The associated $449 million/yr cost includes $141 million/yr for urban/suburban retrofitting, $132 million/yr for agriculture conservation, $130 million/yr for wastewater treatment, and $45 million/yr for atmospheric NOX reduction (Figure 6.10 and Table 6.17).

Pennsylvania covers half of the Delaware Basin and contributes correspondingly high wastewater and agriculture N loads. Therefore, the Commonwealth's annual cost is the highest of the states at $322 million or 72% of the cost. New Jersey bears $87 million or 19% of the total cost. New York State contributes $19 million or 4% of the N load reduction cost. Delaware assumes $16 million or just less than 4% of the cost. Maryland's share is $300,000 (Figure 6.11).

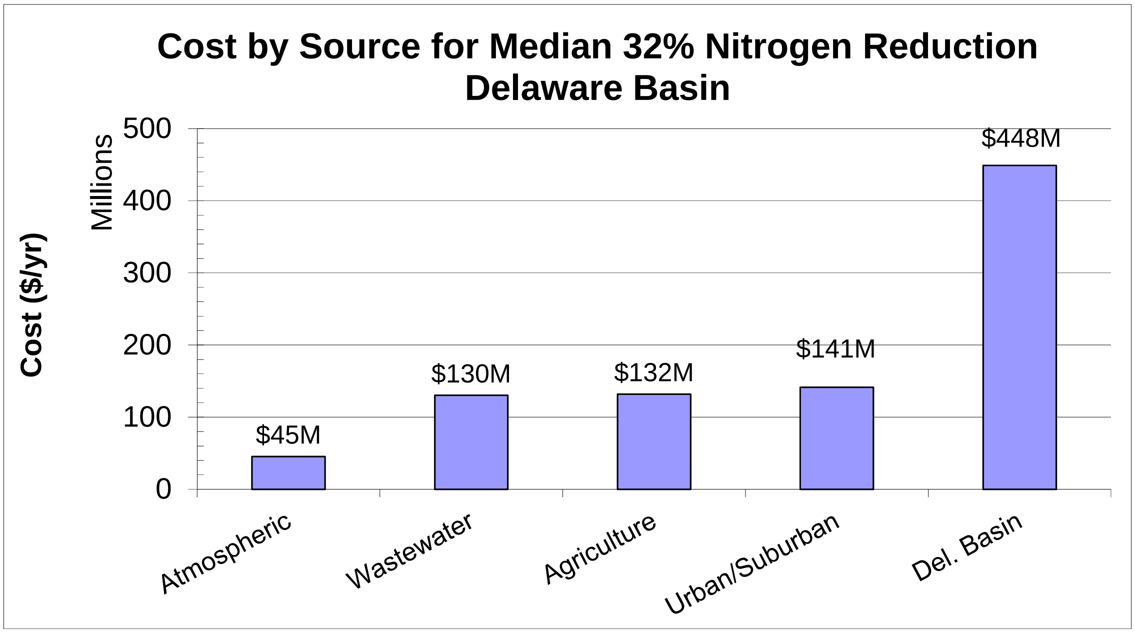


Figure 6.10: Least cost by source to reduce N loads 32% in Delaware Basin

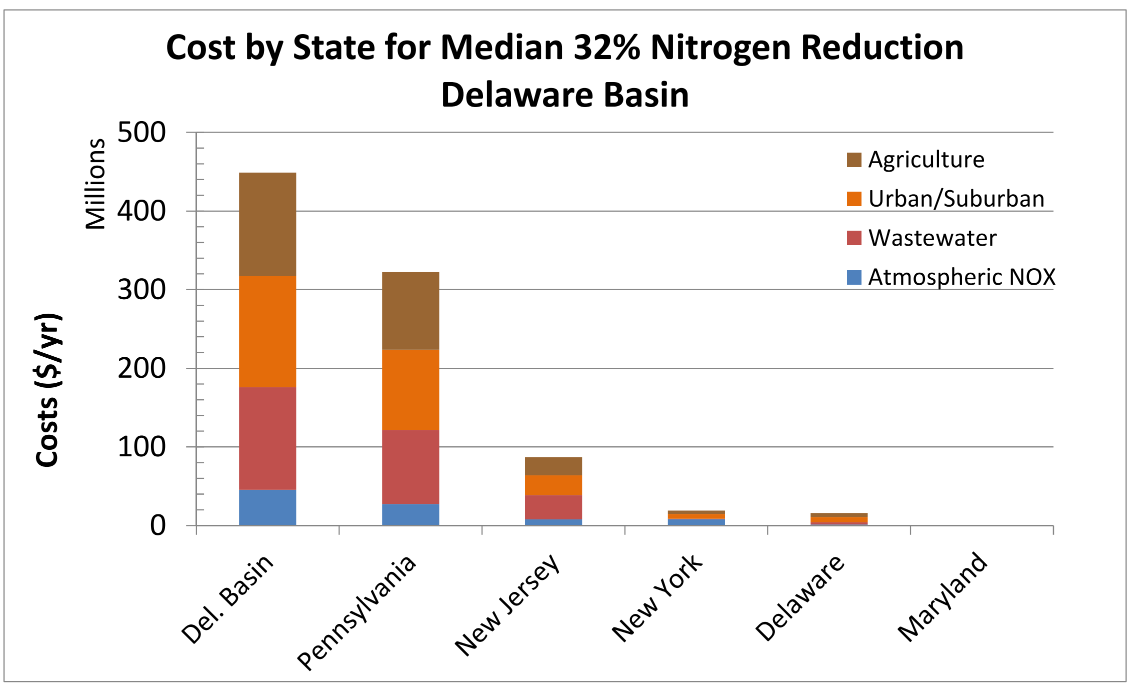


Figure 6.11: Least cost by state to reduce nitrogen loads by 32% in Delaware Basin

Table 6.17: Least cost to reduce nitrogen by 32% in the Delaware Basin

Basin/State	**Drainage Area (mi^2)**	**Nitrogen Reduction (32%) (ton/yr)**	**Atmospheric Deposition (5%) (ton/yr)**	**Wastewater Discharge (10%) (ton/yr)**	**Urban/ Suburban (5%) (ton/yr)**	**Agriculture Conservation (90%) (ton/yr)**
Del. Basin	11,819	16,168	303	2,324	354	13,187
Pennsylvania	5,987	11,982	183	1,680	256	9,863
New Jersey	2,461	3,007	52	551	62	2,341
New York	2,455	501	53	12	16	420
Delaware	908	602	7	56	16	523
Maryland	8	24	0	0	0	24
Basin/State	**Drainage Area (mi^2)**	**Nitrogen Reduction (32%) ($ million/yr)**	**Atmospheric Deposition (5%) ($75/lb/yr) ($ million/yr)**	**Wastewater Discharge (10%) ($28/lb/yr) ($ million/yr)**	**Urban/ Suburban (5%) ($200/lb/yr) ($ million/yr)**	**Agriculture Conservation (90%) ($5/lb/yr) ($ million/yr)**
Del. Basin	11,819	449	45	130	142	132
Pennsylvania	5,987	322	27	94	102	99
New Jersey	2,461	87	8	31	25	23
New York	2,455	19	8	0.6	6	4
Delaware	908	16	1	3	6	5
Maryland	8	0.3	0.02	0	0.08	0.2

The Delaware River above Trenton watershed covers nearly 60% of the basin and contributes 25% of the nitrogen load from predominately agricultural sources with a corresponding N reduction cost of $132 million or 30% of the cost (Table 6.18 and Figure 6.12). The Schuylkill watershed covers 16% of the basin and contributes 30% of the N load mostly from wastewater and agricultural sources with a cost of $124 million or 28% of the cost. The Delaware River watershed between Philadelphia and Trenton covers 10% of the basin and contributes 29% of the N load mostly from wastewater with a cost of $104 million or 24% of the cost. The Brandywine/Christina watershed bears $37 million or 8% of the N load reduction cost where ¾ of the N loads flow from agriculture. The Delaware River watershed between Wilmington and Philadelphia assumes $32 million or 7% of the cost to reduce mostly wastewater N loads. The Delaware Bay watershed between Prime Hook and Wilmington requires $13 million to reduce mostly agricultural N loads from the coastal plain streams on each side of the bay.

Table 6.18: Least cost by watershed to reduce N loads 32% in the Delaware Basin

Basin/State	**Drainage Area (mi^2)**	**Nitrogen Reduction (32%) (ton/yr)**	**Atmospheric Deposition (5%) (ton/yr)**	**Wastewater Discharge (10%) (ton/yr)**	**Urban/ Suburban (5%) (ton/yr)**	**Agriculture Conservation (90%) (ton/yr)**
Del. R. at Pt. Jervis, NY	3,408	726	83	13	29	600
Del. R. abv. Easton, Pa.	1,293	1,080	40	18	38	984
Lehigh R.	1,357	1,579	44	94	55	1,386
Del. R. abv. Trenton	789	914	20	40	21	833
Del. R. at Trenton	6,846	4,299	188	165	143	3,804
Del. R. abv. Phila.	1,246	1,978	23	1,193	68	695
Schuylkill R.	1,894	5,410	54	663	81	4,612
Brandywine/Christina	561	2,618	13	17	20	2,568
Del. R. abv. Wilmington	488	775	9	265	28	473
Del. Bay at Prime Hook	732	912	9	10	5	887
Delaware Basin	**11,767**	**15,992**	**295**	**2,313**	**346**	**13,038**
Basin/State	**Drainage Area (mi^2)**	**Nitrogen Reduction (32%) ($ million/yr)**	**Atmospheric Deposition (5%) ($75/lb/yr) ($ million/yr)**	**Wastewater Discharge (10%) ($28/lb/yr) ($ million/yr)**	**Urban/ Suburban (5%) ($200/lb/yr) ($ million/yr)**	**Agriculture Conservation (90%) ($5/lb/yr) ($ million/yr)**
Del. R. at Pt. Jervis, NY	3,408	31	13	1	12	6
Del. R. abv. Easton, Pa.	1,293	32	6	1	15	10
Lehigh R.	1,357	48	7	5	22	14
Del. R. abv. Trenton	789	22	3	2	8	8
Del. R. at Trenton	6,846	132	28	9	57	38
Del. R. abv. Phila.	1,246	104	3	67	27	7
Schuylkill R.	1,894	124	8	37	33	46
Brandywine/Christina	561	37	2	1	8	26
Del. R. abv. Wilmington	488	32	1	15	11	5
Del. Bay at Prime Hook	732	13	1	1	2	9
Delaware Basin	**11,767**	**442**	**44**	**130**	**138**	**130**

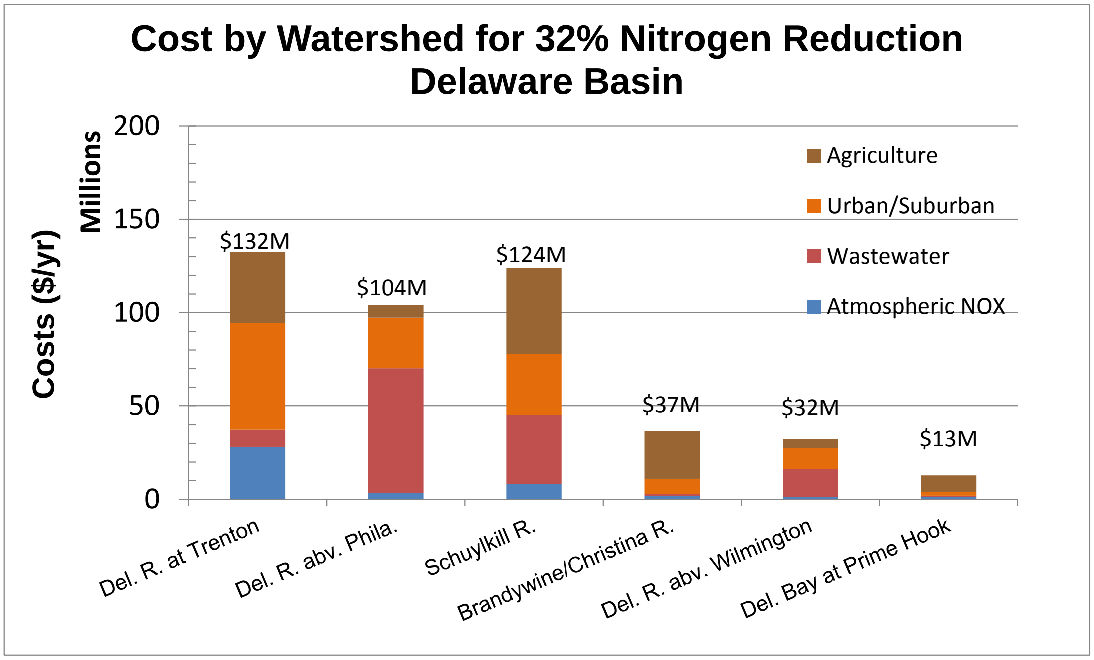


Figure 6.12: Least cost by watershed to reduce N loads 32% in Delaware Basin

Marginal Abatement Costs: Marginal abatement cost curves are constructed to determine the least costs to reduce nitrogen loads by median 32% within a range of 20% (25^{th} percentile) to 48% (75^{th} percentile). The least cost to achieve median 32% reduction in nitrogen loads ($32 million lb/yr) is $449 million/yr within a range of $334 million/yr for 20% ($25^{th}$ percentile) to $904 million/yr for 48% reduction (75^{th} percentile). The MAC curves (Figure 6.13) reveals that 30 million lb/yr of nitrogen can be reduced for $160 million or 90% of the pollutant load can be reduced for 30% of the total cost. The remaining 10% (2 million lb N/yr) requires 70% ($290 million/yr) of the cost.

The N load cost reduction curve is defined by calculating costs in increments ranging from 10% to 90% N load reduction (Tables 6.19, 6.20, 6.21 and Figure 6.14). Least cost agriculture and wastewater treatment reductions are prioritized for implementation first followed by higher cost atmospheric deposition and urban suburban stormwater runoff controls. After the low cost agricultural BMPs are implemented, nitrogen reduction in the Delaware Basin becomes incrementally less cost-effective after 30% N reduction as the slope of the cost curve steepens with increasingly more expensive investments in more costly wastewater, atmospheric and urban/suburban controls.

Table 6.19: Least cost by state to reduce nitrogen by 32% in the Delaware Basin

State/Basin	Drainage Area (mi^2)	Nitrogen Load (ton/yr)	Nitrogen Load (%)	Nitrogen Reduction (32%) (ton/yr)	Nitrogen Reduction (%)	Nitrogen Reduction Cost ($ million/yr)	Nitrogen Reduction Cost (%)
Delaware Basin	11,819	50,525	100%	16,168	100%	449	100%
Pennsylvania	5,987	36,531	72%	11,982	74%	322	72%
New Jersey	2,461	10,404	21%	3,007	19%	87	19%
New York	2,455	1,944	4%	501	3%	19	4%
Delaware	908	1,613	3%	602	4%	16	4%
Maryland	8	33	0%	24	0.1%	0.3	0.1%

Table 6.20: Least cost by watershed to reduce nitrogen by 32% in the Delaware Basin

State/Basin	Drainage Area (mi^2)	Nitrogen Load (ton/yr)	Nitrogen Load (%)	Nitrogen Reduction (32%) (ton/yr)	Nitrogen Reduction (%)	Nitrogen Reduction Cost ($ million/yr)	Nitrogen Reduction Cost (%)
Del. R. at Pt. Jervis, NY	3,408	3,051	6%	726	5%	31	7%
Del. R. abv. Easton, Pa.	1,293	2,833	6%	1,080	7%	32	7%
Lehigh R.	1,357	4,457	9%	1,579	10%	48	11%
Del. R. abv. Trenton	789	2,141	4%	914	6%	22	5%
Del. R. at Trenton	6,846	12,483	25%	4,299	27%	132	30%
Del. R. abv. Phila.	1,246	14,510	29%	1,978	12%	104	24%
Schuylkill R.	1,894	14,463	29%	5,410	34%	124	28%
Brandywine/Christina R.	561	3,684	7%	2,618	16%	37	8%
Del. R. abv. Wilmington	488	3,925	8%	775	5%	32	7%
Del. Bay at Prime Hook	732	1,370	3%	912	6%	13	3%
Delaware Basin	**11,767**	**50,434**	**100%**	**15,992**	**100%**	**442**	**100%**

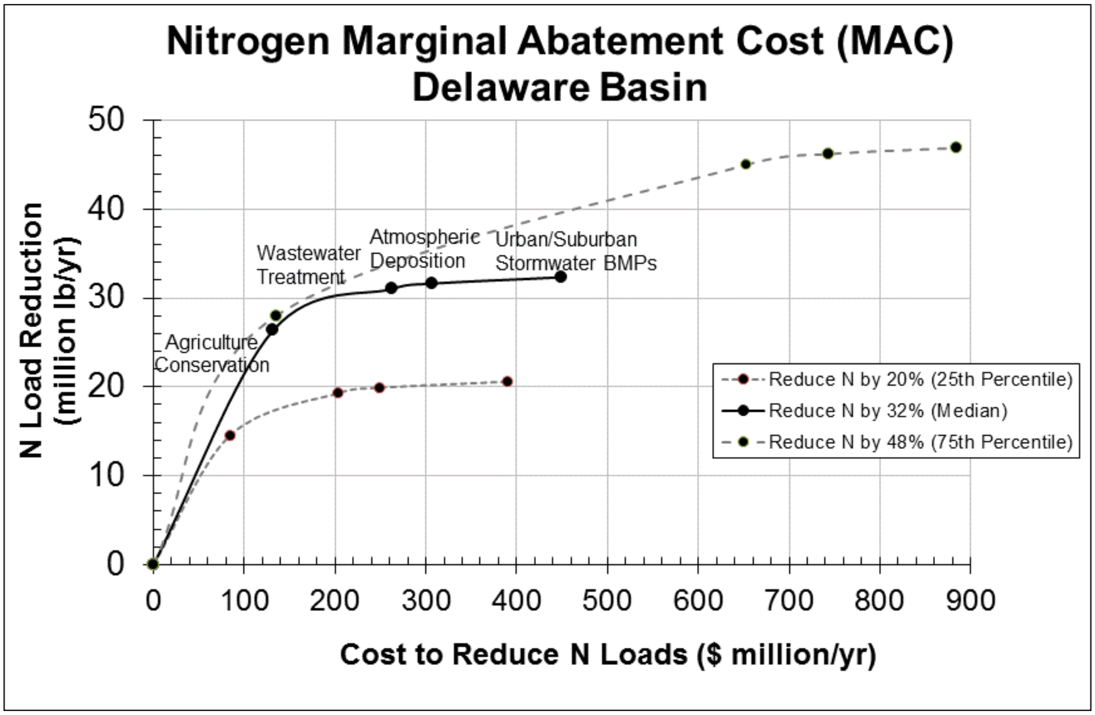


Figure 6.13: Nitrogen marginal abatement cost curves for the Delaware Basin

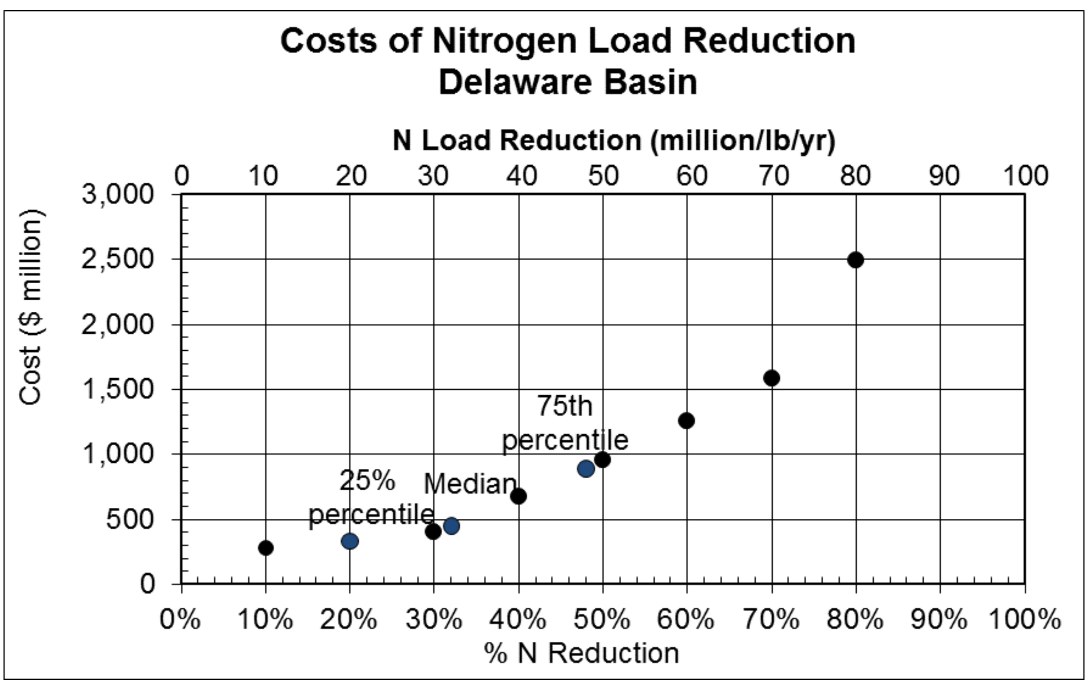


Figure 6.14: Nitrogen reduction cost curve for the Delaware Basin in $2010

Table 6.21: Costs to reduce nitrogen loads by 10% to 90% in the Delaware Basin

N Reduction Option	Atmospheric Deposition	Wastewater	Urban/ Suburban	Agriculture	Total
10% Reduction N	0.05	0.05	0.05	0.25	0.10
N Reduction (million lb/yr)	0.6	2.3	0.7	6.4	10.1
Unit Cost ($/lb N/yr)	75	28	200	5	
Cost ($ million/yr)	45	65	142	32	284
20% Reduction N	0.05	0.05	0.05	0.56	0.20
N Reduction (million lb/yr)	0.6	2.3	0.7	16.4	20.0
Cost ($ million/yr)	45	65	142	82	334
30% Reduction N	0.05	0.06	0.05	0.90	0.30
N Reduction (million lb/yr)	0.6	2.8	0.7	26.4	30.5
Cost ($ million/yr)	45	78	142	132	397
40% Reduction N	0.05	0.27	0.05	0.90	0.40
N Reduction (million lb/yr)	0.6	12.6	0.7	26.4	40.2
Cost ($ million/yr)	45	351	142	132	670
50% Reduction N	0.05	0.49	0.05	0.90	0.50
N Reduction (million lb/yr)	0.6	22.8	0.7	26.4	50.5
Cost ($ million/yr)	45	638	142	132	957
60% Reduction N	0.05	0.72	0.05	0.90	0.60
N Reduction (million lb/yr)	0.6	33.5	0.7	26.4	61.1
Cost ($ million/yr)	45	937	142	132	1,256
70% Reduction N	0.15	0.90	0.05	0.90	0.70
N Reduction (million lb/yr)	1.8	41.8	0.7	26.4	70.7
Cost ($ million/yr)	136	1,171	142	132	1,581
80% Reduction N	0.90	0.90	0.13	0.90	0.80
N Reduction (million lb/yr)	10.9	41.8	1.8	26.4	81.0
Cost ($ million/yr)	819	1,171	368	132	2,490

6.5 Discussion and Conclusions

A synthesis of existing TMDL models by Scatena et al. (2006) suggests that nitrogen loads should be reduced by a median 32% (median) within a range of 20% (25^{th} percentile) to 48% (75^{th} percentile) to increase DO levels from the current DRBC criteria (3.5 mg/l) to a future standard (5.0 mg/l) in the Delaware River. I evaluated several cost scenarios and found the least cost (Option 5) reduces nitrogen loads by a median 32% (32 million lb/yr)) in the Delaware Basin by reducing atmospheric NOX by 5%, wastewater by 10%, urban/suburban by 5%, and agricultural loads by 90%. Annual costs range from \$334, \$449, and \$904 million to reduce nitrogen loads by 20% (25^{th} percentile), 32% (median), and 48% (75^{th} percentile), respectively. The annual least cost to reduce N loads by 32% in the Delaware Basin is \$449 million including \$141 million for urban/suburban retrofitting, \$132 million for agriculture conservation, \$130 million for wastewater treatment, and \$45 million for atmospheric NOX reduction.

Pennsylvania covers over half of the Delaware Basin and contributes correspondingly high wastewater and agriculture N loads. Therefore, the Commonwealth's annual share is \$322 million or 72% of the total cost. New Jersey bears \$87 million or 19% of the total cost. New York State would contribute \$19 million or 4% of the N load reduction cost. Delaware would assume \$16 million or a just less than 4% of the cost. Maryland's share would be \$337,000.

The Delaware River at Trenton contributes 25% of the nitrogen load from predominately agricultural sources with a corresponding N reduction cost of \$132 million or 30% of the total cost. The Schuylkill contributes 30% of the N load mostly from wastewater and agricultural sources with a cost of \$124 million or 28% of the total cost. The Delaware River watershed between Philadelphia and Trenton contributes 29% of the N load mostly from wastewater with a cost of \$104 million or 24% of the total cost. The Brandywine/Christina watershed bears \$37 million or 8% of the N load reduction cost where over ¾ of the N loads flow from agriculture. The Delaware River watershed between Wilmington and Philadelphia assumes $32 million or 7% of the cost to reduce mostly wastewater N loads. The Delaware Bay watershed between Prime Hook and Wilmington would require $13 million to reduce mostly agricultural N loads from the coastal plain streams on either side of the bay.

The marginal abatement cost (MAC) curve defines the most cost effective combination of nitrogen reduction strategies to improve DO to a future DRBC standard to provide year-round propagation of anadromous fish. Least cost agriculture and wastewater treatment reductions would be maximized first followed by higher cost atmospheric deposition and urban suburban runoff controls. After less costly agricultural and wastewater BMPs are implemented, nitrogen reduction in the Delaware Basin becomes incrementally less cost-effective after 30% N reduction as the slope of the cost curve flattens with increasingly higher investments in more costly wastewater, atmospheric and urban/suburban controls with lower reductions in pollutant load.

Based on the nitrogen MAC curve for least cost Option 5, 90% (30 million lb) of nitrogen can be removed for just 35% ($160 million) of the $449 million cost to reduce nitrogen loads. The remaining 10% (2 million lb N/yr) of the N load reduction will require 65% ($290 million/yr) of the total cost.

Based on the delivery fraction of nitrogen (i.e. fraction of nitrogen load delivered to the outlet) implementation of best management practices in watersheds closest to the Delaware Estuary would provide the most immediate improvements in water quality. The SPARROW model indicates that the delivered yield of nitrogen from watersheds far from the estuary such as in the headwaters of the Delaware River in New York State and the upper Lehigh and Schuylkill basins are less likely to influence dissolved oxygen levels in the Delaware Estuary. BMPs should be cost effectively invested in watersheds with the highest incremental delivered yield of nitrogen (Figure 6.15).

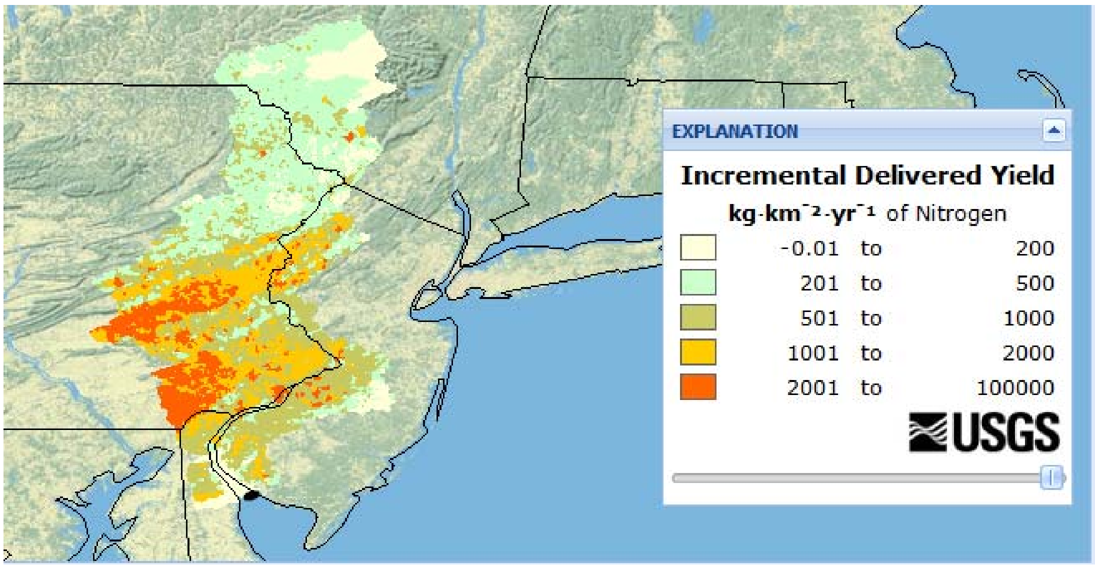


Figure 6.15: Delivered nitrogen yield to Delaware Basin from SPARROW

The SPARROW model estimates mean annual nitrogen loads for flow and land use conditions for a 2002 base year and does not model loads in a more frequent daily or monthly simulation format. Since annual cost estimates are utilized in this dissertation, mean annual loads from the SPARROW model are adequate for this research. Future work should be conducted to update the SPARROW nitrogen load model to more current flow and land use conditions.

The SPARROW model does not account for direct contributions of nitrogen from groundwater to the estuary. It is likely that nitrogen loads to the Delaware Estuary are underestimated in this analysis.

There is a question about whether the first-order process parameterization of in-stream N removal is valid in streams with high nitrogen loads. A higher order process model would be required to address this concern.

Five different hydrodynamic models for the Delaware River exist dating back to the 1960s, however, these models are outdated. A new DRBC unsteady flow hydrodynamic pollutant load and receiving water model that can be used to estimate nitrogen load reductions and changes in water quality in the Delaware Estuary in a more precise format is years away from completion. In the absence of this new hydrodynamic model, nitrogen load reductions were estimated from a synthesis of Total Maximum Daily Load (TMDL) models for the lower Delaware River. These TMDL models indicate that a median 32% reduction in nitrogen is needed within confidence intervals of 20% N reduction (25th percentile) and 48% N reduction (75th percentile). This nitrogen load and cost analysis should be updated when the new DRBC hydrodynamic model is available the next few years.

When not available from case studies in the Delaware Basin, unit nitrogen load reduction costs for the various point and nonpoint sources were adapted through value transfer from a synthesis of the literature from the Chesapeake Bay, New Hampshire, Connecticut River/Long Island Sound, and other watersheds in the United States. Future research should be conducted to compile nitrogen load reduction costs for BMP case studies within the watersheds of the Delaware Basin.

Nitrogen reductions via groundwater transport from agriculture and urban/suburban sources could have a delayed effect on water quality improvement in the

Delaware Estuary. The USGS reported that along the Chesapeake Bay, about 50 percent of nitrogen delivery from nitrogen is through groundwater and groundwater travel time to the estuary ranges from 1 to 50 years with a median of 10 years. Groundwater travel times vary based on the location in the watershed, topography, and physiographic province. For instance groundwater travels more rapidly in the hilly, rocky Piedmont and Ridge and Valley physiographic provinces to the north in the Delaware Basin compared to relatively slow travel times in the flat, sandy Coastal Plain to the south near the bay.

Nitrogen reductions from wastewater treatment and airborne emissions controls and urban/suburban and agricultural surface water control measures, particularly in the hilly, rocky physiographic provinces above the Fall line to the north are expected to have a relatively immediate benefit on water quality in the Delaware River. Nitrogen reduction via groundwater from urban/suburban and agricultural recharge BMPs may have a delayed effect on improved water quality that lags for years after implementation (Table 6.22). Additional geographically resolved hydrodynamic modeling with explicit inclusion of groundwater transport is needed to address this quantitatively.

Table 6.22: Influence of travel time on water quality in the Delaware River

Nitrogen Source Control	**Coastal Plain**	**Piedmont Province**	**Ridge and Valley**	**Appalachian Plateau**
Airborne Emissions	Immediate	Immediate	Immediate	Immediate
Wastewater Treatment	Immediate	Immediate	Immediate	Immediate
Urban/Suburban BMPs				
Surface Water Runoff	Months	Immediate	Immediate	Immediate
Groundwater Recharge	Years	Months to years	Months	Months
Agriculture Conservation				
Surface Water Runoff	Months	Immediate	Immediate	Immediate
Groundwater Recharge	Years	Months to years	Months	Months

Chapter 7

BENEFITS

7.1 Introduction

Now that the annual costs of pollutant load reductions have been computed, what are the economic benefits of improved water quality under the water rights system afforded by the Delaware River Basin Compact?

This chapter estimates the economic benefits of improved water quality for recreation, boating, fishing, fish/wildlife-viewing, property value, agriculture, navigation and water supply uses in the Delaware Basin. Nitrogen load reductions by 32% are projected to increase dissolved oxygen levels from 3.5 mg/l (existing) to a future more protective DRBC standard in the Delaware River and boost boating and fishing trip expenditures, raise property values, and reduce water treatment costs. The economic value of improved water quality in the Delaware River is defined by marginal benefits or the change in benefits as water quality improves from the current condition (DO = 3.5 mg/l) to a future condition (DO = 5.0 mg/l).

7.2. Literature Review

Nature's assets have often been thought of as free (Daily and Allison 2002). Since water is not traded on the open market, its price often does not represent a true value to consumers. Odum (1998) wrote that the pricing system is incomplete in protecting the natural environment and called for accounting of external values previously thought to be free (such as water) to provide a total valuation of nature. Many goods and services provided by rivers are not traded in the marketplace and it is difficult to calculate prices based on market transactions. As markets rarely exist in water pollution, environmental economists define benefits from changes in well-being due to improved water quality using the willingness to pay (WTP) approach (Thacher et al. 2011).

The concept of placing a dollar value on a natural resource goes back almost a century to economists Arthur Pigou in 1920 and John Hicks in 1939 who first outlined that individual preferences are based on one's willingness to pay for benefits (Kramer 2005). Willingness to pay for improved water quality in the Delaware River was first established for industrial, municipal, and recreational fishing, boating, and swimming uses during the 1960s (Hjalte et al. 1977). Studies of nonmarket goods and services in U.S. freshwater systems were published in just 30 refereed articles from 1971 to 1997 (Wilson and Carpenter 1999). Publications focusing on ecosystem services grew from 255 articles in 1997 to 3,080 in 2007 (Searle and Cox, 2009).

Marginal benefits are defined as the incremental change in value resulting from an improvement in an ecosystem service such as water quality (Dixon et al. 1994). The intersection of the marginal cost and marginal benefits curve defines a cost-effective level of water quality in the river (Figure 7.1). The downward sloping demand curve delineates marginal benefits as the WTP for an additional unit of water quality (Koteen, Alexander, and Loomis 2002).

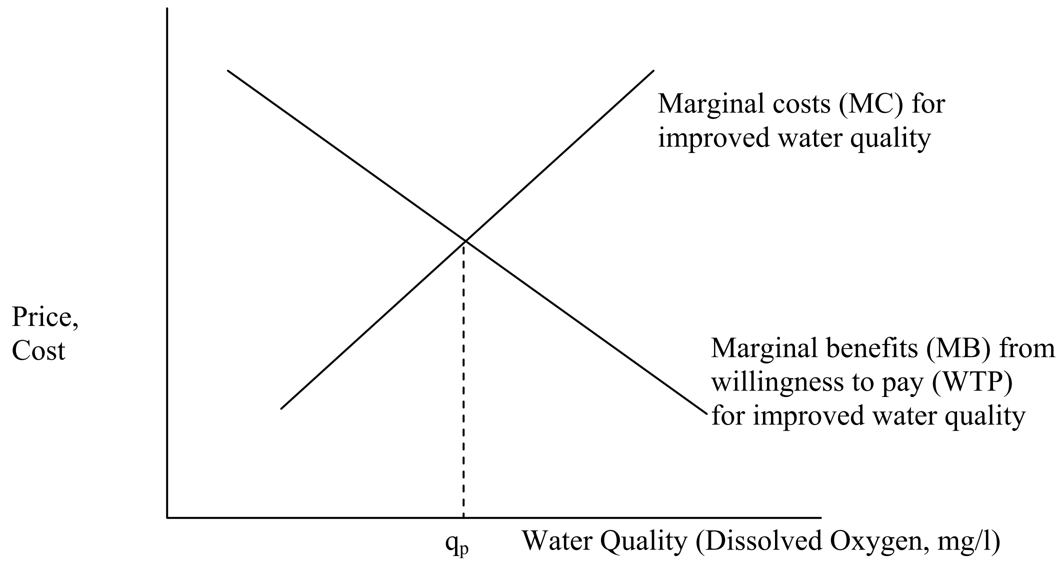


Figure 7.1: Optimal water quality (Hjalte et al. 1977)

Economic benefits are the maximum dollar value of goods and services that individuals are voluntarily willing to pay for improved water quality (Cech 2005). In environmental economics, WTP measures how much people are willing to pay for a given good or service regardless of whether they actually pay or not (Goulder and Kennedy 1997). Consumer surplus is the area under the demand (marginal benefit) curve above its price (or value) measured by the difference between the amount individuals actually pay and the amount they are willing to pay for a benefit such as clean drinking water or enhanced fishing due to improved water quality (Figure 7.2). That is, consumer surplus is the amount people are willing to pay above the price they pay for it (Thurston et al. 2009). If an individual is willing to pay $6.00 per 1000 gallons for drinking water and the price is $5.00, the consumer surplus is $1.00.

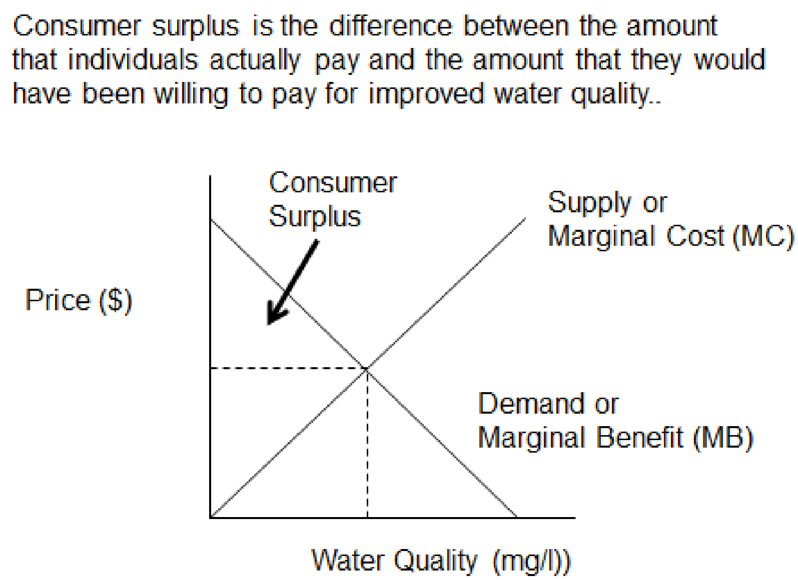


Figure 7.2: Consumer surplus as willingness to pay for improved water quality

The benefits of improved water quality are difficult to assess due to externalities, the free rider effect, and lack of property rights. Traditionally, economics has dismissed negative externalities such as water pollution that may harm people who do not receive compensation. River users are often affected by externalities such as the uncompensated side effects of water pollution. For instance, if the Delaware River is polluted by an upstream industrial discharge in the Schuylkill watershed, then downstream residents in Philadelphia may be harmed by this negative externality because they are not compensated for impaired drinking water quality or reduced boating and fishing activity. To compensate downstream river users for damages, the benefits of improved water quality are compared to costs of runoff reduction to determine the appropriate fees that would provide incentives for the discharger to reduce pollution. Internalization of externalities through a river basin organization such as the DRBC has been touted as a way to set up a system of fair pricing and payment. A free rider is an individual such as a canoe livery who values and benefits from a public good such as improved water quality but does not pay to protect the watershed (Thurston et al. 2009).

When property rights are not clearly defined, the water resource may be overused with no incentive to conserve it. In contrast to the value of land which is more precisely defined as properties are bought and sold in the real estate market, the value of water is not easily quantified due to weak property rights (Libecap 2005). Because water flows, it is not easy to define the property boundaries of this resource. As water supplies become scarce during drought, users compete for less water and conflicts intensify. It is also difficult to measure the flow of water, therefore it is hard to define its economic value.

The dilemma inherent in defining the economic value of water goes back two and a half centuries to the 1776 *Wealth of Nations* when Adam Smith first describing the diamond-water paradox (EPA 2012). If water is so valuable to society, then why is the price of a diamond so high and the price of water so low? The answer was later found to lie in the supply and demand curve which illustrates the costs of producing a good and the benefits that the good provides. Since diamonds are exceedingly rare, their price is correspondingly high. When water is plentiful and pure, the cost of delivering a million gallons of water and the benefits derived from using that water are low, therefore the price of water is low. When water is less abundant such as during drought or in a polluted river, individual willingness to pay for each additional gallon increases and the price of water rises. The opportunity cost of water is low when supply is plentiful but it significantly rises when the supply dwindles.

The diamond-water paradox points out a significant challenge in water resources management in the United States - that the value of water and the prices charged to utilize this resource do not reflect the full opportunity cost at its highest use. Consumers pay for the right to use the water at its average cost when water is abundant and not at its highest value for all uses (not just drinking water) based on its scarcity value. Water is undervalued compared to its highest and best opportunity cost, therefore, governments are inclined to underinvest in water resources and water pollution control programs.

Federal, state, and local water pollution control programs authorized by the 1972 and 1977 Clean Water Act Amendments have improved water quality with annual national benefits of $11 billion (Bingham et al. 2000). The gross domestic product (GDP) in 2004 for coastal and estuary tourism and recreation goods and services was $69.7 billion (Pendleton undated). Leeworthy and Wiley (2001) found that the three coastal states in the Delaware Basin (New Jersey, New York, and Delaware) ranked 4th, 7th, and 19th among the United States in coastal and estuary based recreation activity (Table 7.1). Millions of jobs in the fishing, shipping, tourism, and transportation industries rely on coastal and estuary resources (Table 7.2) according to statistics from the U.S. Bureau of Labor Statistics (NOEP 2010).

Table 7.1: Coastal and estuary recreation in the states of the Delaware Basin (Leeworthy and Wiley 2001)

State	**Participation (% US pop.)**	**Participants in State**	**National Rank**
New Jersey	3.02	6,224,769	4
New York	2.67	5,503,395	7
Delaware	1.05	2,168,108	19

Table 7.2: Industries in the coastal/estuary economy (NOEP 2010)

Sector	Industry	NAICS Code
Construction	Marine Construction	237120, 237990
Living Resources	Fishing	
	Fish Hatcheries and Aquaculture	112511, 112512
	Seafood Markets	445220
	Seafood Processing	311711, 311712
Offshore Minerals	Limestone, Sand and Gravel	212321, 212322
	Oil and Gas Exploration/Production	211111, 213111, 213112
Ship/Boat Building	Boat Building and Repair	336611
	Ship Building and Repair	336612
Tourism/Recreation	Amusement and Recreation Services	611620, 532292, 713990
	Boat Dealers	441222
	Eating and Drinking Places	722110, 722211, 722212
	Hotels and Lodging Places	721110, 721191
	Marinas	713930
	Recreation Vehicle Parks/Campgrounds	721211
	Sporting Goods Retailers	339920
	Zoos, Aquaria	712130, 712190
Transportation	Deep Sea Freight Transportation	483111, 483113
	Marine Passenger Transportation	483112, 483114
	Search and Navigation Equipment	334511
	Warehousing	4931100, 493120, 493130

Ecological valuation studies have found the benefits of improved water quality in the U.S. ranges from \$0.8 to \$42.3 billion per year (Table 7.3). Freeman (1990) estimated that improving water quality by one step supplied national municipal/industrial water treatment and commercial fishing benefits of \$5.2 billion. EPA (1994) utilized WTP data from Carson and Mitchell (1993) and concluded the benefits of President Clinton's Clean Water Initiative in urban areas would be \$0.8-\$6.0 billion. Bingham (1995) estimated annual national benefits of the Clean Water Act Amendments of 1972/1977 were \$11 billion from the increase in human well-being and services from improved water quality. Carson and Mitchell (1993) estimated national benefits of $39.1 billion based on a contingent valuation study that asked individuals how much they would be willing to pay to improve water quality from boatable to fishable to swimmable uses. Freeman (1982) found improved water quality due to the 1972 Clean Water Act provided commercial use and marine recreation benefits of $8.2-$39.6 billion. Brown (2004) from the U.S. Forest Service estimated annual economic value of stream flow in the lower 48 states was $42.3 billion in $2003. Most of these studies combine methods of economic valuation and sum the benefits of different uses.

Table 7.3: 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	0.8-6.0	Pres. Clinton's Clean Water Initiative
U.S.	Bingham 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

Annual benefits of improved water quality in the Willamette River Basin ranged from $120-$260 million when boatable, fishable, and swimmable uses increased by 4.8%-7.5% from 1970 to 1990 (EPA 2002).

In May 2009, President Barack Obama issued Executive Order 13508 that brought renewed emphasis by the EPA and others to define the costs and benefits of cleaning up the Chesapeake Bay to comply with 2017 and 2025 deadlines. Morgan and Owens (2001) established that reduced nutrient loads would improve water quality in the

Chesapeake Bay and provide $358 million to $1.8 billion in recreational boating, fishing, and swimming benefits to District of Columbia, Maryland, and Virginia residents. Cropper and Isaac (2011) concluded that complying with nitrogen TMDLs under the President's Executive Order would improve Bay water quality and raise waterfront property values, boost recreational fishing, swimming and commercial fishing benefits, and provide significant nonuse benefits to people who may never visit the bay but care about its preservation for existing and future generations.

In May 2012 the EPA National Center for Environmental Economics announced plans to conduct a survey of the public willingness to pay for improved water quality in the Chesapeake Bay to comply with TMDLs under the Clean Water Act. Benefits will be estimated through a stated preference survey of 1,500 people who live near the bay together with people who live far away from the bay and may never visit the bay but value the resource. The TMDL restoration calls for 100% reduction by 2025, with a 60% reduction goal by 2017. Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia, and the District of Columbia, have developed watershed implementation plans (WIPs) to comply with the Chesapeake Bay TMDLs.

The economic benefits from improved water quality are defined by the sum of use and nonuse values (Figure 7.3). Use values include direct market benefits such as sales 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 may accrue from the increased value of properties along a restored river and waste assimilation services by wetlands and forests (EPA 2012). Nonuse values are defined as

WTP by individuals 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 and Foster 2008).

Use benefits are directly measured from market prices for fish and water and by revealed preference methods such as travel cost and hedonic models. Use values are derived from the prices of goods such as fish and drinking water and by observing trip and expenditure costs for recreational boating, fishing, and swimming (Kramer 2005). 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.

Nonuse values include existence and bequest values from stated preference studies and contingent valuation 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). A person may be willing to pay to protect the Delaware River even though she never expects to visit it. Bequest value is the value that people place on knowing the river is protected so future generations may enjoy it.

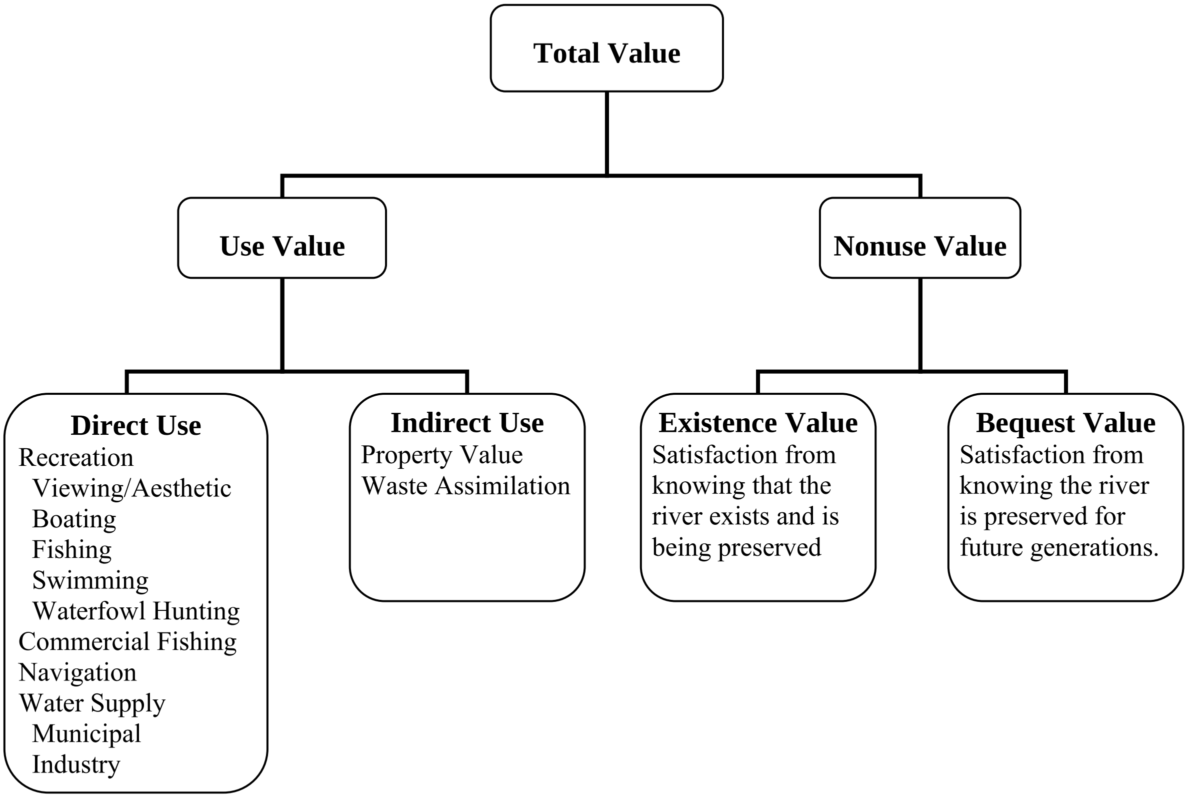


Figure 7.3: Economic benefits of improved water quality in the Delaware Basin

Benefit-cost analyses that rely solely on use benefits may underestimate total benefits because nonuse values can be significant (Loomis 2006). Because nonuse values rely on individual opinions or stated preferences and not hard market data, they 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 has observed “If everyone in the watershed has a small value for the restoration of the Bay, it ends up being a big number." Nonuse benefits were allowed in court to settle the 1989 Exxon Valdez oil spill in Alaska and can significantly exceed use (market) values but are difficult to quantify (Brown 2004).

The nonmarket value of recreation is often overlooked in watershed and estuary policymaking. Markets do not adequately define economic benefits of improved water quality, therefore, environmental economists have defined nonmarket revealed preference and stated preference methods such as travel cost, hedonic pricing, and contingent valuation (Wilson and Carpenter 1999 and World Business Council for Sustainable Development 2011).

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 (Table 7.4). The market price method directly measures the higher prices of water resources good and services such as commercial fish or water purchased by consumers. The productivity method estimates economic value derived from improved water quality that results in decreased municipal water treatment costs or enhanced fishing productivity that boosts fishing jobs and wages. The damage cost avoided method estimates savings from ecosystems such as forests that provide water filtration benefits would need to be replaced by expensive water treatment plants (Emerton and Bos 2004). 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, waterfowl hunting, fishing, and birding trips due to improved water quality (Smith and Desvousge 1986 and Freeman 2003). The hedonic pricing method indirectly measures benefits by recording the higher value of property close to rivers and bays with improved water quality (USDA 1995).

Stated preference methods measure the economic value that individuals indicate they would assign to nonmarket ecosystem services (Kramer 2005). Stated preference surveys ask people how much they would be willing to pay to estimate nonuse value of improved water quality. The stated preference approach includes the contingent valuation (CV) method that asks people how much they would be willing to pay for improved water quality for viewing, boating, fishing, and swimming (Emerton and Bos 2004 and Thurston et al. 2009). CV assigns monetary benefits of nonuse value which do not involve market purchases and includes surveys that ask people how much they would be willing to pay for improved water quality for boating, fishing, and swimming (EPA 2002). CV methods estimate nonuse value by determining willingness to pay to restore the river by those who may or may not visit the resource (Carson and Mitchell 1993).

Table 7.4: Economic valuation methods to determine water quality benefits

Method	Description	Benefits	Constraints
Contigent Valuation	Survey individual willingness to pay	Use (drinking water) and nonuse (recreation)	Hypothetical responses may introduce bias.
Productivity	Assess water quality change with change in prove of goods	Commercial fisheries, drinking water	Dificult to obtain data relating change in market prices to improved water quality.
Property Value	Calculate property value near river	Water quality	Requires extensive parcel data base.
Travel Cost	Measure increased trip expenditures during more trips	Recreation boating, fishing, swimming	Only measures recreation benefits.

The utility of the contingent valuation method is often debated by economists because it is based on what people say they would pay (their stated preference), as opposed to what people actually pay (their revealed preference), which is a strength and a weakness. Some economists are critical of CV because the surveyed individuals are hypothetically stating willingness to pay even if they never do pay instead of buying or selling a good with real money based on the market price.

7.3 Methods

The benefits of improved water quality to go 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 7.5). 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 willingness to pay for improved water quality for existing/future generations.

Table 7.5: Benefits of improved water quality
(Carson and Mitchell 1993, EPA 2012, WBCSD 2011)

Benefit	**Category**	**Examples**	**Benefits 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	Cont. Valuation
	Bequest	Family, future generations	Cont. Valuation

If primary ecological valuation data from the Delaware Basin are not available, then benefits transfer is utilized to translate data to the basin from other watersheds. Benefits transfer involves extrapolating the benefits calculated by previous 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 redundancy and double-counting of benefits (Table 7.6). The benefit transfer method is most reliable when the original site and study site are similar in location and population characteristics, when the water quality change is similar for the two sites, and when the original study used sound valuation techniques (WBCSD 2011). Benefit transfer is often used when it is too expensive or not enough time to conduct an original valuation study, yet measures of benefits are needed. Benefit transfers can only be as accurate as the initial study. EPA (2010) employs benefit transfer to estimate nonmarket benefits of proposed water quality regulations from the Federal Clean Water Act. While it has shortcomings, the benefit transfer method is used here to estimate the benefits of improved water quality in the Delaware River by applying WTP data from similar settings.

Table 7.6: Strengths and weaknesses of the benefits transfer approach (EPA 2010 and WBCSD 2011)

Strengths	**Weaknesses**
Relatively inexpensive and quick to implements	Must be applied transparently to avoid double counting
Most reliable when 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

The first step in benefits transfer is to identify existing study values that can be utilized for the site in question (EPA 2010). The second step is to decide whether existing values are transferable based on several criteria. Is the benefit valued comparable to the value in the existing studies? The third step is to evaluate the quality of transferred studies. If the quality of the initial study is good, then the transferred value will be more accurate. The final step is to adjust original values to reflect the characteristics of the study site. 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 are converted to 2010 dollars based on the average annual change (2.6% rounded to 3%) in the Consumer Price Index (CPI) in the Northeast Region from 1991-2010 as reported by the Bureau of Labor Statistics using the following formula.

$B_{\$2010} = B_b(1+r)^t$

Where:

$B_{\$2010}$= Benefit in 2010 dollars

B_b = Benefits estimated for the base year from the literature

r = Change in Consumer Price Index (3%)

t = time in years between the base year in 2010

For example, benefits of $1 million estimated in 2000 are worth $1.34 million in 2010 dollars $1{,}000{,}000(1+0.03)^{10}$ = $1,340,000.

Travel cost models are 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. Swimmable benefits are not considered as very few safe opportunities for swimming exist along the Delaware River between the C&D Canal and Trenton due to strong tidal currents, lack of accessible beaches, and high bacteria levels that exceed DRBC primary contact recreation criteria (100#/100ml). Annual recreation benefits to achieve boating and fishing water quality are estimated by selecting relevant per person values from travel cost studies and then multiplying by the U.S. Census adult population (>18 yr old) in the watershed.

The Delaware River supports recreation where people go to view wildlife and birds, photograph scenery, boat, fish, and hunt waterfowl. Improved water quality increases user participation for recreational boating, fishing, swimming, waterfowl hunting, bird watching, photographing, and sailing. The enhanced recreational trip experience increases the value of trips and participation by visitors. The unit day value method estimates the value of recreation due to improved water quality by multiplying the number of visitor days by the unit value ($/day) of a recreation day. Recreation benefits of improved water quality are measured by the increase in the number of activity days by participants at the river. An activity day is "equal to one person doing an activity or visiting any setting for any part of a day" (Leeworthy and Wiley 2001). The unit day value method estimates the value of recreation due to improved water quality by multiplying the number of visitor days by the unit value ($/day) of a recreation day.

The economic benefits of improved water quality for recreational boating, fishing, bird watching, waterfowl hunting, and beach going are estimated using a five-step approach. First, determine the number of visitors who participate in recreational activities in each state in the Delaware Basin. Second, scale statewide estimates of recreational participants to the watershed level by proportion of population and/or land area within each state. Third, review the literature to obtain unit day values per person for each recreation activity. Fourth, estimate the existing value of each activity by multiplying the unit day value by the number of recreation visits. Fifth, estimate the benefits by multiplying existing value by % change in value from improved water quality.

7.4 Results

Recreation (Viewing/Boating/Fishing/Swimming): Many river and estuary based recreational activities benefit from improved water quality (Table 7.7). Tourists may enjoy enhanced aesthetic benefits due to improved water quality while hiking, picnicking, and taking photographs along the river. Boating satisfaction and the number of trips increase with improved water quality from increased dissolved oxygen levels and improved clarity of the water. Recreational fishing success and fish abundance rises with reduced nutrient loads and increased DO levels (Lipton and Hicks 2003). Swimming recreation and public health depends on low pathogen and bacteria levels. Bird and wildlife viewing increases with improved water quality and ecosystem health as fisheries provide a large share of the waterfowl diet.

Table 7.7: 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

Travel cost methods estimate consumer surplus for goods not traded in a market (USDA 1995). Figure 7.4 depicts fishing days in the river as improved water quality shifts the demand curve to the right. The angler is inclined to go on more trips to the river as long as the benefits of the added trip is greater than or equal to the cost of that trip (King et al. 2000). As the angler takes more trips, the value placed on the trip drops a little (the principle of diminishing returns). Area A is the cost of taking a fishing trip to the river measured by gasoline, parking, food, accommodation, and equipment expenditures. Area B is the consumer surplus or the value of fishing recreation above the expenditures which is the willingness to pay (WTP) or the benefit for each trip.

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 public willingness to pay (WTP) to achieve viewing, boatable, fishable, and swimmable uses (Table 7.8). Along the Monongahela River near Pittsburgh, a travel cost study found per household benefits in \$1981 ranged from \$3.53 to achieve boatable water quality to \$7.16 for game fishing (Smith and Desvouges 1986). On the St. Albans Bay in Vermont, Ribaubo and Epp (1984) found that improved water quality provided benefits of \$189 per recreational visitor. Parsons, Helm, and Bodelid (2003) estimated recreation benefits along rivers in the northeastern states ranged from $2.25 for viewing, $2.51 for boating, and $1.86 for fishing in $1994.

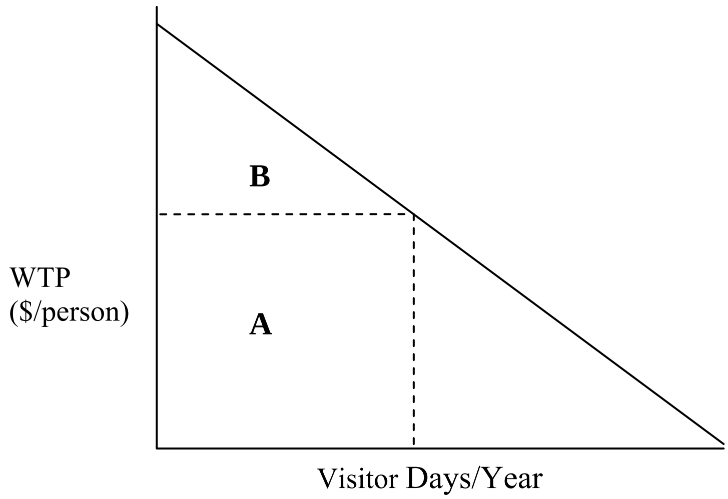


Figure 7.4: Marginal willingness to pay for recreation travel

Table 7.8: Water quality benefits measured by travel cost methods

Publication	**Water Quality Improvement**	**Units**	**Benefit ($)**
Smith and Desvouges 1986	Recreation in 5 counties along Monongahela R., Pa.	Households ($1981)	Loss of Boatable $3.53 Boatable to Gamefishing $7.16
Ribaudo and Epp 1984	Improved water quality, St. Albans Bay, Vt.	Visitors ($1984)	$189
Parsons, Helm, and Bodelid 2003	Attain medium/ high WQ along rivers in 6 NE states	Per person ($1994)	Viewing $2.25, Boating $2.51 Fishing $1.86

Table 7.9 indicates travel cost values in $2010 range from $2.87 for boating and $5.82 for fishing per person from Smith and Desvouges (1986) to $3.61 for viewing, $4.03 for boating, and $2.98 for fishing from Parsons, Helm, and Bodelid (2003). Travel

costs from the 2003 study in the six northeastern states are selected for transfer to the Delaware River as these values are more current than the 1986 study and the base study sites share similar geography along the Atlantic seaboard.

Table 7.9: Recreation water benefits from travel cost methods

Water Quality	Smith and Desvouges 1986		Parsons et al. 2003	
	($1981)	**($2010)[1]**	**($1994)**	**($2010)[1]**
Viewing			2.25	3.61
Boating	1.22	2.87	2.51	4.03
Fishing	2.47	5.82	1.86	2.98

1. Adjusted to $2010 based on 3% annual change in CPI.

Parsons, Helm, and Bondelid (2003) measured the economic benefits of water quality improvements to recreational users using travel cost random utility maximization models in the northeastern states of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut. They defined water quality as low, medium, or high depending on levels of biological oxygen demand (BOD), total suspended solids (TSS), dissolved oxygen (DO), and fecal coliform (Table 7.10). Medium water quality sites have some fishing and few visible signs of pollution such as debris. High water quality sites are aesthetically pleasing and support human contact recreation and sport fisheries.

In July, maximum water temperature approaches 30° C (86° F) in the Delaware River at Philadelphia. At 30° C, DO saturation is 46% at the DRBC criteria (3.5 mg/l) which corresponds to medium water quality and 66% saturation at a future criteria of 5 mg/l which approaches the 83% DO saturation goal for high water quality (Table 7.11).

Table 7.10: Water quality index (Parsons et al. 2003)

WQ Index	BOD (mg/l)	TSS (mg/l)	DO (% saturation)	Fecal Coli. (MPN/100 ml)
Medium	<4.0	<100	>0.45	<2000
High	<1.5	<10	>0.83	<200

Table 7.11: Dissolved oxygen saturation

Temp. (deg C)	DO (mg l)	% Saturation (3.5 mg/l)	% Saturation (5.0 mg/l)	% Saturation (6.0 mg/l)
20	9.07	39%	55%	66%
25	8.24	42%	61%	73%
30	7.54	46%	66%	80%
35	6.93	51%	72%	87%

Per person annual benefits for medium to high water quality along rivers ranged from \$0.00-\$2.25 for viewing, \$0.00-\$2.51 for boating, and \$0.54-\$1.86 for fishing in \$1994 (Parsons et al. 2003). Converting to \$2010, benefits for medium water quality are \$0.00 for viewing, \$0.00 for boating, and \$0.87 for fishing and for high water quality are \$3.61 for viewing, \$4.03 for boating, and \$2.98 for fishing (Table 7.12).

Table 7.12: Recreation benefits from improved water quality along rivers

Use Support	Middle Water Quality		High Water Quality	
	(\$1994)[1]	(\$2010)[2]	(\$1994)[1]	(\$2010)[2]
Viewing	0.00	0.00	2.25	3.61
Boating	0.00	0.00	2.51	4.03
Fishing	0.54	0.87	1.86	2.98
Total	0.54	0.87	6.62	10.62

1. Parsons et al. 2003. 2. Adjusted from \$1994 to \$2010 based on change in CPI.

Low bound annual benefits due to improved water quality are estimated by multiplying the per person benefit in $2010 by the 2010 adult population of 6.7 million in the counties adjacent to the Delaware Estuary. According to the U.S. Census, 78% of the population is over 18 therefore the adult population is 5.2 million (Table 7.13).

Table 7.13: Adult population of the Delaware Estuary watershed in 2010

State	2010 Population	% Adult Pop. (> 18 yr)	Adult Pop. (> 18 yr)
Delaware	642,438	78%	501,102
Maryland	2,324	78%	1,813
New Jersey	1,645,500	78%	1,283,490
Pennsylvania	4,409,742	78%	3,439,599
Delaware Estuary	**6,700,004**	**78%**	**5,226,003**

Low bound annual viewing, boating, and fishing benefits due to improved water quality in the Delaware River range from $4.5 million for medium water quality to $55.5 million for high water quality (Table 7.14). The benefits of medium water quality (DO 3.5 mg/l) are zero for viewing and boating uses and $4.5 million for fishing. Benefits of high water quality (DO 5 mg/l) are $18.8 million for viewing, $21.1 million for boating, and $15.6 million for fishing or 34%, 38%, and 28% of the benefits, respectively.

Table 7.14: Low bound recreation benefits in the Delaware Basin

WQ Use	Adult Population[1]	Medium WQ[2] ($2010/person)	High WQ[2] ($2010/person)	Medium WQ Benefits ($ million)	High WQ Benefits ($ million)
Viewing	5,226,003	0.00	3.61	0	18.5
Boating	5,226,003	0.00	4.03	0	21.0
Fishing	5,226,003	0.87	2.98	4.5	16.0
Total WQ	**5,226,003**	**0.87**	**10.62**	**4.5**	**55.5**

1. >18 years old (U.S. Census). 2. Parsons et al. 2003 adjusted to $2010 based on change in CPI.

High bound of benefits of improved water quality are defined by multiplying the per person benefit in $2010 by the adult Delaware Basin population. The 2010 Delaware Basin population is 8.2 million. According to the U.S. Census, 78% of the population is over 18 therefore the adult population in the Basin is 6.4 million (Table 7.15).

Table 7.15: Adult population of the Delaware Basin in 2010

State	2010 Population	% Adult Pop. (> 18 yr)	Adult Pop. (> 18 yr)
Delaware	643,418	78%	501,866
Maryland	2,324	78%	1,813
New Jersey	1,951,047	78%	1,521,817
New York	124,969	78%	97,476
Pennsylvania	5,533,254	78%	4,315,938
Delaware Basin	**8,255,013**	**78%**	**6,438,910**

Upper bound viewing, boating, and fishing benefits due to improved water quality in the Delaware River ranges from $5.6 million for medium water quality to $68.4 million for high water quality (Table 7.16 and Figure 7.5). The benefits of attaining medium water quality (DO 3.5 mg/l) are zero for viewing and boating uses and $5.6 million for fishing. Benefits of attaining high water quality (DO 5 mg/l) are $23.2 million for viewing, $25.9 million for boating, and $19.2 million for fishing which are 34%, 38%, and 28% of the benefits, respectively.

Table 7.16: Upper bound recreation water quality benefits in the Delaware Basin

WQ Use	Adult Population[1]	Medium WQ[2] ($2010/person)	High WQ[2] ($2010/person)	Medium WQ Benefits ($ million)	High WQ Benefits ($ million)
Viewing	6,438,910	0.00	3.61	0	23.0
Boating	6,438,910	0.00	4.03	0	25.9
Fishing	6,438,910	0.87	2.98	5.6	19.2
Total WQ	**6,438,910**	**0.87**	**10.62**	**5.6**	**68.1**

1. >18 years old (U.S. Census). 2. Parsons et al. 2003 adjusted to $2010 based on change in CPI.

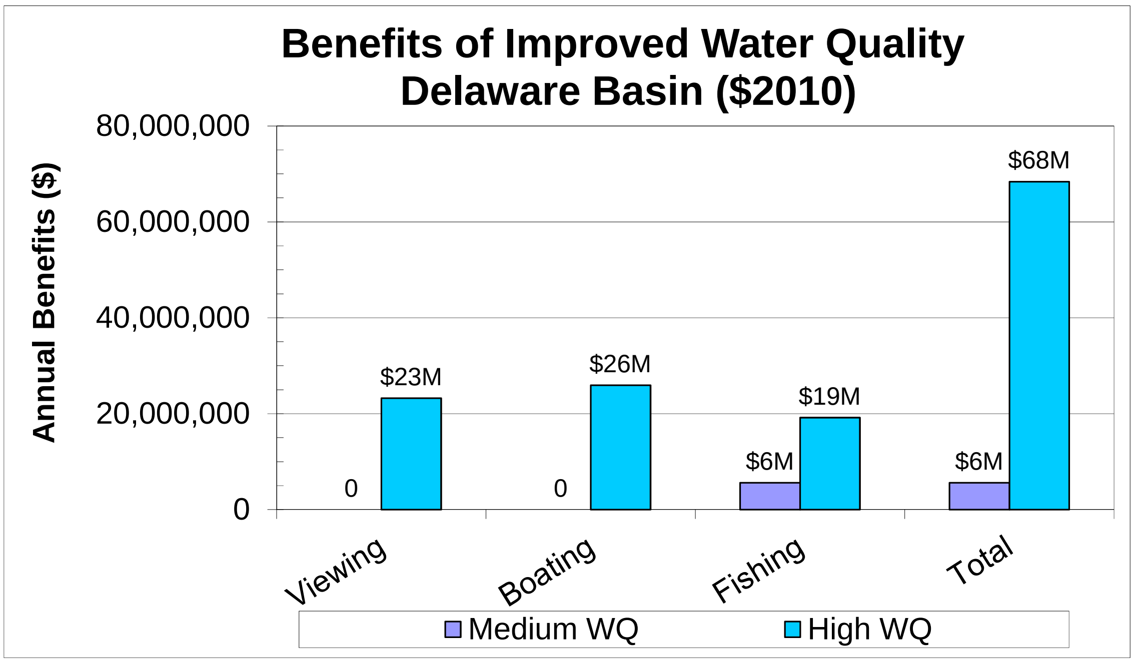


Figure 7.5: Upper bound recreation benefits in the Delaware River

As recreation benefits are proportional to population, $46 million or 2/3 of the benefits accrue to Pennsylvania, $16 million or ¼ apply to New Jersey, about $5 million applies to Delaware, and $1 million goes to New York (Figure 7.6 and Table 7.17).

Table 7.17: Annual recreation benefits by state in the Delaware River

WQ Use Support	2010 Pop.[1]	% Adult Pop. (> 18 yr)	Adult Pop. (> 18 yr)	Medium WQ[2] ($2010/person)	High WQ[2] ($2010/person)	Medium Benefits ($ million)	High Benefits ($ million)
Del. Basin	**8,255,013**	**78%**	**6,438,910**	**0.87**	**10.62**	**5.6**	**68.4**
Viewing	8,255,013	78%	6,438,910	0.00	3.61	0	23.2
Boating	8,255,013	78%	6,438,910	0.00	4.03	0	25.9
Fishing	8,255,013	78%	6,438,910	0.87	2.98	5.6	19.2
Delaware	**643,418**	**78%**	**501,866**	**0.87**	**10.62**	**0.4**	**5.4**
Viewing	643,418	78%	501,866	0.00	3.61	0	1.8
Boating	643,418	78%	501,866	0.00	4.03	0	2.0
Fishing	643,418	78%	501,866	0.87	2.98	0.4	1.5
New Jersey	**1,951,047**	**78%**	**1,521,817**	**0.87**	**10.62**	**1.3**	**16.2**
Viewing	1,951,047	78%	1,521,817	0.00	3.61	0	5.5
Boating	1,951,047	78%	1,521,817	0.00	4.03	0	6.2
Fishing	1,951,047	78%	1,521,817	0.87	2.98	1.3	4.5
New York	**124,969**	**78%**	**97,476**	**0.87**	**10.62**	**0.08**	**1.0**
Viewing	124,969	78%	97,476	0.00	3.61	0	0.4
Boating	124,969	78%	97,476	0.00	4.03	0	0.4
Fishing	124,969	78%	97,476	0.87	2.98	0.08	0.3
Pennsylvania	**5,533,254**	**78%**	**4,315,938**	**0.87**	**10.62**	**3.8**	**45.9**
Viewing	5,533,254	78%	4,315,938	0.00	3.61	0	15.6
Boating	5,533,254	78%	4,315,938	0.00	4.03	0	17.4
Fishing	5,533,254	78%	4,315,938	0.87	2.98	3.8	12.9

1. >18 years old (US Census). 2. Parsons et al. (2003) adjusted to $2010 based on chane in CPI.

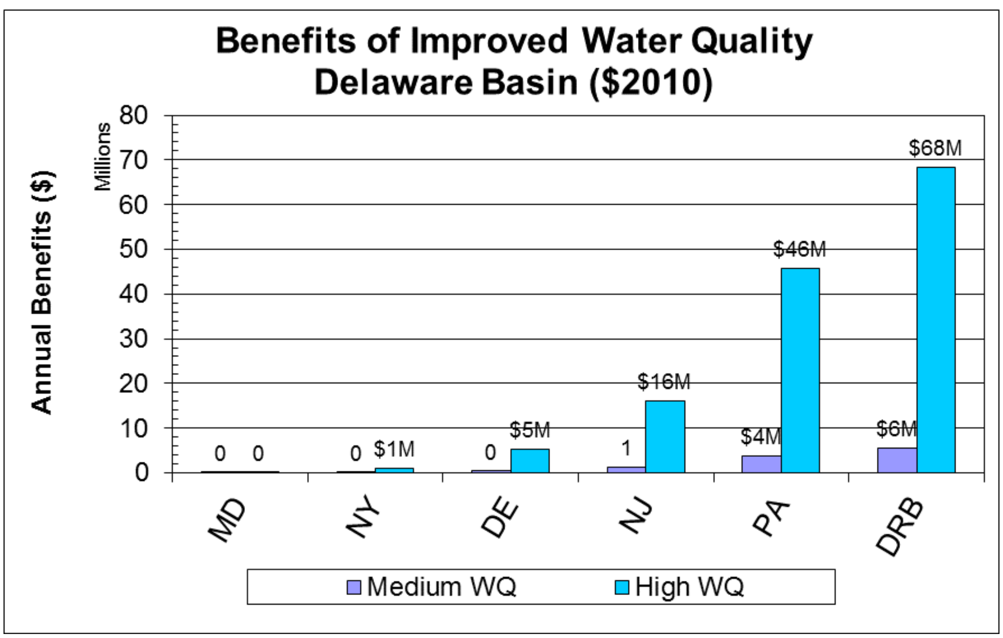


Figure 7.6: Annual recreation benefits by state in the Delaware River

Recreation and Tourism: There are strong connections between a healthy tourist economy and a clean environment. In 2009, the travel and tourism industry contributed $379 billion to the U.S. economy or 2.7% of total GDP. Tourism involving water resources contributes significantly to economic output with beach use a major category. Pendleton (undated) estimated the value of U.S. coastal and estuary recreation was $20 to $60 billion annually for beach-going, angling, birdwatching, and snorkeling/diving. Fishing is one of the most profitable recreation and tourism 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). The 30 million anglers in the U.S. generate about one million jobs and over $45 billion in retail sales annually (Southwick Associates 2008). The Outdoor Industry Association (2006) found the outdoor recreation economy contributed $730 billion annually to the economy and supported 6.5 million jobs.

Water-based activities such as fishing, boating, and swimming and recreational pursuits such as hiking, hunting, and wildlife viewing rely on clean water (EPA 2012). Impaired water quality reduces the value of recreation in a watershed. Hiking, jogging, picnicking, and wildlife viewing are less enjoyable along polluted, unsightly, and malodorous rivers. Water pollution reduces fish populations, fouls fishing lines with algae, and diminishes the angler's fishing experience. Water pollution reduces recreational boating by blurring visibility and increasing chances of collisions from floating debris. Water pollution reduces visibility and increases bacteria levels that diminish swimmer health and aesthetic experience. Water pollution decreases bird watcher's aesthetic enjoyment and reduce waterfowl populations which impairs the hunting experience.

Use and nonuse benefits are defined using water quality parameters such as total suspended solids, dissolved oxygen, and temperature. 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 7.18). 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 7.18: 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.

Kaval and Loomis (2003) reviewed 1,239 observations in the U.S. over 30 years and tabulated per person consumer surplus for fishing, boating, and wildlife viewing recreation (Table 7.19). Rosenberger and Loomis (2000) from Oregon State University compiled a national database of mean consumer surplus for recreation (Table 7.20).

Table 7.19: Average consumer surplus for water recreational activities in $2004 (Kaval and Loomis 2003)

Activity	Studies	Mean ($/visit)	Low Range ($/visit)	High Range ($/visit)
Bird Watching	4	29.60	5.80	78.46
Fishing	129	47.16	2.08	556.82
Rafting/Canoeing	20	100.91	2.70	390.82
Beach Going	5	39.43	3.78	117.82
Hiking	21	30.84	0.40	262.04
Hunting	192	46.92	2.60	250.90
Motor Boating	15	46.27	3.78	203.62
Swimming	11	42.68	2.20	134.34
Wildlife Viewing	69	42.36	2.40	347.88

Fishing, paddling (canoeing, kayaking, and rafting), and wildlife viewing are water-based outdoor recreation activities that drive the local economy along the Brandywine, Lehigh, Schuylkill, and Delaware rivers in the Delaware Basin. 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 (Table 7.21). The Delaware Basin is home of 7,611,595 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 7.20: 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

Table 7.21: Outdoor recreation activity in the Delaware Basin

Recreation	Activity	Mid-Atlantic Region[1]	Delaware Basin[2]
Fishing	Gear/Trip Sales and Contributions	$1,768,000,000	$327,000,000
	# Participants	1,890,000	349,650
Paddling	Gear/Trip Sales and Contribution	$784,000,000	$145,000,000
	# Participants	1,586,000	293,410
Wildlife viewing	Gear/Trip Sales and Contribution	$1,756,000,000	$325,000,000
	# Participants	4,990,000	923,150

1. Outdoor Industry Association (2006). 2. Scaled by proportion of Delaware Basin population in NJ, NY, and PA (7.6 million) to mid-Atlantic region population (40.9 million) = 18.5%.

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 motorboating (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 (2010) announced Delaware, Pennsylvania, and New Jersey were ranked 7th, 17th, and 23rd in the U.S., respectively, in expenditures for powerboats, outboard engines, boat trailers, and accessories. The scaled estimate of powerboat expenditures within the Basin is $392 million/yr (Table 7.22).

Table 7.22 : Recreational powerboat expenditures in the Delaware Basin (NMMA 2010)

State	Rank in Expenditures	Powerboat Expenditures ($ million)	% Pop. of State in Basin	Del. Basin Expenditures ($ million)
Delaware	7	344	74%	254
New Jersey	23	183	22%	40
Pennsylvania	17	226	43%	97
Total		**753**		**392**

Pennsylvania, New Jersey, and Delaware were ranked 13th, 28th, and 40th in recreational boat registrations in 2009 and had 229,000 registrations in the Delaware Basin in 2009 (Table 7.23).

Table 7.23: Recreational boat registrations in the Delaware River Basin (NMMA 2010)

State	Rank Registrations	Total Boat Registrations	% Pop. of State in Basin	Basin Boat Registrations
Delaware	40	61,523	0.74	45,527
New Jersey	28	173,994	0.22	38,279
Pennsylvania	13	337,747	0.43	145,231
Total		**573,264**		**229,037**

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. In the Delaware Estuary, approximately 100,000 and 149,000 people participated in recreational boating such as motorboating, sailing, canoeing, kayaking, and rowing in Delaware and New Jersey, respectively, based on scaled estimates from the National Survey on Recreation and the Environment (Leeworthy et al. 2001) as listed in Table 7.24. An additional Pennsylvania 145,000 boaters visit the estuary based on a scaled estimate of the number of boat registrations reported by NMMA (2010).

Table 7.24: Boating participants along the Delaware Estuary

Boating Activity	Delaware Participants		New Jersey Participants		Penna. Participants	
	State	**Watershed[1]**	**State**	**Watershed[1]**	**State**	**Watershed[2]**
Motorboating	381,000	72,000	894,000	98,000	338,000	145,000
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
	Delaware Boating Days		**New Jersey Boating Days**		**Penna. Boating 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

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 $30.00 to $65.82 per day in $2010. Bergstrom and Cordell (1991) developed community demand models using the Public Area Recreation Visitors Study at 200 sites in the U.S and found the unit day value for motorized boating was $22.53 or $34.03 in $2010. For the U.S. Forest Service, Walsh et al. (1992) conducted a survey of 287 travel cost and contingent valuation studies and estimated mean unit-day values for motorized boating was $43.59 or $65.82 in $2010 (Table 7.25). Using travel cost demand methods, Johnston et al. (2002) from the University of Rhode Island computed consumer surplus or WTP for recreational boating due to improved water quality in the Peconic Estuary watershed on Long Island, New York at $19.23 per trip in $1995 or $30.00 in $2010. Kaval and Loomis (2003) from Colorado State University prepared a study of outdoor recreation values for the National Park Service and found mean per person consumer surplus for the Northeast region was $24.73 for motorboating in $1996 or $37.34 in $2010 (Table 1).

Table 7.25: Consumer surplus for recreational boating

Source	**Consumer Surplus ($/person)**		**Comments**
	($)	($2010)[1]	
Johnston et al. 2002	19.23	30.00	Peconic Estuary on Long Island, NY
Bergstrom and Cordel 1991	22.53	34.02	Recreation visitors studies at 200 sites
Kaval and Loomis 2003	24.73	37.34	Northeast Region National Park Service
Walsh et al. 1992	43.59	65.82	Survey of 287 TC and CV studies for Forest Service

1. Converted to $2010 based on average 3% change in CPI.

Several studies demonstrated that improved water quality provides significant recreational boating benefits. Smith and Desvouges (1986) found that if DO saturation increases by 1% due to pollution abatement, then boatable benefits improve by $1.54/trip in $1986 or $3.13/trip in $2010. 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 $62.60/trip (20% increase in DO saturation x $3.13/trip). In the Chesapeake Bay, median WTP by boaters for a one-step improvement in water quality was $17.50 per year (Lipton 2003). Bockstael et al. (1989) conducted a revealed preference study of 496 trailer boat owners in the Chesapeake Bay and concluded a 20% reduction in total nitrogen plus phosphorus (TNP) was worth $59/yr per boater in $1987 which is $116/yr in $2010.

The low bound value of existing recreational boating is $159 million determined by multiplying the low estimate of $30/trip by 5.3 million activity days. The low bound benefit of improved water quality is $46 million determined by multiplying 394,000 boaters by per participant benefits of $116/yr per boater in $2010 translated from Bockstael (1989). The upper bound value of recreational boating is $350 million determined by multiplying 5.3 million activity days by the high estimate of $66/trip. The high bound benefit of improved water quality is $334 million determined by multiplying 5.3 million activity days by unit benefits of $63/trip in $2010 translated from Smith and Desvouges (1986). Improved water quality in the Delaware Estuary provides annual recreational boating benefits that range from $46 to $334 million (Table 7.26).

Table 7.26: Recreational boating benefits in the Delaware Estuary

Estimate	Unit Value ($2010/day)	Boating Activity (million days	Existing Value ($ million)	Boating Participants	WQ Benefit ($)	Benefit ($ million)
Lower Bound	30	5.3	159	394,000	$116/boater	46
Upper Bound	66	5.3	350	394,000	$63/trip	334

The upper bound estimate of existing value ($350 million) from the unit day method compares favorably to the National Marine Manufacturers Association (2010) study that revealed scaled powerboat expenditures within the Delaware Estuary watershed were $392 million/year with $254 million in Delaware, $40 million in Pennsylvania, and $97 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 that 25 million anglers in 2006 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 fishermen take 4.5 million to 7.9 million fishing trips per year to the Delaware River and Bay (Table 7.27). Scaled data from the National Survey of Fishing, Hunting, and Wildlife Recreation (USFWS 2008) show that anglers spent $335 million on 4.5 million fishing trips during 2006 to the Delaware River and Bay or $75/day (Table 7.28). 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 NOAA Fisheries and Statistics Division indicate that 106,000 striped bass anglers participated in 3.0 million fishing days per year in the Delaware Estuary (Table 7.29). 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, respectively, 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 7.31).

Table 7.27: Recreational fishing days in the Delaware River and Bay

Source	Fishing Days (million)
USFWS 2008	4.5
NMFS 2001, EPA 2002	5.4
Leeworthy and Wiley 2001	7.9

Table 7.28: 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 in basin[2]	NJ in basin[2]	PA in basin[2]	Del. River
Fishing Days (mil)	1.8	8.8	18.0	28.6	0.9	2.3	1.2	4.5
Expenditures ($ mil)	97	753	1,293	2,142	48	196	90	335
$/Day	53	85	72	75	53	85	72	75

1. USFWS 2008. 2. Scaled by ratio of state area in basin to state area, Del. (0.50), NJ (0.26), Pa. (0.07).

Table 7.29: Striped bass anglers in the Delaware Estuary (NOAA)

State	Anglers in State	% State in Watershed	Anglers in Watershed	Activity Days/year
Delaware	69,000	50%	35,000	972,000
New Jersey	274,000	26%	71,000	1,994,000
Total	343,000		106,000	2,966,000

Table 7.30: Recreational fishing in Delaware Bay and Atlantic Coast (EPA 2002 and NMFS 2001)

Fishing Mode	Fishing Days
Delaware	
Private/Rental Boat	391,000
Shore	367,000
Charter Boat	43,000
New Jersey	
Private/Rental Boat	2,596,000
Shore	1,597,000
Charter Boat	404,000
Total	**5,398,000**

Table 7.31: Recreational fishing days in the Delaware Estuary (1999-2000) (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

Several travel cost, random utility, and contingent valuation models indicate the value of recreational fishing ranges from a lower bound of $40/trip to an upper bound of $75/trip in $2010 (Table 7.32). Walsh et al. (1992) conducted a survey of 287 travel cost and contingent valuation studies in U.S. Forest Service regions that estimated the value of recreation fishing was $32.52/trip. McDonnell and Strand (1994) estimated the average annual value for a fishing trip was $26.59 or $42.67 in 2010 dollars. Rosenberger and Loomis (2000) from Oregon State University compiled a recreational use values database that defined the mean consumer surplus for fishing was $29.53 or $39.68 in $2010.

Kaval and Loomis (2003) from Colorado State University prepared a study of outdoor recreation values for the National Park Service and found mean per person consumer surplus for fishing for the northeast region was $27.17 in $1996 or $41.03 in $2010. Using travel cost demand methods, Johnston et al. (2002) from the University of Rhode Island computed WTP for recreational fishing due to improved water quality in the Peconic Estuary watershed on Long Island, New York at $40.25 per trip in $1995. The national survey of marine fishing statistics found the average recreational fishing trip cost was $62.43 (EPA and NMFS 2002). The U.S. Fish and Wildlife Service (2008) reported fishing equipment and travel expenditures averaged $75.00 per trip in Delaware, New Jersey, and Pennsylvania.

Table 7.32: Recreational fishing value studies

Region	Author/Date	Value ($/trip)	2010[1] ($/trip)	Methods
National	Rosenberger and Loomis 2000	29.53	39.68	Mean of Studies
Northeast	Kaval and Loomis 2003	27.17	41.03	Mean of Studies
Delaware	McConnell and Strand 1994	26.59	42.67	Travel Cost/Random Utility
National	Walsh et al. 1992	32.52	49.11	Travel Cost/CV studies
National	EPA and NMFS 2002		62.43	Travel Cost
New York	Johnston et al. 2002	40.25	62.79	Travel Cost
DE, NJ, PA	USFWS 2008	75.00	75.00	Trip/Equipment Expenditures

1. Converted to $2010 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 $216 to $337 million estimated by multiplying the low bound trip value ($40/trip) by 5.4 million fishing trip days and upper bound value ($75/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 $130 to $202 million/yr (Table 7.33).

Table 7.33: Recreational fishing benefits in the Delaware Estuary

Estimate	Unit Value ($2010/day)	Activity (million days)	Existing Value ($ million)	Benefit with Improved DO (3.5-5.0 mg/l)	Rec. Fishing Benefit ($ million)
Lower Bound	40	5,400,000	216	60%	130
Upper Bound	75	4,500,000	337	60%	202

The existing value of recreational fishing from the unit day approach ($216-$337 million) compares favorably with scaled estimates from the Outdoor Industry Association (2006) that reported fishing in the Delaware Basin 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/Bird Watching: Wildlife and bird watching are water-dependent activities that significantly add to the U.S. recreation economy. Over 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's ecological economy. The river and bay is one of the most important feeding grounds in North America where up to a million shorebirds feed on horseshoe crab eggs during their spring migration. In 1988, over 90,000 bird watchers spent $5.5 million in the greater Cape May area at a rate of $61 per viewer. The U.S. Fish and Wildlife Service estimates that the 16,000 acre Bombay Hook National Wildlife Refuge in Delaware was the 4th most visited refuge in the nation with nearly 271,000 recreational visits in 2006 (Carver and Caudill 2007). The Bombay Hook National Wildlife Refuge is the 6th most valuable refuge in the U.S. as it contributed $20.2 million to the local economy from food, lodging, equipment, and transportation expenditures with $13.4 million from bird watching alone. 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. The Cape May National Wildlife Refuge provides habitat for endangered least tern and piping plover. An EPA (1994) national demand for water recreation report estimated 1.4 million people took 5.1 million trips for recreational wildlife viewing in the Delaware Basin.

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 7.34).

Table 7.34: Bird/wildlife watching along the Delaware Estuary

	Delaware		New Jersey	
Recreation Activity	**State Participants**	**Watershed[1] Participants**	**State Participants**	**Watershed[1] Participants**
Bird Watching	428,000	214,000	795,000	207,000
Viewing Other Wildlife	221,000	111,000	592,000	154,000
Total	650,000	325,000	1,386,000	360,000
Recreation Activity	**State Activity Days**	**Watershed Activity Days**	**State Activity Days**	**Watershed Activity Days**
Bird-Watching	14,027,000	7,013,000	18,804,000	4,889,000
Viewing other Wildlife	5,461,000	2,730,000	8,293,000	2,156,000
00Total	19,488,000	9,744,000	27,097,000	7,045,000

1. Leeworthy et al. (2001 and 2005)
2. Scaled by proportion of state area within basin in Delaware (50%) and New Jersey (26%).

About 864,000 to 923,000 visitors spent $307 to $325 million on trip/equipment expenditures to go wildlife watching in the Delaware Basin in Delaware, New Jersey, and Pennsylvania. Scaled data from the USFWS (2008) indicates 864,000 participants engaged in bird/wildlife watching in the Delaware Basin during 3.3 million visitor days in 2006 and spent $307 million/yr for trip (food, lodging, transportation) and equipment expenditures or $68 to $154 per day (Table 7.35). Scaled by basin population, the Outdoor Industry Association (2008) reported 923,000 people participating in wildlife viewing under a $325 million program in the Delaware Basin.

User day values for wildlife viewing range from $43.94 (Kaval and Loomis 2003) to $92.00 (USFWS 2008) in $2010 (Table 7.36). For the U.S. Forest Service, Walsh et al. (1992) conducted a survey of 287 travel cost and contingent valuation studies and estimated mean unit-day values for bird/wildlife watching was $43.59 or $65.82 in $2010. Using travel cost demand methods, Johnston et al. (2002) from the University of Rhode

Island found consumer surplus or WTP for recreational bird watching due to improved water quality in the Peconic Estuary watershed on Long Island was $49.83/trip in $1995 or $77.73 in $2010. Kaval and Loomis (2003) from Colorado State University prepared a study of outdoor recreation for the National Park Service and found mean per person consumer surplus for the Northeast region was $29.05 for bird/wildlife watching in $1996 or $43.94 in $2010. In the Delaware Basin, wildlife and bird watchers spent about $92.00/visit according to the U.S. Fish and Wildlife Service (2008).

Table 7.35: 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 basin[2]**	**NJ in basin[2]**	**PA in basin[2]**	**Del. Basin**
Participants	285,000	1,713,000	3,947,000	5,945,000	142,000	445,000	276,000	864,000
Visitor Days	855,000	7,965,000	11,972,000	20,792,000	427,500	2,070,900	838,000	3,336,000
Expenditures ($ mil)	131	537	1,443	2,111	66	140	101	307
$/Day	153	67	121	102	154	68	121	92

1. USFWS 2008. 2. Scaled by ratio of state area in watershed to total state area, Del. (0.50), NJ (0.26), Pa. (0.07).

Table 7.36: Consumer surplus for recreational bird/wildlife watching

Source	**Consumer Surplus ($/trip)**		**Comments**
	($)	($2010)[1]	
Kaval and Loomis 2003	29.05	43.94	Northeast Region National Park Service
Walsh et al. 1992	43.59	46.81	Survey of 287 TC and CV studies for Forest Service
Johnston et al. 2002	49.83	77.73	Peconic Estuary on Long Island, NY
U.S. Fish and Wildlife Service 2008	92.00	92.00	Trip and equipment expenditures

1. Converted to $2010 based on average annual 3% change in CPI.

The existing recreational value of bird and wildlife watching ranges from $307 to $325 million based on scaled data from the U.S. Fish and Wildlife service (2008) and the Outdoor Industry Association (2008). 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 $15 million to $33 million per year (Table 7.37).

Table 7.37: Recreational wildlife/bird watching benefits in the Delaware Estuary

Estimate	Participants	Existing Value ($ million)	Increase Improved WQ	Benefit ($ million)
Lower Bound	864,000	307	5%	15
Upper Bound	923,000	325	10%	33

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 7.38).

Table 7.38: Waterfowl hunting along the Delaware Estuary

Source	Delaware		New Jersey	
Source	State Activity Days	Watershed[1] Activity Days	State Activity Days	Watershed[1] Activity Days
USFWS 2008	164,000	82,000		
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 $1.4 million to $15.8 million determined by multiplying lower and upper bound estimates of consumer surplus by the number of activity days (Table 7.39). Waterfowl hunting benefits due to improved water quality range from $70,000 to $1.6 million per year by multiplying existing recreation value by an estimated 5% and 10% increase in value due to improved water quality.

Table 7.39: Recreational waterfowl hunting benefits in the Delaware Estuary

Estimate	Unit Value ($2010/day)	Activity Days	Existing Value ($ million)	WQ Benefit	Benefit ($)
Lower Bound	17	82,000	1.4	5%	0.07
Upper Bound	69	229,000	15.8	10%	1.7

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 are not expected to be significant 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 Atlantic Ocean.

Beach Going: Beaches are leading 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 7.40). 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 7.40: 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%), 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 $7.29 to $58.81 per day in $2010 (Table 7.41).

Table 7.41: Beach visitor studies in the mid-Atlantic U.S.

State	**Author/Date**	**Consumer Surplus ($/day)**	**Consumer Surplus[1] $2010/day**	**Methods**
Massachusetts	Kline and Swallow 1998	5.36	7.29	
Delaware, New Jersey	Parsons et al. 1999	12.70	16.89	Travel Cost
New Jersey	Leeworthy and Wiley 1991	31.45	58.81	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 $39.20/trip in $2010. 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 value of beach going to the Delaware Estuary above the C&D Canal ranges from $6 to $50 million based on multiplying the scaled activity day estimates by a low and high estimate of the daily use value from the literature. The benefits of improved water quality on beach going in the Delaware Estuary ranges from $2 to $16 million based on the findings from Bockstael et al (1989) that a 20% reduction in TNP resulted in a 20% increase in beach going activity. By similarity, a 32% reduction in nitrogen would result in a 32% increase in beach going benefits in the Delaware Estuary (Table 7.42).

Table 7.42: Recreational beach visitor benefits in the Delaware Estuary

Estimate	Unit Value ($2010)	Beach Activity Days[1]	Existing Value ($ million)	Increase Improved WQ	Benefit ($ million)
Lower Bound	7.29	854,000	6	32%	2
Upper Bound	58.81	854,000	50	32%	16

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 for 3.8 million pounds or $3.5 million in Delaware ($0.92/lb) and $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 DO 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 7.7 (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, 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.

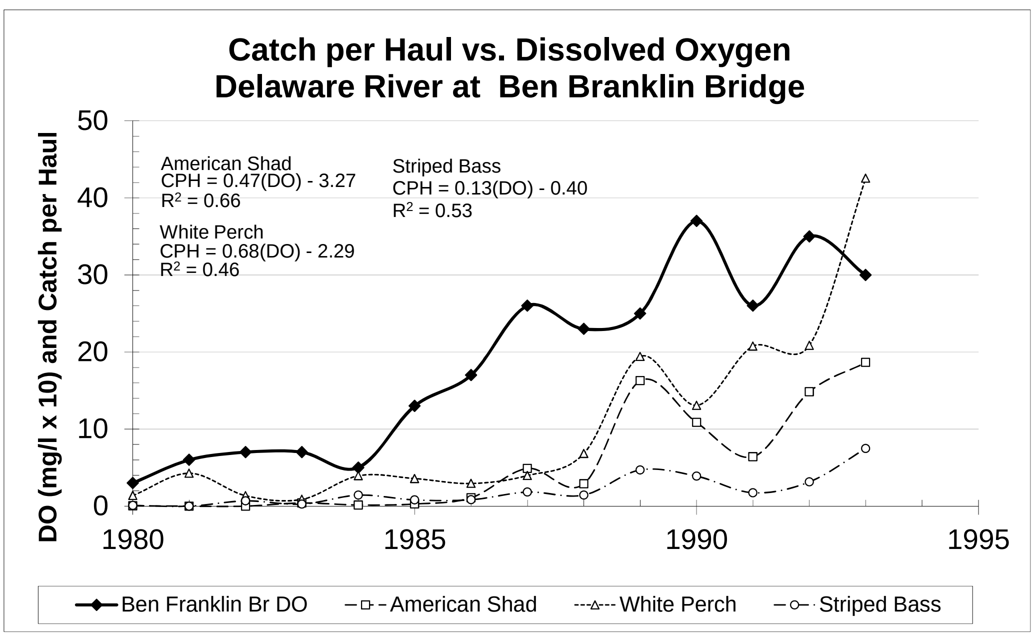


Figure 7.7: Dissolved oxygen and fish catch in the Delaware Estuary (Weisberg et al. 1996)

The NOEP (2010) reported the annual value of commercial fish landings in the Delaware Estuary was $25 million in $2000 or $34 million in $2010 (Table 7.43). The most valuable commercial Delaware Estuary fisheries 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 in the Delaware Estuary improves by 50% from existing DO (3.5 mg/l) to future criteria (5.0 mg/l), then commercial fish landing value may increase by 50% or $17 million.

Table 7.43: Commercial fishery benefits in the Delaware Estuary

Species	**2000 Landings[1] (lb)**	**2000 Value[1] ($)**	**2010 Value[2] ($)**	**WQ Benefit[3] ($)**
Crab, Blue	8,436,188	10,800,000	14,472,000	7,236,000
Flounder, Summer	1,702,977	3,999,000	5,360,000	2,680,000
Menhaden, Atlantic	37,720,009	3,200,000	4,288,000	2,144,000
Oyster, Eastern	524,160	2,721,000	3,647,000	1,823,000
Bass, Striped	752,882	1,717,000	2,301,000	1,151,000
Eel, American	298,940	626,000	838,000	419,000
Herring, Atlantic	6,039,473	563,000	755,000	377,000
Bluefish	277,217	508,000	681,000	340,000
Whelk,Chan'd/Knob	1,423,282	511,000	685,000	342,000
Weakfish	189,110	261,000	350,000	175,000
Shad, American	130,426	119,000	160,000	80,000
Perch, White	88,060	84,000	113,000	57,000
Shellfish	30,130	76,000	102,000	51,000
Perch, Yellow	20,527	72,000	96,000	48,000
Snails (Conchs)	30,250	59,0006	79,000	39,000
Crab, Horseshoe	229,602	49,000	66,000	33,000
Carp. Common	10,488	28,000	37,0008	19,000
Drum, Black	39,230	22,000	30,000	15,000
Catfish, Channel	6,922	4,000	$5,000	2,500
Herring, Blueback	1,434	600	800	$40
Total	**57,951,307**	**25,422,000**	**34,066,000**	**17,033,303**

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

Agriculture: Soil erosion curtails agricultural production through reduced soil fertility and loss of crop production and sales. In the Chesapeake Bay watershed, agricultural conservation practices that reduce total nitrogen loads by 32% were observed to also reduce sediment loads by 57% (USDA 2011). Similarly if the least cost pollution control option reduces agricultural N loads by 90% in the Delaware Basin, then cropland BMPs will reduce sediment loads by at least that amount. That is, agricultural best management practices such as cover crops and no till farming that reduce nitrogen loads by 90% will also reduce soil erosion and sediment loads by at least 90%.

In the Delaware Basin states, the USDA (2009) estimated the annual market value of agricultural products sold is $4.8 billion on almost 2.9 million acres (4,465 mi^2) for crops (corn, wheat, oats, barley, soybeans, potatoes, and vegetables) and livestock and poultry (Table 7.44). On over 1.9 million acres (3,010 mi^2) of farmland within the Delaware Basin, the estimated annual market value of agricultural products sales was $3.3 billion or $1,676/acre. The Delaware Basin covers 12,769 mi^2 or just 13% of the combined land areas of Delaware (1,953 mi^2), New Jersey (7,417 mi^2), New York (47,214 mi^2), and Pennsylvania (44,816 mi^2) yet accounts for $3.3 billion or 27% of total annual farm products sold in the four states.

Soil erosion and sediment loss from cropland averages 1.2 ton/acre in the adjacent Chesapeake Bay watershed (USDA 2011). The Chesapeake Bay watershed and Delaware Basin share similar climatic, topographic, and soil patterns therefore soil erosion in the Delaware Basin is assumed to occur at a similar rate (1.2 ton/acre). Soil erosion from 1.9 million acres of farmland in the Delaware Basin delivers 2.3 million ton/yr of sediment. If the average top soil thickness is 3 inches and loose soil density is 75 lb/ft^3, then the erosion rate of 2.3 million ton/yr equates to taking 5,600 acres of cropland out of production in the Delaware Basin. At an average value of farm products sold ($1,676/ac), the value of lost farm production due to loss of 5,600 acres from soil erosion in the Delaware Basin is $9.4 million. If farm conservation BMPs in the Delaware Basin are funded to reduce nitrogen and sediment loads by 90%, then the annual benefit of restoring cropland through soil erosion control programs is $8.4 million (0.90 x $9.4 million).

Table 7.44: Value of cropland and agriculture in the Delaware Basin

County	Farmland by state[1] (ac)	Products sold by state[1] ($ million)	Products sold by state[1] ($/ac)	Farmland in Del. Basin (ac)	Products sold in Del. Basin ($ million)
Delaware	432,773	1,083	2,500	254,143	600
New Jersey	631,150	752	1,200	505,507	600
New York	503,151	282	500	187,561	100
Pennsylvania	1,290,796	2,672	2,000	979,313	2,000
Delaware Basin	**2,857,870**	**4,790**	**1,700**	**1,926,524**	**3,300**

1. Census of Agriculture 2007 (USDA 2009). 2. Scaled by ratio of farm area in basin to state.

Pimentel et al. (1995) concluded 4 billion tons of soil are lost from 64 million acres of cropland in the U.S at a cost of $7 billion per year ($110/ac) due to water erosion and siltation damages at downstream recreation, water storage facilties, navigation, flood damages, and water treatment facilties. At $110/ac, estimated soil erosion damages due to sediment loss from 1.9 million acres of farmland in the Delaware Basin is about $209 million/yr. If optimally designed farm conservation BMPS simultaneously reduce nitrogen and sediment loads by 90%, then agricultural benefits from reduced soil erosion damages in the Delaware Basin is $188 million/yr (0.90 x $209 million).

Navigation: The Economy League of Greater Philadelphia (2008) concluded that the Delaware River port from Wilmington to Philadelphia and Trenton:

- Generates $81 million in tax revenues to Delaware, Pennsylvania, and New Jersey.
- Imports 1/2 of the nation's cocoa beans, 1/3 of bananas, and 1/4 of all fruit and nuts.
- Ranks 5th among U.S. ports in import cargo value and 20th in export value.
- Handled 16% of container trade tonnage and 51% of container trade value in the U.S.
- Delivered top exports such as motor vehicles (31%) and petroleum products (12%)
- Delivered top imports such as petroleum (65%) and iron and steel (7%).

Pollutant load reductions in the watershed can decrease sediment loads which in turn have the potential to reduce navigation dredging costs in the Delaware River ship channel. Navigation benefits are estimated by multiplying sediment load reductions (lb/yr or yd^3/yr) that could result from urban/suburban stormwater retrofitting and agricultural conservation BMPs by the unit cost of dredging ($/yd^3) estimated by the U.S. Army Corps of Engineers.

From 1950 through 2009, the average annual sediment discharge to the Delaware Estuary from the Delaware River at Trenton, Schuylkill at Philadelphia, and Brandywine at Wilmington was 2.2 million CY or 1.3 metric tons (PDE 2012). The average annual dredging volume to maintain the Delaware River navigation channel is 4 million CY where 10 million CY of sediment was dredged during 1937, 1967, and 1985 and 4 million CY was dredged during 2010 (Figure 7.8)

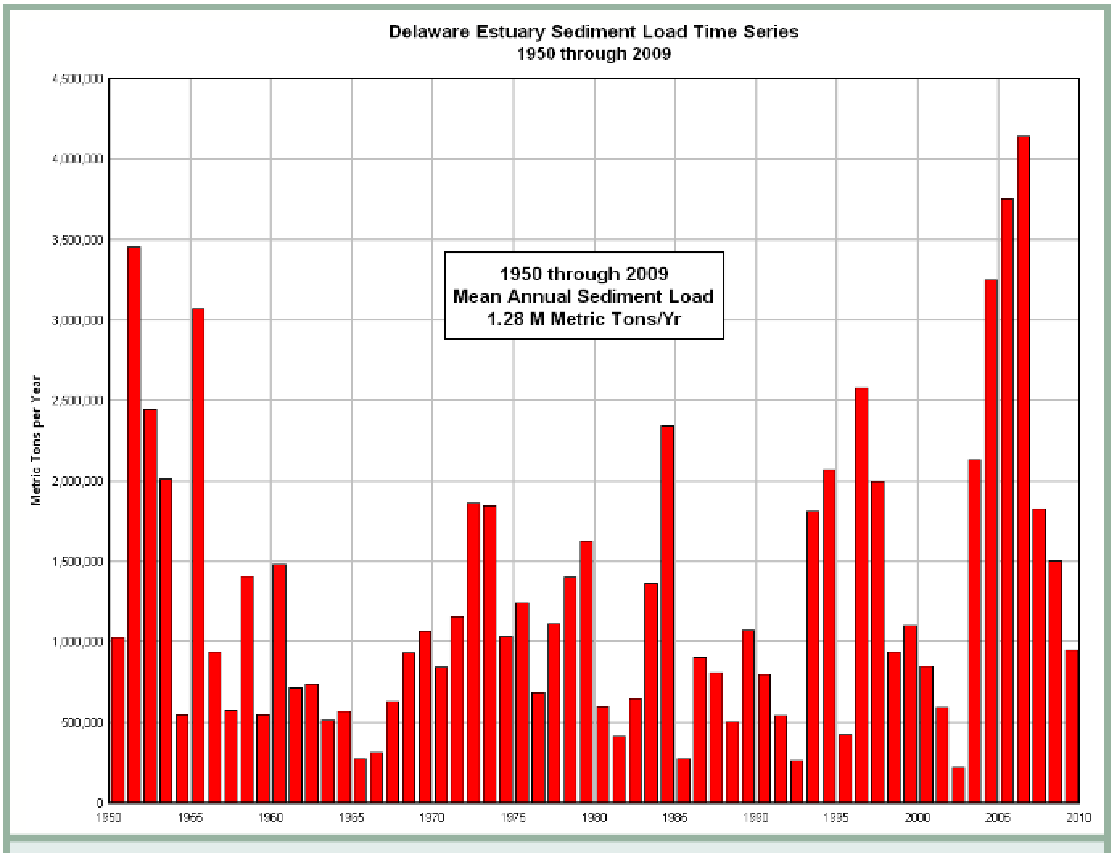


Figure 7.8: Delaware Estuary sediment load time series (PDE 2012)

Dredging costs range from \$3.75/CY nationwide to \$8.09/CY along the Delaware River. According to U.S. Army Corps of Engineers statistics for FY05, 255 million CY of material were dredged in the U.S. at a unit cost of \$3.75/CY. In 2010 the U.S. Army Corps of Engineers began a \$267 million dredging project to deepen the Delaware River ship channel to 45 feet and remove 33 million CY of material at a unit cost of \$8.09/CY.

Urban/suburban and agricultural conservation BMPs can reduce sediment loads by 90% and provide water quality benefits through the avoided costs of dredging.

Without watershed BMPs to reduce sediment loads, the annual cost to dredge 4 million CY from the Delaware River at costs of $3.75 to $8.09/CY ranges from $15 to $32 million. If watershed BMPS are installed to reduce the annual 2.2 million CY sediment discharge to the Delaware River by 90%, then the savings or benefits from avoided dredging costs range from $7 to $16 million (Table 7.45).

Table 7.45: Navigation benefits due to avoided dredging in the Delaware River

	Without Watershed BMPs		**With Watershed BMPS (reduce sediment by 90%)**	
	Low	High	Low	High
Dredge Volume (CY)	4,000,000	4,000,000	4,000,000	4,000,000
Sediment Discharge (CY)	2,200,000	2,200,000	2,200,000	2,200,000
w/ 90% BMP Reduction (CY)	0	0	2,000,000	2,000,000
Required Dredge Volume (CY)	4,000,000	4,000,000	2,000,000	2,000,000
Unit Cost ($/CY)	3.75	8.09	3.75	8.09
Dredging Cost ($ million)	15	32	7	163
Reduced Dredging Benefits ($ million)	7	16		

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 has a demonstrable effect on property values with potential economic benefits of $12.1 million within a 95% confidence interval of $3.8 to $20.5 million 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.

Watershed BMPs that reduce nitrogen, sediment, and bacteria loads and improve DO can increase the property value of land adjacent to the Delaware River by enhancing aesthetic value and supplemental benefits. The property benefits of improved water quality are defined by multiplying the area of property 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 7.46). 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 7.9). 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). Due to improved water quality, shoreline property values within 2000 feet of waterways can increase by a lower bound of 4% and an upper bound of 8% along the tidal Delaware River between Wilmington and Trenton.

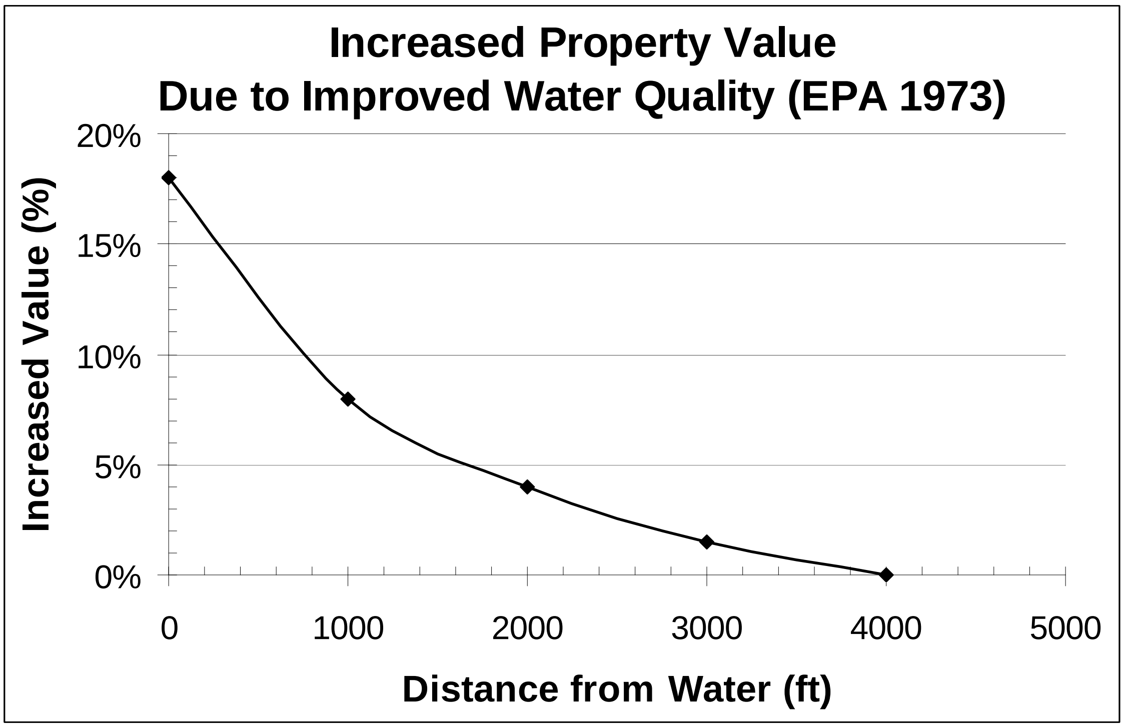


Figure 7.9: Increased property value due to improved water quality (EPA 1973)

Table 7.46: 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%

Improved water quality can increase shoreline property values within 2000 feet of the tidal Delaware River by $13 to 27 million/yr. (Table 7.47). At an average real estate price of $192,000/ac, the annual value of 34,764 acres of riverfront property within 2000 ft of the Delaware River between the C & D Canal and head of tide at Trenton is $334 million over a 20 year period. If property value is boosted by 4% to 8% due to improved water quality in the Delaware River, then the amenity value ranges from $13 to $27 million/yr.

Table 7.47: Increased property value along the Delaware River

State	Shoreline Length[1] (ft)	Area 2000 ft of water (ac)	Annual Value @ $192,000/ac ($ million)	Annual Property Value ($ million/yr)	Increased Property Value @ 4% ($ million/yr)	Increased Property Value @ 8% ($ million/yr)
Delaware	114,000	5,200	1,005	50	2	4
New Jersey	357,000	16,400	3,151	158	6	13
Pennsylvania	286,000	13,100	2,518	126	5	10
Del. Estuary	**757,000**	**34,800**	**6,675**	**334**	**13**	**27**

1. Length of Delaware River between C&D Canal and Trenton.

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 7.48). 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. The quality of municipal water supplies can have a measureable effect on its value (EPA 2012). In 1993, cryptosporidium from cattle farms passed through the Milwaukee, Wisconsin water filtration system and caused 403,000 illnesses and 104 deaths at a cost of $96 million. The EPA regulates drinking water quality according to Safe Drinking Water Act standards.

Table 7.48: 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 purveyors require water quality at the highest level as inputs to the water treatment process (Koteen et al. 2002). If water quality is insufficient, municipal water suppliers may have to find water elsewhere at substantial cost. Water supplies with low turbidity have lower water treatment costs due to less filtration and disinfection requirements. Municipal water suppliers benefit from improved water quality that lowers water treatment costs. For example, before the Second World War, water quality in the river was so poor that the City of Philadelphia looked seriously at building what would have been a prohibitively expensive, 100 mile-long pipeline to the Delaware Water Gap to secure a pure water supply source.

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 and odor control, energy use, and screening/filtration processes. A survey of 27 water utilities found water treatment costs declined by 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).

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.

Improved water quality can reduce water treatment costs for water utilities that withdraw drinking water from the Delaware River and its tributaries. 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 7.49). The largest public water supply withdrawals include United Water Delaware and Wilmington in Delaware; the Delaware & Raritan Canal diversion, New Jersey American, Trenton, and Camden in New Jersey, and City of Philadelphia and AQUA in Pennsylvania. 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 the 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 Philadelphia Water Department 2013). If improved water quality in the Delaware River can reduce water treatment costs by 6% to 12%, then public drinking water supply benefits range from $12 to $24 million/yr.

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.

Table 7.49: Public water supply benefits in the Delaware Basin

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

1. DRBC 2012.

The DRBC has issued industrial water supply withdrawal dockets that total 804 mgd in the watersheds that drain to the Delaware Estuary. A study of the economic value of freshwater 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 7.50). The value of industrial withdrawals based on DRBC allocations is $3,800,000 per day or $140 million/year. If improved water quality in the Delaware River reduces industrial water treatment costs by 6% to 12%, the benefits range from $8 to $16 million/yr (Table 7.51).

Table 7.50: National water values by use converted from $1994 to $2010 (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	64	197
Industrial	132	405	212	650
Thermoelectric Power	29	89	47	143
Domestic Water Supply	97	298	156	478

Table 7.51: Industrial water supply benefits in the Delaware Basin

Watershed	Withdrawal[1] (mgd)	Value ($0.61/1000 gal) ($ million/yr)	Benefit @ 6% ($ million/yr)	Benefit @ 12% ($ million/yr)
Schuylkill Valley	40	9	0.5	1.1
Upper Estuary	132	29	1.8	4
Lower Estuary	446	99	6	12
Delaware Bay	12	3	0.1	0.4
Total	**630**	**140**	**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). Nonuse benefits accrue from the existence value people place on the knowledge that a resource (such as a river) exists and could be improved and the bequest value that the river will be preserved for future generations. The contingent value method estimates nonuse benefits through a survey of individual willingness to pay for improved water quality for recreational viewing, boating, fishing, and swimming uses. Nonuse values comprise a significant percentage of the value of water resources. If nonuse values are omitted from economic analysis, then the total economic value and benefits will be underestimated.

Johnston et al. (2003) synthesized data on 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 with $p < 0.01$. Therefore, based on this relationship we assume that nonuse value equals 33% of the total use plus nonuse value or 50% of the use value.

Houtven, Powers, and Pattanayak (2007) surveyed 90 publications from 1977-2003 and found 131 estimates of annual WTP for improved water quality ranged from \$26 to \$331 with a mean of \$83 per person in 2000 dollars (Table 7.52). 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 the annual willingness to pay for swimmable water quality in the Chesapeake Bay in annual benefits for Washington and Baltimore nonusers was \$44.6 million. Van Houtven (2009) estimated the willingness to pay to increase the water quality index by one unit in the Chesapeake Bay swimmable provided \$159.1 million in annual benefits to District of Columbia, Maryland, and Virginia nonusers.

Table 7.52: Publications concerning WTP for improved water quality in $2000 (Houtven, Powers, and Pattanayak 2007)

Publication	**Geographic Focus**	**Water Quality Change**	**Mean WTP ($2000**
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 (CV) study to estimate the national benefits of freshwater pollution control to meet the goals of the Clean Water Act. The study surveyed public preferences or willingness to pay (WTP) for improved water quality to achieve use (instream, withdrawal, aesthetic, ecosystem) benefits and nonuse (vicarious consumption and stewardship) benefits (Table 7.53). The authors measured nonmarket benefits through a 1983 contingent valuation survey that asked 813 people at 61 sites their willingness to pay more taxes for cleaner water.

Table 7.53: Typical benefits from improved freshwater quality
(Carson and Mitchell 1993)

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

Individuals were asked how much they would be willing to pay to achieve boatable, fishable, and swimmable uses based on a water quality ladder (Figure 7.10). According to the water quality ladder, the Delaware River between Philadelphia and Wilmington (where DO declines below 3.5 mg/l during the summer) would be rated as boatable (C rating) but not yet fishable (B rating). The tidal Delaware River is not swimmable (A rating) since fecal coliform bacteria levels often exceed 200 #/100 ml.

Table 7.54: 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 actions to improve DO from the current 3.5 mg/l standard to meet a future year-round fishable DO standard of 5 mg/l in the Delaware River are based on contingent valuation surveys that define public willingness to pay for improved water quality from nonsupport (impaired) to boatable and fishable uses. Swimmable benefits are not estimated because the tidal currents along the Delaware River and pollutant load reductions are unlikely to reduce bacteria levels to below the DRBC primary contact recreation criteria (100#/100 ml).

Nonuse benefits are estimated by benefits transfer from Carson and Mitchell (1993) and Houtven, Powers, and Pattanayak (2007) and others and then converting to 2010 dollars based on individual willingness to pay to improve water quality in the Delaware River from nonsupport to boatable use (DO 3.5 mg/l) and from boatable to fishable use (5.0 mg/l). Nonuse benefits are determined by multiplying individual WTP ($/person) by the adult population (>18 yr old) of the watershed and then multiplying this value by 33% (Johnston et al. 2003). Nonuse values from WTP are based on the population of the Delaware Estuary watershed (the counties surrounding the river) as a low bound and population of the entire Delaware Basin as a high bound estimate.

Carson and Mitchell (1993) concluded that mean annual household willingness to pay to improve water quality was $93 to go from nonsupported to boatable use and $70 to go from boatable to fishable uses in 1983 dollars. Low to high estimates based on 95% confidence intervals of WTP ranged from $77-109 to achieve boatable uses and $58-$82 for fishable uses. Based on an average of 2.9 persons per household, mean 1983 WTP per person was $32 to improve to boatable and $24 to improve to fishable water quality.

Adjusting for an annual 3% change in the CPI due to increased cost of living and changing public views toward clean water, annual WTP per person is $71 for boatable and $54 for fishable uses in $2010 (Table 7.55).

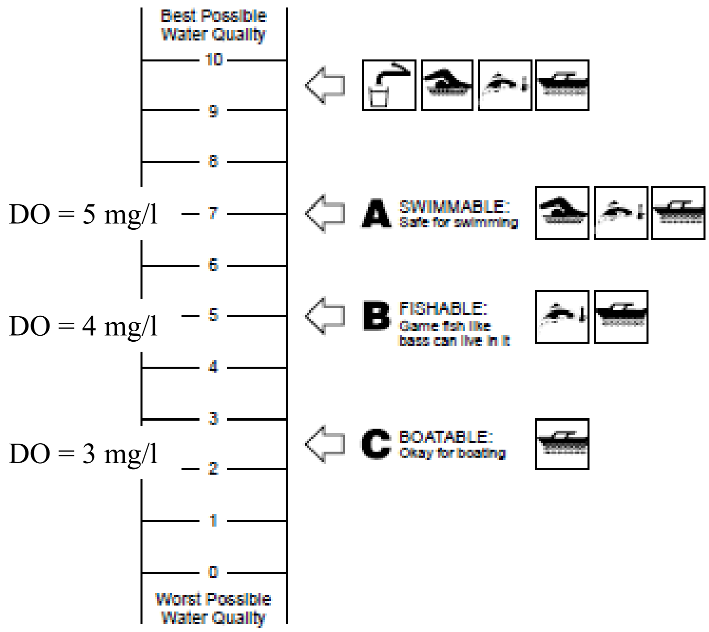


Figure 7.10: Water quality ladder
(Carson and Mitchell 1993 from Resources for the Future)

Annual willingness to pay per person from Carson and Mitchell (1993) to improve water quality from nonsupport to boatable and fishable uses is $125 in 2010 dollars which compares favorably to a mean WTP of $83 within a range of $31-$331 from a survey of 90 publications from 1977-2003 conducted by Houtven, Powers, and Pattanayak (2007). Since 1982, EPA has conducted a half dozen benefit-cost studies that estimated nonuse boating, fishing, and swimming recreation benefits adapted from WTP values published by Carson and Mitchell (1993).

Table 7.55: Annual willingness to pay for improved water quality

Water Quality Use Support	1983 Mean WTP[1] ($/hhold)	1983 95% CI WTP[1] ($/hhold)	1983 Mean WTP ($/person)[2]	1983 95% CI WTP ($/person)[2]	2010 Mean WTP[3] ($/person)	2010 95% CI WTP[3] ($/person)
Boatable	93	77-109	32	27-38	71	59-83
Fishable	70	58-82	24	20-28	54	44-63
Total WQ	163	135-191	56	47-56	125	103-146

1. Carson and Mitchell 1993. 2. At 2.9 person/ household. 3. Adjusted to $2010 by 3% change in CPI.

Annual nonuse benefits from improved water quality are estimated by multiplying mean per person WTP by the adult population in the watershed then multiplying by 33%. The low bound estimate includes the population of the Delaware Estuary watershed (6.7 million) which includes the tidal Delaware River and bay and tributaries downstream from Trenton in Delaware, New Jersey, and Pennsylvania. The high bound estimate is based on the population of the entire Delaware basin (8.2 million) in Delaware, New Jersey, New York, and Pennsylvania. From the U.S. Census, 78% of the population is over 18, therefore the adult population of the Delaware Estuary watershed and Delaware Basin is 5.2 million and 6.4 million, respectively (Table 7.56).

Nonuse benefits from WTP for improved water quality for boatable use (DO 3.5 mg/l) in the Delaware River ranges from a low bound of $102 million/year to a high bound of $151 million/yr. To achieve fishable water quality (DO 5.0 mg/l), nonuse benefits range from a low bound of $76 million/yr to a high bound of $115 million/yr (Table 7.57 and Figure 7.11). Total WTP to improve from nonsupport (impaired) to boatable and fishable uses in the Delaware River range from $178 million/yr to $266 million/yr in $2010. Approximately 57% of the nonuse benefits are from boatable water quality and 43% result from fishable water quality.

Table 7.56: Adult population in the Delaware Basin in 2010

State	% Adult Pop. (> 18 yr)	Del. Estuary 2010 Population	Del. Estuary Adult Pop. (> 18 yr)	Del. Basin 2010 Population	Del. Basin Adult Pop. (> 18 yr)
Delaware	78%	642,438	501,102	643,418	501,866
Maryland	78%	2,324	1,813	2,324	1,813
New Jersey	78%	1,645,500	1,283,490	1,951,047	1,521,817
New York	78%			124,969	97,476
Pennsylvania	78%	4,409,742	3,439,599	5,533,254	4,315,938
Delaware Basin	**78%**	**6,700,004**	**5,226,003**	**8,255,013**	**6,438,910**

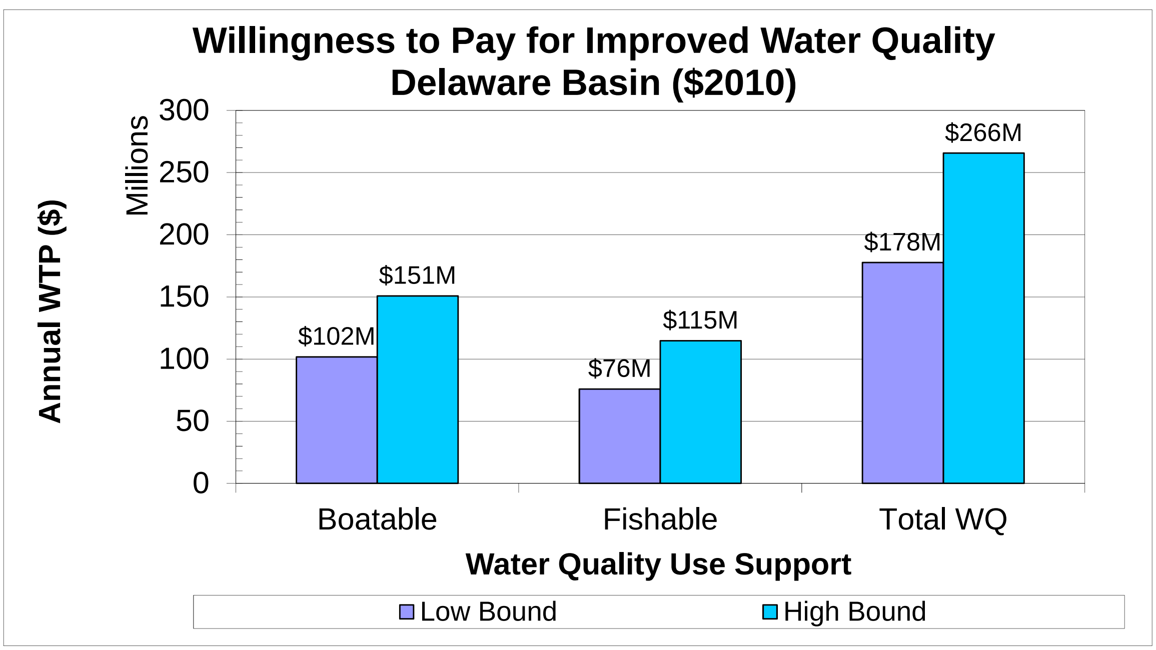


Figure 7.11: Nonuse benefits of improved water quality in the Delaware Basin

Table 7.57: Nonuse benefits of improved water quality in the Delaware Basin

WQ Use	Del. Estuary Adult Pop.[1]	Low WTP[2] ($/person)	Low WTP ($ million/yr)	Low Nonuse[3] ($ million/yr)
Boatable	5,226,003	59	308	102
Fishable	5,226,003	44	230	76
WQ Use	**Del. Basin Adult Pop.[1]**	**High WTP[2] ($/person)**	**High WTP ($ million/yr)**	**High Nonuse[3] ($ million/yr)**
Boatable	6,438,910	71	457	151
Fishable	6,438,910	54	348	115

1. Adult pop. (>18 years old). 2. Carson and Mitchell 1993 adjusted to $2010 based on 3% annually. 3. Nonuse benefits are 33% of WTP.

WTP is based on the population who live in the watershed and care for the Delaware River so 66% of nonuse benefits go to Pennsylvania, 25% go to New Jersey, 9% go to Delaware, and 2% go to New York (Figure 7.12 and Tables 7.58 and 7.59).

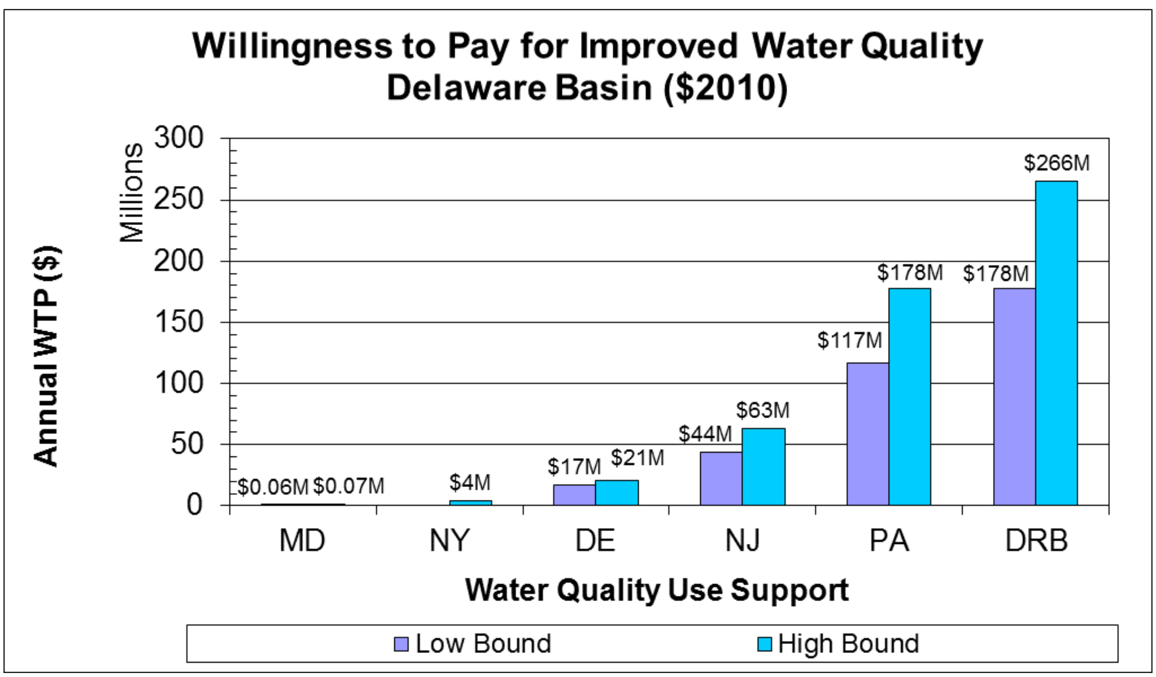


Figure 7.12: Nonuse water quality benefits by state in the Delaware Basin

Table 7.58: WTP for improved water quality in the Delaware Estuary watershed

Water Quality Use Support	2010 Population	Adult Population (> 18 yr)	2010 WTP[1] ($/person)	2010 WQ Benefits ($ million)	Nonuse Benefit[2] ($ million/yr)
Delaware Estuary	**6,700,004**	**5,226,003**	**103**	**538**	**178**
Boating	6,700,004	5,226,003	59	308	102
Fishing	6,700,004	5,226,003	44	230	76
Delaware	**642,438**	**501,102**	**103**	**52**	**17**
Boating	642,438	501,102	59	29	10
Fishing	642,438	501,102	44	22	7
New Jersey	**1,645,500**	**1,283,490**	**103**	**132**	**44**
Boating	1,645,500	1,283,490	59	76	25
Fishing	1,645,500	1,283,490	44	57	19
Pennsylvania	**4,409,742**	**3,439,599**	**103**	**354**	**117**
Boating	4,409,742	3,439,599	59	203	67
Fishing	4,409,742	3,439,599	44	151	50

1. Carson & Mitchell 1993 adjusted to $2010 by CPI. 2. Nonuse benefits 33% of WTP.

Table 7.59: Willingness to pay for improved water quality in the Delaware Basin

Water Quality Use Support	2010 Population	Adult Population (> 18 yr)	2010 WTP[1] ($/person)	2010 WQ Benefits ($ million/yr)	Nonuse Benefit[2] ($ million/yr)
Delaware Basin	**8,255,013**	**6,438,910**	**125**	**805**	**266**
Boating	8,255,013	6,438,910	71	457	151
Fishing	8,255,013	6,438,910	54	348	115
Delaware	**643,418**	**501,866**	**125**	**63**	**21**
Boating	643,418	501,866	71	36	12
Fishing	643,418	501,866	54	27	9
New Jersey	**1,951,047**	**1,521,817**	**125**	**190**	**63**
Boating	1,951,047	1,521,817	71	108	36
Fishing	1,951,047	1,521,817	54	82	27
New York	**124,969**	**97,476**	**125**	**12**	**4**
Boating	124,969	97,476	71	7	2
Fishing	124,969	97,476	54	5	2
Pennsylvania	**5,533,254**	**4,315,938**	**125**	**539**	**178**
Boating	5,533,254	4,315,938	71	306	101
Fishing	5,533,254	4,315,938	54	233	77

1. Carson and Mitchell 1993 adjusted to $2010 by CPI. 2. Nonuse benefits are 33% of WTP.

Annual WTP per household for improved water quality in the Monongahela River in Pennsylvania based on nonuse value for change from impaired to fishable goals was $19/person in $1997 or $14/person (lower) to $28/person (upper bound) in $2010 (Desvousges et al. 1987). Passive benefits based on WTP for improved water quality to attain fishable uses along the Delaware River ranges from a low bound of $94 million/yr in the Delaware Estuary watershed to $230 million/yr in the Delaware Basin. This compares favorably to nonuse benefits transferred from Carson and Mitchell (1993) that range from $178 to $266 million/yr.

7.5 Discussion and Conclusions

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 7.60). 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 7.13. 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 7.14). 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 7.15 illustrates a series of downward sloping marginal benefit curves for recreation, commercial fishing, agriculture, navigation, property value, water supply, and nonuse benefits. Marginal benefits are defined by the change in benefits between the value of existing water quality (DO 3.5 mg/l) and a future DRBC criteria (DO 5.0 mg/l).

Table 7.60: Benefits of improved water quality in the Delaware River in $2010

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	4.5	5.6	55	68
	Boating	159	350	46	334
	Fishing	216	337	129	202
	Shad fishing	0	6.5	0	3.9
	Bird/Wildlife Watching	307	325	15	33
	Waterfowl Hunting	1.4	16	0.1	1.6
	Swimming	0	0	0	0
	Beach Going	6	50	2	16
Commercial	Fishing	34	34	0	17
	Agriculture	0	0	8	188
	Navigation	81	81	7	16
Indirect Use	Property Value	333	333	13	27
Water Supply	Municipal Water Supply	196	196	12	24
	Industrial Water Supply	140	140	8	17
Nonuse					
Existence/Bequest	WTP Boatable to Fishable WQ	102	151	76	115
Total		**1,580**	**2,025**	**371**	**1,063**

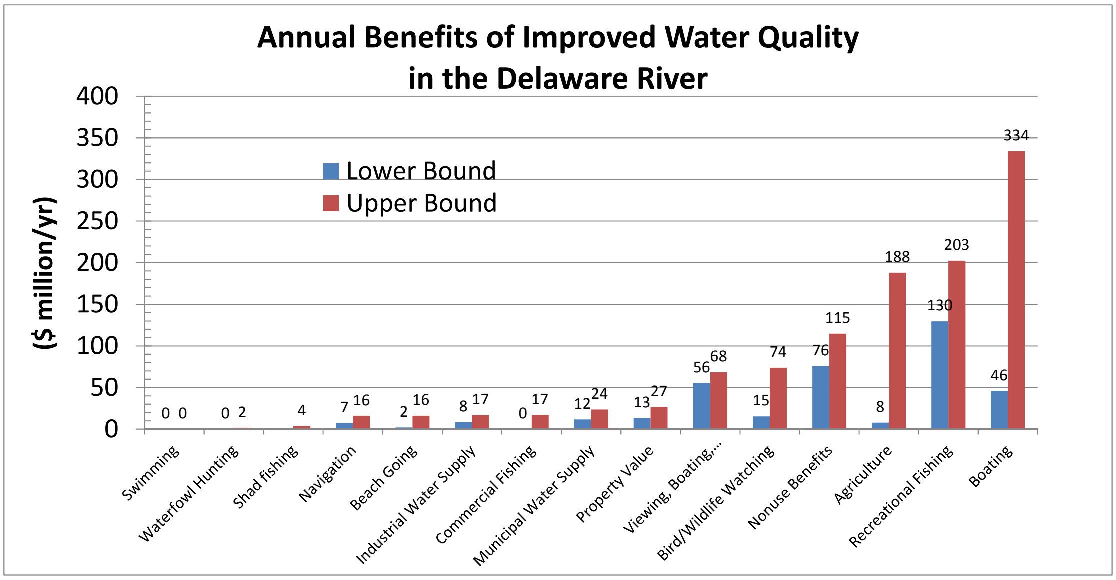


Figure 7.13: Lower and upper bound water quality benefit in the Delaware River

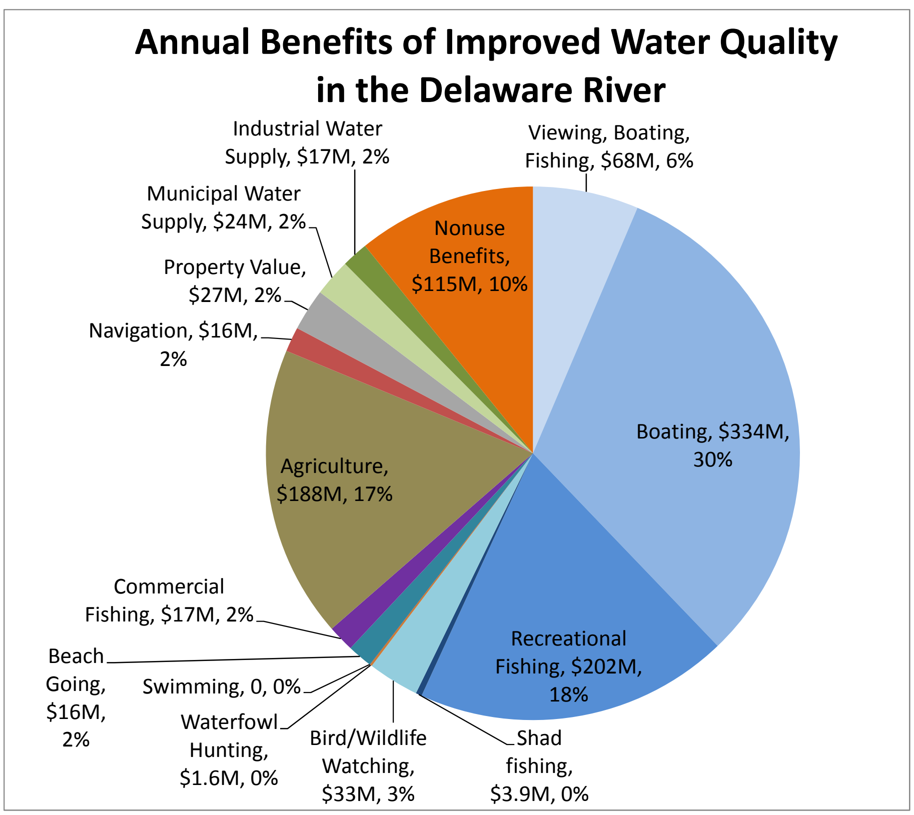


Figure 7.14: Upper bound water quality benefits in the Delaware River

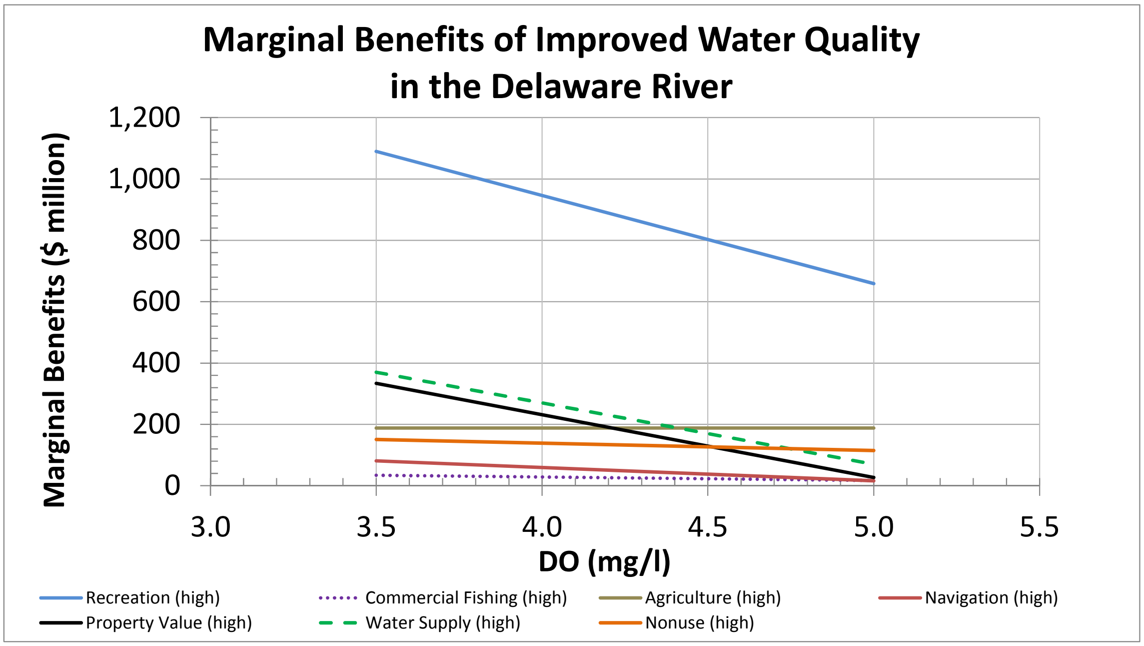


Figure 7.15: Marginal benefits of improved water quality in the Delaware River

Where possible, benefits were derived from market and nonmarket data developed in Delaware River Basin. If basin specific data was not available, economic data for some categories were scaled and transferred from other watersheds to the Delaware Basin using the principles of benefits transfer (value transfer). Benefits transfer is relatively inexpensive and quick to implement, however, it must be applied carefully to avoid redundancy and double-counting of benefits. Benefit transfers can only be as accurate as the initial study. While it has shortcomings, the benefit transfer method is used here to estimate the benefits of improved water quality in the Delaware River by applying willingness to pay (WTP) data from similar settings (such as the Chesapeake Bay). Future research (such as contingent valuation and travel cost studies) should be conducted to obtain revealed and stated preference WTP data for populations in the Delaware River Basin.

To scale the economic data to a common base year, benefits data from previous studies were translated to 2010 dollars based on an average 3% annual change in the Northeastern Consumer Price Index (CPI) as reported by the U.S. Bureau of Labor Statistics. Future research should be conducted to obtain more up to date economic benefits data particularly in the Delaware Basin.

Nonuse benefits are counted here and translated to $2010 from a willingness to pay study published by Carson and Mitchell in 1993. These are the benefits accrued by individuals who stated that they would be willing to pay for improved water quality because of its intrinsic value for existing and future generations. Some economists feel that nonuse benefits may be unrealistic because the population only states what they would be willing to pay and do not actually make a transaction or pay a price in a market. Other ecological economists declare that if nonuse benefits were omitted then total benefits may be undercounted. The EPA and other agencies have a policy of including nonuse benefits in benefit cost analysis that are required by Federal law. Future research should be conducted and conduct a stated preference survey of the basin population in the Delaware Basin to more precisely measure nonuse benefits based on what they would be willing to pay for improved water quality in the river.

Nutrient reduction measures that improve water quality in the Delaware River will provide auxiliary benefits that are not tabulated here. Agricultural practices will reduce bacteria loads that may improve major tributaries to swimmable uses. Reduced pollutant loads in the headwaters will provide significant freshwater recreation and nonuse benefits from improved water quality in the tributaries to the Delaware River. The benefits of improved water quality in the tributaries are expected to be substantial but they are not attributed here. The benefits of improved water quality in the tributaries of the Delaware River are not directly counted, therefore the benefits of reduced pollutant loads in the watersheds of the Delaware Basin are probably underestimated in this analysis.

Chapter 8

21^{ST} CENTURY BENEFIT-COST ANALYSIS

8.1. Introduction

This chapter conducts a modern 21^{st} century benefit-cost analysis (BCA) to determine an optimal level of improved water quality based on dissolved oxygen levels in the Delaware River. Optimal water quality is defined as the intersection of the marginal cost and benefits curves or the point where marginal costs equal margin benefits.

Two techniques are used to compare costs and benefits and define the most cost-effective level of water quality. Net benefits are defined by subtracting costs from benefits and if the difference is positive the option is deemed cost-effective. The benefit/cost ratio (B/C) should exceed one for an option to be worth considering.

8.2. Literature Review

Clean water is an environmental good that has economic value because people are willing to pay for it (Thurston et al. 2009). When marginal costs equal marginal benefits (MC = MB), then the investments in water pollution control have reached optimal scale. The benefit-cost analysis (BCA) is used to determine whether a project should be done (Thacher et al. 2011). A BCA evaluates the opportunity costs of policy actions and determines whether the benefits will leave everyone well off without hurting no one, the

Pareto criterion. The policy that maximizes net benefits to society (those who live in or utilize the waters of the Delaware Basin) is considered the most optimal.

Benefit-cost analysis helps to determine whether it is worthwhile for governments to spend on environmental amenities such as watersheds and river basins (Douglas and Taylor 1999 and King et al. 2000). BCA is a decision tool employed by policy makers that measures the net gain or loss to society due to a certain policy or project (Thurston et al. 2009). Goldberg (2007) offered benefit-cost valuation as an efficient way to make cost-effective decisions by policy makers and create a market to fund watershed services.

Faced with tightening budgets, government agencies must make difficult decisions about how to allocate public investments to restore the natural environment (King et al. 2000). Federal agencies such as the USDA, EPA, and NOAA use BCA to do more in an era of lean budgets to: (1) compare the benefits of different watershed projects and programs, (2) prioritize and allocate public spending on watershed restoration projects, (3) justify to Congress that investments maximize watershed restoration benefits per dollar spent, (4) identify tradeoffs between restoration costs and benefits due to improved water quality, and (5) decide how to allocate public spending on conservation, preservation, or restoration.

A half century ago, the Harvard Water Program advocated planning and design of water resources projects based on optimizing social, environmental, and economic costs/benefits (Maass et al. 1962). The Harvard Water Program advocated the efficient river basin authority (such as DRBC) as a “legal expedient” to analyze the benefits and costs of water pollution control programs and levy charges to finance operations and provide economic incentives for dischargers to reduce pollutant loads into the river.

In 1965, Congress passed the Water Resources Council Act which defined Federal criteria for multi-objective cost-benefit analysis and advocated national water planning objectives based on sustainable goals of economic prosperity, environmental health, and social equity (Stakhiv 2012, USWRC 1973, 1983). Schaumburg (1967) examined the policies of a river basin authority (the DRBC) and Pareto efficient economics of water quality control to reduce discharger waste loads by treatment technology, effluent standards, and effluent charges and fees. The Harvard Water Program envisioned the river basin authority as the ideal actor for implementing a "Pareto admissible pollution abatement plan" to balance the benefits of improved water quality with the costs for attaining it (Dorfman, Jacoby, and Thomas 1972).

Building on the work in Cambridge, Kneese and Bower (1984) from Resources for the Future in Washington, D.C. explored the river basin commission as the ideal basin-wide firm to deliver economic efficiencies in water quality management. They envisioned the river basin firm as a central agency responsible for operating in competitive markets or where public authorities set prices equal to marginal costs. By assuming ownership of these measures, the river basin firm would internalize the inefficient externalities of conventional water resources management. In response to a series of droughts and floods, the U.S. Army Corps of Engineers wondered if it might be time to resurrect the economic and environmental benefits model first offered in the 1960s by the Harvard Water Program and Water Resources Council Act (Reuss 2003).

In 2012, the EPA National Center for Environmental Economics reviewed the use of benefits transfer and nonuse value methods used by EPA since the 1980s to define monetary benefits from improved water quality (Griffiths et al. 2012). In 1981, Ronald Reagan issued Executive Order 12291 that required benefit-cost analyses for proposed regulations with costs of more than $100 million per year as designated by the Office of Management and Budget (OMB). Since then, every President has required benefit-cost analyses of all major proposed regulations. To comply with Executive Order 12291, the EPA conducted benefit-cost analysis using willingness to pay (WTP) methods for 17 surface water regulations from 1982 to 2009 (Table 8.1). Nonuse recreation benefits of improved water quality for boating, fishing, and swimming were estimated from WTP (Carson and Mitchell 1993) in six of the EPA BCA studies. The 2009 Construction and Development regulation employed the USGS SPARROW water quality model to define benefits of reduced sediment loads to lower dredging and water treatment costs. In October 2011, the EPA National Center for Environmental Economics and Resources for the Future held a seminar in Washington D. C. to discuss further research to estimate the costs and benefits of improved water quality in the Chesapeake Bay.

8.3 Methods

The following benefit-cost analysis compares the annual costs to reduce nitrogen loads from wastewater, atmospheric deposition, urban/suburban, and agriculture sources with benefits from willingness to pay for improved water quality in the Delaware River, all in 2010 dollars. This BCA updates a 1960s Delaware River economic study (FWPCA 1966 and Kneese and Bower 1984) conducted by the Federal Water Pollution Control

Administration (forerunner to EPA) and incorporates modern ecological economics methods such as marginal abatement cost curves and MB/MC curves to assess benefits based on willingness to pay for improved water quality. Nitrogen pollution load reductions from atmospheric, wastewater, urban/suburban, and agriculture sources are estimated to meet a future, more stringent DRBC dissolved oxygen standard of 5 mg/l (up from existing 3.5 mg/l) to provide year-round propagation of diadromous fish in the Delaware River. Costs are based on controls for five options needed to achieve a median 32% reduction in nitrogen estimated from Delaware Basin total maximum daily load (TMDL) models within confidence intervals ranging from 20% N reduction (25^{th} percentile) to 48% N reduction (75^{th} percentile). Benefits of improved water quality are based on enhanced market and nonmarket use value of viewing/boating/fishing recreation, commercial fishing, agriculture, navigation, property value, and water supply and nonuse value based on willingness to pay (WTP) for boatable and fishable water quality.

Cost-effective approaches to reduce pollution loads and improve water quality in the Delaware River are defined by calculating net benefits (total benefits minus costs) and the benefit-cost (B/C) ratio. The intersection of the marginal cost and marginal benefits (WTP) curve defines the level of optimal water quality (q_p) measured by dissolved oxygen in the Delaware River (Figure 8.1). Marginal cost is the additional cost from one more unit purchased such as a pound of nitrogen reduced. Marginal benefit is the additional benefit from one more unit consumed such as improved water quality (Thurston et al. 2009).

Table 8.1: EPA benefit-cost analysis of surface water regulations (Griffiths et al. 2012)

Date	Regulation	Pollutants	Benefits Category
1982	Iron and Steel Manufacturing	TSS, pH, oil	Benefits of water pollution control.
1987	Organics, Plastics, Synthetic Fibers	BOD, TSS, 128 toxics	Nonuse recreation benefits (Carson and Mitchell 1993) and Carson 1984) and avoided costs
1995	Great Lakes Water Quality Guidance	29 toxics	Recreation fishing (Lyke 1993) wildlife viewing (Walsh et al. 1988, 1990), commercial fishing (Crutchfield et al. 1997).
1998	Pulp, Paper, Paperboard	(15 toxics).	Lift fish consumption advisories (Lyke 1993) and (McKean 1990).
1998	Pharmaceuticals	32 toxics	Water quality exceedances (Lyke 1993) and (Walsh, Johnson, and McKean 1990) and nonuse as 50 percent of use benefits
2000	Centralized Waste Treatment	BOD, TSS, 36 toxics	Estimate nonuse as 50% of use benefits
2000	California Toxics Rule	23-57 toxics	Recreation benefits (Lyke 1993), saltwater fishing (Walsh, Johnson, and McKean 1988), nonuse 50% of use benefits
2003	Metal Products and Machinery	TSS, Oil/Grease	Recreation benefits of improved wildlife viewing and boating (Bergstrom and Cordell 1991), nonuse as 50% of use benefits
2003	Confined Animal Feed Operation	TSS, pathogens, N, P	Nonuse recreation (Carson and Mitchell 1993), increased commercial shellfish harvests, and avoided costs for drinking water treatment
2004	Meat and Poultry Products	TSS, oil/grease, N, P, coliform	Nonuse recreation (Carson and Mitchell 1993) and avoided costs of drinking water treatment
2004	Conc. Aquatic Animal Production	TSS, P, N, drugs/pesticides	Nonuse recreation from (Carson and Mitchell 1993)
2006	Cooling Water Intake Structures	impacts to aquatic life	Recreation benefits of increased fish catch from random utility model, increased commercial fish harvest from market prices
2009	Construction and Development	TSS, turbidity	Recreation nonuse from regression of 45 studies and avoided costs for dredging and drinking water treatment.

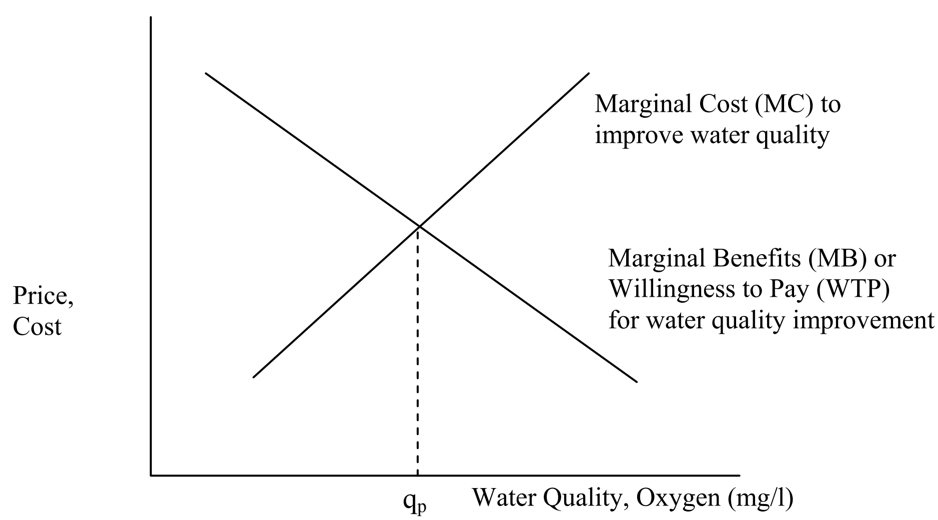


Figure 8.1: Optimal water quality

8.4 Results

Costs: As discussed in Chapter 6, a survey of TMDL models (Scatena et al 2006) indicates nitrogen loads should be reduced by 32% (median) within a range of 20% (25th percentile) to 48% (75th percentile) to increase DO levels from current DRBC criteria (3.5 mg/l) to a future more protective year-round fishable standard of 5.0 mg/l in the Delaware River. We coupled this with results from the USGS SPARROW model (Moore et al. 2011) to obtain estimates of annual costs, ranging from $334, $449, and $904 million to reduce nitrogen loads by 20%, 32%, and 48%, respectively.

The relationship between percent nitrogen load reduction (median 32%) and dissolved oxygen level to meet a future 5.0 mg/l DO standard in the Delaware River is assumed to be linear while the correlation is slightly curvilinear. This is important because a curvilinear trend in meeting the DO target may intersect the marginal cost curve differently than for a linear trend. Plots of pollutant load reduction and DO levels (Figure 8.2) from the 1960s economic study of the Delaware River indicate the coefficient of determination (r^2) for the linear measure of best fit (0.92) is nearly identical to the r^2 for the curvilinear (exponential) regression (0.94). Since the linear and curvilinear regressions are nearly identical, the assumption of linear relationship between % N load reduction and DO levels in the Delaware River is adequate for this research. Future work on an emerging DRBC hydrodynamic model will improve on these pollutant load and DO relationships.

By maximizing least cost agricultural and wastewater BMPs and minimizing higher cost airborne emissions and urban stormwater controls, annual costs to reduce N loads by 32% in the Delaware Basin are cut by over 300% from $1.66 billion for Option 1 (reduce N all sources by 32%) to $845 million for Option 2 (reduce Ag N by 32%, $652 million for Option 3 (reduce Ag N by 60%), $552 million for Option 4 (reduce Ag N by 75%), and $449 million for Option 5 to reduce Ag N by 90% (Table 8.2).

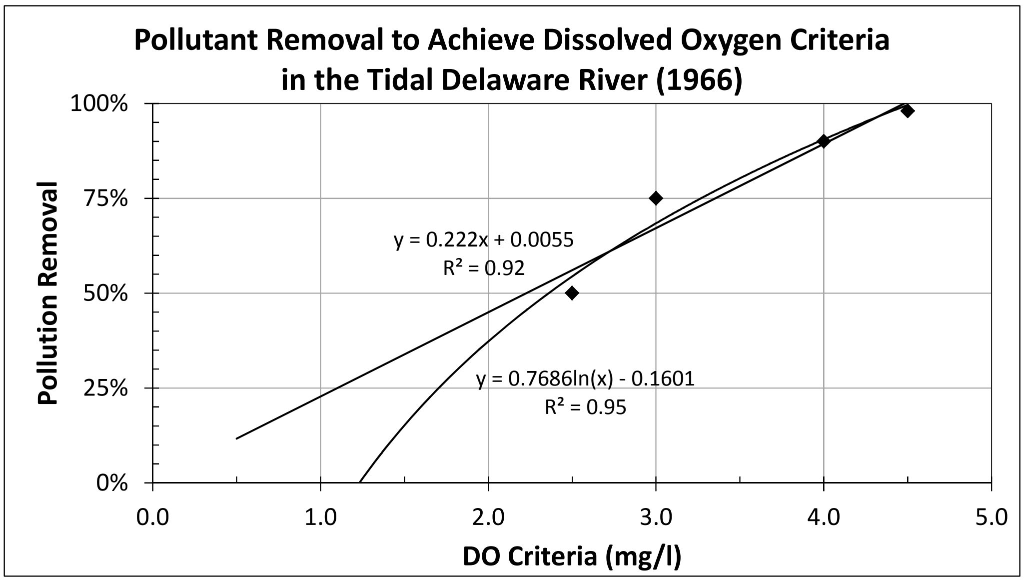


Figure 8.2: Pollutant removal to achieve DO criteria in the Delaware River (FWPCA 1966)

The marginal abatement cost (MAC) curve defines the optimal and most cost effective combination of nitrogen reduction strategies to improve DO to a future DRBC standard to provide year-round propagation of anadromous fish. Moving from left to right on the nitrogen MAC curve, the most cost effective approach is to prioritize implementation of agricultural conservation and wastewater treatment controls as these BMPs have lower unit costs for each pound of nitrogen removed followed by atmospheric deposition and urban/suburban stormwater BMPs which have higher per pound N removal costs (Figure 8.3). Based on the nitrogen MAC curve for least cost

Option 5 (reduce Ag N by 90%), 29 million pounds or 90% of the nitrogen can be removed for just 35% ($160 million) of the $449 million cost.

Table 8.2: Costs of nitrogen load reduction in the Delaware Basin in $2010

N Reduction Option	Atmospheric	Wastewater	Urban/ Sub.	Agriculture	Total
1. Reduce N 32% all sources	**0.32**	**0.32**	**0.32**	**0.32**	**0.32**
N Reduction (lb/yr)	3,880,000	14,874,000	4,528,000	9,378,000	32,660,000
Cost ($ million/yr)	291	416	905	47	1,660
2. Reduce Ag N by 32%	**0.05**	**0.47**	**0.05**	**0.32**	**0.32**
N Reduction (lb/yr)	606,000	21,848,000	708,000	9,378,000	32,538,000
Cost ($ million/yr)	45	612	141	47	846
3. Reduce Ag N by 60%	**0.05**	**0.29**	**0.05**	**0.60**	**0.32**
N Reduction (lb/yr)	606,000	13,480,000	708,000	17,582,000	32,376,000
Cost ($ million/yr)	45	377	141	88	652
4. Reduce Ag N by 75%	**0.05**	**0.20**	**0.05**	**0.75**	**0.32**
N Reduction (lb/yr)	606,000	9,296,000	708,000	21,978,000	32,588,000
Cost ($ million/yr)	45	260	141	110	557
3. Reduce Ag N by 90%	0.05	0.10	0.05	0.90	0.32
N Reduction (lb/yr)	606,000	4,648,000	708,000	26,374,000	32,336,000
Cost ($ million/yr)	45	130	141	132	449

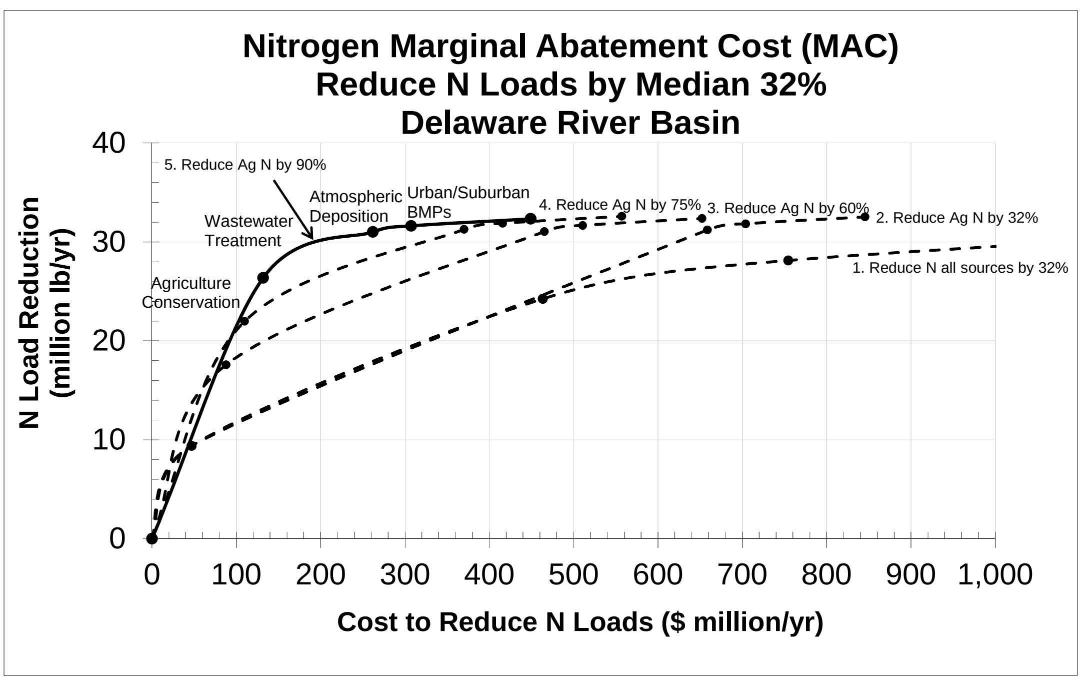


Figure 8.3: Nitrogen marginal abatement cost curves in the Delaware Basin

Benefits: Annual benefits due to improved water quality in the Delaware River range from a low bound of $371 million to a high bound of $1.1 billion in $2010 (Table 8.3). Recreational viewing, fishing, and boating provide 45% of benefits followed by agriculture (17%), nonuse (10%), wildlife/birdwatching, waterfowl hunting, and beach recreation (6%), water supply (4%), and commercial fishing, navigation, and property value benefits each at 2% of the total.

Table 8.3: Benefits of improved water quality in the Delaware River in $2010

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	4.5	5.6	55	68
	Boating	159	350	46	334
	Fishing	216	337	129	202
	Shad fishing	0	6.5	0	3.9
	Bird/Wildlife Watching	307	325	15	33
	Waterfowl Hunting	1.4	16	0.1	1.6
	Swimming	0	0	0	0
	Beach Going	6	50	2	16
Commercial	Fishing	34	34	0	17
	Agriculture	0	0	8	188
	Navigation	81	81	7	16
Indirect Use	Property Value	333	333	13	27
Water Supply	Municipal Water Supply	196	196	12	24
	Industrial Water Supply	140	140	8	17
Nonuse					
Existence/Bequest	WTP Boatable to Fishable WQ	102	151	76	115
Total		**1,580**	**2,025**	**371**	**1,063**

Benefit-Cost Analysis: Net benefits are estimated by subtracting total costs from benefits (Table 8.4). Optimal water quality occurs at a DO level of 4.5 mg/l where maximum net benefits range from $97 to $559 million/yr. At a DO of 5.0 mg/l, maximum net benefits ($614 million/yr) occur for the high bound curve, however net benefits are negative for the low bound curve. Based on the benefit/cost ratio, the most cost effective DO level is 4.0 mg/l where maximum BC ranges from 2.5 to 7.1.

Table 8.4: Benefit- cost analysis of improved water quality in the Delaware River

DRBC Criteria	**DO (mg/L)**	**N Load (ton/yr)**	**32% N Reduction (ton N/yr)**	**Costs ($ million**	**Benefits ($ million)**		**Net Benefits ($ million)**		**B/C**	
					Low	**High**	**Low**	**High**	**Low**	**High**
Existing	3.5	50,525	0	0	0	0	0	0	0	0
↓	4.0			50	124	354	74	304	2.5	7.1
	4.5			150	247	709	97	559	1.6	4.7
Future	5.0	34,357	16,168	449	371	1,063	-78	614	0.8	2.4

The total cost and total benefits curve (Figure 8.4) indicates that high bound benefits exceed the costs for Options 2 through 5 (Reduce Ag N by 32% to 90%). High bound benefits exceed costs for Option 1 (reduce N from all sources by 32%) until the costs exceed $850 million which corresponds to a dissolved oxygen level of 4.7 mg/l. The total cost curves for the five options cross the low bound benefits line between a DO level of 4.2 mg/l (Option 1) and 4.8 mg/l (Option 5). This suggests that the optimal DO level in the Delaware River where total costs equal total benefits is close to 4.5 mg/l.

The total cost and marginal cost curves are curvilinear in form due to increasingly higher costs of nitrogen load reductions as one progresses from left to right on the marginal abatement cost curve (MAC) from less expensive agriculture and wastewater controls to more costly airborne emissions and urban/suburban control measures.

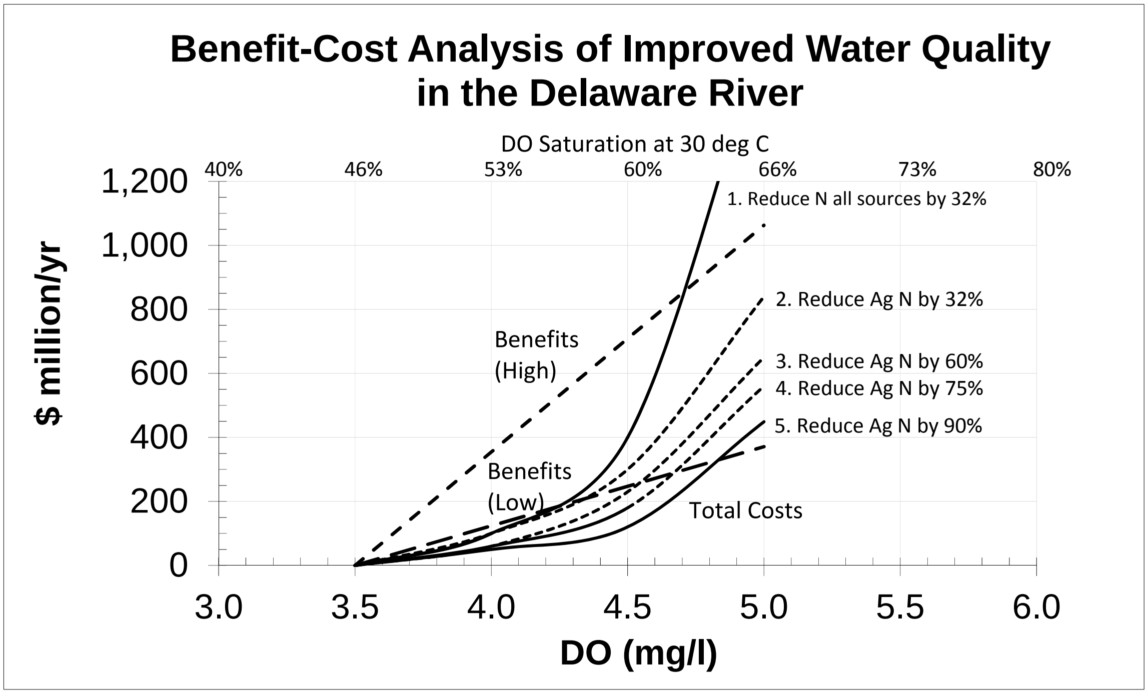


Figure 8.4: Total cost/benefit curves in the Delaware River

Optimal water quality occurs where the marginal cost (MC) curve intersects the marginal benefits (MB) curve or the point where the economic system is in equilibrium (Table 8.5 and Figure 8.5). The marginal cost and marginal benefits curves illustrate five cost options based on a nitrogen reduction of 32% and low and high bound benefits curves. The five marginal cost curves fan out and intersect the low bound marginal benefits line at a DO level between 4.3 mg/l for Option 1 and 4.6 mg/l for Option 5. The five MC curves intersect the high bound MB line at a DO between 4.5 mg/l (Option 1) and 4.7 mg/l (Option 5). The intersections of these MC/MB curves suggests the optimal level of DO is close to 4.5 mg/l.

Based on benefit-cost analysis, the optimal level of water quality in the Delaware River as measured by dissolved oxygen ranges from 4.2 mg/l to 4.8 mg/l. A DO level of 4.2 mg/l could be achieved at a cost of $150 million with benefits of $150 to $500 million/yr. A DO level of 4.8 mg/l could be achieved at a cost of $350 million with benefits of $350 to $950 million/yr. If efficiency in administering the water quality regulations is desired, then the most cost-effective future DRBC DO standard could be rounded to 4.5 mg/l. A DO level of 4.5 mg/l could be achieved at a cost of $250 million with benefits of $250 to $700 million/yr (Table 8.6).

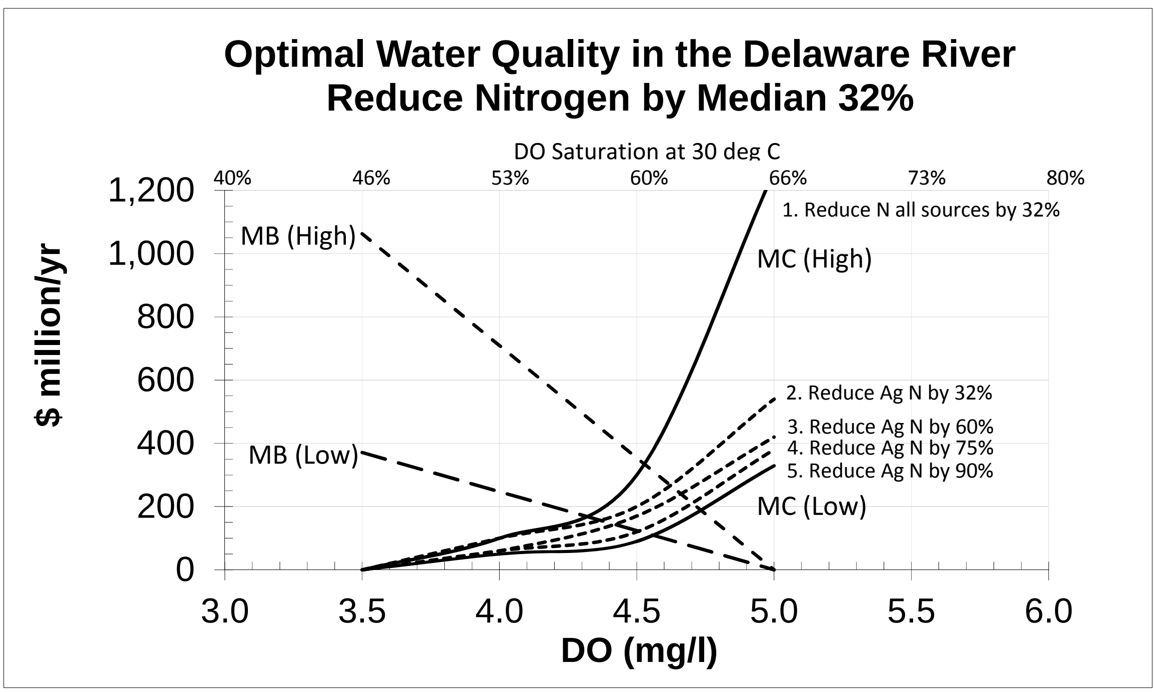


Figure 8.5: Marginal costs and benefits of improved water quality

Table 8.5: Marginal costs/benefits of improved water quality in the Delaware River

DRBC Criteria	DO (mg/L)	Costs ($million)	Marginal Costs ($ million	Benefits ($ million)		Marginal Benefits ($ million)	
				Low	High	Low	High
Existing	3.5	0	0	0	0	371	1,063
↓	4.0	50	50				
	4.5	150	100				
Future	5.0	449	299	371	1,063	0	0

Table 8.6: Costs/benefits of optimal water quality in the Delaware River

Option	Optimum DO (mg/L)	% DO Saturation at 30 deg C	Costs ($ million)	Benefits ($ million
1. Reduce N all sources by 32%	4.2	55%	150	150-500
2. Reduce N from Ag by 32%	4.3	57%	200	200-600
3. Reduce N from Ag by 60%	4.5	60%	250	250-700
4. Reduce N from Ag by 75%	4.7	62%	300	300-850
5. Reduce N from Ag by 90%	4.8	64%	350	350-950

8.6 Discussion and Conclusions

While a future DO standard of 4.5 mg/l would reflect an efficient level of water quality where the marginal costs equal the marginal benefits, this criteria would be less protective than say 5 mg/l for the year-round propagation of anadromous fish. The literature indicates a minimum DO criteria of 6 mg/l may be needed to protect juvenile sturgeon. However a DO level of 6 mg/l (80% saturation) may be difficult to achieve at summer water temperatures that approach 30°C in the Delaware River at Philadelphia. A DO standard of 5 mg/l (66% saturation) may be more readily achieved at these warm water temperatures but will be less protective than 6 mg/l. This BCA indicates that a DO standard of 5 mg/l could be achieved at an annual cost of $449 million with benefits that range from $371 to $1,063 million.

The cost analysis is based on a median 32% reduction in nitrogen to the Delaware River bounded by 20% N reduction (25th percentile) and 48% N reduction (75th percentile) confidence intervals. This analysis includes five options that vary from the highest cost Option 1 (reduce N from all sources by 32%) at a costs almost four times more than the least cost Option 5 (reduce N from agriculture by 90%). A plot of the five options indicate the marginal cost (MC) and marginal benefit (MB) curves intersect just below and just above the economically efficient 4.5 mg/l DO criteria. This is important for two reasons: (1) letting the economics optimize the target may fail to ensure environmental goals (such as a stricter definition of the fishable standard) and (2) this suggests that implementation efficacies and/or costs may be critical to choosing a target that considers economics in addition to environmental conditions.

An additional consideration is the inverse relationship between dissolved oxygen saturation and water temperature and salinity. The costs and benefits of achieving improved water quality in the Delaware River through higher dissolved oxygen criteria are based on warm water temperatures that approach 30°C (86°F) during July and August. At 30°C, freshwater DO saturation is 7.54 mg/l. At this temperature DO is 46% saturated at 3.5 mg/l, 53% saturated at 4.0 mg/l, 60% saturated at 4.5 mg/l, 66% saturated at 5.0 mg/l, and 80% saturated at 6.0 mg/l. If water temperatures in the tidal Delaware River increase in the future by 2°C to peak summer levels of 30° C, based on saturation, DO will decline by about 0.2 mg/l (Figure 8.6). Research using a future DRBC hydrodynamic model should be conducted to more closely explore the influence of water temperature and salinity on DO levels in the Delaware Estuary.

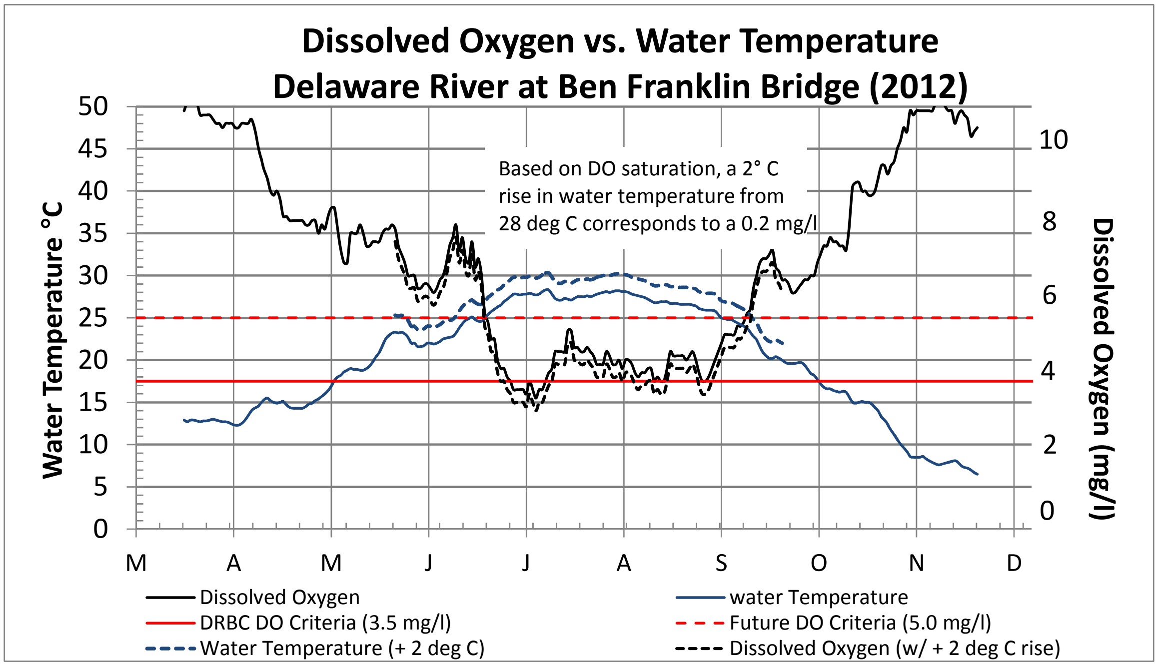


Figure 8.6: Dissolved oxygen/water temperature along the Delaware River

Adjusting to 2010 dollars and starting from a base DO level of 3 mg/l, annual costs from the 1966 Delaware Estuary economic study ranged between $58-$87 million to achieve summer DO of 4.0 mg/l and $180-209 million to reach 4.5 mg/l (Table 8.7). These estimates from an economic study conducted almost fifty years ago correspond reasonably well with the 21st century least cost (Option 5) of $50 million to reach 4.0 mg/l, $150 million to reach 4.5 mg/l, and $449 million to reach 5.0 mg/l.

Table 8.7: Costs/benefits to meet water quality criteria in the Delaware Estuary

Objective	DO Summer (mg/l)	Annual Costs ($2010 in millions)	
		1966 Study[1]	21st Century
	5.0		449
I	4.5	180-209	150
II	4.0	58-87	50
III	3.0	0	0

1. FWPCA (1966) adjusted from $1964 to $2010 by based on 3% annual change in CPI.

Now that the costs and benefits of improved water quality are quantified for the Delaware River, how would a sustainable watershed restoration program be funded during an era of declining government water appropriations and increasingly tight budgets?

Chapter 9

SUSTAINABLE WATERSHED FUNDING

9.1 Introduction

This chapter explores market-based funding options to pay for Delaware Basin water quality improvements. Sustainable funding vehicles such as investments in watershed services (IWS), fees, charges, and water quality trading have provided incentives to reduce water pollution control in river basins in the U.S. and around the world. The following funding options are considered for potential implementation in the Delaware Basin:

- Investment in Watershed Services (IWS)
- User Pays (Water Use Charge)
- Polluter Pays (Effluent or Emissions Fee)
- Watershed (Stormwater) Utility Fee
- Water Quality Trading

Funding options are considered to pay for a least cost (Option 5) water pollution control program that reduces nitrogen loads by a median 32% (32.3 million lb/yr) in the Delaware Basin at an annual cost of $449 million with $141 million for urban/suburban retrofitting, $132 million for agriculture conservation, $130 million for wastewater treatment, and $45 million for atmospheric NOX reduction. Nitrogen reduction costs are shared by Pennsylvania ($322 million), New Jersey ($87 million), New York ($19 million), Delaware ($16 million), and Maryland ($340,000).

Water resources funding to the Delaware Basin totaled $740 million in FY12 with $8 million from interstate sources (1%), $285 million from Federal funds (38%), $264 million from the four states (36%), and $183 million (25%) from New York City and Philadelphia (Figure 9.1). This existing funding stream results in a level of water quality where dissolved oxygen during the summer dips below the DRBC standard of 3.5 mg/l in the tidal Delaware River. Up to $449 million/yr in additional funding would be needed to boost DO to a future standard of 5.0 mg/l, an investment that would provide more protection for year-round propagation of the anadromous fishery and yield substantial economic benefits to the Delaware Basin as discussed in previous chapters.

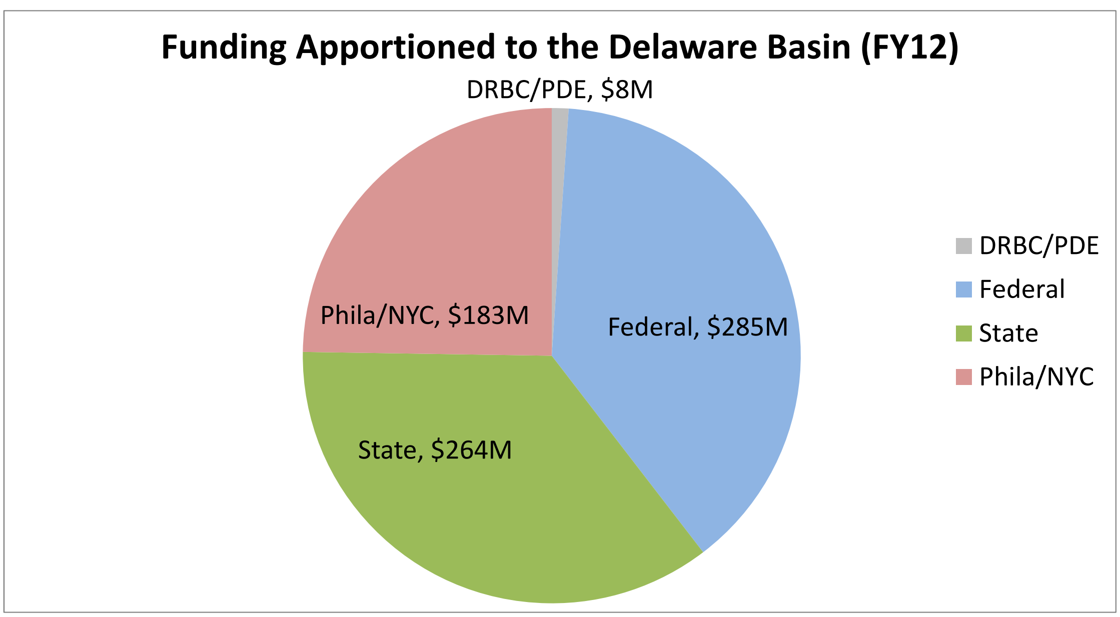


Figure 9.1: Funding apportioned to the Delaware Basin (FY12)

9.2 New Business Model

In free markets where goods and services are bought and sold, the allocation of resources is usually performed in an efficient manner. But because markets rarely exist in water pollution control and water is undervalued, the free market cannot allocate water efficiently (Daly and Farley 2011). Traditionally, economics has not accounted for negative externalities in the environment such as water pollution that can harm people living downstream and who do not receive compensation (Daily and Allison 2002). A water quality market administered by a river basin organization (such as the DRBC or DRBA) that involves fees would "internalize the externalities" and set up a pricing system that provides financial incentives for dischargers to reduce water pollution.

For close to a century, economists have called for management of the environment based on cost-effective principles. In the 1920s, Pigou raised the issue of negative externalities by polluters who impair others but are not required to pay for damages (Pearce 2002). Coase won the 1991 Nobel Prize for Economics by proposing that either a tax on the polluter or a subsidy where the polluter is paid not to pollute would equally address the externality problem.

In 1961, the President and Congress created the DRBC as the first Federal/state watershed agency with powers to establish cost-sharing formulas and share financial responsibility among the signatory parties. In 1962, the Harvard Water Program advocated a cost-benefit approach to river basin management based on social, environmental, and economic principles (Maass et al. 1962). In 1965, Congress passed the Water Resources Planning Act and created the U.S. Water Resources Council that later introduced national water planning principles and standards based on economic, environmental, and equity goals (USWRC 1983). Schaumburg (1967) examined the performance of the DRBC and Pareto efficient economics of water quality control in three areas: (1) command and control wastewater standards, (2) effluent standards, and (3) effluent charges or fees based on the quantity of pollutant discharges. The Organization for Economic Co-operation and Development (OECD) in Paris developed the "Polluter Pays Principle" in the early 1970s where each polluter would pay to reduce pollution provided the cost is less than the price of a permit.

Kneese and Bower (1984) from Resources for the Future offered the "economic approach" as the "science of choice" to make efficient decisions about water resources management. They cited the Delaware Basin as an example where externalities are not fully internalized because in a free market, wastewater dischargers may meet the standards but they did not fully pay the costs of waste disposal and often pass their costs to downstream users. Whereas if the DRBC managed water use, then the tendency to pass off costs to downstream users would evaporate because negative externalities would become internal within the basin organization. Kneese and Bower also discussed economic theory applied to river basins in England, France, and West Germany and along the Ohio, Potomac, and Delaware rivers and raised three key concerns. Do we want good water quality 90%, 95%, or 98% of the time? How can we achieve a desired level of good water quality at least cost? What are the best institutional arrangements for managing water quality in river basins?

Over the last decade, dwindling Federal and state funding and the strain on public budgets has caused shortfalls in water infrastructure investments. The Water Economic Forum estimates the U.S. spends about $23 billion a year to meet EPA environmental standards. Annual drinking water investment needs from 2000 to 2019 range from $7.7 to $22.3 billion according to the Congressional Budget Office, EPA, and the Water Infrastructure Network (WIN). In 2010, spending on water, wastewater, and stormwater infrastructure was $36.2 billion or $55 billion less than needed. Federal funding in water infrastructure has declined even though 95% of the U.S. public rank clean water as the most important government service and 87% believe the government should invest in clean water. While overall Federal water spending is flat since the 1980s at $7 to $8 billion per year, water and wastewater treatment appropriations have plummeted from a high of $14 billion during the 1970s Clean Water Act era to $4 billion by 2007 (Figure 9.2). State agencies estimate their current resources are either at or at less than one-half of that needed to adequately administer the Clean Water Act and Safe Drinking Water Acts. The U.S. Council of Mayors found that state and local governments spent $82 billion on water and wastewater infrastructure in 2004-2005 (Krop et al. 2008).

Public water resources funding is insufficient now but more is needed in the future. The American Society of Civil Engineers (ASCE) reported that if current funding is not increased, the water infrastructure funding deficit will grow to $84 billion by 2020 which will cost U.S. businesses $147 billion and the economy 700,000 jobs over the next decade and customers will pay $900 more per year in increased water rates. The EPA, Water Infrastructure Network, and Congressional Budget Office (CBO) estimated $630 billion should be invested over the next 20 years ($32 billion/yr) to keep up with water investment needs (Green For All 2011). The Mayor's Water Council tabbed local water infrastructure spending needs to be $150-$240 billion/yr between 2009 and 2028 (Green For All 2011).

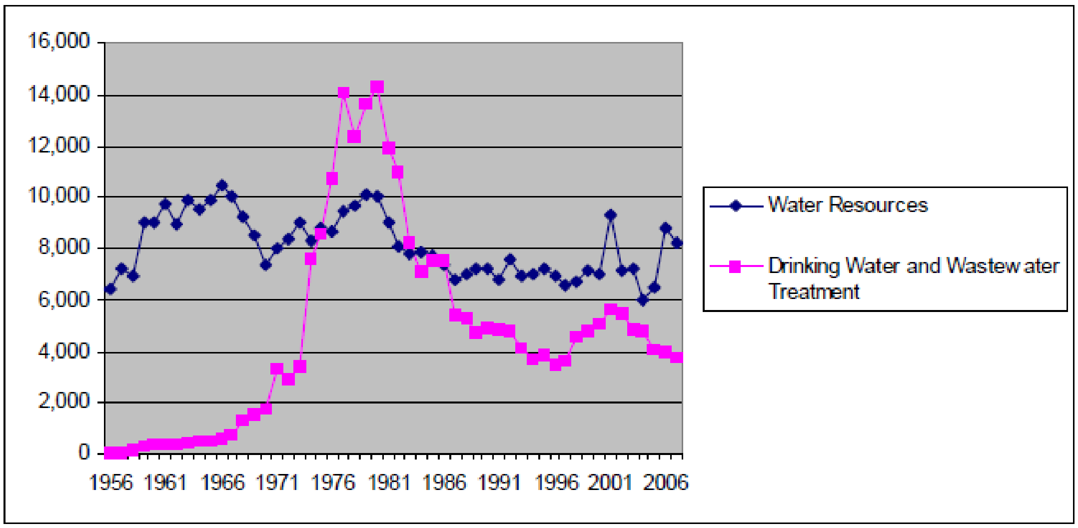


Figure 9.2: Federal water resources spending in 2006 dollars
(Congressional Research Service 2008)

These public water resources funding gaps have reignited interests to adopt more progressive economic policies to fund water quality control programs. In 2003, Federal water funding cuts prompted the U.S. Army Corps of Engineers Institute of Water Resources to consider if it might be time to resurrect the economic and environmental cost-benefit model first offered by the Harvard Water Program 40 years before (Reuss 2003). In 2007, Congress passed the Water Resources Development Act over President George W. Bush's veto that authorized the Army Corps of Engineers to develop principles and guidelines (P&Gs) to develop “water resources projects based on sound science that maximize net national economic, environmental, and social benefits." In 2009 reacting to an American Society of Civil Engineers report card that gave drinking water infrastructure a “D-“, Congress considered and then tabled legislation to re-establish the dormant 1965 National Water Commission (Cody and Carter 2009).

The American Water Works Association (2010) unsuccessfully petitioned Congress to create a Water Infrastructure Finance Innovations Authority (WIFIA) to lower the cost of capital for water utilities while not increasing the Federal budget deficit. In 2011, the Clean Water Affordability Act (HR1189), a proposed amendment of the Federal Clean Water Act, was introduced to the Subcommittee on Water Resources and Environment to appropriate $1.8 billion in grant funding for water resource infrastructure improvements but the bill died in the committee. In 2012, the National Association of Water Companies (NAWC) called for Congress to form a national commission on water and allow water utilities to pay for projects with tax free bonds and also allow private water companies to tap into the Clean Water State Revolving Fund which is currently open only to public utilities. In 2012, the Corps Institute for Water Resources (IWR) reiterated the call for a new national water policy initiative to maximize net benefits based on the old Harvard Water Program and establish a new Presidential water commission by Executive Order modeled after the defunct Water Resources Council (Stakhiv 2012).

These proposals to create a new business model for water resources management in the U.S. are tempting to many elected officials and Congress because these investments create jobs and boost the economy. The U.S. Conference of Mayors notes that each public dollar invested in water infrastructure increases private GDP output by $6.35. The Department of Commerce estimates that each job created in the local water and sewer industry creates 3.68 jobs in the national economy. Every $1 billion invested yields up to 15,000 jobs in water supply, 20,000 jobs in stormwater management, and 22,000 jobs in urban conservation (Pacific Institute 2013). The Water Puts America to Work campaign asserts that every billion dollars invested in water and wastewater infrastructure funds 28,000 jobs and generates $3.5 billion in economic activity. At these ratios, a $449 million annual expenditure to reduce pollutant loads and improve water quality in the Delaware River would boost GDP by 3.1 billion dollars, fund 12,600 direct water jobs and 46,000 jobs in the national economy, and generate $1.6 billion in economic activity.

9.3 Watershed Funding Options

With declining Federal and state funding; watershed managers and policy makers have focused renewed interest on market-based models such as fees, charges, and water quality trading as more efficient alternatives to the traditional command and control regulatory approach that relies on subsidies and grants. The University of Maryland Environmental Finance Center (2008) prepared a finance feasibility study for the Delaware Estuary that examined watershed financing options such as wastewater discharge fees and watershed district user fees and innovative license plate, State income tax checkoff, and utility bill roundup programs. The balance of this chapter examines these market-based funding options for potential implementation to fund water quality improvements in the Delaware Basin.

Traditional Regulatory Approach: Traditional command and control regulations impose numerical water quality standards through Clean Water Act, DRBC, and state regulations that are easier for regulatory agencies to administer, monitor, and enforce. Wastewater dischargers recover the costs of treatment to comply with regulations by collecting sewer rate fees from municipal, commercial, and industrial customers. For instance, the City of Wilmington wastewater rate is $5.15/1000 gal which for a 100 mgd system raises about $188 million in annual revenue. However, water quality standards provide weak financial incentives for the waste discharger to reduce pollution below the standard. Additionally, regulations often fail to minimize costs because it ignores differences in discharger control costs (Brown 1999). Regulations have proved effective at reducing water pollution (see the Delaware River) but command and control does not allow dischargers to balance incremental costs and benefit and does not raise revenues to fund water quality improvement projects.

Investments in Watershed Services: Investment in watershed services (IWS) programs involve downstream consumers who directly (through user fees) or indirectly (through taxes) pay to compensate upstream landowners for conservation activities, land acquisition and restoration (Dlugolecki 2012). IWS involves funding by downstream users such as water suppliers or wastewater dischargers in upstream watershed restoration, reforestation and agricultural conservation projects to improve water quality in a tradeoff less costly than building expensive drinking water treatment plants (Bennett et al. 2012).

One of the benefits of upstream investments by downstream water users is that both parties maintain local control and have the greatest knowledge about the watershed. Upstream farmers who may not have enough money to implement watershed conservation programs may be convinced to join the effort when provided with funding from downstream use charges.

One of the more popular payment for services programs is the USDA Conservation Reserve Program (CRP) that provides compensation to farmers who agree to take pasture or cropland out of use for 10-15 years. The enrolled land is managed for conservation through cover crops or reforestation to prevent erosion and runoff. The CRP reduces soil erosion by 750 million tons/yr in the U.S.

Boston, New York, San Francisco, and Seattle have funded $1.7 billion in IWS on 2.7 million acres under the EPA Surface Water Treatment Rule by the 1989 SDWA Amendments (Table 9.1). These IWS programs invest in low cost upstream restoration, reforestation, and agriculture conservation programs to protect water supplies in lieu of constructing expensive microfiltration treatment plants back in the cities. Restoration costs are higher at New York City's Catskill and Boston's Quabbin/Wachusset reservoirs because just 10% to 25% of the watershed area is city-owned compared to lower costs at San Francisco's Hetch Hetchy reservoir in Yosemite National Park and Seattle's Red Cedar River where nearly 100% of the watersheds are owned by city government.

In 1997, the classic IWS case study began when the EPA required New York City to construct a $10 billion drinking water microfiltration system under the terms of the Safe Drinking Water Act (Bennett et al. 2012). Three reservoirs in the Catskill headwaters of the Delaware River can provide up to 800 mgd of drinking water to New York City through the 60 mile Delaware Aqueduct. As an alternative to the $10 billion treatment plant, the City agreed with EPA to pass a water rate surcharge and fund a $1.5 billion watershed protection program of septic/sewer/wastewater improvements, reforestation, open space acquisition, and agriculture conservation projects to protect drinking water in the Catskill reservoir watersheds. The city protected 35% of the watershed for $1.5 billion (Thacher et al. 2011) and avoided the $10 billion cost of building expensive water treatment facilities, a benefit-cost ratio (B/C) of 6.5 to 1 (Figure 9.3). NYC residents benefit from this IWS approach as they drink high-quality drinking water at a much lower price than if the city built a costly new filtration plant.

Table 9.1: Investment in watershed services programs in the United States

Watershed	Year of Filtration Avoidance	Transactions by 2011 ($ million)	Protected Watershed (ac)
Quabbin/Wachusett, Boston, MA	1985	131	129,695
Cedar River, Seattle, WA	1992	82	100,497
Catskill-Delaware Reservoirs, New York, NY	1997	1,500	1,262,078
Hetch Hetchy, San Francisco, CA	2004	50	1,254,393
Total		**1,763**	**2,746,663**

The Philadelphia Water Department (PWD) employs IWS to protect the source waters of its Schuylkill intake. The City operates three water treament plants along the Schuylkill and Delaware River with a 560 mgd capacity to serve 1.5 million people or 20% of the Delaware Basin’s population. Since 2006, the Schuylkill Action Network (SAN) has invested $1.9 million raised from water and electricity rate revenues to provide grants to governments and nonprofits for stormwater, agricultural conservation, and abandoned mine drainage projects in the upstream source waters. The PWD also has developed a source water protection initiative with the PADCNR to preserve forests in the Delaware Basin headwaters far above the City's intakes.

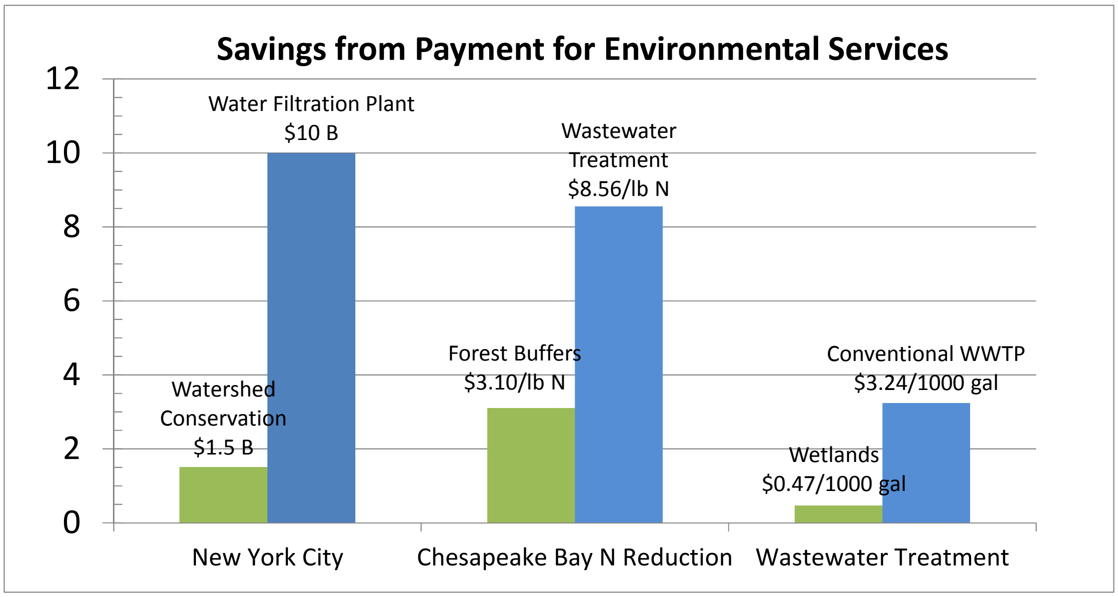


Figure 9.3: Savings from payment for environmental services (Thacher et al. 2011)

From 2002-2008, the U.S. funded $8.3 billion in IWS through the USDA Farm Bill, EPA Clean Water Act Section 319, and 1996 Safe Drinking Water Act programs. USDA conservation programs provided 5.2 million contracts worth $5.1 billion in cost-share payments for farmers to voluntarily build water quality and erosion control projects. The EPA Clean Water Act Section 319 Program provided 7,171 grants to states and tribes to implement $1.5 billion in nonpoint source projects to protect watersheds. The 1989 EPA Safe Drinking Water Act Amendments established the Surface Water

Treatment Rule which allotted $1.7 billion to restore watersheds while exempting cities from extremely expensive filtration plant requirements

Two innovative IWS funds have emerged, one in the humid East and the other in the arid West. The Pinchot Institute for Conservation in Milford, Pa. operates the Common Waters Fund that has issued over $1 million in grants to conserve and reforest 13,000 acres of easements on 48 properties in the upper Delaware River basin to improve water quality for downstream water suppliers at Easton, Trenton, and Philadelphia. In a 2008 cost-share agreement with the U.S. Forest Service, Santa Fe, New Mexico agreed to assess an annual fee of $6.50 per customer to finance 50% of the Forest to Faucets program to reforest the Santa Fe River watershed and protect the City's water intakes.

IWS is practiced in Latin America. In 2003, the Mexican government formed the National Program for Hydrological Environmental Services, a voluntary network that paid landowners $8.4 million in 2008 and protected 324,000 hectares of watershed forests. The Costa Rica Payment for Ecosystem Services provided $13 million in 2008 to protect 652,000 hectares for over 7,000 buyers who pay $10/ha/year and include hydroelectric companies *Energia Global* and *Hidroelectrica Platanar* and beer brewing company, *Compania Nacional Fuerza y Luz.*

Subsidies (Grants): In contrast to command and control standards, water pollution subsidies prompt dischargers to achieve equal marginal abatement costs because the discharger is inclined to stop polluting when the costs of polluting equal the benefits to the individual and society. Subsidies involve a user pays approach where society pays the polluter to reduce water pollution which is the opposite of a tax where the polluter pays society for the right to pollute. A subsidy involves a grant or payment to dischargers to reduce water pollution to a level where the marginal abatement cost equals the marginal benefit. If pollution abatement costs are lower than the subsidy, then the discharger will reduce pollution. The law of increasing marginal cost means there are diminishing returns for additional pollution reduction costs moving to the right on the marginal abatement cost curve (Daly and Farley 2011). If the discharger is compensated by the subsidy, the negative externality diminishes and pollution reduces until the marginal benefits equaled marginal costs for both the polluter and society. The Coase theorem of economics suggests that if property rights on water use are assigned, regardless of whether the discharger has the right to pollute or the individual has the right to clean water, pollution will be the same when marginal costs of pollution are equal to the marginal benefits to the discharger.

The disadvantages of the subsidy system include the need to raise funds through taxes and equity concerns where some dischargers are paid more than their fair share. In the worst case, subsidies may provide financial incentive to expand industries that ironically would cause more pollution.

After the 1972 Clean Water Act Amendments, Congress authorized the EPA construction grants program to provide massive grants to cities during the 1970s to fund municipal sewage treatment projects. The National Water Commission was initially against Federal subsidies that reduced the need for local funding, however a significant Federal sewage treatment plant grants program was sorely needed during the 1970s to rapidly improve water quality on a “national scale” because water pollution was so bad then (i.e. DO in the Delaware River was zero). The annual Federal Clean Water Act subsidy peaked at $4.5 billion in 1978 and declined to $1.25 billion by 2002. During 1980s, Ronald Reagan led a movement to reduce the Federal government and severely cut the Clean Water Act grant program. In 1989 while George H. W. Bush was President, Congress replaced the sewage treatment plant grant program with a less attractive subsidy involving loans. Currently, the EPA operates the Clean Water State Revolving Fund loan program that appropriates Federal money to the states. In turn, the states provide loans to local governments for wastewater and watershed projects which are repaid at low public interest rates.

A host of Federal water agencies receive Congressional appropriations to fund subsidies, grants, and loans for water quality and watershed restoration projects (EPA 2008 and Cody and Carter 2009). In the U.S. Department of Agriculture, the Forest Service Cooperative Forestry Assistance Grants provides $1 million grants to state forestry agencies to manage non-federal forests and other rural lands. The Agricultural Water Enhancement Program (AWEP), a subprogram of EQIP, provides financial assistance to farmers to address water quality concerns on agricultural land. The Conservation Reserve Enhancement Program (CREP) is a voluntary land retirement program that helps farmers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water. The Conservation Reserve Program (CRP) provides annual rental payments to producers to replace crops on highly erodible and environmentally sensitive land with long-term (10-15 year) resource conserving plantings, including buffer and filter strips. The Conservation Stewardship

Program (CSP) encourages producers to improve, maintain, and manage existing conservation activities, including water quality concerns. The Environmental Quality Incentives Program (EQIP) provides financial assistance to farmers to install vegetative management practices on agricultural lands to alleviate water quality concerns. The Wetlands Reserve Program (WRP) provides financial assistance to landowners to address wetland, wildlife habitat, soil, and water concerns on agricultural lands.

In the U.S. Department of Commerce, the NOAA Coastal Nonpoint Pollution Control Program provides grants to states with approved Coastal Zone Management Programs to develop Coastal Nonpoint Pollution Control Programs to implement nonpoint source pollution controls.

The EPA administers a Source Water Assessment Fund that provides grants to states to identify potential sources of contamination in drinking water areas. The National Estuary Program (NEP) is funded under Section 320 of the CWA to restore water quality and ecological integrity of estuaries of national significance with a Comprehensive Conservation and Management Plan. The Drinking Water State Revolving Fund (DWSRF) under the 1996 Safe Drinking Water Act Amendments authorizes funding to assist public water systems to protect public health.

The EPA Clean Water State Revolving Fund (CWSRF) under Title VI of the 1987 Clean Water Act provides federal monies to states to capitalize low interest, 20-year loans to communities to finance nonpoint source pollution control, watershed protection/restoration, estuary management, wetlands restoration, and municipal wastewater treatment projects. Between 1988 and 2010, the CWSRF provided $74 billion through 25,000 assistance agreements for wastewater infrastructure, nonpoint source, and estuary projects (Arbuckle 2012). The President's FY14 requested CWSRF appropriation was $1.095 billion, down $360 million from FY13, a cut that reflects "Sequestration" and the fiscal austerity mood on Capitol Hill.

CWA Section 319 Nonpoint Source Pollution Grants fund state water quality agencies to reduce nonpoint sources of water pollution in priority watersheds. In FY12, the Federal Section 319 appropriation was $165 million, down from the peak of $240 million during FY01-04 (Figure 9.4). The FY12 Section 319 NPS appropriation amounts to just fifty cents per person in the U.S.

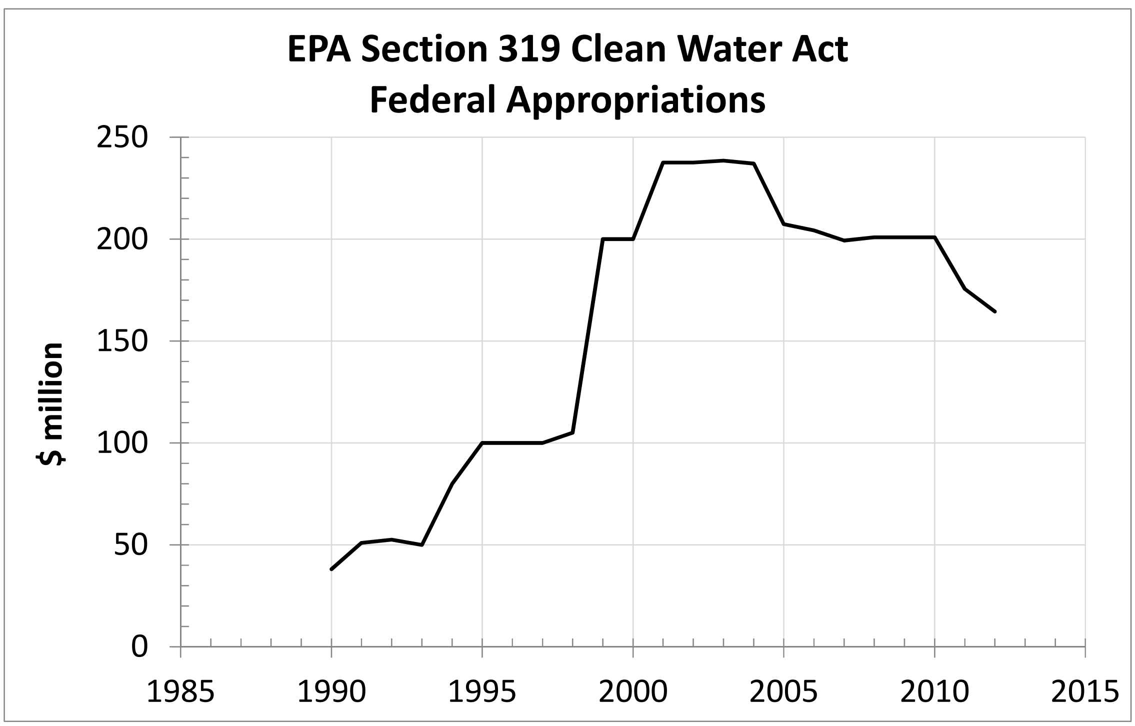


Figure 9.4: EPA Section 319 of the Clean Water Act appropriations.

In the Department of Interior, the Fish and Wildlife Service Habitat Conservation Program provides technical assistance to restore aquatic species habitat. The Fish and Wildlife Service Wetland Conservation Grants funds wetland conservation projects through the North American Wetlands Conservation Act. The National Park Service funds programs designed to protect aquatic and marine resources within NPS units and administer the Wild and Scenic Rivers Act to preserve designated rivers in a free-flowing condition and administer comprehensive river protection management plans.

In the Department of Defense, the U.S. Army Corps of Engineers restores river systems through the Water Resources Development Act of 1986 and Flood Control Act of 1970 and provides Planning Assistance to States to prepare comprehensive plans to conserve water resources.

In FY13, the Chesapeake Bay Program requested $448 million, up $55 million from FY2012. Federal investment in the Chesapeake is from the EPA ($179 million), USDA ($160 million), Defense ($76 million), Interior ($27 million), and NOAA ($7 million). Under the 2013 Farm Bill, the USDA plans to invest $121 million to install agricultural conservation practices on 4 million acres (6,250 mi^2) or 10% of the bay watershed by 2025. The Farm Service Agency administers the Conservation Reserve Program (CRP) that enrolls farmers in 10-year contracts on 287,000 acres including 4,000 miles of riparian forest buffers, 43,000 acres of grass filter strips, and 160,000 acres of grass plantings in the bay watershed. The Conservation Reserve Enhancement Program (CREP) provides 80% Federal money to match 20% local funds in the six bay states on 237,000 acres (370 mi^2). Federal agencies have formed an Environmental

Markets Team (EMT) to develop market-based water quality trading in the Chesapeake Bay watershed funded by $350,000 appropriated to the USDA Office of Chief Economist.

The U.S. Forest Service (2102) plans to invest $2.9 million to reforest the Chesapeake Bay watershed and reduce nitrogen, phosphorus, and sediment through USDA CREP, CRP, EQIP, and WRP programs. Urban reforestation reduces nitrogen loads by 4 to 13 lb/ac. Washington, DC is the first jurisdiction in the Bay watershed to include annual tree planting goals in its MS4 (Municipal Separate Storm Sewer System) permit. Forests in Prince William County, Virginia removed 227 tons of nitrogen dioxide (NO_2) annually with an air quality benefit of $37 million.

The Delaware River Basin Conservation Act was introduced to the 112th Congress in June 2011 by Senator Carper of Delaware and Representative Carney of Delaware. Unlike other large river basins in the U.S. such as Lake Champlain that receives $4 million and Chesapeake Bay that receives $50 million per annum, the Delaware Basin lacks dedicated federal funding support (Figure 9.5). The Act would require the Secretary of the Interior to establish the Delaware River Basin Restoration Program within the U.S. Fish and Wildlife Service to provide an annual appropriation of $5 million to be awarded to watershed groups for habitat restoration projects.

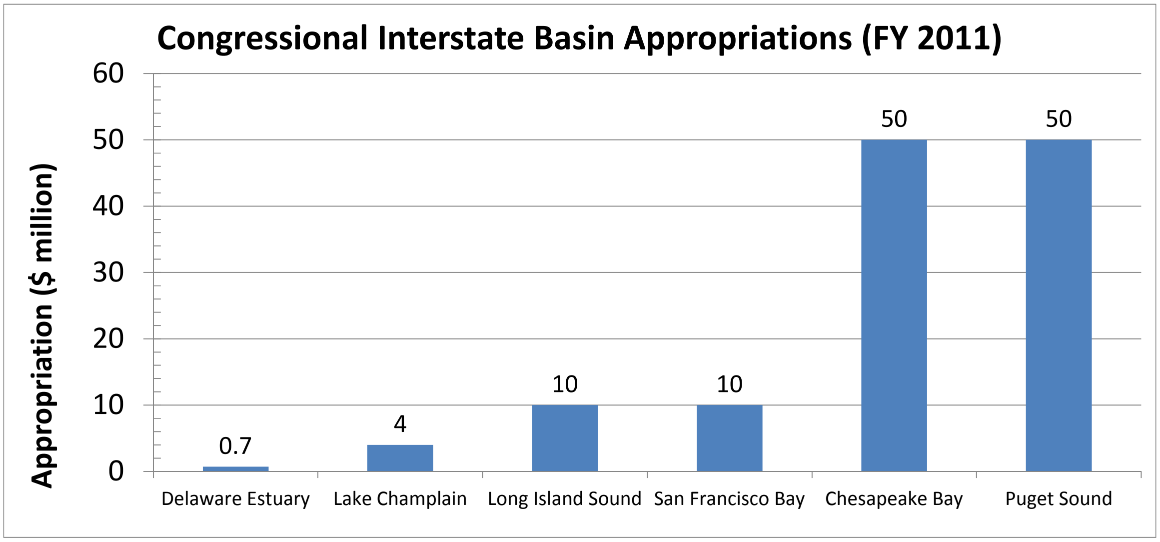


Figure 9.5: Congressional interstate basin appropriations (Northeast-Midwest Institute)

Polluter Pays (Fees or Charges): A fee (or tax or charge) employs the polluter pays principle to provide economic incentives to reduce pollution. Taxes assign a property right to the government where dischargers are permitted to pollute but must pay for pollution damages in the form of a fee or charge on the volume of wastewater emitted ($/1000 gal) or mass of pollutant discharged ($/lb N). Firms with high marginal abatement costs will pay the tax or fee. Firms with low marginal abatement costs may decide it is less expensive to abate pollution than pay the tax or fee. Dischargers pay a tax or fee on pollution on a per pound basis thus providing incentive to further reduce pollution more cost-effectively than command and control regulations. Market-based instruments such as pollution fee are designed to send a price signal to reduce pollution and incentivize polluters to reduce compliance costs and employ pollution abatement technology to avoid the tax.

Water quality standards and effluent fees (or taxes) accomplish similar objectives. A wastewater discharger has a marginal abatement cost (MC) curve (Figure 9.6). If the discharger is unregulated, it will reduce zero units of pollution and avoid treatment costs defined by the area under the MC curve (B+C+D). If the optimal level of pollution reduction is the intersection of the marginal benefit (MB) and marginal cost (MC) curves, then the resulting water quality is q_p.

If a fee or tax is set along a horizontal line where MB equals MC, it will be less expensive for the discharger to reduce emissions when the MC is lower than the fee. The fee (A+B) exceeds the MC to the left of the standard line (B), therefore the dischargers will choose to reduce emissions. To the right of the standard line, the MC (C+D) is more than the fee so the discharger will pay the fee and continue to pollute. An efficient level of efficient emissions is achieved at q_p where the treatment cost is B+D and revenue raised for the basin agency is D.

Alternatively, a standard can be established to cap the level of emissions where MB = MC as defined by the vertical standard line. For a standard, the economically efficient level of emissions occurs at q_p and the treatment cost is B.

Both a fee and standard will theoretically achieve the optimal reduction in emissions at the least cost. The cost to the discharger is less for the standard. The fee is advantageous as it provides a double dividend: (1) an economic incentive for the discharger to reduce pollution and (2) generates revenue for the basin agency to fund and administer water pollution control programs.

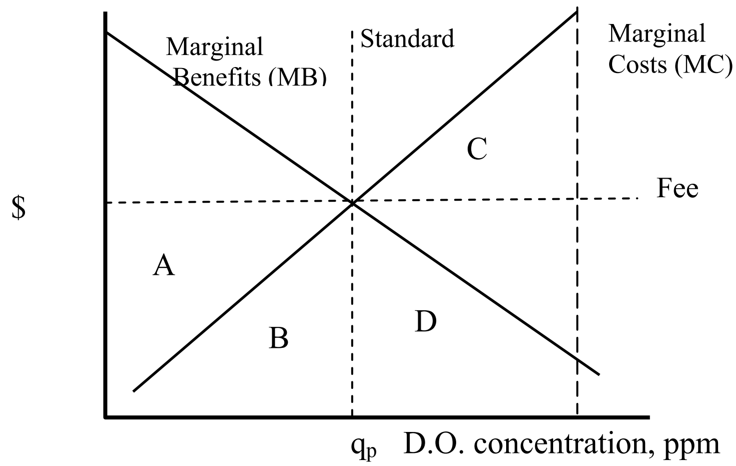


Figure 9.6: Effluent fee versus water quality standard

In 1999, the Pennsylvania Growing Greener Fund was signed into law, providing nearly $650 million to address the state's most pressing environmental challenges. In 2005, Growing Greener II was signed into law, investing $625 million to fund cleanup and restoration of watersheds, and construction of new and upgraded water and sewer systems. Counties, local governments, authorities, conservation districts, watershed associations and nonprofit groups may apply for Growing Greener grants. The Growing Greener Program is the largest single investment to protect the environment in Pennsylvania's history, amounting to $1.2 billion dollars. Act 13 signed in 2012 by the Governor now allocates fees from Marcellus shale natural gas drilling royalties as a new source of revenue to the PA Growing Greener Fund.

User Pays (Water Use Charge): The user pays approach is one of six founding principles of the International Network of Basin Organizations (2011) who advocate that the most effective river basin organizations rely on dedicated and reliable funding streams such as fees or charges to implement water pollution control projects and fund, operate, and staff the basin organization. A water surcharge fee by definition is temporary and could be waived when the economy improves. The fee, as opposed to a tax, is voluntary and control lies totally with the consumer. If one wishes not to pay the surcharge, one simply conserves water.

In a user pays (beneficiary pays) model, individuals such as drinking water purveyors who benefit from upstream restoration programs contribute to a water endowment fund. A water use charge imposes a fee ($/1000 gal) on water withdrawn from a river basin. The charges are collected and deposited in an endowment fund to pay for upstream water quality improvement programs, a form of investment in watershed services. Depending on the annual rate of return, the earned interest from the endowment is invested in watershed restoration while the principal is left intact. Participation and contributions may be voluntary.

Because water is a public good, river basin agencies are directly funded by public appropriations and/or charges and fees. Some basin organizations (such as the DRBC) rely more on fluctuating and volatile annual appropriations from government budgets and less on equitable user fees. River basin appropriations may fluctuate from year to year depending on the economy. Every fiscal year, basin agencies must compete for the appropriations with other government priorities such as education, roads, and health care.

To supplement appropriations, basin agencies have been urged to consider water use charges to pay for water quality programs to reflect the incremental external cost which a water supplier imposes on the overall watershed system (Kneese and Bower 1984, GWP and INBO 2010). User pay sources of revenue can provide more equitable and reliable cash flow to the basin organization to set up a fund to pay for watershed-wide pollution control projects. River basin user charges tend to be less volatile as the revenues "flow in" every year based on the volume of water withdrawals and are less vulnerable to political tampering during the annual appropriations process. River basin organizations (such as DRBC) have statutory powers under the compact to raise revenue from dedicated use charges to be clearly dedicated for water management which avoids occasions where the funds may be transferred away to the government "general fund".

Established by Congress in 1965, the National Water Commission urged that river basin commissions adopt an equitable user pays approach where those who benefit from the resource pay to protect it (Cody and Carter 2009). The NWC also warned that while cost-sharing may efficiently allocate scarce federal funds, implementing user pays policies is politically difficult.

In other nations, river basin agencies are authorized to impose tariffs as a surcharge to water bills. Water utilities willing to restore upstream water quality put the revenues into a bank and used the funds for upstream investments. In 1990, the Mexico National Water Commission increased water use fees by 1700% that reduced sugar factory water use by 94% and wastewater loads by 20%. Costa Rica's Payments for Environmental Services program funds reforestation projects on uncultivated farmland. A South Australia water and wastewater utility (SA Water) invests water rate fees to implement upstream catchment farm projects to improve water quality.

In the U.S., water use surcharges are authorized in several watersheds. The Rhode Island Water Board assesses the Aqua Fund, a popular penny per 100 gallon water use surcharge that collects funds for Narragansett Bay water quality improvement programs with $18 million disbursed since 1994. Presently, the DRBC collects a water supply use charge of $0.08 per 1000 gallons that raises approximately $3 million annually to pay for upstream storage that provides water quantity and water quality benefits to downstream users. This $0.08/1000 gal water use charge in the Delaware Basin is less than the rates in other nearby watersheds which range from $0.10/1000 gal for the Rhode Island Aqua Fund and $0.28/1000 gal in the Susquehanna River Basin to $0.97/1000 gal in the Manasquan System of the N.J. Water Supply Authority (Table 9.2).

Table 9.2: Water use charges

Basin Organization	Charge ($/1000 gal)
Delaware River Basin Commission	0.08
Rhode Island Water Board	0.10
Susquehanna River Basin Commission	0.28
N.J. Water Supply Authority (Manasquan)	0.97

Effluent (Emissions) Fees: An effluent or emissions fee is a polluter pays approach that provides financial incentives for dischargers to reduce loads to meet water quality standards. The effluent charge is set at optimal water quality (q_p) where marginal costs of pollution reduction equal the marginal benefits of improved water quality. By levying an effluent fee, river basin authorities provide incentives to a municipality or industry to adjust their wastewater treatment practices to minimize downstream costs. In contrast to subsidies, the basin agency levies fees on each gallon ($/1000 gal) or pound of waste ($/lb N) discharged. An effluent charge also provides a double benefit as it produces revenue for the river basin organization to administer and pay for water pollution control programs while effluent standards and subsidies do not. Effluent fees are collected and deposited in a bank to pay for upstream investments in pollution reduction programs. Wastewater dischargers often oppose effluent fees because they are permitted by governments to get by without paying for the external costs of water pollution that impair downstream users and individuals.

The effluent fee concept in the U.S. evolved during the 1960s when environmentally-minded economists first advocated an economic approach to river basin management. Fox and Smith (1966) recommended forming agencies with powers to implement river basin plans and internalize the external costs imposed by the wastewater dischargers on downstream individuals and governments. An economic study of the Willamette River near Portland, Oregon concluded that an effluent charge of $0.10/lb of BOD would achieve a 3 to 4 mg/l DO goal and collect $7 million/yr in revenue for the agency (Kerri 1966). The Federal Water Pollution Control Administration (1966) estimated that an effluent charge of $0.08 to $0.10/lb of biological oxygen-demanding (BOD) substance would produce large DO improvements in the Delaware River and provide $5 million in annual revenue to the basin organization. Kneese and Bower (1984) called for EPA to fund water pollution control program through a national effluent charge on waste discharges and offered the DRBC as the ideal basin firm to impose an effluent charge to reduce wastewater discharges to the Delaware Estuary. These recommendations to reduce water pollution through the economic approach were never implemented.

In 2004, Maryland passed a law authorizing the Chesapeake Bay Restoration Fund financed by a $2.50 monthly fee on users of wastewater treatment plants and a separate fee on septic systems. This "flush tax" is used to fund nutrient removal projects (nitrogen and phosphorus) by upgrading Maryland's 66 largest wastewater treatment plants, eliminating failed septic systems, and supporting agriculture cover crop programs. Maryland DNR funds $65 million annually for wastewater treatment and $12 million for septic system upgrades.

The Europeans have long emphasized river basin planning funded by revenue raised from effluent fees on waste discharges (GWP and INBO 2011). The European Water Framework Directive requires EU countries to employ a user/polluter pays approach to fund river basin programs. The German Ruhr Water Associations (*Genossenschaften*) set up the first effluent charge program in 1905 and the Federal Effluent Charge Law of 1976 set up a water pollution control market. Spain set up nine *Confederaciones Hidrograficas* funded by a polluter pays approach through levies and discharge fees. In Russia, centralized state ownership of 17 river basin agencies is funded by the polluter pays approach. The 1964 French water law established six *Agencies de L'eau* and *Comites de Bassin* that collect user charges (*redevance)* from dischargers and over 6 years collected $11.6 billion which were reinvested in water pollution control projects. The Dutch water boards (polders) are among the oldest democracies in Europe where landowners vote and pay taxes to the board. In Portugal, 15 river basin authorities collect funds based on user (water withdrawal) and polluter (discharger) pays principles.

Countries in the Americas also tend to fund water pollution control programs through the polluter pays approach. The Mexico National Water Commission oversees 25 river basin councils and 6 basin commissions funded by user fees. In Columbia, the *Corporación Autónoma Regional* receives an allocation of local government property taxes. In 2005, the Brazil *Piracicaba, Capivari, and Jundiai* river basin (PCJ) committee assesses water use charges of $0.04/1000 gallons of water consumed and an effluent charge of $50 per ton of discharge.

Another form of emissions fee puts a price on the right to pollute by addressing air pollution at the source. Over 30% of nitrogen and mercury water pollution originates from atmospheric emissions from motor vehicles, industries, and power plants. Under Title V of the Federal Clean Air Act, states charge permitted dischargers a fee of $25 per ton for emitted pollutants. Emissions charges create incentives to innovate and create mechanisms to reduce air pollution.

Watershed (Stormwater) Utility Fee: Watershed (stormwater) utilities impose a fee ($\$/ft^2$) on the amount of impervious roof and pavement area to fund stormwater projects. The watershed fee employs an equitable polluter pays approach based on the hydrologic principle that the volume and quality of stormwater runoff is proportional to the amount of impervious cover. Almost 700 local governments in the U.S. have adopted stormwater utilities (Figure 9.7). The mean monthly stormwater fee for single family residential parcels is $3.67 within a range of $1.50 in Burlington, Vermont to $3.43 in Orono, Maine and $14.26 in Ft. Collins, Colorado. Stormwater utilities have several advantages because the dedicated user fee:

- Treats stormwater as utility resource like drinking water.
- Is equitable based on the amount of stormwater from impervious cover on a parcel.
- Is based on a hydrologic relationship between impervious and stormwater runoff.
- Accrues to tax paying and tax exempt properties unlike a tax.
- Is a nonvolatile municipal funding source preferred by S&P bond rating services.
- Utilizes a billing system in place for water, sewer, property assessment.

In Maryland, House Bill 987 requires the 10 largest NPDES MS4 Phase 1 counties in Anne Arundel, Baltimore, and Howard counties to implement a stormwater utility fee by July 2013 that will provide a dedicated revenue source to pay for stormwater management.

Philadelphia, Wilmington, and Lewes, Delaware are the only three cities in the Delaware Basin that have adopted stormwater utility fees. Stormwater utilities charge monthly residential fees of $2.71 in Wilmington and $10.80 in Philadelphia. Wilmington utilizes stormwater utility revenue to abate combined sewer overflows and fund upstream farms to improve water quality on the Brandywine Creek which is the City's sole drinking water source.

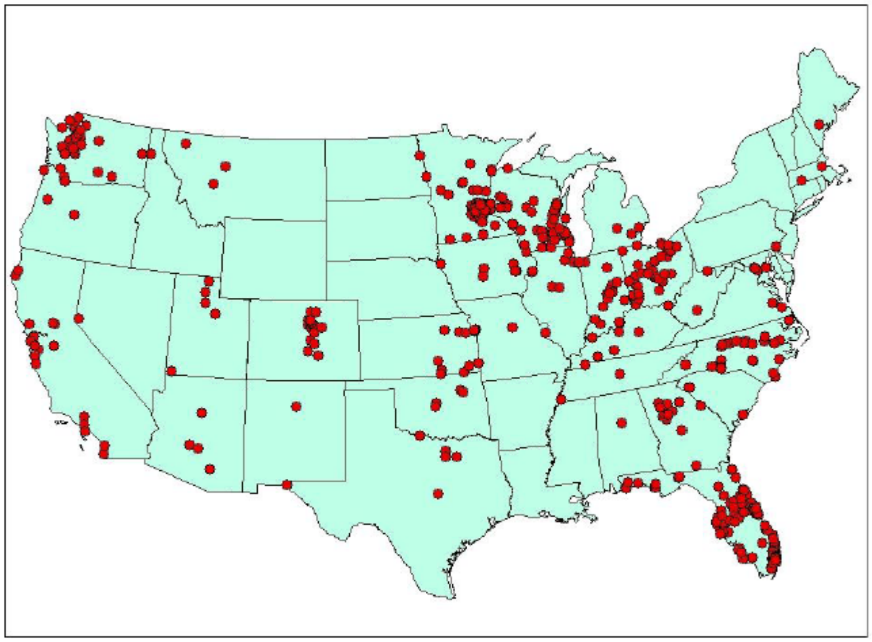


Figure 9.7: Stormwater utilities in the United States
(Western Kentucky University 2008)

In July 2010, the City of Philadelphia created a stormwater fee based on the amount of impervious surface area on a parcel (Valderrama et al. 2012). Philadelphia invests stormwater fees in CSO abatement projects, green stormwater retrofitting, and upstream source water projects through the Schuylkill Action Network (SAN). Philadelphia's stormwater fee will fund retrofits at 1,400 of the largest city properties for \$438 million using an impervious cover charge of \$0.0083/ft^2. The stormwater utility provides a 100% credit for nonresidential owners who install BMPs to treat the first inch of rainfall. The program plans to retrofit 10,000 impervious acres of public/private property over the next 25 years. Under the new utility, the largely paved Philadelphia airport will pay an increased fee of $126,000/month while the landscaped University of Pennsylvania campus will save $11,000/month.

In 2009 Newark City Council considered then tabled a stormwater utility proposal that would have reduced residential property taxes for 80% of the parcels in the City and assess a $0.01/ft^2 fee on impervious cover to raise $720,000/year (Kauffman and Homsey 2009). Annual stormwater fees would range from $25 for a ¼ acre single residential lot to $547 for a drug store to $6,063 for a shopping center (Table 9.3).

Table 9.3: Typical stormwater fees for parcels in the City of Newark

Parcel	**Area (ft^2)**	**Impervious (ft^2)**	**Impervious (%)**	**Annual Fee (@ $0.01/ft^2**
¼ ac SF Residential	10,000	2,500	25%	$25
Restaurant	17,100	17,100	100%	$171
Church	53,850	23,820	44%	$238
Drug Store	89,200	54,700	60%	$547
School	519,610	170,300	33%	$1,703

Water Quality Trading: Environmental trading has successfully reduced air pollution through the Federal Clean Air Act and Regional Greenhouse Gas Initiatives between the states. Since 1990, Title IV Amendments to the Clean Air Act capped SO_2 emissions to reduce acid rain under a trading policy. Congress capped the emission of SO_2 and allowed coal and oil-fired electric power plant emitters to use market forces to find cost-effective mechanisms. EPA estimated the trading market reduced SO_2 emissions with a savings of $16 billion (Scatena et al. 2006). The Regional Greenhouse Gas Initiative (RGGI) was developed by Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont to cap and reduce power plant CO_2 emissions by 10% by 2018. The states sell emission credits during annual auctions and invest the revenues in clean energy programs. The December 2012 RGGI auction sold 19,774,000 credits to 29 bidders at a CO_2 price of $1.93/ton. The successes of air pollution cap and trade programs have convinced some policy makers that trading could be applied to water pollution control (Ecosystem Marketplace Team 2008).

Water quality trading involves establishing a market or bank for buying and selling credits to reduce water pollution. EPA (2003) released a national water quality trading policy that offered a more cost effective way to reduce water pollution on a watershed basis. Trading provides financial incentives for dischargers with high treatment costs to meet water quality standards by purchasing pollutant reduction credits from another source (such as agriculture) with lower unit costs thus reducing the cost of compliance (Letnes 2011). Instead of expensive wastewater treatment improvements, funds are invested upstream in less costly agricultural conservation projects. A growing number of watershed-based Total Maximum Daily Loads (TMDLs) mandated by EPA and the Clean Water Act establish pollutant load reductions as the basis for water quality trading. Water quality trading addresses the Federal Clean Water Act provisions for water quality standards, National Pollutant Discharge Elimination (NPDES) permits, and TMDLs (Kardos and Obropta 2011). Water quality trading pollutant load reductions are estimated by the SPARROW, BASINS, SWAT, and AGNPS watershed models. Increased wastewater treatment costs coupled with dwindling Federal/state water appropriations are driving the search for more innovative market-based funding mechanisms such as water quality trading.

For water quality trading to be successful, it must be (1) voluntary, (2) driven by Clean Water Act and state regulations, (3) motivated by differential costs with a unit of trade (such as $/lb N), (4) governed by rules that define record keeping, inspections, and reporting, and (5) transparent with public notice through the TMDL and NPDES permit process. Farmers may be reluctant to participate in water quality trading (Ecosystem Marketplace Team 2008).

Trading can produce substantial cost savings while meeting water quality goals (EPA 2001). At the Long Island Sound in Connecticut, nitrogen trading among 79 water treatment plants saved over $200 million in TMDL costs.

In 2011, water quality trading occurred in 17 states although just five programs have a large trade volume (Kardos and Obropta 2011, Bennett et al. 2012). Water quality trading programs have exchanged nitrogen credits at costs ranging from $1.21/lb in Long Island Sound to $4.52/lb in the Neuse River in North Carolina (Table 9.4). The Tar-Pamlico Association in North Carolina formed a trading program in 1989 that generated $52 million in nutrient reductions at $25/lb with $10.8 million in transactions in 2008. The Long Island Sound nutrient point source trading program in Connecticut involves 79 public treatment plants to achieve TMDLs by 2014. The Chesapeake Bay trading program in Virginia involves 125 point source dischargers to meet tributary strategies. In Washington D.C., a proposed stormwater trading program is designed to cost-effectively meet an NPDES Municipal Separate Storm Sewer System (MS4) permit. The Ontario

Ministry of Environment prompted the South Nation Conservation Authority to purchase credits from nonpoint sources to reduce phosphorus below a 0.03 mg/l standard. Water quality trading may play a significant role in obtaining cost-effective reductions that will assist New Jersey to successfully meet its goal of assigning total phosphorus effluent limitations of 0.1 mg/l for point source discharges to waterways improve water quality (Obropta and Rusciano 2004).

In the Southern Hemisphere, the New South Wales Environmental Protection Authority established an emissions trading program in 1996 that allowed 3 sewage treatment plants to cost effectively reduce phosphorus by 83% and nitrogen by 50% compared to conventional command and control. In the Lake Taupo Trading Program in New Zealand, the Waikato Regional Environmental Authority reduced nitrogen by 20% through land conservation practices.

Basic types of trading include point source to point source and point source to nonpoint source. Nonpoint source to nonpoint source trading is not typically practiced as agriculture is not regulated under the Clean Water Act. A PS-NPS trade may involve a buyer who owns a wastewater treatment plant facing high nitrogen reduction costs. A seller is typically an unregulated nonpoint source such as agriculture with low N reduction costs. Farms can reduce N loads for 2% to 5% of the cost that wastewater treatment plants pay to reduce emissions (Ecosystem Marketplace Team 2008).

Table 9.4: Water quality trading programs in the U.S.
(EPA 2003, Scatena et al. 2006, Bennett et al. 2012)

State	Location	N/P	2008 Reductions (lb)	2008 Transactions ($)	2008 Cost ($/lb)
CO	Bear Creek	**P**	137	6,197	45.23
CO	Dillon Reservoir				
CT	Long Island Sound	N	7,300,000	8,806,500	1.21
DE	Inland Bays				
MA	Charles River				
MN	So. MN Beet Sugar Coop	P	10,633	425,320	40.00
MN	Red Cedar River	P	12,091	14,908	1.23
MN	Minnesota River	P	10,955		
NJ	Passaic River				
NY	Croton Watershed				
NC	Neuse River Basin	N	5,906	207,886	4.53
NC	Tar-Pamlico River	N	64,000		18.92
OH	Great Miami River	N	318,031	591,970	1.86
OH	Sugar Creek/Alpine Cheese Co	P	16,743		
ON	South Nation	P	1,157	20,822	17.99
PA	Pennsylvania	N	82,859		3.10
VA	Chesapeake Bay	N	246,309		

Water quality trading involves a buyer, seller, and administrator. Buyers include municipal and industrial dischargers with high wastewater treatment costs who may be willing to purchase cheaper point or nonpoint source pollutant credits. Sellers are usually nonpoint sources of pollution such as farms who can implement inexpensive BMPs such as forest stream buffers, reduced fertilizer use, manure management, fencing farm animal stream fencing, and cover crops. Administrators establish trading rules and monitor transactions with funding available from USDA NRCS Conservation Innovation Grants and EPA Clean Water Act Section 319 program.

Trading can occur directly between a buyer and seller or through a third party via a credit exchange. A credit exchange is usually managed by the state or watershed agency who purchases credits generated by nonpoint sources by low cost implementation of BMPs then sells these credits to point sources. Credit exchanges reduce transaction costs and facilitate trades by eliminating the need for point sources to negotiate with other point sources. A broker brings point sources and nonpoint sources together to trade directly with each other.

Universities are suited to oversee water quality trading. The University of Massachusetts partnered with the Massachusetts Executive Office of Environmental Affairs to develop nitrogen trading programs. The Alpine Cheese Company partnered with Ohio State University to conduct research and facilitate program design. Rutgers University facilitates the Passaic River trading efforts.

Consider a simple water quality trading example. Facility A offers to sell 80 lb of nitrogen for sale at $20/lb. Facility B is a buyer that can reduce nitrogen at $75/lb and needs to reduce 50 lb of N. Nonpoint source C is a seller with 50 lb of nitrogen for sale at $5/lb. Facility B will bargain to buy nitrogen credits from C which has the least nitrogen reduction cost (Figure 9.8).

The EPA and the states established the Chesapeake Bay Fund to conduct water quality trading and implement watershed wide TMDLs established in 2011. President Obama issued an Executive Order in May 2009 that directed the EPA to clean up the Bay by enforcing the Clean Water Act. The Chesapeake Bay Commission estimates it will cost $1.47 billion per year to pay for the nutrient load reductions mandated by the TMDL.

Water quality trading can reduce pollution control costs by 80% and save $1.2 billion/yr in the Chesapeake Bay watershed (CBC).

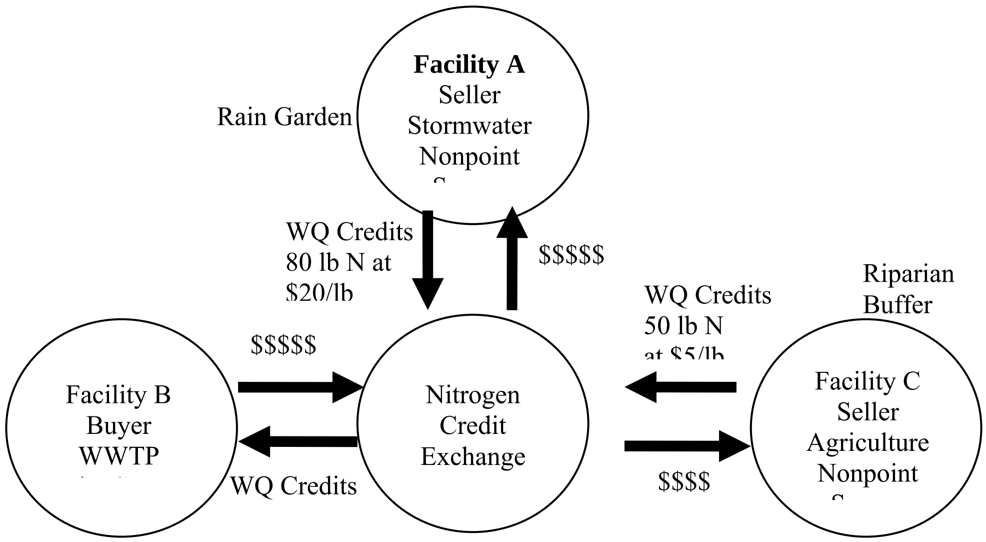


Figure 9.8: Typical water quality trading exchange (Letnes 2011)

In 2009, the Chesapeake Bay Foundation established a water quality trading market to fund habitat restoration, farm conservation, and forestry projects through a Market Environmental Registry. The World Resources Institute evaluated nutrient trading to provide financial incentives to reduce nutrient loads to the Chesapeake Bay (Jones et al. 2010). A bay-wide nutrient trading market for the Chesapeake Bay watershed would allow credits to be exchanged across state lines and among the watershed's nine river basins to cost-effectively achieve nutrient pollution limits (the TMDLs).

Nutrient trading would generate new revenue for farmers, reduce removal costs by 60%, and save municipal stormwater programs over $100 million/yr. By selling credits, farmers could earn $45 to $300 million/yr in revenue in a Chesapeake Bay nitrogen trading market which would complement existing USDA agriculture conservation cost-share programs in the bay watershed that awarded $180 million in FY2009. If the nitrogen credit price is $20/lb and the annual cost of wastewater treatment is $47/lb, nutrient trading could yield a 60% cost saving for 40 wastewater plants that need improvements. WWTPs with low N reduction costs could earn revenue and save money for customers by reducing discharges below standards and selling surplus credits to other WWTPS or municipal separate storm sewer systems (MS4s) that have high abatement costs. A bay-wide trading program could save MS4s hundreds of millions of dollars per year by allowing cities to invest in upstream agricultural conservation projects at $5/lb N reduced or 40 times less than the average stormwater retrofit cost of $200/lb N.

Water quality trading is supported through seed funding from the USDA Conservation Reserve Program (CRP), Wetlands Reserve Program (WRP), and Environmental Quality Incentives Program (EQUP). The 2008 Farm Bill established the USDA Office of Environmental Markets (OEM) to encourage market-based water quality trading by farmers, ranchers, and landowners and create environmental markets in the Chesapeake Bay and Mississippi River basins. From 2004-2008, the USDA awarded 12 Conservation Innovation Grants that funded $6.6 million to set up water quality trading programs with grants ranging from $58,000 to $1 million.

In 2012, the USDA awarded $26 million in Conservation Innovation Grants to fund 59 projects in 17 states. Twelve of the grants will fund water quality trading markets including 5 grants for the Chesapeake Bay. The largest grant ($1.6 million) funded WQT by the Willamette River Partnership near Portland, Oregon. The Electric Power Research Institute (2012) was awarded a $1 million CIG grant to work with Indiana, Kentucky and Ohio to develop interstate water quality pilot trades in the Ohio River Basin in 2012. In the Chesapeake Bay, five awardees will be facilitating and building infrastructure for water quality trading markets by the Alliance for the Chesapeake Bay, Chesapeake Bay Foundation, Borough of Chambersburg, Virginia Department of Conservation and Recreation, and Maryland Department of Agriculture.

The EPRI (2012) established the Ohio River Basin Trading Project in Ohio, Indiana, Kentucky, West Virginia, Illinois or Tennessee as the first interstate, multi-pollutant trading program. EPRI received a $1 million USDA CIG grant to conduct water quality trading in the Ohio River Basin and American Electric Power and Duke Energy provided $400,000 in private funds. Power companies, farmers, and industries will establish a market to trade credits for reducing nitrogen and phosphorus to cost effectively restore the Ohio River Basin. Rather than paying for more expensive controls, wastewater treatment facilities will have incentive to purchase less expensive nitrogen credits from agriculture. The project proposes to conduct trades with at least 3 power plants or up to 50 farms to implement agricultural conservation practices on 20,000 acres across to reduce nitrogen by 45,000 pounds annually. A full-scale WQT program will be conducted in eight states and create a market for 46 power plants, 1000 wastewater plants, and 230,000 farmers. If 5% of the 230,000 farmers in the Ohio River Basin actively trade, they could implement conservation practices to reduce nutrient runoff on 2.2

million acres. ESRI will be assisted by the Ohio Farm Bureau Federation, Miami Conservancy District, and Ohio River Valley Water Sanitation Commission.

The University of Pennsylvania (Scatena et al. 2006) reported to the William Penn Foundation that there were no apparent legal or administrative obstacles to establish water quality trading in the Delaware River because the Delaware Basin:

- Provides clear watershed boundaries to define the trading program.
- Has many dischargers with wide variability in marginal pollution reduction cost.
- Has the DRBC, EPA, and states that administer TMDLs as regulatory incentives.
- Provides a strong central authority (DRBC) to operate the trading market.

The PENN study recommended that DRBC work with EPA and the states to develop a regional water quality trading policy to include: (1) regional guidelines for monitoring the effectiveness of specific trades, (2) an agreement or MOU to promote water quality trading in the Delaware Basin, (3) watersheds where trading is expedited through caps based on TMDLs and NPDES permits, and (4) an annual budget of $200,000 to run the trading program with two professional positions.

A market-based water quality trading program in the Delaware Basin could provide significant cost savings by encouraging atmospheric NOX ($75/lb N), wastewater treatment ($28/lb N), and urban/suburban stormwater ($200/lb N) sources with high nitrogen marginal abatement costs to buy credits from sellers in agriculture ($5/lb N) that have low N abatement costs. Farm conservation programs at $5/lb N can reduce nitrogen for just 2% of urban/suburban stormwater retrofitting, 7% of atmospheric NOX abatement, and 18% of wastewater treatment costs.

Without incentives proved by market practices such as water quality trading, N load reductions of 32 million lb/yr (32%) would be applied evenly across all sources in the Delaware Basin at a high cost of $1.7 billion/yr. With water quality trading, atmospheric, wastewater, and urban/suburban producers would be motivated to buy nitrogen credits from agriculture and the cost to reduce N loads by 32 million lb/yr (32%) would be reduced to $449 million/yr.

A water quality trading program to reduce nitrogen loads by 32 million lb/yr (32%) in the Delaware Basin could save $1.2 billion annually (Figure 9.9). Trading would provide savings of $844 million in Pennsylvania, $230 million in New Jersey, $76 million in New York, and $44 million in Delaware. Atmospheric sources would save $246 million/yr by buying 3 million pounds of nitrogen credits from agriculture. Wastewater treatment plants would save $286 million/yr by buying 10 million pounds of nitrogen credits from agriculture. Urban/suburban sources in towns and cities would save $764 million/yr by buying 4 million pounds of nitrogen credits from agriculture. Farmers would earn $1.2 billion in annual revenue from the water quality trading program by selling 17 million pounds of nitrogen credits at $5/lb N to atmospheric, wastewater, and urban/suburban stormwater sources. With water quality trading that focuses on agricultural conservation with low marginal nitrogen abatement costs, 9/10 of the nitrogen loads can be reduced for 1/3 of the total cost.

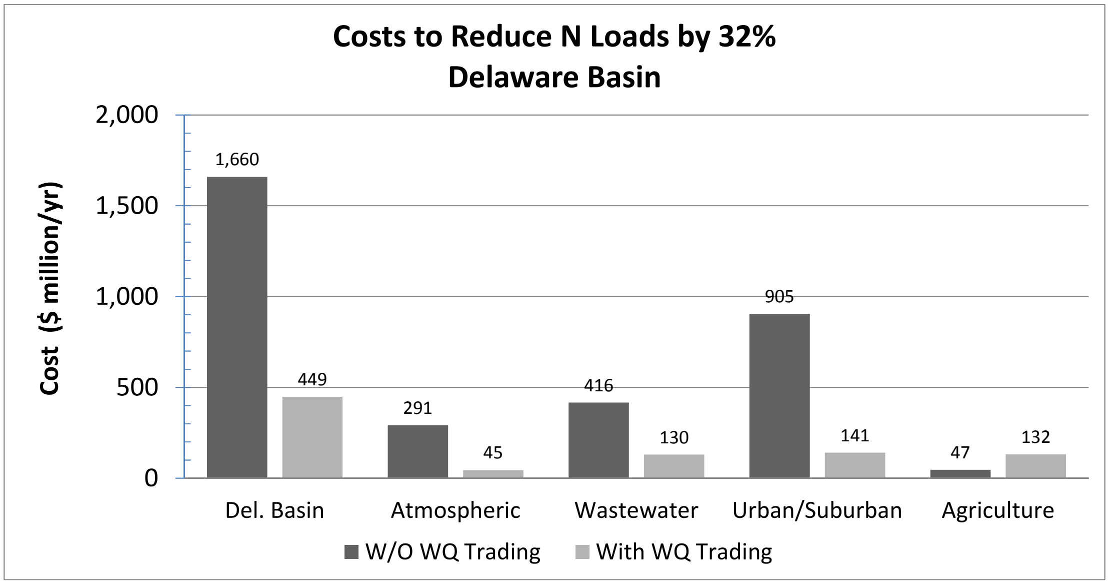


Figure 9.9: N reduction costs from water quality trading in the Delaware Basin

9.4 Sustainable Funding Approach

The following sections analyze funding vehicles to pay for a median 32% reduction in nitrogen loads to the Delaware Basin at an annual cost of $449 million including $45 million for atmospheric NOX reduction, $130 million for wastewater treatment, $132 million for agriculture conservation, and $141 million for urban/suburban stormwater retrofitting.

Atmospheric NOX Reduction: Atmospheric sources deposit 12.1 million lb/yr or 12% of the nitrogen load to the Delaware River (Moore et al. 2011). To improve dissolved oxygen levels in the Delaware River, atmospheric sources of nitrogen (nitrogen oxide or NOX) should be reduced by 5% or 606,000 lb/yr at a cost of $45.5 million/yr (Table 9.5). Airborne NOX sources include the burning of oil, gas, and coal in thermoelectric power plants and gasoline and diesel fuel in motor vehicles. Under the

Clean Air Act of 1970 and amendments of 1977 and 1990, the EPA set standards on NOX emissions by power plants, industries, and motor vehicles. In January 2012, the Cross-State Air Pollution Rule required 27 states in the eastern U.S. to reduce power plant NOX emissions by 54% or 1.4 million tons/yr by 2014. Power plant NOX emissions are reduced by installing noncatalytic combustion controls and switching from coal and oil to natural gas which emits 5 times less NOX than coal. Through the Clean Air Act, EPA requires motor vehicle NOX reductions through tail pipe emissions standards, alternative fuels (ethanol and low sulfur diesel), multimodal railroads and bicycle paths, and DOT vehicle inspection and maintenance programs.

Table 9.5: Costs to reduce nitrogen 5% from airborne sources in the Delaware Basin

Basin/State	**Atmospheric N Load (lb/yr)**	**Atmospheric N Reduction (5%) (lb/yr)**	**Atmospheric N Load % Reduction**	**5% Atmospheric N Reduction ($75/lb N) ($ million/yr)**
Delaware	290,000	14,000	5%	1.1
Maryland	6,000	0	0%	0.02
New Jersey	2,080,000	104,000	5%	7.8
New York	2,138,000	106,000	5%	8.0
Pennsylvania	7,306,000	366,000	5%	27.4
Del. Basin	**12,126,000**	**606,000**	**5%**	**45.5**

Potential options to fund a $45.5 million/yr atmospheric NOX reduction program in the Delaware Basin include (1) water use charge on thermoelectric power plant withdrawals, (2) clean energy fee on power, (3) air emissions charge, and (4) motor vehicle toll surcharge.

Water Use Charge: The Delaware Basin provides 5,400 mgd of cooling water from the Delaware, Schuylkill, and Lehigh rivers to run nuclear, coal, and gas fired power plants that generate 13,376 megawatts of electricity (DRBC 2010, EIA 2002 and NETL 2009). About 95% of the cooling water returns to the river or bay (nonconsumptive use) and 5% evaporates (consumptive use). Resources for the Future (Frederick et al. 1996) estimated the median value of cooling water withdrawals was $0.09/1000 gal or $0.14/1000 gal in $2010. If a $0.14/1000 gal water use charge is assessed on consumptive use (5% of the withdrawal) to fund NOX reductions from thermoelectric power plants in the Delaware Basin, then the annual revenue raised is $13.6 million including $23,000 in Delaware, $9.8 million in New Jersey, and $3.8 million in Pennsylvania (Table 9.6).

Clean Energy Fee: Thermoelectric power plants in the Delaware Basin generate approximately 13,376 megawatts of power. If a $10 per kilowatt ($1,000 per megawatt) clean energy fee is assessed on power produced to fund thermoelectric power plant NOX reduction projects, then $13.4 million/yr in revenue may accrue to the Delaware Basin or $1.1 million/yr in Delaware, $4.8 million/yr in New Jersey, and $7.5 million/yr in Pennsylvania. A one megawatt (100 kilowatt) power station is enough to power 1,000 homes, therefore a $10 per kilowatt clean energy fee will cost each homeowner a dollar per year.

Air Emissions Charge: Emissions charges put a price on the right to pollute by providing economic incentive for emitters to reduce airborne pollution at the source. In the Delaware Basin, 6,063 ton/yr or 12% of nitrogen water pollution originates from atmospheric emissions from motor vehicles, industries, and power plants. In 2006, EPA determined under Title V of the Clean Air Act that states may charge dischargers a fee of $39.48 per ton as incentive to reduce NOX emissions. If atmospheric deposition N loads are 6,063 ton/yr in the Delaware Basin, then a $39.48/ton air emissions charge will raise $240,000 in revenue or $5,700 in Delaware, $41,000 in New Jersey, $42,204 in New York, and $144,000 in Pennsylvania.

Motor Vehicle Toll Fee: Motor vehicles emit nitrogen oxide which causes air and water pollution in the Delaware Basin. Every year, over 578 million vehicles travel on toll bridges and roads through the Delaware Basin in Delaware, New Jersey, and Pennsylvania. Motor vehicles ride vehicles ride on roads that have a significant impervious cover impact on watersheds. Motor vehicles deposit contaminants such as oil, grease, gasoline, worn tires and break lining metals that flow to waterways. This mechanism would assess a $0.03 fee on motor vehicle tolls at Delaware River bridges owned by the Burlington County Bridge Commission, Delaware River and Bay Authority, Delaware River Joint Toll Bridge Commission, Delaware River Port Authority, and toll roads run by the Delaware Transportation Corp. (I-95/Route 1), New Jersey Turnpike Authority, and Pennsylvania Turnpike Authority. The three cents per toll fee would raise $17.3 million annually to reduce airborne nitrogen in the Delaware Basin including $1.1 million in Delaware, $9.6 million in New Jersey, and $6.6 million in Pennsylvania (Table 9.7).

Table 9.6: Water use charge from power plant withdrawals in Delaware Basin

Power Plant	Fuel Source	Capacity[1] (megawatts)	Withdrawal (mgd)	Consumptive[2] Use (mgd)	Charge[3] ($/day)	Use Charge[3] ($/yr)
Delaware		**1,009**	**9**	**0.5**	**63**	**23,000**
Delmarva Delaware City		9				
Conectiv Edgemoor	Gas	1,000				
New Jersey		**4,838**	**3,830**	**192**	**26,810**	**9,800,000**
PSEG Salem 1 and 2	Nuclear	2,275				
PSEG Hope Creek	Nuclear	1,268				
Chambers Cogen. Salem	Gas	285				
Logan Generating	Gas	242				
PSEG Mercer Trenton		768				
Pennsylvania		**7,529**	**1,500**	**75**	**10,500**	**3,800,000**
PECO Chester	Gas	56				
PECO Cromby	Gas	417				
PECO Croyden	Gas	546				
PECO Delaware (Phila.)	Gas	392				
PECO Eddystone	Gas	1,448				
PECO Fairless Hills	Gas	75				
PECO Falls	Gas	64				
PECO Limerick	Nuclear	2,230				
PECO Moser	Gas	64				
PECO Richmond (Phila.)	Gas	132				
PECO Schuylkill (Phila.)	Oil	233				
PECO Southwark (Phila.)	Gas	74				
PGE Northamp. Lehigh	Gas	134				
PPL Martins Creek	Coal	1,664				
Delaware Basin		**13,376**	**5,339**	**267**	**37,373**	**13,600,000**

1. EIA 2002, NETL 2009, and DRBC 2010. 2. Consumptive use at 5% of withdrawal.
3. Use charge of $0.14/1000 gal in $2010 from Frederick et al. 1996.

Table 9.7: Motor vehicle toll fees in the Delaware Basin

Toll Road/Bridge	Annual Vehicle Trips	Revenue @$0.03/toll ($/yr)
Burlington Co. Bridge Commission	24,611,000	738,330
Delaware River and Bay Authority	17,593,000	527,790
Del. River Joint Toll Bridge Comm.	37,366,000	1,120,980
Delaware River Port Authority	54,064,000	1,621,920
Delaware Transportation Corp.	28,000,000	840,000
New Jersey Turnpike Authority	254,000,000	7,620,000
Pennsylvania Turnpike Authority	162,450,000	4,873,500
Total	**578,084,000**	**17,300,000**

Potential user pays options to fund airborne nitrogen reduction in the Delaware Basin include a power plant water use charge ($13.6 million), clean energy fee ($13.4 million), air emissions fee ($240,000), and motor vehicle toll fee ($17.3 million) for a total of $44.5 million/yr (Table 9.8).

Table 9.8: User pays options to reduce airborne nitrogen in the Delaware Basin

Basin/State	Atmospheric N Load Reduction (5%) (ton/yr)	Atmospheric N Load Reduction Cost @ $75/lb/yr	Water Use Charge ($/yr)	Clean Energy Fee ($/yr)	Air Emission Fee ($/yr)	Motor Vehicle Toll Fee ($/yr)	Total Funding ($/yr)
Delaware	7	1,088,775	$23,000	$1,100,000	$5,700	$1,100,000	$2,228,700
New Jersey	52	7,803,000	$9,800,000	$4,800,000	$41,000	$9,600,000	$24,241,000
New York	53	8,019,000			$42,204		$42,204
Pennsylvania	183	27,398,250	$3,800,000	$7,500,000	$144,000	$6,600,000	$18,044,000
Del. Basin	**303**	**$45,472,500**	**$13,600,000**	**$13,400,000**	**$240,000**	**$17,300,000**	**$44,500,000**

Wastewater Discharges: Wastewater discharges contribute 46.5 million lb/yr or 46% of the nitrogen load to the Delaware River (Moore et al. 2011). To improve water quality in the Delaware River, wastewater sources of nitrogen should be reduced by 10% or 4.7 million lb/yr at a cost of $130 million/yr (Table 9.9). The EPA regulates wastewater through the National Pollution Discharge Elimination System (NPDES) permit program. The EPA delegates authority for the NPDES program to states that issue permits to municipal/industrial wastewater dischargers in 5 year cycles. Wastewater dischargers remove nitrogen and ammonia through advanced tertiary treatment processes such as denitrification, enhanced nutrient removal (ENR), biological nutrient removal, and switching from surface water to land application of wastewater to achieve effluent quality of 3 mg/l total N. Potential polluter pays options to fund an annual $130 million wastewater N reduction program in the Delaware Basin include discharge fees, effluent charge, and wastewater treatment fund.

Table 9.9: Costs to reduce nitrogen 10% from wastewater in the Delaware Basin

Basin/State	Wastewater Discharge N Load (lb/yr)	Wastewater N Reduction (5%) (lb/yr)	Wastewater Discharge N Load % Reduction	Wastewater Discharge (10%) ($28/lb/yr)
Delaware	1,130,000	112,000	10%	3,200,000
New Jersey	11,028,000	1,102,000	10%	30,900,000
New York	234,000	24,000	10%	650,000
Pennsylvania	33,608,000	3,360,000	10%	94,100,000
Del. Basin	**46,484,000**	**4,648,000**	**10%**	**130,000,000**

Discharge Fee: Polluter pays approaches such as discharge (emissions) fees charge industrial and residential customers for wastewater services. Under the Clean Water Act administered by EPA, municipal dischargers hold NPDES permits to treat and discharge up to 1,180 mgd of wastewater to the Delaware Basin including 106 mgd in Delaware, 218 mgd in New Jersey, 7 mgd in New York, and 849 mgd in Pennsylvania (Table 9.10). If a $0.50/1000 gal discharge fee is assessed on wastewater discharges in the Delaware Basin, annual revenue to invest in nitrogen removal technology would be $ 21.5 million or $1.9 million in Delaware, $4.0 million in New Jersey, $131,000 in New York and $15.5 million in Pennsylvania.

Effluent Charge: Wastewater discharges contribute 46.5 million lb/yr of nitrogen to the Delaware Basin. A wastewater effluent charge of $1.00 per pound of nitrogen discharged to the Delaware Basin would raise $46.5 million/yr in revenue to invest in nitrogen removal technology or $1.1 million/yr in Delaware, $11.0 million/yr in New Jersey, $234,000/yr in New York and $33.6 million/yr in Pennsylvania. The discharge fee would cost each of the 8.2 million people in the Delaware Basin approximately $6 per year.

Wastewater Treatment Fund: In 2012, Maryland passed House Bill 446 which revised Senate Bill 320 and reauthorized the Chesapeake Bay Restoration Fund financed by a $5.00 monthly fee or $60 annually on customers of wastewater treatment plants and a $60/household annual fee on septic systems. This "flush tax" funds nutrient removal projects that upgrade Maryland's 66 largest wastewater treatment plants and eliminate failed septic systems.

In 2010, the Delaware Basin population was 8,255,013 including 5,898,500 served by wastewater utilities and 2,356,513 served by individual septic systems. At a density of 2.5 people/dwelling unit, 2,359,400 households are served by wastewater utilities and 942,604 households are served by septic systems. If a $25 annual fee were assessed on the households served by wastewater utilities and septic systems in the Delaware Basin, the fund would raise $82.5 million/yr to invest in nitrogen reduction technology.

Table 9.10: Wastewater discharge fee in the Delaware Basin

NPDES ID	Facility	Location	State	Wastewater Flow[1] (mgd)	Discharge Fee[2] ($/day)	Discharge Fee ($/yr)
DE0020338	Kent Co. Levy Court WWTR	Frederica	DE	15.0	750	273,750
DE0021512	Lewes City POTW	Lewes	DE	0.8	40	14,600
DE0020320	Wilmington Wastewater Plant	Wilmington	DE	90.0	4,500	1,642,500
Delaware			**DE**	**105.8**	**5,290**	**1,900,000**
NJ0027481	Beverly City Sewer Auth. STP	Beverly	NJ	1.0	50	18,250
NJ0024678	Bordentown Sewerage Auth.	Bordentown	NJ	3.0	150	54,750
NJ0024651	Cumberland Co. Auth. WWTP	Bridgeton	NJ	7.0	350	127,750
NJ0024660	Burlington City STP	Burlington	NJ	2.7	135	49,275
NJ0021709	Burlington Twp. DPW	Burlington	NJ	1.6	80	29,200
NJ0026182	Camden County MUA	Camden	NJ	80.0	4,000	1,460,000
Other			NJ	122.5	6,125	2,235,625
New Jersey				**217.8**	**10,890**	**4,000,000**
NY0020265	Delhi WWTP	Delhi	NY	0.8	40	14,600
NY0030074	Liberty WWTF	Liberty	NY	1.6	80	29,200
NY0022454	Monticello STP	Monticello	NY	3.1	155	56,575
NY0029271	Sidney WWTP	Sidney	NY	1.7	85	31,025
New York				**7.2**	**360**	**131,000**
PA0026867	Abington Twp. STP	Abington	PA	3.9	195	71,175
PA0026000	Allentown City WWTP	Allentown	PA	40.0	2,000	730,000
PA0026042	Bethlehem City STP	Bethlehem	PA	90.0	4,500	1,642,500
PA0021181	Bristol Borough Water and Sewer	Bristol	PA	1.2	60	21,900
PA0027103	Delaware Co. Reg. Water Auth.	Chester	PA	44.0	2,200	803,000
PA0026859	Coatesville WWTP	Coatesville	PA	3.8	190	69,350
Other				666.0	33,300	12,154,500
Pennsylvania			**PA**	**848.9**	**42,445**	**15,500,000**
Del. Basin			**Basin**	**1,179.7**	**58,985**	**21,500,000**

1. DRBC and USEPA. 2. Effluent fee @ $0.50/1000 gal

Potential polluter pays options to fund nitrogen reduction from wastewater sources in the Delaware Basin include a discharge fee ($21.5 million), effluent charge ($46.5 million), and wastewater treatment fund ($82.5 million) for a total of $150.5 million/yr (Table 9.11).

Table 9.11: Funding to reduce nitrogen in wastewater in the Delaware Basin

State	Wastewater N Reduction (5%) (lb/yr)	Wastewater Discharge (10%) ($28/lb/yr)	Discharge Fee ($/yr)	Effluent Charge ($/yr)	Wastewater Treatment Fund ($/yr)	Total Funding ($/yr)
Delaware	112,000	3,161,480	1,930,850	1,130,000	6,434,175	9,495,025
Maryland	0	0		0	113,250	113,250
New Jersey	1,102,000	30,879,072	3,974,850	11,028,000	19,510,475	34,513,325
New York	24,000	653,184	131,400	234,000	1,249,700	1,615,100
Pennsylvania	3,360,000	94,103,856	15,492,425	33,608,000	55,332,550	104,432,975
Del. Basin	**4,648,000**	**130,000,000**	**21,500,000**	**46,500,000**	**82,500,000**	**150,500,000**

Urban/Suburban Stormwater: Urban/suburban stormwater runoff contributes 14.1 million lb/yr or 14% of the nitrogen load to the Delaware River (Moore et al. 2011). To improve water quality in the Delaware River, urban/suburban stormwater sources of nitrogen should be reduced by 5% or 708,000 million lb/yr at a cost of $141.5 million/yr (Table 9.12). The EPA and states control stormwater sources of nitrogen through the Clean Water Act Municipal Separate Storm Sewer System (MS4) National Pollution Discharge Elimination System (NPDES) permit and Total Maximum Daily Load (TMDL) allocation programs. The EPA issues TMDLs in concert with the states and delegates authority for the NPDES stormwater permit program to the states who in turn issue permits to local counties and municipalities. In accordance with state standards, the local governments pass stormwater ordinances designed to control the quantity and quality of runoff from new development. Local governments and landowners design and install stormwater BMPs such as extended detention ponds, stormwater wetlands, rain gardens, bioretention facilities, porous paving, and recharge basins to reduce nitrogen loads from stormwater runoff at a mean cost of $200/lb N/yr.

Potential options to fund an annual $141.5 million urban/suburban stormwater nitrogen reduction program in the Delaware Basin include the Clean Water State Revolving Fund loan, Clean Water Act Section 319 Nonpoint Source Pollution Program grants, and Watershed (Stormwater Utility).

Table 9.12: Costs to reduce nitrogen by 5% from stormwater in the Delaware Basin

Basin/State	Urban/ Suburban N Load (lb/yr)	Urb/Sub N Reduction (5%) (lb/yr)	Urban/ Suburban N Load % Reduction	Urban/ Suburban (5%) ($200/lb/yr)
Delaware	646,000	32,000	5%	6,400,000
Maryland	8,000	0	0%	80,000
New Jersey	2,496,000	124,000	5%	25,000,000
New York	622,000	32,000	5%	6,200,000
Pennsylvania	10,228,000	512,000	5%	102,300,000
Del. Basin	**14,148,000**	**708,000**	**5%**	**141,500,000**

Clean Water State Revolving Fund Program: In 1987, Congress amended the Clean Water Act (CWA) to replace the Construction Grants program with Title VI that established the Clean Water State Revolving Fund (CWSRF) Program. In FY12, EPA appropriated a CWSRF Title VI funds of $1,468,806,000 to the states which based on proportion of U.S. population includes $6,908,000 for Delaware (0.72%), $57,755,000 for New Jersey (1.67%), $156,001,000 for New York (3.4%), and $55,984,000 for Pennsylvania (2.95%). Up to 20% of the CWSRF can be dedicated to the Green Project Reserve that includes green infrastructure and watershed restoration projects such as bioretention basins and stream buffers to control stormwater runoff. The CWSRF program is a water infrastructure bank capitalized by federal and state funding with loans that can be forgiven (loan forgiveness) by EPA that in effect act like grants.

CWSRF allotments to the Delaware Basin states totaled $267 million in FY12. Approximately 74%, 22%, 0.7%, and 43% of the population of Delaware, New Jersey, New York, and Pennsylvania live in the Delaware Basin. Given 20% of the CWSRF is dedicated to the Green Project Reserve and scaling by proportion of population, annual funds in the basin to reduce urban/suburban stormwater nitrogen loads total $8.6 million or $1.0 million in Delaware, $2.5 million in New Jersey, $218,000 in New York, and $4.8 million in Pennsylvania (Table 9.13).

Table 9.13**:** Clean Water State Revolving Fund allotment to the Delaware Basin

State	FY12 CWSRF Allotment ($)	Green Project Reserve 20% ($)	DRB Population 2010	% of Basin/State Pop.	DRB CWSRF ($)
Delaware	6,908,000	1,381,600	643,418	74%	1,000,000
New Jersey	57,755,000	11,551,000	1,951,047	22%	2,500,000
New York	156,001,000	31,200,200	124,969	0.70%	220,000
Pennsylvania	55,984,000	11,196,800	5,533,254	43%	4,800,000
Del. Basin	**276,648,000**	**55,329,600**	**8,255,013**		**8,600,000**

Clean Water Act Section 319 NPS Grants: Congress amended the Clean Water Act in 1987 to establish the Section 319 Nonpoint Source Program to control stormwater pollution. In FY 12, the EPA Clean Water Act Section 319 appropriation was $164.5 million. Based on proportion of U.S. population, the FY12 Section 319 program included $1,184,400 for Delaware (0.72%), $57,755,000 for New Jersey (1.67%),

$5,593,000 for New York (3.4%), and $4,852,750 for Pennsylvania (2.95%). Scaling by proportion of state population in the basin to total state population, Section 319 funds dedicated to reduce nitrogen loads in urban/suburban stormwater runoff total $3.6 million/yr or $880,000 in Delaware, $600,000 in New Jersey, $40,000 in New York, and $2.1 million in Pennsylvania (Table 9.14).

Table 9.14: Section 319 Nonpoint Source Program funding in the Delaware Basin

State	Sec. 319 Funding ($)	% of U.S. Pop.	Sec. 319 Allottment ($)	Del. Basin Population 2010	% of Basin/State Pop.	DRB Sec. 319 Fund ($)
Delaware	164,500,000	0.72%	1,184,400	643,418	74%	880,000
New Jersey	164,500,000	1.67%	2,755,000	1,951,047	22%	600,000
New York	164,500,000	3.40%	5,593,000	124,969	0.70%	40,000
Pennsylvania	164,500,000	2.95%	4,852,750	5,533,254	43%	2,100,000
Del. Basin	**164,500,000**		**14,377,300**	**8,255,013**		**3,600,000**

Watershed (Stormwater) Utility: A watershed (or stormwater) utility is an equitable funding model that finances stormwater programs based on the amount of impervious cover (roof and pavement area) in a watershed. Delaware Basin municipalities that have adopted stormwater utilities include Philadelphia, Wilmington, and Lewes, Delaware. Stormwater fees are assessed at rates that range from $0.005 to $0.01/ft^2 of impervious cover. If a fee of $0.008/ft^2 of impervious cover were assessed on 15.6 billion ft^2 of impervious cover in the Delaware Basin (Figure 9.10 and Table 9.15), it would raise $125 million to reduce N loads in urban/suburban stormwater or $7.5 million in Delaware, $32 million in New Jersey, $2.6 million in New York, and $83 million in Pennsylvania.

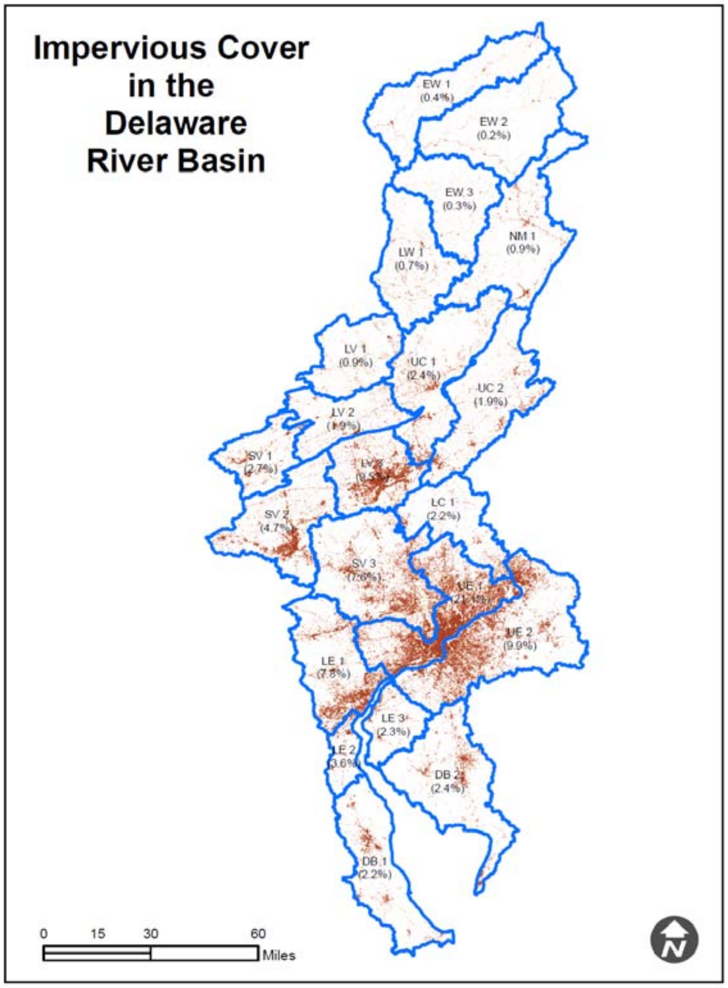


Figure 9.10: Impervious cover in the Delaware Basin

Table 9.15: Watershed utility fee in the Delaware River Basin

Watershed	Area (mi^2)	% Imp.	Imp. Area (mi^2)	Imp. Area (ft^2)	Fee @ \$0.01/ft^2 (\$)
Delaware	965	3.5%	34	943,126,272	7,500,000
New Jersey	2,961	4.8%	143	3,996,145,613	32,000,000
New York	2,555	0.5%	12	331,585,690	2,700,000
Pennsylvania	6,280	5.9%	372	10,374,193,843	83,000,000
Delaware Basin	**12,761**	**4.4%**	**561**	**15,645,051,418**	**125,000,000**

Potential user pays approaches to fund nitrogen reduction from urban/suburban stormwater sources in the Delaware Basin include the EPA Clean Water State Revolving Fund ($8.6 million), EPA Section 319 Nonpoint Source Grant ($3.6 million), and Watershed or Stormwater Utility Fee ($125 million) for a total of $137 million/yr (Table 9.16).

Table 9.16: Options to fund stormwater nitrogen reduction in the Delaware Basin

State	Urban/Sub. N Reduction (5%) (lb/yr)	Urban/ Suburban (5%) ($200/lb/yr)	EPA CWSRF ($)	Sec 319 NPS Fund ($)	Watershed Utility Fee ($)	Total ($)
Delaware	708,000	141,470,000	1,022,384	876,456	7,545,010	9,400,000
Maryland	32,000	6,452,000		0		0
New Jersey	0	79,200	2,541,220	604,373	31,969,165	35,100,000
New York	124,000	24,969,600	218,401	39,151	2,652,686	2,900,000
Pennsylvania	32,000	6,220,800	4,814,624	2,086,683	82,993,551	89,900,000
Del. Basin	**512,000**	**102,286,800**	**8,600,000**	**3,600,000**	**125,000,000**	**137,000,000**

Agriculture: Runoff from agriculture contributes 29.3 million lb/yr or 29% of the nitrogen load to the Delaware River (Moore et al. 2011). To improve water quality in the Delaware River, agricultural sources of nitrogen should be reduced by 90% or 26.4 million lb/yr at an annual cost of $131.9 million including $5.2 million in Delaware, $240,000 in Maryland, $23.4 million in New Jersey, $4.2 million in New York, and $98.6 million in Pennsylvania (Table 9.17). The USDA Natural Resources Conservation Service and Farm Services Agency and county soil conservation districts fund agricultural conservation programs through the Farm Bill to reduce nutrient and sediment loads. A cadre of USDA programs such as the Conservation Reserve Program (CRP) and

Environmental Quality Incentives Program (EUIP) provide Federal payments to farmers to install conservation BMPs such as no till crops, reforestation, and bioswales that reduce nitrogen loads at a cost of $5/lb N/yr. Potential user pays options to fund agriculture nitrogen reduction program in the Delaware Basin include USDA Conservation Program Funding and Investment in Watershed Services (IWS) by downstream water suppliers.

Table 9.17: Funding to reduce agriculture N loads by 90% in the Delaware Basin

State	Agriculture Source N Load (lb/yr)	Agriculture N Load Reduction (90%) (lb/yr)	Agriculture N Load % Reduction	Agriculture N Load Reduction (90%) ($5/lb/yr)
Delaware	1,162,000	1,046,000	90%	5,200,000
Maryland	52,000	48,000	90%	240,000
New Jersey	5,202,000	4,682,000	90%	23,400,000
New York	934,000	840,000	90%	4,200,000
Pennsylvania	21,918,000	19,726,000	90%	98,600,000
Del. Basin	**29,304,000**	**26,374,000**	**90%**	**131,900,000**

USDA Conservation Program Funding: The world's largest and longest-running investment in watershed services (IWS) program is the USDA Conservation Reserve Program which pays about $1.8 billion a year to farmers and landowners. In exchange for payments, farmers agree to plant land cover to improve water quality, control soil erosion and enhance waterfowl habitats.

The Pennsylvania Department of Environmental Protection together with the USDA and county conservation districts have kicked off a Delaware River Conservation Reserve Enhancement Program (CREP) that plans to enroll 390 square miles in agricultural conservation practices in Pike, Monroe, Northampton, Lehigh, Bucks, Montgomery, and Delaware counties. The Delaware River CREP will pay forest riparian buffer costs of $2,500/acre with annual soil rental payment of $120/acre for 15 years with goals to reduce agriculture sediment loads by 557 tons/yr and nitrogen loads by 349,500 lb/yr through conservation practices such as grass waterway, contour buffer strips, filter strips, riparian buffers, and wetland restoration. The estimated Federal cost is $72 million over 15 years including $64 million for rental rates and $5.5 million for conservation practices. At an annual cost of $550,000, the cost to reduce nitrogen is $1.57/lb. The cost to Pennsylvania is $10.5 million for conservation practices ($5.5 million), incentive payments ($240,000), and monitoring CREP ($3.1 million), and administration ($1.5 million).

In FY12, the Farm Bill funded $5.048 billion for USDA NRCS and Farm Services Agency agricultural conservation programs in the United States. USDA funding in the Delaware Basin states was $194.9 million or $20.5 million in Delaware, $34.5 million in Maryland, $37.4 million in New Jersey, $48.0 million in New York, and $54.5 in Pennsylvania. If the ratio of farmland in the basin to the entire state is 50% in Delaware, 69% in New Jersey, 3% in New York, 13% in Pennsylvania (Table 9.18), then the scaled USDA investment is $35.6 million in the Delaware Basin or $10.3 million in Delaware, $1.0 million in Maryland, $15.8 million in New Jersey, $1.4 million in New York, and $7.1 million in Pennsylvania (Table 9.19).

Table 9.18: Farmland in the Delaware Basin states

County	Farmland in state[1] (ac)	Farmland in basin (ac)	Ratio farmland in basin/state
Delaware	510,253	254,143	50%
New Jersey	733,450	505,507	69%
New York	7,174,743	187,561	3%
Pennsylvania	7,809,244	979,313	13%
Total	**16,227,690**	**1,926,524**	**12%**

1. Census of Agriculture 2007 (USDA 2009).

Table 9.19: USDA conservation funding (FY12) in the Delaware Basin

State	CSP ($ mil)	CTA ($ mil)	CRP ($ mil	EQIP ($ mil)	FLP ($ mil	WRP ($ mil)	WHIP ($ mil)	WRP ($ mil)	Total ($ mil)
Delaware	0.4	2.5	0.2	3.2	2.0	0.5	0.2	1.4	10.3
Maryland	0.1	0.2	0.1	0.3	0.0	0.2	0.0	0.1	1.0
New Jersey	0.1	1.7	0.4	4.0	0.7	7.2	0.3	1.3	15.8
New York	0.0	0.2	0.3	0.4	0.2	0.2	0.0	0.2	1.4
Penna.	0.2	0.6	1.3	1.9	0.4	0.5	0.1	2.2	7.1
Del. Basin	**0.9**	**5.2**	**2.3**	**9.8**	**3.2**	**8.5**	**0.7**	**5.2**	**35.6**

Conservation Stewardship Program (CSP), Conservation Technical Assistance (CTA), Conservation Reserve Program (CRP), Environmental Quality Incentives Program (EUIP), Forest Legacy Program (FLP), Wetlands Reserve Program (WRP), Wildlife Habitat Incentives Program (WHIP), Wildlife Restoration Program (WRTP)

Investment in Watershed Services: IWS involves funding by downstream water suppliers in upstream agricultural conservation projects to more cost effectively improve water quality compared to expensive construction of water treatment plants. IWS includes the establishment of a water fund that collects user fees as a small percentage of water withdrawals. Water use fees are deposited in the water fund for investment in upstream agriculture conservation projects.

The Delaware Basin provides significant public drinking water supplies (1,804 mgd) with 44% in New York (800 mgd), 38% in Pennsylvania (679 mgd), 16% in New Jersey (284 mgd), and 2% in Delaware (40 mgd). The largest public water suppliers in the Delaware Basin include United Water Delaware and Wilmington in Delaware; Delaware and Raritan Canal diversion, New Jersey American, Trenton, and Camden in New Jersey, New York City, and Philadelphia Water Department and Aqua Pennsylvania in Pennsylvania (Table 9.20). If a $0.15/1000 gal water use fee were collected on public water supply withdrawals, then $98.7 million/yr in revenue would be raised for the IWS water fund to invest upstream and reduce nitrogen loads from agriculture. The annual water use charge would raise $2.2 million from Delaware, $15.6 million from New Jersey, $43.8 million from New York, and $37.1 million from Pennsylvania (Table 9.21). The average annual water use by residential customers is 60,000 gallons, therefore the IWS water fund would cost each household in the basin just $4.00 per year.

Potential user pays approaches to fund nitrogen reduction from agricultural sources in the Delaware Basin include the USDA NRCS and Farm Services Agency farm conservation programs ($35.6 million) and an investment in watershed services by water use charges ($98.7 million) for a total of $134 million/yr (Table 9.22).

Table 9.20: Public water supplies in the Delaware River Basin (DRBC 2010)

Water Purveyor	Supply (mgd)	Water Purveyor	Supply (mgd)	Water Purveyor	Supply (mgd)
Delaware	**40.10**				
United Water Del.	18.46	Dover AFB	0.44	Milford	0.17
Wilmington	10.40	New Castle MSC	0.41	Georgetown	0.13
Dover	4.74	Smyrna	0.37	Frederica	0.08
Newark	2.22	Harrington	0.36	Felton	0.08
Lewes BPW	0.98	Camden-Wyoming	0.31	Delaware State Fair	0.05
Tidewater Utilities	0.64	Milton	0.17	Magnolia	0.05
				Frederica Perkiomen	0.05
New Jersey	**284.19**	Willingboro MUA	4.65		
Del. & Raritan Canal	100.00	NJ American Mt. Holly	4.48	Hackettstown MUS	2.57
NJ American Western	39.37	Bridgeton	3.63	Millville Water Dept	2.55
Trenton	26.10	Wildwood	3.59	Moorestown	2.51
Camden	10.89	Aqua NJ Phillipsburg	3.46	Bordentown	2.21
Vineland	8.33	Aqua NJ Hamilton Sq.	3.39	Burlington Twp.	2.00
Merchant.-Pennsauken	6.05	Aqua NJ Blackwood	2.96	Other	31.19
Washington Twp. MUA	4.79	Evesham MUA	2.82		
New York State	**800.03**				
New York City	800.00				
Pennsylvania	**679.30**				
Philadelphia	287.77	North Penn Water	8.59	PA Amer. Coatesville	4.07
Aqua PA Main System	102.18	Easton	7.13	Allentown City	4.02
Forest Park Pt. Pleasant	20.16	Schuylkill Co. Authority	5.15	Northampton Boro.	3.74
Bethlehem	15.69	Pottstown Water Auth.	4.64	East Stroudsburg	3.69
Allentown	15.46	Easton Suburban Water	4.47	PA American Yardley	3.20
North Wales Water	15.09	Schuylkill Co. Auth.	4.36	Phoenixville	3.01
Bucks Co. Water/Sewer	14.99	Muhlenberg Twp.	4.31	Morrisville	2.89
Reading Area Authority	14.31	Lehigh County	4.22	PA American Home	2.88
Bucks County SW	13.79	PA American Nazareth	4.13	PA American Penn	2.76
PA Amer. Norristown	10.10	Hazelton	4.12	Misc. Water Purveyors	79.73
Lower Bucks County	8.66	Easton Suburban Water	4.47		

Table 9.21: Water use charge revenue in the Delaware Basin

State	Withdrawal (mgd)	Water User Charge ($/1000 gal)	Water Use Charge ($/day)	Water Use Charge ($/yr)
Delaware	40	0.15	6,000	2,200,000
New Jersey	284	0.15	42,600	15,600,000
New York	800	0.15	120,000	43,800,000
Pennsylvania	679	0.15	101,850	37,200,000
Del. Basin	**1,803**	**0.15**	**270,450**	**98,700,000**

Table 9.22: Funding to reduce agricultural nitrogen in the Delaware Basin

State	Ag N Load Reduction (90%) (lb/yr)	Ag N Load Reduction (90%) (lb/yr)	USDA Funding ($)	Water Use Charge ($)	Total ($)
Delaware	1,162,000	1,046,000	10,300,000	2,190,000	12,490,000
Maryland	52,000	48,000	1,000,000	0	1,000,000
New Jersey	5,202,000	4,682,000	15,800,000	15,549,000	31,349,000
New York	934,000	840,000	1,400,000	43,800,000	45,200,000
Pennsylvania	21,918,000	19,726,000	7,100,000	37,175,250	44,275,250
Delaware Basin	**29,304,000**	**26,400,000**	**35,600,000**	**98,700,000**	**134,300,000**

9.5 Discussion and Conclusions

A series of market-based funding options are available to finance an annual $449 million program to reduce nitrogen loads by 32% and improve water quality in the Delaware River (Table 9.23 and Figure 9.11). Atmospheric NOX reduction costs of $44.5 million/yr can be funded by a $0.14/1000 gal water use charge on power plant withdrawals ($13.6 million), $10/kW clean energy fee on power plants ($13.4 million), $39.48/ton N air emission fee ($0.2 million) and $0.03/toll motor vehicle toll fee in the Delaware Basin ($17.3 million). Wastewater N load reductions that cost $150.6 million/yr can be paid by a $0.50/1000 gal wastewater discharge fee ($21.5 million), $1.00/lb N wastewater effluent charge ($46.5 million), and $25 per household wastewater treatment fund ($82.6 million). Nitrogen load reductions in urban/suburban runoff that cost $137.4 million/yr can be financed by the EPA Clean Water Revolving Fund Green Reserve fund ($8.6 million), Clean Water Act Sec. 319 nonpoint source funding ($3.6 million), and a $0.008/ft^2 of impervious cover watershed utility fee ($125.2 million). Agricultural conservation programs that cost $134.3 million/yr can be funded by the

USDA NRCS and Farm Services Agency under the Farm Bill ($35.6 million) and upstream investments by water suppliers from a $0.15/1000 gal water use charge ($98.7 million/yr).

These programs provide incentives for users or beneficiaries of the water resource to reduce emissions and discharges and pay for upstream water pollution control programs without increasing Federal or state budgets. An annual $449 million water quality improvement program would cost each of the Delaware Basin's 8.2 million residents just $5.00 per month. If the 16 million people who obtain drinking water from the Delaware Basin contributed to pay for improved water quality, the cost to each consumer would be just $2.50 per month.

Table 9.23: Funding programs to improve water quality in the Delaware Basin

Funding Program	DE ($mil)	MD ($mil	NJ ($mil	NY ($mil)	PA ($mil)	Del. Basin ($mil)
Atmospheric NOX Reduction	**2.2**	**0.0**	**24.2**	**0.0**	**18.0**	**44.5**
Water Use Charge ($0.14/1000 gal0	0.0	0.0	9.8	0.0	3.8	13.6
Clean Energy Fee ($10/kW)	1.1	0.0	4.8	0.0	7.5	13.4
Air Emission Fee (($39.48/ton N)	0.0	0.0	0.0	0.0	0.1	0.2
Motor Vehicle Toll Fee ($0.03/toll)	1.1	0.0	9.6	0.0	6.6	17.3
Wastewater Treatment	**9.5**	**0.1**	**34.5**	**1.6**	**104.4**	**150.6**
Discharge Fee ($0.50/1000 gal)	1.9	0.0	4.0	0.1	15.5	21.5
Effluent Charge ($1.00/lb N)	1.1	0.0	11.0	0.2	33.6	46.5
Wastewater Treatment Fund ($25/hh/yr)	6.4	0.1	19.5	1.2	55.3	82.6
Urban/Suburban Runoff	**9.4**	**0.0**	**35.1**	**2.9**	**89.9**	**137.4**
Clean Water Revolving Fund (20% Green)	1.0	0.0	2.5	0.2	4.8	8.6
Sec 319 CWA Fund	0.9	0.0	0.6	0.0	2.1	3.6
Watershed Utility Fee ($0.008/$ft^2$ imperv.)	7.5	0.0	32.0	2.7	83.0	125.2
Agriculture Conservation	**12.5**	**1.0**	**31.3**	**45.2**	**44.3**	**134.3**
USDA NRCS/FSA Funding (Farm Bill)	10.3	1.0	15.8	1.4	7.1	35.6
Water Use Charge ($0.15/1000 gal)	2.2	0.0	15.5	43.8	37.2	98.7
Total	**33.7**	**1.1**	**125.2**	**49.8**	**256.6**	**466.8**

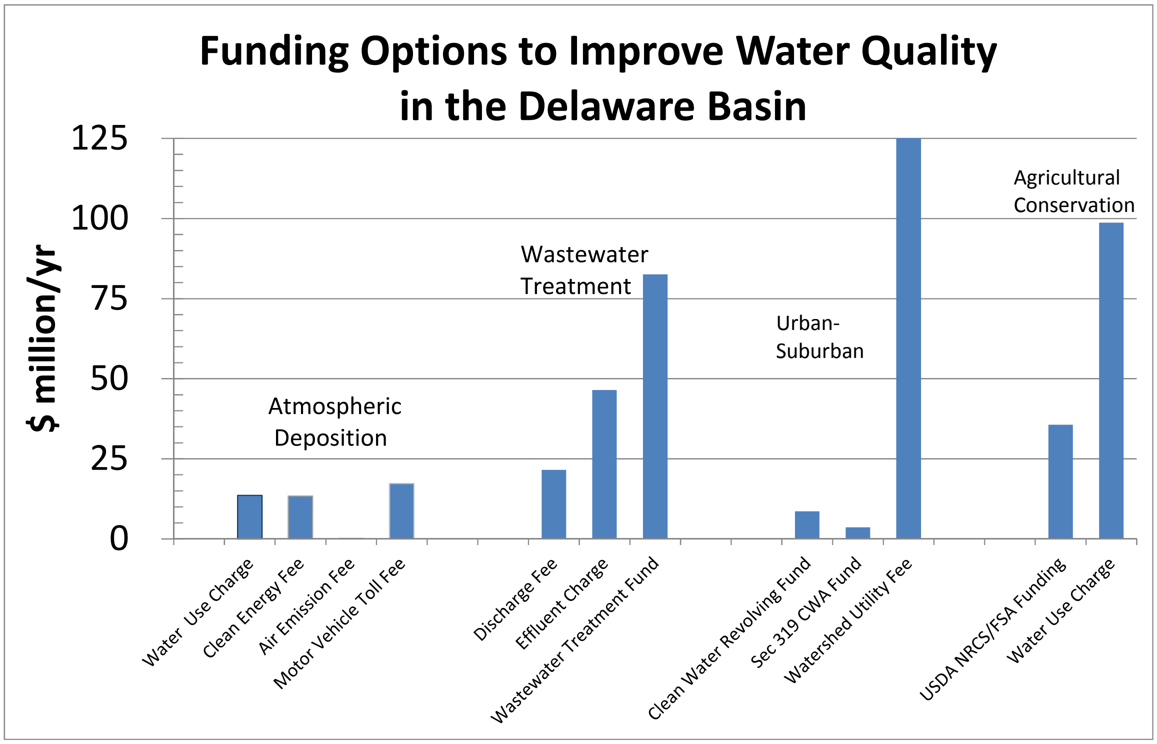


Figure 9.11: Funding options to improve water quality in the Delaware Basin

In light of declining Federal and state appropriations, the DRBC should consider adopting beneficiary-pays funding models such as an expansion of the water use charge program to pay for basin water quality improvements. The challenge is political as there is a reluctance by Federal, state, and local officials to raise fees to pay for investments in infrastructure in the United States.

Chapter 10

POLICY CONTRIBUTIONS AND FUTURE RESEARCH IDEAS

This concluding chapter summarizes policy contributions of the research, limitations of the research, and future research ideas.

10.1 Contributions of the Dissertation

The Delaware River and its tributaries have made a marked recovery in the half-century since the birth of JFK's Delaware River Basin Commission Compact in 1961 and Richard Nixon's EPA in 1970 and Congressional approval of Clean Water Act Amendments during the 1970s. A first-of-its-kind 1966 benefit-cost analysis conducted by the old Federal Water Pollution Control Administration (FWPCA) concluded that it would be cost-effective for the DRBC to fund a multi-million dollar per year waste load abatement program to raise dissolved oxygen levels to boatable and fishable standards that would in turn generate economic activity. In 1967, the DRBC used this benefit-cost analysis to set DO criteria at 3.5 mg/l along the urban river from Philadelphia to Wilmington where the water quality standard has stood for over four decades.

The FWPCA and DRBC were indeed prescient as multi-billion dollar investments in water pollution control programs have boosted water quality as measured by DO from a state of anoxia (zero) during the turbulent '60s to levels that now meet the DRBC criteria of 3.5 mg/l most of the year except during hot summer days. With improved water quality, anadromous American shad, striped bass, waterfowl, and the bald eagle have returned along with a growing river-based tourism, boating, fishing, and bird-watching recreation economy.

While the Delaware has made one of the most extensive water quality recoveries of any estuary in the world, scientists with the Partnership for the Delaware Estuary's Science and Technical Advisory Committee (STAC) have called for the DRBC to raise the DO standard from 3.5 mg/l that has stood since the 1960s to a higher level of protection. The current 3.5 mg/l standard provides for seasonal protection of anadromous fish during fall and spring (not year-round) but violations of the standard are becoming more frequent as water temperatures climb close to 30° C (86° F) during increasingly hot summers. A more rigorous standard of 4, 5, or even 6 mg/l would provide for more year-round protection of anadromous fish such as the recovering American shad and the nearly extirpated Atlantic sturgeon (just placed on the Federal Endangered Species List). This more rigorous standard would also provide a hedge against atmospheric warming that is projected to raise water temperatures, sea levels, and chloride levels that in combination will further reduce DO saturation.

But what are the costs of achieving improved water quality in the Delaware River and what are the benefits to those in society who use the resource?

Nitrogen marginal abatement cost (MAC) curves constructed for this dissertation show it would be more cost-effective to prioritize investments in agricultural conservation and wastewater treatment as these controls have lower unit nitrogen reduction costs up to an order of magnitude less than the more expensive airborne emissions and urban/suburban best management practices. The MAC curve reveals that 30 million lb/yr of nitrogen can be reduced for $160 million or 90% of the pollutant load can be reduced for 35% of the total cost ($449 million).

This dissertation developed a benefit-cost analysis that utilized modern ecological economics techniques to define the cost-effectiveness of water pollution control measures to reduce nitrogen loads and raise DO levels to a more protective, year-round fishable standard in the Delaware River. Based on this economic approach, the BCA suggests that the DRBC would have several options in setting a higher DO standard in the Delaware River.

The first option would be to invest $449 million per year to achieve year-round DO criteria of 5.0 mg/l with benefits of $371 million to $1.1 billion per year. The monthly cost would range from $2.39 per capita for the 16 million people who depend on drinking water from the basin in Delaware, New Jersey, New York, and Pennsylvania including North Jersey and New York City to $4.46 per capita for the 8.2 million residents of the Delaware Basin (Table 10.1). A $449 million annual investment would generate 12,600 direct water jobs and boost the GDP by $3.1 billion.

A second option would establish less protective DO criteria at 4.5 mg/l at an efficient level that balances costs of $150 million per year with the benefits. If $150 million per year were invested to achieve an efficient level of water quality (where MC = MB) with DO at 4.5 mg/l with benefits of $250 to $700 million, the monthly cost would range from $0.78 per capita for the 16 million people who depend on drinking water from the Basin to $1.52 per capita for the 8.2 million residents of the Delaware Basin. This

$150 million annual investment would generate 4,200 water jobs and add $1 billion in GDP to the annual economy.

Table 10.1: Water pollution control finance program in the Delaware Basin

Option	DO Criteria (mg/l)	N load Reduction (%)	Cost ($M/yr)	Benefits ($M/yr)	Cost per Capita[1,2] ($/month)	Jobs	Boost in GDP ($M)
Efficient WQ (MC = MB)	4.5		150	250-700	0.78-1.52	4,200	1,000
Year-round Fishable WQ	5.0	32%	449	371-1,060	2.39-4.46	12,600	3,100

1. Based on population of 8.2 million in the Delaware Basin. 2. Based on 16 million people who draw drinking water from the Delaware Basin.

Marginal cost and marginal benefits curves illustrate five cost options based on a nitrogen reduction of 32% and low and high bound benefits curves (Figure 10.1). The marginal cost curves intersect the low bound marginal benefits line at a DO level between 4.3 mg/l for Option 1 and 4.6 mg/l for Option 5. The MC curves intersect the high bound MB line at a DO between 4.5 mg/l (Option 1) and 4.8 mg/l (Option 5). These MC/MB curves suggests the optimal level of DO is close to 4.5 mg/l.

Based on benefit-cost analysis, the optimal level of water quality in the Delaware River as defined by dissolved oxygen ranges from 4.2 mg/l to 4.8 mg/l. A DO level of 4.2 mg/l could be achieved at a cost of $150 million with benefits of $150 to $500 million/yr. A DO level of 4.8 mg/l could be achieved at a cost of $350 million with benefits of $350 to $950 million/yr. If efficiency in administering the water quality regulations is desired, then the most cost-effective future DRBC DO standard could be rounded to 4.5 mg/l. A DO level of 4.5 mg/l could be achieved at a cost of $250 million with benefits of $250 to $700 million/yr (Table 10.2).

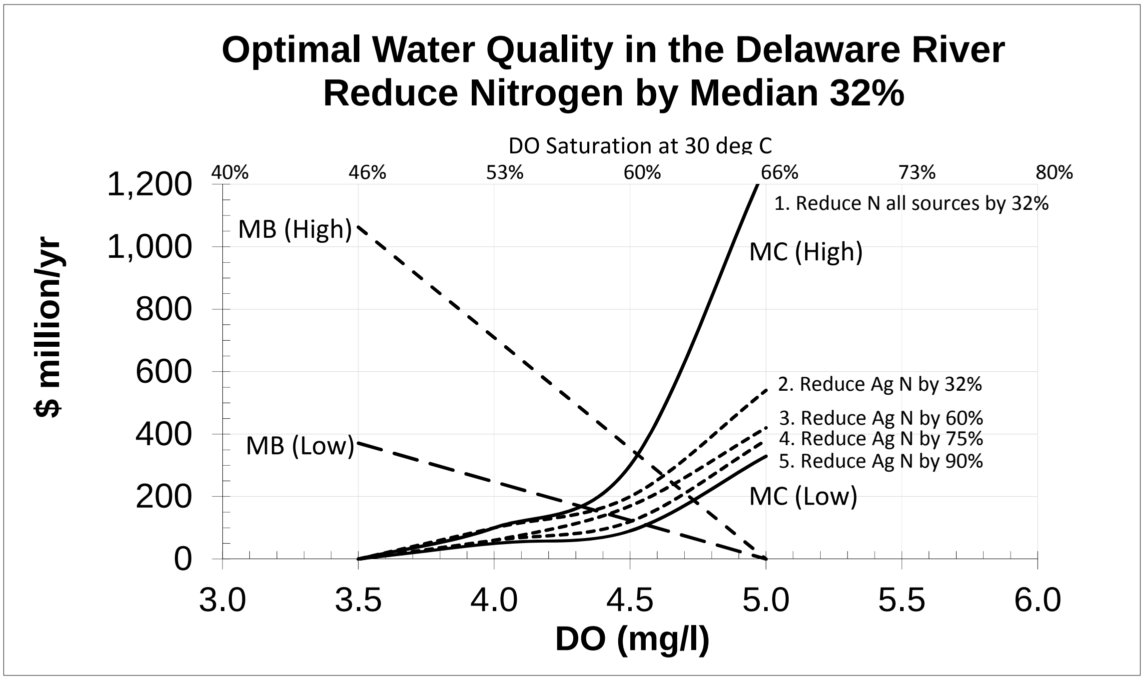


Figure 10.1: Marginal cost/benefits of improved water quality in the Delaware River

Table 10.2: Costs and benefits of optimal water quality in the Delaware River

Option	Optimum DO (mg/L)	% DO Saturation at 30°C	Costs ($ million)	Benefits ($ million
1. Reduce N all sources by 32%	4.2	55%	150	150-500
2. Reduce N from Ag by 32%	4.3	57%	200	200-600
3. Reduce N from Ag by 60%	4.5	60%	250	250-700
4. Reduce N from Ag by 75%	4.7	62%	300	300-850
5. Reduce N from Ag by 90%	4.8	64%	350	350-950

While a future DO standard of 4.5 mg/l would reflect an efficient level of water quality where the marginal costs equal the marginal benefits, this criteria would be less protective than say 5 mg/l for the year-round propagation of anadromous fish. The literature indicates a DO criteria of 6 mg/l may be needed to protect juvenile sturgeon. However a DO level of 6 mg/l (80% saturation) may be difficult to achieve at summer water temperatures that approach 30°C in the Delaware River at Philadelphia. A DO standard of 5 mg/l (66% saturation) may be more readily achieved at these warm water temperatures but will be less protective than 6 mg/l. This BCA indicates that a DO standard of 5 mg/l could be achieved at an annual cost of $449 million with benefits that range from $371 to $1,063 million.

The cost analysis is based on a median 32% reduction in nitrogen to the Delaware River bounded by 20% N reduction (25th percentile) and 48% N reduction (75th percentile) confidence intervals. These analysis also includes five options that vary from the highest cost Option 1 (reduce N from all sources by 32%) that costs almost four times more than the least cost Option 5 (reduce N from agriculture by 90%). A plot of the five options indicate the marginal cost (MC) and marginal benefit (MB) curves cross just below and just above the economically efficient 4.5 mg/l DO criteria. This is important for two reasons: (1) letting the economics optimize the target may fail to ensure environmental goals (such as a stricter definition of fishable) and (2) this suggests that implementation efficacies and/or costs may be critical to choosing a target that considers economics in addition to environmental condition.

Given that Federal and state water resources appropriations have been declining, other sources of revenue are needed to fund a several hundred million dollar water pollution control program in the Delaware Basin. These “new” revenue sources include the user (beneficiary) pays and/or polluter pays approaches that have long been touted by the Harvard Water Program, Resources for the Future, and the now defunct U.S. Water Resources Council. These more cost-effective ways to improve water quality would address the negative externalities from upstream water pollution that impair downstream users under the current arrangement. The user/polluter pays approach has been used to some effect in Europe, Latin America, and Australia and in a dozen river basins in the U.S. Successful investments in watershed services (IWS) programs that rely on the user pays approach have been funded by water use charges by New York City, Boston, San Francisco, and Seattle. Water quality trading has the potential to reduce water pollution control costs using principles successfully demonstrated by the Clean Air Act over 20 year ago to reduce SO_2 and acid rain from atmospheric emissions.

While the financial need is great, the Delaware River is fortunately one of just a few river basins in the United States or the world that has a governance structure capable of administering a water pollution control program using the economic approach. The 1961 DRBC Compact provides the power by force of Federal and state law to administer water pollution control programs in the four states under one umbrella with the authority to levy fees and charges. Since the late 1970s, the DRBC has administered a water supply use charge (now $0.08/1000 gal) on public, industrial, power, and recreation withdrawals that earn almost $3 million per year for water supply storage projects. The DRBC might be persuaded to expand and/or redirect this user charge to fund water pollution control programs that would benefit drinking water supplies.

This sustainable watershed funding analysis suggests that a portfolio of beneficiary pays models could be adopted by the DRBC and/or Federal and state governments to finance up to a hundreds of million dollars per year water pollution control program in the Delaware Basin.

The diamond-water paradox points out one of the most significant challenges in water resources management in the United States, that the value of water and the prices charged to utilize this resource do not reflect the full opportunity cost at its highest use. Consumers pay for the right to use the water at its average cost when water is abundant and not at its highest value for all uses (not just drinking water) based on its scarcity value. Since water is undervalued compared to its highest and best opportunity cost; Federal, state, and local governments are inclined to underinvest in water resources and water pollution control programs.

A more successful Delaware River Basin Commission would adopt the following three changes in the area of budget and finance to more effectively manage the watershed. One, the DRBC should petition the Administration to appoint a different cabinet department such as the EPA or Department of Interior (instead of the U.S. Army Corps of Engineers) as the Federal Commissioner and restore the Federal signatory share of the DRBC budget through a line item appropriation in that Department's annual budget. Two, given that the annual appropriations from New York and Pennsylvania seem to waver from year to year, the DRBC should seek a more formal funding relationship with the two largest local governments and water users that benefit from the basin (New York City and Philadelphia) as their collective annual budgets in the basin exceed $180 million.

And three, since annual signatory member contributions from some states are volatile and Federal water funding is in decline, the DRBC should work toward making up the gap through less volatile beneficiary pays approaches such as an expansion of the existing water supply use charge program that has been in place since the 1970s.

The Watershed Approach: Chapter 2 concludes that governance of the Delaware River is an advanced form of the watershed approach to managing water resources and river systems. Since the Clean Water Act amendments were approved by Congress during the 1970s, the watershed approach has evolved to balance the economic, environmental, and social interests of the many governments and stakeholders that benefit from a river system. Because watershed and government boundaries often do not coincide, water managers face complex institutional and governance challenges and competition for scarce water supplies. The watershed approach is beneficial because it balances competing uses between upstream and downstream stakeholders, balances institutional objectives at the Federal, State and local levels, utilizes a multidisciplinary science and policy approach, and provides for cost sharing among watershed stakeholders. Watershed management remains challenging because it is difficult for a diverse group of people to agree on a unified course of action, hydrologic boundaries do not usually coincide with political boundaries, and of the frustration with fragmented authority at Federal, state and local levels.

While river basin management (RBM) has long been practiced around the world, it is practiced in only about a dozen rivers in the United States, primarily in the east. River basin authorities financed through user charges and discharge fees are well established in France (*Agences de l'Eau*), Germany (*Genossenschaften*), Netherlands (Polders), Portugal, Great Britain, Spain (*Confederaciones Hidrograficas*), Russia (Volga River Basin), Mexico, Australia (Darling Basin), and New Zealand (Regional Catchment Councils).

The Federal government has experimented with many forms of interstate river basin management organizations such as single federal administrators, regional authorities, interstate watershed councils, basin interagency committees, and interstate compact commissions. Established by treaties between the Federal government and states, river basin commissions have the most authority of any of the RBM organizations as they are granted compulsory powers through a compact between Federal and state governments, established by government legislation by force of law, and have a permanent office and staff (secretariat).

In the eastern United States, Federal and state governments have formed seven congressionally approved interstate basin compacts with roles in conflict resolution, regulation, water quality planning, flood mitigation, source water protection, water supply regulation, and public outreach. The Interstate Environmental Commission (1936) and New England Interstate Water Pollution Control Commission (1947) are single purpose basin organizations that focus on water pollution while the Interstate Commission for the Potomac River Basin (1940), Susquehanna River Basin Commission (1970), and Great Lakes Commission (2008) are comprehensive multiple purpose agencies with responsibilities in most areas of water management. The Delaware River

Basin Commission (DRBC) is the only Federal-state basin compact with authority in all areas including water supply, water quality, flood mitigation, and watershed management.

The seven eastern basin compacts touch 20 states and cover 19% of the contiguous United States yet manage water resources for 109 million people or 1/3 of the nation's population. The DRBC, SRBC, and Great Lakes Commission receive no Federal appropriations whereas the Interstate Environmental Commission, New England Interstate Water Pollution Control Commission, and Ohio River Valley Sanitary Commission receive over half their funding from Federal sources. The DRBC, IEC, and ORSANCO rely on the states for over a third of their funding while the GLC relies on grants and contracts for over 90% of its funding and the SRBC relies on permit fees for about 80% of its funding. DRBC revenues are spread between 46% state, 35% permit/fees and 20% grants/contracts. It is a noticeable omission that one of the more successful interstate river basin governance organizations in the United States has not received a Federal appropriation since 1997.

The Delaware Basin: Chapter 3 shows that the Delaware Basin covers just 0.4% of the continental U.S. yet supplies drinking water to over 16 million people (5% of the U.S.) population and the first (New York City) and seventh (Philadelphia) largest metropolitan economies in the nation. The DRBC Compact of 1961 is a novel governance instrument that formed the first Federal/state regional water agency united to manage a river basin without regard to political boundaries. The DRBC compact links together dozens of federal, state, and interstate water agencies and a politically fragmented basin governed by 4 Governors, 8 U.S. Senators, 25 Congressmen, 24 counties, and 838 municipalities.

By signing the DRBC Compact, the Federal government was willing for the first time to employ Federalism principles to share interstate water resources management power with the states. Federalism is a system where sovereignty is shared between a central governing authority (Federal government) and political units (states). The DRBC utilizes a shared power structure under the principle of comity or legal reciprocity where the Federal government and four states extend certain courtesies to each other without demeaning the sovereign laws of each jurisdiction.

The DRBC coordinates dozens of regional, Federal, state, local, and nonprofit agencies that fund at least $740 million per year in water resources programs in the Delaware Basin including FY12 appropriations of $8 million from interstate sources (1%), $285 million in Federal funds (38%), $264 million from the four states (36%), and $183 million (25%) from New York City and Philadelphia. The funding amounts to $3.76/capita/month for the 16 million people who draw drinking water from the basin to $7.52/capita/month for the basin population of 8.2 million.

The DRBC manages the basin by equity (one state, one vote) through five commissioners representing the highest offices in the land by the President of the United States and Governors of Delaware, New Jersey, New York, and Pennsylvania. The DRBC executive director and deputy director manage 48 staff organized in 5 divisions at headquarters in West Trenton, New Jersey. The DRBC annual budget is approximately

$6 million funded by signatory party appropriations by the federal (0%) and state governments (46%), permit and water use fees (35%), and grants and contracts (20%).

The DRBC compact specifies that the five Commissioners (the U.S. and 4 States) share in funding the Commission's annual budget. The DRBC FY12 budget received was $5,787,900 including signatory party appropriations of $2,588,000 (45%), permit review and water use fees $1,958,000 (35%), and income from grants and contracts of $1,114,000 (20%). The signatory funding of $2,588,000 was appropriated by Delaware (17%), New Jersey (35%), New York (14%), and Pennsylvania (35%).

Based on basin area, population, water supply, wastewater, and pollutant load criteria, equitable formulas for signatory state contributions to the DRBC budget are Delaware (4-9%), New Jersey (16-24%), New York (4-20%), and Pennsylvania (38-66%). Delaware seems to contribute more than its fair share as the FY12 appropriation was 17% or double the amount suggested by the criteria. New Jersey's appropriation of 35% is higher than the formula based on these factors. New York's appropriation of 14% is higher than the criteria suggested by population, wastewater, and nitrogen load but is less than the level suggested by land area and far less than calculated based on water supplies. However, New York State's shortfall based on water supply criteria is more than made up by the millions of dollars of contributions from New York City DEP to protect the Catskill-Delaware reservoir watersheds. Pennsylvania covers over half the Delaware Basin and its funding of 35% is less than the equitable level suggested by the criteria (38-66%). While low, the Commonwealth's contribution to DRBC is supplemented somewhat by over a hundred million dollars in funding apportioned to the basin by the Philadelphia Water Department.

Among the largest challenges facing the DRBC are declining government appropriations to fund the administration and operation of this acclaimed river basin governance organization. The DRBC has not received its Federal appropriation of $750,000 since 1997 when Congress zeroed out the funding during decentralization of Federal functions. In recent years, the states of New Jersey, New York, and Pennsylvania have reduced or withheld their contributions to the DRBC.

Answers to these financial challenges may lie in the economic approach to river basin management where the users who benefit from the river bear some of the costs of restoring the basin. Since JFK formed the DRBC in 1961; the Harvard Water Program, National Academy of Sciences, and Interstate Council on Water Policy and others have touted the Commission as an ideal river basin governance organization with unique authority by Federal/state compact to reduce water pollution using an economic benefit-cost approach.

The DRBC already employs this user pays approach to some degree and since the 1970s has used the authority of the DRBC Compact to levy water supply use charges (now at $0.08/1000 gallons) to provide fund about a quarter to a third of the annual budget. The advantages of the water use charge are that it (1) equitably spreads out the costs basin-wide to those who consume or benefit from the water supply, (2) helps to diversify the DRBC budget while government appropriations are falling due to the recession, and (3) taps a less volatile revenue base for a more financially secure DRBC which is necessary for optimal management of drinking water supplies for over 16 million people in the four-states.

The top twenty water withdrawals in the Delaware Basin provide about $1.9 million annually or 70% of the total water use charges. Five of the largest water users (Philadelphia, Trenton, PSE&G Mercer, US Steel Fairless Works, and Aqua Pennsylvania) do not pay water supply charges as these withdrawals were in place prior to the DRBC Compact of 1961 and retain an entitlement or exemption from the program. If the pre-Compact entitlement water users were included in the program, for instance if the water utility was sold to another owner, the additional revenue would exceed a half million dollars. The DRBC water use charge ($0.08/1000 gal) is less than the fees assessed by the Rhode Island Water Board ($0.10/1000 gal), Susquehanna River Basin Commission (40.28/1000 gal), and N.J. Water Supply Authority ($0.97/1000 gal).

Water Quality: Chapter 4 shows that while nitrogen loads from the Delaware Basin are the largest of any estuary along the Atlantic seaboard, eutrophic susceptibility is moderate in the Delaware Estuary. Wetlands that rim the estuary help to assimilate nutrient loads along the Delaware and New Jersey bayshore. Despite very high nutrient loading and concentrations, the Delaware Estuary does not show the classical eutrophication symptoms of hypoxia or Chesapeake Bay-like algal blooms. The lack of algal blooms may be due to high turbidity, high flushing and low light in the Delaware Estuary.

The most severe impact of over nitrification in the Delaware Estuary is the 50% saturation DO sag that occurs from Philadelphia to Wilmington with high water temperatures during late spring, summer, and early fall that can significantly limit propagation and spawning of anadromous fish such as the American shad, striped bass, and Atlantic and shortnose sturgeon.

Approximately 16% of assessed stream miles are impaired in the Delaware Basin according to biannual surveys conducted by the four states for the EPA in accordance with Section 305b of the Clean Water Act. Over the last half century, water quality improvements in the Delaware River and its tributaries have coincided with a recovering anadromous fishery. In 1967, the DRBC set a minimum dissolved oxygen water standard of 3.5 mg/l in the tidal river near Philadelphia for spring/fall passage but not year-round propagation of diadromous fish. The 3.5 mg/l DO standard is increasingly violated during the summer when water temperatures approach 30° C (86° F) and DO saturation plunges to less than 50%. The DRBC is considering setting a more protective DO standard along the tidal Delaware River (to 4, 5, or perhaps 6.0 mg/l) to sustain year-round propagation of anadromous fish such as American shad and Atlantic sturgeon. A more stringent DO standard would also serve as a hedge against atmospheric warming and rising sea levels that could increase water temperatures and salinity in the tidal river which in combination would further depress DO saturation. A watershed restoration program that reduces nutrient pollution would improve water quality and boost the economies of tourism, commercial fishing, recreation, hunting, real estate, and water treatment that depend on clean water.

1966 Benefit-Cost Analysis: Chapter 5 reviews a 1966 study of the Delaware Estuary by the Federal Water Pollution Control Administration (FWPCA) that was one of the first economic analyses in the U.S. that evaluated the costs and benefits of achieving water quality goals. The 1966 FWPCA study noted the Delaware Basin was the only watershed in the U.S. empowered by Federal and state law (the DRBC Compact) to conduct regional, interstate water quality management using an economic approach and estimated costs of municipal/industrial wastewater controls to achieve minimum DO levels that ranged from 0.5 mg/l to 4.5 mg/l for 1975-1980 drought conditions. While the economic study was notable for its time, the analysis did not evaluate the costs of nonpoint atmospheric, urban/suburban, and agricultural runoff controls as little was known then about these diffuse sources of water pollution. Nonuse benefits from modern willingness to pay concepts available today were not incorporated either.

In January 1967, the DRBC water use advisory committee composed of the public, industry, government, recreation, conservation, and fish and wildlife stakeholders examined the FWPCA benefit-cost analysis to recommend establishing a water quality standard. Municipal and industrial interests recommended adopting Objective III (DO 3.0 mg/l) with the highest net benefits of $130 million. Conservation interests and local elected officials recommended that DRBC adopt Objective II (4.0 mg/) as the more protective option with the highest marginal benefits ($20-$30 million). Over 50 people testified at the hearings and the public format for debate and discussion was hailed as unique and progressive for the time. In 1968, the DRBC Commissioners adopted a combination of Objective Sets III (3 mg/l) and II (4 mg/l) as the most cost-effective option and as a compromise established the summer 24 hour DO standard at 3.5 mg/l for the Delaware Estuary between Philadelphia and Wilmington.

Adjusting to 2010 dollars, the 1966 Delaware Estuary economic study indicates the costs to achieve summer DO of 2.5 mg/l would be $58-$87 million versus benefits of $70-$162 million and the costs to reach 4.5 mg/l would be $284 million with benefits of $93-203 million.

The 1960s Delaware Estuary study concluded that higher water quality could be justified almost entirely on aesthetic and recreational grounds since the benefits for municipal and industrial water users were very small. If a value of $2.50 a day were placed on boating, then it would have been justified to maintain 3 mg/l DO even if no other benefits were considered. To fund the water pollution control effort, the FWPCA recommended that the DRBC adopt an effluent charge of $0.08 to $0.10 per pound of biochemical oxygen demand (BOD) substances discharged to produce the largest DO increase in the Delaware Estuary. This FWPCA study concluded that a user charge would raise $7 million annually for the DRBC waste load abatement effort, a modest amount that was unlikely to disrupt the regional economy.

Costs: Chapter 6 estimates the costs of reducing point source (wastewater) and nonpoint source (atmospheric, urban/suburban, agricultural) pollution to improve water quality in the Delaware River. The cost analysis suggests that nitrogen loads should be reduced by 32% (median) within a range of 20% (25^{th} percentile) to 48% (75^{th} percentile) to increase DO levels from the current DRBC criteria (3.5 mg/l) to a future year-round fishable standard (5.0 mg/l) in the Delaware River. Annual costs range from $334, $449, and $904 million to reduce nitrogen loads by 20% (25^{th} percentile), 32% (median), and 48% (75^{th} percentile), respectively. The least cost option to reduce nitrogen loads by a median 32% (16,168 ton/yr) in the Delaware Basin is achieved by reducing atmospheric NOX by 5%, wastewater by 10%, urban/suburban by 5%, and agricultural loads by 90%. The least cost to reduce N loads by 32% in the Delaware Basin is $449 million including $141 million for urban/suburban retrofitting, $132 million for agriculture conservation, $130 million for wastewater treatment, and $45 million for atmospheric NOX reduction.

Pennsylvania covers over half of the Delaware Basin and contributes correspondingly high wastewater and agriculture nitrogen loads, therefore the Commonwealth's annual share is $322 million or 72% of the total cost. New Jersey bears $87 million or 19% of the total cost. New York State would contribute $19 million or 4% of the N load reduction cost. Delaware would assume $16 million or a just less than 4% of the cost. Maryland's share would be $337,000.

The Delaware River at Trenton contributes 25% of the nitrogen load from predominately agricultural sources with a corresponding N reduction cost of $132 million or 30% of the total cost. The Schuylkill watershed contributes 30% of the N load mostly from wastewater and agricultural sources with a cost of $124 million or 28% of the total cost. The Delaware River watershed between Philadelphia and Trenton contributes 29% of the N load mostly from wastewater with a cost of $104 million or 24% of the total cost. The Brandywine/Christina watershed bears $37 million or 8% of the N load reduction cost where over ¾ of the N loads flow from agriculture. The Delaware River watershed between Wilmington and Philadelphia assumes $32 million or 7% of the cost to reduce mostly wastewater N loads. The Delaware Bay watershed between Prime Hook and

Wilmington would require $13 million to reduce mostly agricultural N loads from the coastal plain streams on either side of the bay.

The marginal abatement cost (MAC) curve defines the most cost effective combination of nitrogen reduction strategies to improve DO to a future DRBC standard to provide year-round propagation of anadromous fish. Least cost agriculture and wastewater treatment reductions would be maximized first followed by higher cost atmospheric deposition and urban suburban runoff controls. After less costly agricultural and wastewater BMPs are implemented, nitrogen reduction in the Delaware Basin becomes incrementally less cost-effective after 30% N reduction as the slope of the cost curve flattens with increasingly higher investments in more costly wastewater, atmospheric and urban/suburban controls with lower reductions in pollutant load.

Based on the nitrogen MAC curve, 90% (30 million lb) of nitrogen can be removed for just 35% ($160 million) of the $449 million cost to reduce nitrogen loads and raise DO in the Delaware River to a future DRBC standard (DO 5.0 mg/). The remaining 10% (2 million lb N/yr) of the N load reduction will require 65% ($290 million/yr) of the total cost.

Based on the delivery fraction of nitrogen from the SPARROW model or the percentage of nitrogen delivered to the streams, implementation of best management practices in watersheds closest to the Delaware Estuary would provide the most immediate improvements in water quality. The SPARROW model indicates that the delivered yield of nitrogen from watersheds far from the estuary such as in the headwaters of the Delaware River in New York State and the upper Lehigh and

Schuylkill basins are less likely to influence dissolved oxygen levels in the Delaware Estuary. Nonpoint source pollutant load reduction practices for urban/suburban land and agriculture may take years to improve estuary water quality due to the slow travel time of groundwater through shallow aquifers.

Benefits: Using modern ecological economics techniques, Chapter 7 concludes that the annual 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 $1.1 billion per year. 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. 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). 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.

Nutrient reduction measures that improve water quality in the Delaware River will provide auxiliary benefits that are not tabulated here. Agricultural practices will reduce bacteria loads that may improve major tributaries to swimmable uses. Reduced pollutant loads in the headwaters will provide significant freshwater recreation and nonuse benefits that accrue from improved water quality in the tributaries to the Delaware River. The benefits of improved water quality in the tributaries are expected to be substantial but they are not attributed here.

21st Century Benefit-Cost Analysis: Chapter 8 conducts a modern benefit cost analysis that compares the costs of pollutant load reductions to improve water quality versus the benefits to society (those who utilize or draw on the waters of the Delaware Basin). Optimal water quality occurs where the marginal cost (MC) curve intersects the marginal benefits (MB) curve or the point where the economic system is in equilibrium. The marginal cost and marginal benefits curves illustrate five cost options based on a nitrogen reduction of 32% and low and high bound benefits curves. The marginal cost curves intersect the low bound marginal benefits line at a DO level between 4.3 mg/l for Option 1 and 4.6 mg/l for Option 5. The MC curves intersect the high bound MB line at a DO between 4.5 mg/l (Option 1) and 4.7 mg/l (Option 5). These MC/MB curves suggest the optimal level of DO is close to 4.5 mg/l.

Sustainable Watershed Funding: Chapter 9 analyses a portfolio of market-based funding models available to finance an annual $449 million program to reduce nitrogen loads by 32% and improve water quality in the Delaware River.

Atmospheric NOX reduction costs of $44.5 million can be funded by a $0.14/1000 gal water use charge on thermoelectric power plant withdrawals ($13.6 million), $10/kW clean energy fee on energy produced by power plants ($13.4 million), $39.48/ton N air emission fee ($0.2 million) and $0.03/toll motor vehicle toll fee along bridges and roads in the Delaware Basin ($17.3 million).

Wastewater N load reductions that cost \$150.6 million can be paid for by a \$0.50/1000 gal wastewater discharge fee (\$21.5 million), \$1.00/lb N wastewater effluent charge (\$46.5 million), and \$25 per household annual wastewater treatment fund (\$82.6 million).

Nitrogen load reductions in urban/suburban runoff that cost \$137.4 million can be financed by the EPA Clean Water Revolving Fund 20% Green Reserve fund (\$8.6 million), Clean Water Act Sec. 319 nonpoint source funding (\$3.6 million), and a \$0.008/ft^2 of impervious cover watershed utility fee (\$125.2 million).

Agricultural conservation programs that cost \$134.3 million can be funded by USDA NRCS and Farm Services Agency appropriations under the Farm Bill (\$35.6 million) and upstream investments by public water suppliers from a \$0.15/1000 gal water use charge (\$98.7 million).

These programs provide incentives for users or beneficiaries of the water resource to reduce emissions and discharges and pay for upstream water pollution control programs without increasing Federal or state budgets. An annual \$449 million water quality improvement program would cost each of the Delaware Basin's 8.2 million residents just \$4.46 per month. If the 16 million people who obtain drinking water from the Delaware Basin were asked to pay to improve water quality, the cost to each consumer would be just \$2.39 per month. A \$449 million annual expenditure to reduce pollutant loads and improve water quality in the Delaware River would boost GDP by 3.1 billion dollars, yield 12,600 direct water jobs and 46,000 jobs in the national economy, and generate \$1.6 billion in economic activity.

A water quality trading program to reduce nitrogen loads by 32% (32 million lb/yr) in the Delaware Basin could save $1.2 billion annually or $844 million in Pennsylvania, $230 million in New Jersey, $76 million in New York, and $44 million in Delaware (Figure 10.6). Atmospheric, wastewater, and urban/suburban sources would save over a billion dollars annually by nitrogen credits from agriculture. Farmers could earn additional revenue from the water quality trading program by selling 17 million pounds of nitrogen credits at $5/lb N to atmospheric, wastewater, and urban/suburban stormwater sources. With water quality trading that focuses on agricultural conservation with low marginal nitrogen abatement costs, 90% of the nitrogen loads can be reduced for 30% of the total cost.

10.2 Limitations of the Research

Given the current level of understanding of the linkages between watershed pollutant load modeling and benefit-cost analysis in the Delaware Basin, this research has the following limitations. These limitations provide opportunities to conduct future research into the science and policy implications of a cost-effective approach to restore the waters of the Delaware River Basin.

Pollutant Load Model: The most up to date and calibrated USGS SPARROW model estimates mean annual nitrogen loads for flow and land use conditions for a 2002 base year and does not model loads in a more frequent daily or monthly simulation format. Since annual cost estimates are utilized in this dissertation, mean annual loads from the SPARROW model are adequate for this research. Future work should be conducted to update the SPARROW nitrogen load model to more current flow and land use conditions

The SPARROW model does not account for contributions from nitrogen in groundwater. It is likely that nitrogen loads via groundwater to the Delaware Estuary are underestimated in this analysis.

There is a question about whether the SPARRPW model's first-order process parameterization of in-stream N removal is valid in streams with high nitrogen loads. A higher order process model would be required to address this concern.

Hydrodynamic Model: A new DRBC unsteady flow hydrodynamic pollutant model that can be used to estimate nitrogen load reductions in a more precise format is years away from completion. Five different hydrodynamic models for the Delaware River exist dating back to 1960s. In the absence of this new hydrodynamic model, nitrogen load reductions were estimated from a synthesis of Total Maximum Daily Load (TMDL) models for the lower Delaware River. These TMDL models indicate that a median 32% reduction in nitrogen is needed within confidence intervals of 20% N reduction (25th percentile) and 48% N reduction (75th percentile). Future research should be conducted to update the nitrogen load model and benefit-cost analysis when the new DRBC hydrodynamic model becomes available in the next few years.

Nitrogen Load Reduction Costs: When not available from case studies in the Delaware Basin, unit nitrogen load reduction costs for the various point and nonpoint sources were adapted through value transfer from a synthesis of the literature from the Chesapeake Bay, New Hampshire, Connecticut River/Long Island Sound, and other watersheds in the United States. Future research should be conducted to compile nitrogen load reduction costs for best management practice case studies in local settings within the watersheds of the Delaware Basin.

Sector Reduction Efficiency: This analysis examines five options that range from Option 1 (reduce N from all sources including Ag by median 32%) with a cost 0f $1.6 billion to Option 5 (reduce N from Ag by 90%), the least cost option with a cost of $450 million. If Ag N were not reduced by 90%, say by 60% instead, the MAC curves indicate that the total cost would rise to $650 million and the difference in cost for Ag reduction would be $40 million which would be reallocated to more costly wastewater treatment practices. Monitoring should be conducted as part of an optimization program to measure N reductions from Ag and other sources as pollutant load reduction projects are implemented.

Additionally, SPARROW has a model delivery factor algorithm that may need to be improved to more precisely estimate nitrogen loading from agriculture located far from the estuary (for instance in the headwaters of the Schuylkill River) compared to farms located near the estuary. Improved science-based pollutant load modeling is needed to better quantify the near-versus far-source delivery factors using better spatial resolution. More research is needed before these delivery factors can be incorporated into any water quality trading mechanism. This improved modeling would allow the DRBC to update the “optimal” strategy accordingly based on what is actually accomplished and implemented on the ground. This limitation has policy implications for strategy implementation in the Delaware Basin because:\

- The per-farm benefit of trading may be differentiated by the delivery factor.
- The cost-effectiveness of measures for agriculture is based on the assumptions of per unit costs for N reduction coupled with the model delivery factor that influences near- versus far-source reductions.
- N load reduction efforts may result in lower efficacy of control "leakage" where instead of reducing Ag N by 90% it may occur that a lessor result (perhaps 40% or 60%) may be accomplished in the future.
- Given that the per-farm delivery factor in the SPARROW model may be insufficient to assign any other than an average water quality trading price for agricultural sources, implementation should take advantage of improved future modeling to ensure that funding is invested most efficiently spatially in the basin.

Relationship between Water Temperature and DO: An additional consideration is the inverse relationship between dissolved oxygen saturation and water temperature and salinity. The costs and benefits of achieving improved water quality in the Delaware River through higher dissolved oxygen criteria are based on peak water temperatures that approach 30°C (86°F) which usually occurs in July and August. At 30°C, freshwater DO saturation is 7.54 mg/l, therefore at this temperature DO is 46% saturated at 3.5 mg/l, 53% saturated at 4.0 mg/l, 60% saturated at 4.5 mg/l, 66% saturated at 5.0 mg/l, and 80% saturated at 6.0 mg/l. If water temperatures in the tidal Delaware River increase in the future by 2°C to peak summer levels of 30° C, based on saturation, DO levels will decline by about 0.2 mg/l. Research using a future DRBC hydrodynamic model should be conducted to explore the influence of water temperature and salinity on DO levels in the Delaware Estuary.

Groundwater Transport of N Loads: Nitrogen reductions from groundwater recharge from agriculture and urban/suburban sources could have a delayed effect on water quality improvements in the Delaware Estuary. The USGS reported that along the Chesapeake Bay, about 50% of nitrogen delivery is through groundwater and groundwater travel time to the estuary varies from 1 to 50 years with a median of 10 years. Groundwater travel times vary based on spatial location in the watershed, topography, and physiographic province. For instance groundwater travels faster in hilly, rocky Piedmont and Ridge and Valley physiographic provinces to the north in the Delaware Basin compared to relatively slow travel times in the flat, sandy Coastal Plain to the south near the estuary (Table 10.3). Nitrogen reductions from surface water control measures for wastewater treatment and airborne emissions and urban/suburban and agricultural sources are expected to have an almost immediate benefit to water quality in the Delaware River. Nitrogen reduction from urban/suburban and agricultural recharge BMPs through groundwater could have a delayed effect on improved water quality in the estuary that lag for years after implementation. Future modeling, particularly geographically resolved hydrodynamics with groundwater transport, should be conducted to address this quantitatively.

Table 10.3: Influence of travel time on improved water quality in the Delaware River

Nitrogen Source Control	Coastal Plain	Piedmont Province	Ridge and Valley	Appalachian Plateau
Airborne Emissions	Immediate	Immediate	Immediate	Immediate
Wastewater Treatment	Immediate	Immediate	Immediate	Immediate
Urban/Suburban BMPs				
Surface Water Runoff	Months	Immediate	Immediate	Immediate
Groundwater Recharge	Years	Months to years	Months	Months
Agriculture Conservation				
Surface Water Runoff	Months	Immediate	Immediate	Immediate
Groundwater Recharge	Years	Months to years	Months	Months

Benefits Transfer: Where possible, benefits were derived from market and nonmarket data with origins in the Delaware River Basin. If basin-specific data was not available, economic data for some categories were transferred from other watersheds to the Delaware River using the principles of benefits transfer (value transfer) as defined in Chapter 8. To scale the economic data to a common base year, benefits transfer from earlier studies were translated to 2010 dollars based on an average 3% annual change in the Northeastern Consumer Price Index (CPI) as reported by the U.S. Bureau of Labor Statistics. Benefits transfer is relatively inexpensive and quick to implement, however, it must be applied carefully to avoid redundancy and double-counting of benefits Benefit transfers can only be as accurate as the initial study. While it has shortcomings, the benefit transfer method is used here to estimate the benefits of improved water quality in the Delaware River by applying willingness to pay (WTP) data from similar settings (such as the Chesapeake Bay). Future research such as contingent valuation and travel cost studies should be conducted to obtain updated revealed and stated preference WTP data for populations in the Delaware River Basin.

Nonuse Benefits: These intrinsic benefits are counted here and translated to $2010 from a willingness to pay study published by Carson and Mitchell in 1993. These are the benefits accrued by a population who state that they would be willing to pay for improved water quality because of its value for existing and future generations. Some feel that nonuse benefits may be unrealistic because individuals only state what they would be willing to pay and do not actually make a transaction or pay a price in a market. Many ecological economists declare that if nonuse benefits were omitted then total benefits may be undercounted. The EPA and other Federal agencies have a policy of including nonuse benefits in BCA studies. Future research should be conducted to more precisely measure nonuse benefits for the local setting in the Delaware Basin by conducting a stated preference survey of the basin population to measure what they would be willing to pay for improved water quality in the river.

Benefits in the Tributaries: The benefits of improved water quality in the tributaries of the Delaware River are not directly counted here, therefore the benefits of reduced pollutant loads in the tributaries and watersheds of the Delaware Basin are probably underestimated in this analysis.

Linear Assumption for N Load Reduction and DO: The relationship between percent nitrogen load reduction and dissolved oxygen levels in the Delaware River is assumed to be linear while the correlation is slightly curvilinear. This is important because a curvilinear trend in meeting the DO target may intersect the marginal cost curve differently than for a linear trend. Plots of pollutant load reduction and DO levels from the 1960s Delaware River economic study indicates the coefficient of determination for the linear measure of best fit ($r^2 = 0.92$) is nearly identical to the curvilinear (logarithmic) regression ($r^2 = 0.94$). Since the linear and curvilinear regressions are nearly identical, the assumption of a linear relationship between percent N load reduction and DO levels in the Delaware River is adequate for this research. Future work on an new DRBC hydrodynamic model will improve these pollutant load and DO relationships.

Total cost and marginal cost curves are curvilinear in form due to the increasingly higher costs of nitrogen load reductions as one progresses to the right on the marginal abatement cost curve (MAC) from less expensive agriculture and wastewater controls to more expensive airborne emissions and urban/suburban control measures.

10.3 Future Research Ideas

This dissertation recommends the following research in governance, policy, and economics that could lead to future improvements in water quality in the Delaware Basin.

Hydrodynamic Model: When the DRBC hydrodynamic model becomes available in the next few years, update the nitrogen pollutant load estimates and benefit-cost analysis to more precisely reflect the influence between watershed spatiality, water temperature, salinity, groundwater transport on dissolved oxygen levels in the Delaware Estuary.

Basin Restoration Optimization Modeling: Conduct basin optimization modeling at the subbasin watershed scale to gather local nitrogen reduction cost data and identify cost-effective locations and watershed specific benefits and costs of priority restoration best management practices to improve water quality in the river and its tributaries. Monitoring should be conducted as part of an optimization program to measure N reductions from Ag and other sources before/during/after implementation.

Willingness to Pay Research: Conduct primary economic valuation studies (revealed preference and stated preference) in the Delaware Basin that survey residents for their willingness to pay for clean water in the Delaware River and its tributaries.

Market-based Funding Mechanisms: Commission research that evaluates the feasibility of the DRBC and states to adopt user (beneficiary) and/or polluter pays funding mechanisms to provide incentives to conserve water supplies and reduce pollutant discharges and pay for the administration and implementation of water pollution control programs.

Community Outreach: Conduct communications and social science research designed to inform the public and elected officials and outline the environmental, economic, and social benefits of the beneficiary pays approach to pay for improved water quality in the Delaware Basin.

DRBC New Business Model: The DRBC should consider the following three changes in the area of budget and finance to more effectively manage the watershed. One, the DRBC should petition the Administration to appoint a different cabinet department such as the EPA or Department of Interior (instead of the U.S. Army Corps of Engineers) as the Federal Commissioner and restore the Federal signatory share of the DRBC budget through a line item appropriation in that Department’s annual budget. Two, given that the annual appropriations from New York and Pennsylvania seem to waver from year to year, the DRBC should seek a more formal funding relationship with the two largest local governments and water users in these states that benefit from the basin (New York City and Philadelphia) as their collective annual budgets exceed $180 million. And three, since annual signatory member contributions from some states are volatile and Federal water funding is in decline, the DRBC should work toward making up the gap through less volatile beneficiary pays approaches perhaps from an expansion of the existing water supply use charge program that has been in place since the 1970s.

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