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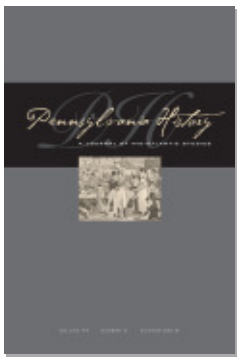
Gerald J. Kauffman Jr.



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THE DELAWARE RIVER REVIVAL: FOUR CENTURIES OF HISTORIC WATER QUALITY CHANGE FROM HENRY HUDSON TO BENJAMIN FRANKLIN TO JFK

Gerald J. Kauffman Jr.
University of Delaware

Since Henry Hudson sailed to the bay 400 years ago in August 1609, water quality in the Delaware River has changed from pristine, to polluted, to partly recovered. Water pollution was so noticeable by 1769 that a visiting Englishman named Isaac Weld was moved to comment on the "mess" in the Delaware River at Philadelphia. Due to pollution in the river after the American Revolution, Ben Franklin left money in his will to build a drinking water supply system in America's largest city. In 1940 the Interstate Commission on the Delaware River called the tidal river at Philadelphia "one of the most grossly polluted areas in the United States." During the Second World War, water pollution was so bad that a newly painted ship faded to the colors of the rainbow as it sailed onto the river and Navy pilots were instructed to ignore the stench of the river as they flew a mile overhead.[1]

After the war, the urban Delaware River was one of most polluted in the world with zero oxygen levels during the summer.

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During the 1950s, American shad were unable to migrate through the anoxic barrier at Philadelphia and a prominent ichthyologist lamented "a near extirpation of the species with genetic origins in the basin." In 1973, three years after Richard M. Nixon created the U. S. Environmental Protection Agency, a pessimistic USEPA official concluded that the Delaware Estuary would never achieve fishable uses.[2]

The watershed came when environmental laws led to a Delaware River revival. In 1961, Pennsylvania Governor David Lawrence convinced a reluctant JFK to sign the law forming the Delaware River Basin Commission between Delaware, New Jersey, New York, and Pennsylvania, the first ever Federal-state watershed compact. In 1968, the DRBC was the first agency to impose load allocations on river dischargers, holding them to standards more stringent than USEPA issued years later. In 1972, Congress led by George McGovern overrode Nixon's veto and passed the Clean Water Act, a law that invested $1.5 billion in new wastewater plants along the Delaware River. Phosphate detergent bans by New York in 1973 and Pennsylvania in 1990, along with a 1994 halt on manufacture prompted phosphorus declines by over 25% in many rivers.[3]

River historian Richard C. Albert wrote in 1988 that "the cleanup of the Delaware Estuary represents one of the premier water pollution control success stories in the United States." By 2005, dissolved oxygen at Philadelphia exceeded 4 parts per million, the fishable water quality standard, and migratory shad and striped bass returned to the river in numbers not recorded since the late nineteenth century. Bald eagles, protected species that rely on a fish-laden diet, returned to the cleaner waters of the Delaware River in growing numbers, even nesting in South Philadelphia at the Navy Yard in March 2007. Historic water quality recovery occurred in the Delaware River during an environmental era that coincided with the return of migratory fish populations.[4]

The Delaware River Basin

The Delaware River is governed by two regional watershed organizations, the Delaware River Basin Commission (DRBC) and the Partnership for the Delaware Estuary (PDE). The DRBC oversees water resources management in portions of Delaware, Pennsylvania, New Jersey, and New York. The DRBC is led by five commissioners representing the Governors and a Federal

designee, the U. S. Army Corps of Engineers. In 1968, the DRBC was noted as one of the first actors in the environmental movement when Stewart Udall, JFK's Secretary of the U. S. Department of the Interior stated: "Only the Delaware among the nation's river basins is moving into high gear in its program to combat water pollution."

The Delaware Estuary reached national prominence when USEPA and Congress designated it as one of twenty eight members in the National Estuary Program under the Federal Water Quality Act of 1987 to protect estuarine systems of national significance. The Partnership for the Delaware Estuary formed in 1996 and is managed by an executive director and staff with headquarters along the Delaware River at Wilmington, Delaware.

The Delaware is the longest un-dammed river east of the Mississippi, extending 330 miles from Hancock, New York to the mouth of the Delaware Bay at Cape May. The Delaware Estuary extends 130 miles from the mouth of the bay to the head of the tide at Trenton, New Jersey. The river is fed by 216 tributaries, the largest being the Schuylkill and Lehigh Rivers in Pennsylvania (Figure 1). The basin contains 13,539 square miles, draining parts of Pennsylvania (51%), New Jersey (23%), New York (18%), and Delaware (18%). In 2001, the Delaware Basin was covered by 14% developed, 26% agriculture, 55% forest, and 5% wetland land uses.

Almost 8 million people live in the Delaware Basin and 15 million people (5% of the nation's population) rely on the river for drinking water, but the watershed drains only 4/10 of 1% of the continental USA. Over 7 million people in New York City and New Jersey live outside the basin and receive drinking water from the Delaware River. New York City draws 50% of its drinking water from three reservoirs located in the Catskill Mountain in the headwaters of the Delaware River. The Delaware Estuary is the largest freshwater port in the world and generates $19 billion in annual economic activity. The Delaware is home to the third largest petrochemical port in the U. S. with five of the largest East Coast refineries. The Delaware River refinery complex provides 70% of the heating oil and gasoline for the East Coast and is the largest North American port for steel, paper, and meat imports and the largest importer of cocoa and fruit on the East Coast. Over 65% of South American fruits imported into the United States arrive through Delaware Estuary ports. Wilmington, Delaware is the largest U.S. banana port with one million tons imported annually.[5]

This essay traces four centuries of historic water quality transformation along the Delaware River and its tributaries during periods of colonization and revolution, industrialization, war, and the recent watershed era.

Colonization and Revolution

By 600 CE, the Lenni Lenape lived in the Delaware Valley, a land they called *Lenapehoking*. As noted by the first European visitors ten centuries later, the indigenous peoples of the valley found vast populations of fish and fowl in the pristine waters along the forested Delaware River and Bay.

On August 28, 1609, Henry Hudson sailed for the Dutch East India Company in the name of commerce on the *Half Moon* and discovered a "great bay" at latitude 39 degrees 5 minutes north. Hudson sailed only about fifteen miles up the bay concluding: "he that will thoroughly discover this great bay must have a small pinnace that will draw but four to five feet of water, to sound before him." Hudson called the bay "South River" and he turned to port and sailed north to discover the river that now bears his name on a quest to find an inner passage to India.

In 1614, Dutch Captain Cornelius Jacobsen Mey visited the bay and sighted the promontory now mapped as Cape May. The indigenous people and first Europeans living in the Delaware Valley have called the river by many names. The native Lenni Lenape called the river *Pautaxat, Mariskitton, Makerishkisken, Lenape, or Whittuck*. The Swedes who came in 1638 called it New Swedeland stream, New Port May, or Godyns Bay. The Dutch settlers of the seventeenth century called the river *Zuyt* or South River, Nassau River, Prince Hendrick River, or Charles River.[6] A year after Hudson's visit, British Captain Samuel Argall sailed to the bay and named the cape and river after Lord De La Warre, governor of the Jamestown Colony.

The Dutch ship *Iron Hog* made the first extended European voyage up the Delaware River in 1616 while looking for a southwest passage to Asia. The *Iron Hog* was one of the first European ships built in North America and its crew mapped the Delaware River and claimed the stream for the Dutch while in pursuit of beaver pelts for fashionable European hats.[7]

In 1633, Dutchman David De Vries recorded that the river was filled with so many fish that one net caught enough perch to feed thirty men. In his ship's log of 1634, Captain Thomas Yong filed an early water quality report on the Delaware River writing: "the river aboundeth with beavers, otters,

FIGURE 1: The Delaware River Basin. (Delaware River Basin Commission 2007.)

and other meaner furs . . . I think few rivers of America have more . . . the quantity of fowle is so great as hardly can believed. Of fish here is plenty, but especially sturgeon." In 1638, Swedes aboard the *Kalmar Nyckel* established a trading colony at Fort Christina at the confluence of the Brandywine and Christina Rivers, the first permanent European settlement in the Delaware Valley and site of present day Wilmington, Delaware.

In 1655 the Dutch under Governor Stuyvesant of New Amsterdam sent seven vessels to the Delaware and forced the Swedes to surrender their log forts. In 1664 following capture of New Netherlands from the Dutch, King Charles II of England named his brother James II, the Duke of York, as proprietor of the Atlantic coast giving the English control of the Delaware.

English Quaker William Penn sailed up the Delaware River in 1682 on the *Welcome* and founded Philadelphia at the mouth of the Schuylkill. Penn wrote of oysters six inches long from the Delaware, too big to be eaten whole and large sturgeon that played in the river all summer. By 1700, Penn's City of Brotherly Love had 5,000 residents and, given the primitive sanitary disposal standards of the day, the river began to show signs of pollution.[8]

After a century of colonization along the Delaware, one of the first published accounts of water pollution was filed by Benjamin Franklin, often called America's first environmentalist. In 1739, a thirty three year-old Franklin and his Philadelphia neighbors petitioned the Pennsylvania General Assembly to remove the tanneries and slaughterhouses that were polluting Dock Creek and the Delaware River near his Market Street print shop. Franklin wrote in his Gazette that the creek was choked with hair, horns, guts and skins and that the fish swimming in the creek "soon floated belly up." Between 1762 and 1769, scientist Franklin led a Philadelphia committee to regulate water pollution in the city between the Schuylkill and the Delaware.[9]

On July 4, 1776, the Declaration of Independence was signed along the banks of the Delaware River in Philadelphia, the largest city in America at the time (Figure 2). On Christmas Day 1776, George Washington crossed the icy Delaware River from Pennsylvania to New Jersey and defeated the Hessians at Trenton, a turning point in the American Revolution. Earlier than usual Spring 1778 runs of American shad, celebrated as America's founding fish by Princeton author John McPhee, migrated upstream from the Delaware and fed General Washington's starved troops at Valley Forge along the Schuylkill.[10]

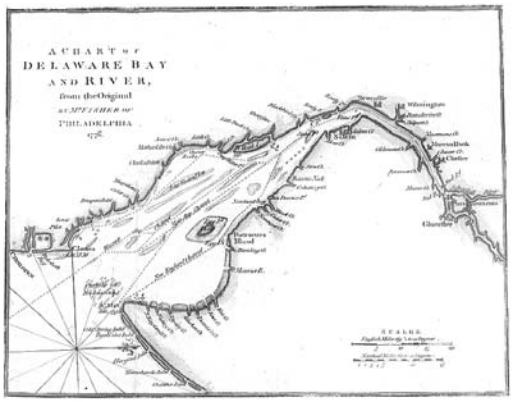

FIGURE 2: Chart of the Delaware River and Bay. (Fischer 1776 as archived by the University of Delaware Library, Newark, Delaware.)

Industrialization

After the American Revolution, Philadelphians became increasingly concerned about polluted drinking water from the Delaware River. Upon his death in 1790, Ben Franklin left funds in his will to develop a water system in Philadelphia due to concerns about polluted drinking water. In 1799, the first American government pollution survey noted contamination entering the Delaware River from ships and sewers. In 1801 Philadelphia developed the first municipal water system in the United States and in 1819 opened a water works on the Schuylkill near the Philadelphia Art Museum. By the 1850s, the City began purchasing land in the watershed to protect the drinking water supply. The land preserve became Fairmount Park, now the largest municipal park in the United States.

By 1802, the DuPont family established gunpowder mills along the falls of the Brandywine River above Wilmington thus serving as one of the first industries in the Delaware Valley. The energy source of one of the world's future largest corporations was the Brandywine, a river with a hydropower head greater than Niagara Falls.

During the nineteenth century, the Industrial Revolution led to indiscriminant dumping from factories along the Delaware River and pollution from coal mines in the headwaters of the Schuylkill and Lehigh Rivers, the two largest tributaries to the Delaware. In 1832, cholera caused by contamination

of drinking water by human and animal waste killed over 900 people in Philadelphia. Typhoid outbreaks led Philadelphia to build a water supply intake in 1850 on the Delaware River at Kensington above the present day Tacony Bridge. However, water supplies from the Delaware were unfiltered and cholera broke out again in 1891 and 1899.[11]

In his 1885 Sanitary Survey of the Schuylkill Valley, Assistant Engineer Dana Barber from the Philadelphia Water Department made an itemized accounting of the rampant dumping of sewage, chemicals, and animal parts into streams that were typical in nineteenth century industrial cities. In his meticulously detailed records, Engineer Barber writes that none of the towns had sewerage systems. Thus, the inhabitants along the Schuylkill operated businesses such as the Pullman Palace Car Company that had "privies for 250 men over a brook entering the park east of Fortieth Street, above Girard Avenue." An aggregate of 4,150 people utilized water-closets that drained directly into the Schuylkill between the Flat Rock and Fairmount Dams. The J & P Baltz brewery leaked 60 gallons a minute of spoiled beer into the river. The Powers and Weightmans Chemical works above the Falls Bridge dumped chemicals into the river such as "alum, oil of vitriol, green vitriol, and tartaric and citric acids." The A.D. Faust and Sons tannery treated 100 western cow hides per week and the hides and decomposed animal matter were deposited on the blackened stream bank for three quarters of a mile. The Grebes Blanket Mill scoured 137 blankets per day with 34 pounds of soap and 9 pounds of ash and all the waste including water closet discharges from 16 workers were discharged into the creek. Such was the state of water pollution control during the Industrial Revolution-a civilized society indeed![12]

During the Gay Nineties the Philadelphia newspapers had a field day reporting on the filthy rivers. In November 1896, an Inquirer editorial about the "ink-colored" Schuylkill asked the readers "Did You Wash Yesterday?" after they bathed in the unfiltered water. In January 1897, the Inquirer reported on a Philadelphia councilman who mistakenly thought the Schuylkill water in his glass was lemonade. During 1904, contaminated drinking water was linked to 44 new typhoid cases in a day, residents were warned to avoid typhoid fever, and boil water alerts were sounded.[13]

Near the close of the nineteenth century, Delaware River water quality was plummenting and barely sufficient to sustain a fragile and overworked fishery. The Delaware River of the late 1800s supported the largest Atlantic sturgeon population in the world. The sturgeon was such a lucrative fish that boom town Caviar (Bayside) near Greenwich, New Jersey was founded to process

the roe for worldwide export. In 1880, 1,400 sailing vessels took oysters from the Delaware Estuary. In 1887, 21.9 million pounds of oysters were harvested from the Delaware Bay. In 1886, nationally famous hotels in Gloucester, N. J. served 10,000 planked shad dinners at events that resembled modern day blue crab feasts. In 1896 over 14 million pounds of shad were caught with a value of $400,000 ($10 million in 2008 dollars). In 1896, a fisheries report to the governor of Pennsylvania listed the catch of a seventy six pound striped bass above Gloucester, New Jersey. Record harvests combined with declining water quality and low reproductive rates essentially eradicated the Atlantic sturgeon and shad populations by the late 1800's.

By the turn of the 20th century the American shad fishery in the Delaware collapsed from 16 million pounds harvested in 1900 to 3 million pounds by 1905 (Figure 3). By 1916, only a million pounds of shad were harvested from the Delaware. In 1921, only 200,000 oily shad were taken from the river.[14]

Fledgling progress in water pollution control occurred between 1899 and 1911 when the City of Philadelphia constructed sand filters and chlorine disinfection works to treat drinking water from the Delaware and Schuylkill water supplies. Although noticeable taste and odor problems remained, chlorination and disinfection of the drinking water supply reduced cholera and

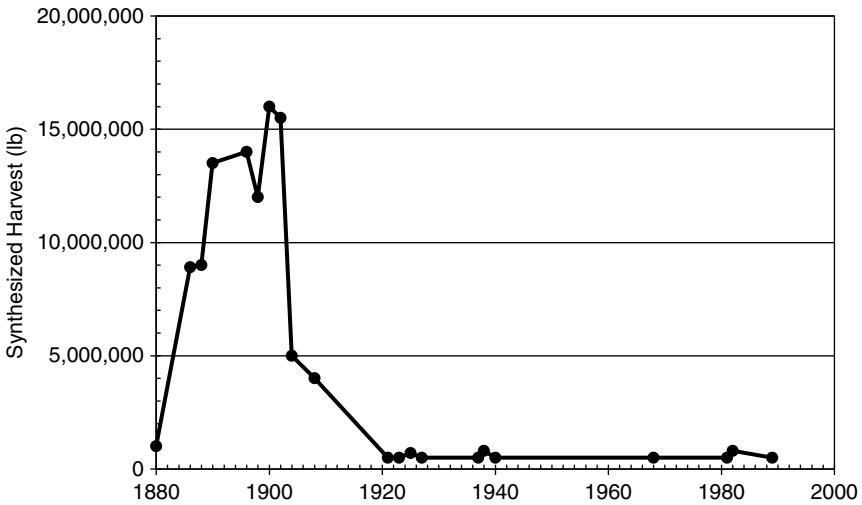

FIGURE 3: Synthesized American shad harvest in the Delaware Estuary. (Adapted from Delaware Estuary Program 1996.)

typhoid cases by 90%. Typhoid rates declined from 60 per 100,000 between 1902 and 1906 to only 7.5 per 100,000 in 1914.

The War Era

By 1914, depleted dissolved oxygen levels near 1 part per million were recorded along the Delaware River near Philadelphia and Camden. During World War I, shipbuilding at the largest U.S. Navy base in the world at Philadelphia accelerated along the "Clyde of America" as industries and cities dumped untreated sewage into the river. After the war, the Schuylkill was so dirty that Philadelphians joked that "people emerged from their tubs blacker than they had entered them."[15]

During the Roaring Twenties, the taste and odor of Philadelphia's drinking water from the Delaware was so inferior that the City proposed to build a reservoir 100 miles north in the Delaware Water Gap in the Pocono Mountains to capture clean water and pipe it back to the city. In 1927, the first interstate Delaware River compact between the Federal government, New York, New Jersey and Pennsylvania was proposed to develop the reservoir plan. New Jersey's interest in the compact dwindled due to Trenton's concern about reduced flows from the State of New York that could increase the concentration of acid pollution from coal mines along the Lehigh River. This first Delaware River compact was never adopted and the river remained severely polluted. Philadelphia's combined sewers and industries discharged untreated sewage into layers 12 feet deep at the bottom of the Delaware River. The river wastes decomposed, unveiling sulfide fumes that caused sailors to seek refuge on land rather then sleep in their ship berths.

In May 1931, the United States Supreme Court intervened in a conflict between the states and authorized New York City to divert up to 440 million gallons per day from the Delaware River Basin to its water supply system in the Hudson River Basin. The decree required that New York City release sufficient flow from its Catskills reservoirs to maintain a minimum flow in the Delaware River at Port Jervis, New York to protect downstream water supplies in Delaware, Pennsylvania, and New Jersey.[16]

In 1936, New Jersey, New York, and Pennsylvania created the Interstate Commission on the Delaware River Basin (INCODEL) as the first serious watershed movement to clean up pollution. Delaware joined in 1939. INCODEL initiated a water pollution control program to bring primary sewage treatment

to cities along the Delaware River and clean up coal mine wastes. By 1940, Trenton was the only city with a sewage treatment plant along the Delaware River. Other cities dumped raw, untreated sewage into the river.

In 1940, INCODEL called the tidal Delaware River below Trenton at Philadelphia and Camden one of the most grossly polluted areas in the United States. "More than 400 million gallons of untreated domestic sewage and industrial wastes were discharged daily" into the river between Chester, Pennsylvania and Burlington, New Jersey. Shad and herring were unable to migrate from the Atlantic Ocean to their ancestral upriver spawning grounds through the zero oxygen barrier along the Delaware River at Philadelphia.

During the Second World War, the INCODEL water pollution control plan was shelved and water pollution and dumping continued unabated as defense industries along the river churned around the clock to meet the war effort. Navy pilots flying a mile overhead were instructed by their commanders to ignore the sulfurous stench from the Delaware River. President Roosevelt ordered an investigation in 1941 to determine if pollution was hampering the U. S. war effort. A newly painted hospital ship turned into the colors of a rainbow as it sailed out into the toxic Delaware River. The U. S. Navy found that harbored ships in the Delaware required additional painting due to the harshness of the water and maintenance needs were intensified to corrosion of naval ship instruments. The Schuylkill was so choked with acid mine wastes from the headwaters that the Admiralty gave British officers on the HMS Nelson berthed at the Philadelphia Navy Yard extra allowances to replace gold braid tarnished by corrosive river gases. Admiral Milo Draemel, Commandant of the Navy Yard, left silver change on his dresser that corroded black overnight when exposed to the gaseous river air.[17]

During the war the Delaware received more waste than any other time in history, but the Federal government did not want to impede industrial production for the war. The vapors from the Port of Philadelphia became so foul that ships refused to tie up there. Up to 350 mgd of raw sewage poured into the Delaware River from Philadelphia alone. The river ran black with the stench of hydrogen sulfide gas. Pollution from war industries resulted in a 1946 report by the U.S. Fish and Wildlife Service that recorded all-time worse anoxia from shore to shore.[18]

After World War II, the Delaware was a dead river, as dead as any in the United States. During summers in the late 1940s, oxygen levels were typically 1 ppm or less over a 20 mile section of river from the Ben Franklin Bridge in Philadelphia to Marcus Hook near Delaware. In 1950, the urban reach of the

Delaware River was noted as one of most polluted stretches of river in the world. The pollution suffocated schools of fish and prevented spawning shad from swimming upstream in the spring and swimming back down to the Atlantic Ocean in the fall. By the late 1940s, the shad mostly disappeared above Wilmington, Delaware as only 38,000 pounds of shad were caught in 1949 which lead to a Pennsylvania law to preserve the shad from extinction. In 1952, ichthyologist Edward Raney lamented the Delaware as an "outstanding example of destruction of (striped) bass habitat by industrial and domestic pollution."[19]

The 1948 Federal Water Pollution Control Act put pollution of interstate waters under Federal jurisdiction and provided Federal funding for river restoration. With the war over, INCODEL revived the wastewater control program started during the 1930s. In 1951, every large city still dumped untreated sewage into the Delaware River except for Trenton which installed primary wastewater treatment in 1927. The first water quality improvements in the Delaware Estuary occurred during the early 1950s after construction of sewage treatment plants by Philadelphia, Camden, and Wilmington between 1951 and 1954. Philadelphia funded an $80 million plan to build primary sewage treatment plants which were completed in 1955. The INCODEL program resulted in towns with sewage treatment increased from 63 municipalities in 1935 to 236 in 1959. More tolerant to low oxygen levels than other species, blue crabs were among the first sentinels to revive as landings in the Delaware Estuary increased during the 1950s (Figure 4).[20]

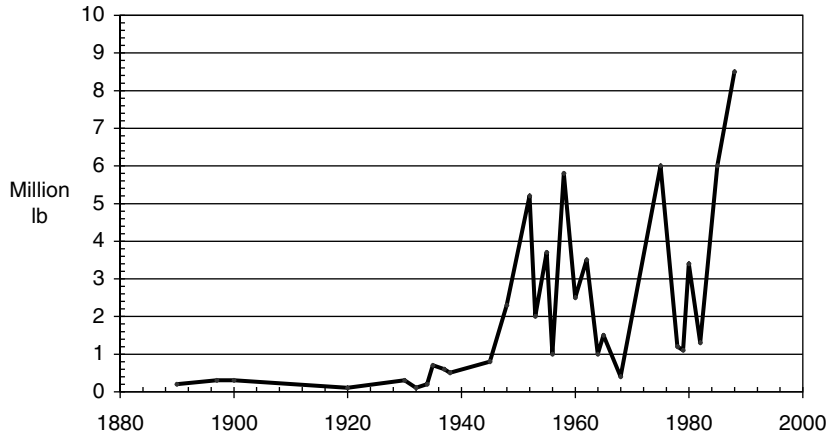

FIGURE 4: Synthesized blue crab harvest in the Delaware Estuary. (Adapted from Killam and Richkus 1992.)

To accommodate rising population and prosperity during the period between the wars, New York, New Jersey, and Pennsylvania failed to develop agreements to jointly manage water supplies in the Delaware Basin. Moving alone, New York City proposed to develop new reservoirs in the headwaters of the Delaware Basin to pump drinking water to the Hudson Basin and Manhattan. In 1930, New Jersey, Pennsylvania, and Delaware sued New York City in the U. S. Supreme Court seeking to prevent the City from diverting water from the Delaware Basin. On May 25, 1931, the Supreme Court ruled for New York City granting the right to withdraw 440 mgd from two proposed reservoirs (Neversink and Pepacton) along the headwaters of the Delaware River. Construction of the reservoirs slowed during World War II.

In 1952, New York City petitioned the Supreme Court to increase its diversion from the Delaware Basin as the decree states of Delaware, Pennsylvania, and New Jersey returned to court. The court issued an amended decree adopted by all parties in June 1954 that permitted New York City to withdraw 800 mgd with the construction of Neversink and Pepacton Reservoirs in 1955 and a third, Cannonsville Reservoir, later in 1967. New York City agreed to release sufficient water from the three reservoirs to meet a 1,750 cubic feet per second (cfs) flow objective at Montague, New Jersey to provide sufficient streamflows to downstream interests at Trenton and below and prevent upstream movement of tidal saltwater at the Philadelphia and Wilmington water intakes.

In August 1955, Hurricanes Connie and Diane hammered the Delaware Basin causing killer floods that left 99 people dead, caused $150,000,000 in damages, and left an "oily film of silt . . . and a terrible stench—an aroma of feces and rotting flesh." The hurricanes also washed toxic sediments downstream and temporarily purified the Delaware as shad came back to the river by the late 1950s. By 1960, as fresh water flow decreased and the salt line moved upstream, MSX disease devastated oyster stocks in the Delaware Bay. Only a million pounds of oysters were taken during 1960, down from over 15 million pounds harvested during the 1930s (Figure 5).[21]

During the late 1950s, water quality was good above the head of tide at Trenton due to reforestation in the mountain headwaters and deteriorated to poor downstream in the tidal Delaware River and Bay. In September 1958, dissolved oxygen declined from 95% saturated at Trenton to 15% at urbanized Philadelphia, rising to 50% at Wilmington and increasing to 75% saturated at the C and D Canal (Figure 6).[22]

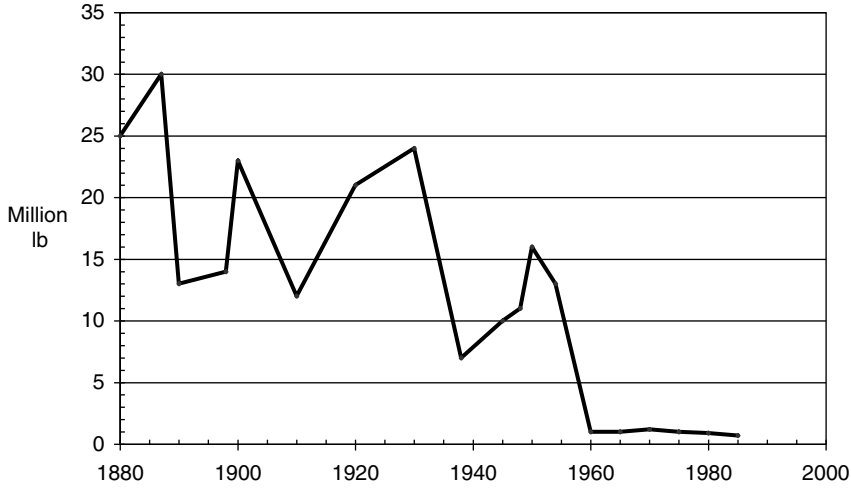

FIGURE 5: Oyster landings in the Delaware Estuary. (Adapted from University of Delaware Sea Grant Program 1988.)

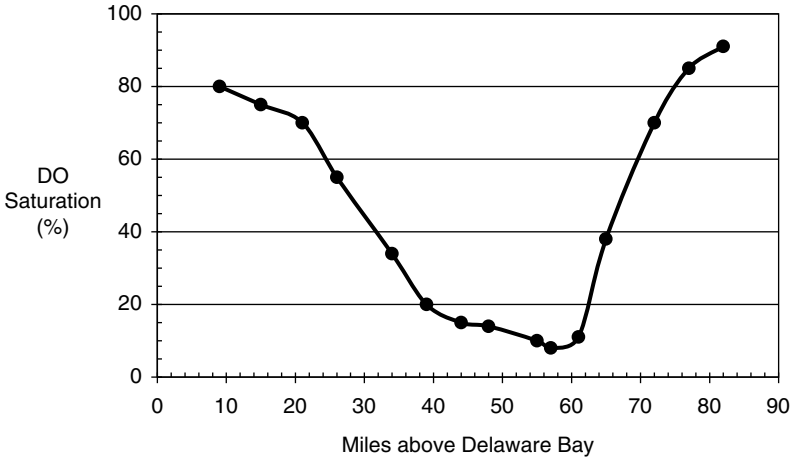

FIGURE 6: Dissolved oxygen during high water slack along the tidal Delaware River, 1958, RM 55 = Philadelphia. (Adapted from Smith et al. 1959.)

The Watershed Era

The watershed commenced in 1961 when the Delaware River Basin Commission replaced INCODEL as the first ever Federal/state water resources

compact signed into law by John F. Kennedy, Jr. The DRBC compact authorized the five commissioners, the governors of Delaware, New Jersey, New York, and Pennsylvania and a Federal Presidential appointee, to work together to clean up water pollution and address flooding. JFK was reluctant at first to sign the DRBC compact due to concerns expressed by his Secretary of Interior Stewart Udall about constitutionality as Article 1, Section 10 of the U. S. Constitution requires the approval from Congress concerning any treaty or agreement between the States. Pennsylvania Governor David Lawrence convinced JFK to sign the DRBC Compact and the President's signature marked the start of the Delaware River revival.[23] Congress voted in 1961 to approve the DRBC compact noting:

> "The establishment of a single agency to coordinate federal interests in the Delaware River Basin is as much importance as the joining together of the four states and the resultant coordination of the various state activities. In brief, there is one river, one basin, all water resources are functionally inter-related, and each one is dependent on the other. Therefore, one comprehensive plan and one coordinating and integrating agency are essential for efficient development and operation."

From 1961 through 1966, the Delaware River Basin suffered through a multi-year drought of record, the driest spell recorded since at least 1895. With conditions exacerbated by the drought and resulting low flows, dissolved oxygen in the Delaware River between Wilmington and Philadelphia commonly reached near zero from May through October mostly due to high ammonia levels from untreated wastewater (Figure 7). Droughts in 1961–1996 led to severe pollution blocks at Philadelphia, again preventing shad migration. Dr. Harmic of the Delaware Fish and Game Commission in 1963 remarked "the future outlook for the shad in the Delaware presents a rather gloomy picture." Stormy weather in 1962 and 1964 caused higher river flows and shad were briefly able to swim by the Philadelphia pollution block. [24]

A $1.2 million Delaware Estuary Comprehensive Study by the U. S. Public Health Service found that nearly 100 cities and industries were discharging waste into the Delaware River. In 1967, five years before the Clean Water Act was passed, the DRBC and the four states started a river-wide point source pollution abatement program. In 1968, the DRBC issued waste load allocations to 90 Delaware Estuary dischargers to secondary treatment

standards more stringent than later defined by the 1972 Clean Water Act. These wastewater treatment upgrades resulted in an 89% decrease in chemical biochemical oxygen demand (CBOD) loading from municipal and industrial sources to the Delaware Estuary between 1958 and 1995 (Figure 8). By

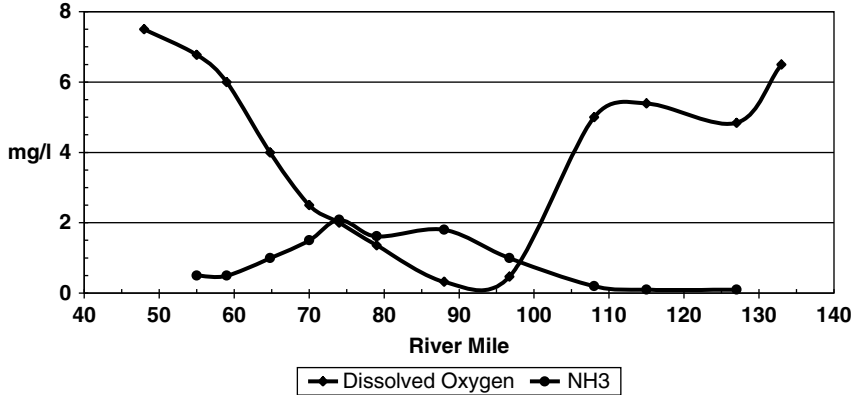

FIGURE 7: Water quality along the Delaware River and Bay, July 1967, RM 100 = Philadelphia. (Adapted from Thomann 1972.)

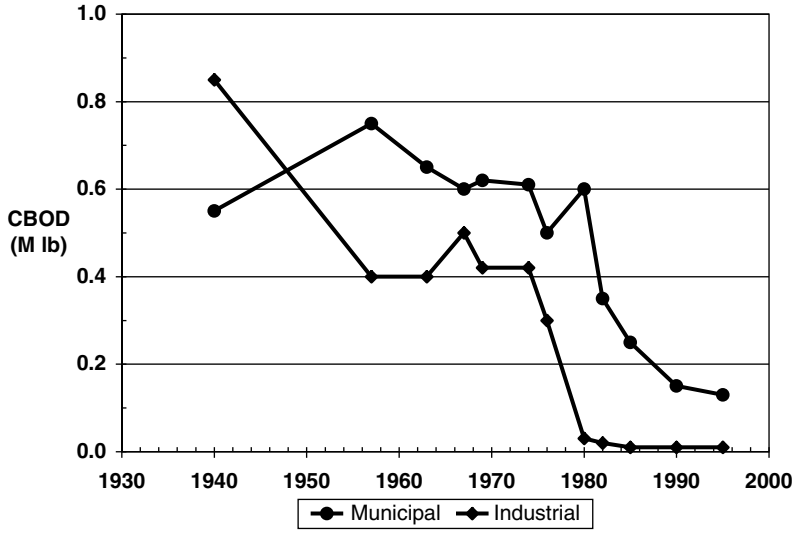

FIGURE 8: CBOD loading along the Delaware Estuary, 1940–1995. (Adapted from USEPA 2000.)

the end of the 1960s, mean oxygen levels along the Delaware River inched up to 2 mg/l, but still too low to meet fishable water quality standards.[25]

By 1970, the Delaware River was still polluted as American shad landings in the Delaware Basin were down to less than 0.5 million pounds, 30 times lower than during the late nineteenth century when over 15 million pounds of shad were caught annually. By 1971, ichthyologist M. E. Chittendon concluded that "gross pollution of tidal freshwater had extirpated the striped bass from its historical chief spawning and nursery areas in the Delaware River."[26]

The environmental movement rose from the social unrest of the turbulent '60s and prompted Earth Day, first celebrated by Americans on April 22, 1970. The same year, a pragmatic Richard Nixon, never accused of being an environmentalist, signed the law creating the United States Environmental Protection Agency which absorbed the responsibilities of the U. S. Water Pollution Control Administration. In 1972, Congress and George McGovern overrode Richard Nixon's veto and passed the Federal Clean Water Act amendments which set goals for returning the nation's waterways to fishable and swimmable status.

In June 1972, Hurricane Agnes caused a surge of heavy freshwater runoff, lowering salinity and suppressing the MSX parasite, resulting in the best setting of seed oysters that oystermen could remember. In 1972, water quality was good in the nontidal Delaware River above Trenton, extremely poor in the Delaware Estuary in the Philadelphia area, and recovered to good in the Delaware Bay. In 1973, a pessimistic USEPA official concluded that the tidal Delaware River would never achieve fishable standards.

New York became the first state in the Delaware Basin to ban phosphate detergent in 1973 followed by Pennsylvania in 1990. By 1994, due to state bans, manufacturers stopped producing phosphate detergent which led to sizable phosphorus reductions in basin streams.

In 1974, water quality in the tidal Delaware at Philadelphia was improving but still poor as fisheries biologist Chittenden asserted that due to water quality concerns and threat of a Tocks Island dam at the Delaware Water Gap: "extirpation of the remnant (shad) runs is a distinct possibility."[27]

In 1975, typical dissolved oxygen levels along the Delaware River were 1.7 ppm at Philadelphia, 1.2 ppm at Chester, and 3.1 ppm at Wilmington, all less than the 4 ppm fishable water quality standard. Rutgers Professor and Brigadier General William Whipple called for better regional planning along the Delaware River and was one of the first to warn of pollution caused by stormwater runoff from streets and cities.[28]

By 1981, dissolved oxygen levels in the Delaware near Philadelphia were rising but still did not meet the fishable standard of 4 ppm. Wastewater treatment plants at Philadelphia, Camden, and Trenton had still not yet met standards set by the DRBC waste load allocation program. In 1985, drought caused high salinities and MSX again devastated oyster stocks in the Delaware Bay.

By the end of the 1980's over $1.5 billion was spent on new wastewater treatment plants along the Delaware River between Wilmington, Philadelphia and Trenton. Wastewater treatment improvements prompted by the 1968 DRBC waste load allocations and 1972 Federal Clean Water Act caused significant improvements in the water quality of the Delaware River and Bay. Along the Delaware River at Philadelphia, average oxygen levels improved from 2 ppm in 1968, to 3.5 ppm in 1981, to 5 ppm by 1987.

With improved dissolved oxygen levels, the states detected spawning fish again in the tidal river downstream from Trenton. In 1985, Delaware, New Jersey, Pennsylvania and other mid-Atlantic states closed the striped bass fishery. This action and the wastewater treatment investments resulted in improved water quality as striped bass and American shad returned to the Delaware River in large numbers during the 1990s. In 1991, the economic value of the renewed recreational fishery in the Delaware Bay was estimated at $25 million per year.

By 1988, DRBC historian Richard Albert observed that the Delaware Estuary had better water quality than at any time in a century due to pollution abatement programs such as wastewater treatment, reforestation, agriculture conservation, and acid mine drainage cleanup conducted over the last 50 years. The Delaware Estuary cleanup was called "one of the premier water quality success stories in the United States." Between 1974 and 1987; Trenton, Philadelphia, Camden, and Wilmington utilized Federal Clean Water Act funds to construct secondary wastewater plants which treated over 700 mgd of sewage before discharge into the Delaware Estuary.[29]

Water quality in the Delaware River continued to improve near the end of the twentieth century due to reforestation and retrofit programs that reduced nonpoint source loads from urban and agricultural stormwater runoff. In 1991, the heavily forested Middle Delaware Scenic and Recreational River between Port Jervis and Stroudsburg near the Delaware Water Gap had exceptional water quality which exceeded standards.[30] In 1993, University of Delaware scientists concluded that phosphorus in the tidal Delaware River had decreased fourfold over the last 30 years due to wastewater treatment and phosphorus detergent bans.[31]

Between the mid 1980s and 1995, USEPA reported water quality in the Delaware Estuary improved significantly. Dissolved oxygen in the Delaware River at Philadelphia improved from 1 ppm in 1958 to 5 ppm by 1995. Nitrogen in the Delaware Bay near the C & D Canal was 4 ppm during in 1970 and decreased to 2.5 ppm by 1990. Phosphorus along the Delaware River at Philadelphia decreased from 0.45 ppm during 1970 to 0.15 ppm during 1990. At Marcus Hook, phosphorus declined from 0.8 ppm in 1966 to 0.1 ppm by 1995 and ammonium declined from 1.4 ppm to 0.2 ppm during the same period (Figure 9).

By 1995, ninety nine major dischargers were regulated along the Delaware Estuary, most in compliance with DRBC water quality standards. By 1996, over 90% of the Delaware Estuary met the fishable and swimmable goals of the Federal Clean Water Act.

Fisheries biologists found increased landings of American shad, striped bass, and white perch between 1980 and 1993 were statistically correlated with improved water quality in the Delaware Estuary. During a beach seine survey conducted annually from 1980–1993, the number of captured fish species increased, particularly in the Delaware Estuary downstream from Philadelphia, where water quality had improved the most. Juvenile striped bass and American shad abundance, migratory species usually susceptible to water quality problems, both increased 1000-fold over the previous decade

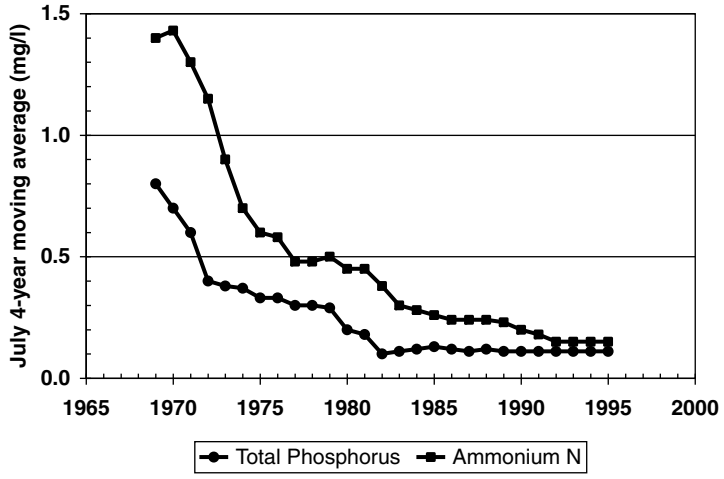

FIGURE 9: Water quality along the Delaware River at Marcus Hook, PA. (Adapted from USEPA 2000.)

(Figure 10). The increase in fish abundance in the tidal Delaware River was tied to improved water quality. [32]

In 1996, Congress along with USEPA and Delaware, New Jersey, and Pennsylvania formed the Delaware Estuary Program that later resulted in a Comprehensive Conservation and Management Plan. The Delaware Estuary Program reported in 1996 that there have been "dramatic improvements in water quality since the 1960s." The Delaware River was cited as "a prime example of the environmental benefits of secondary sewage treatment." From 1977–1991, phosphorus, nitrogen, and DO levels improved during a period which saw major upgrades to sewage treatment plants along the Delaware Estuary.

A 1999 water quality survey of the lower Delaware River between Trenton and the Delaware Water Gap indicated that fecal coliform bacteria levels improved since 1987. The main stem of the Delaware River had lower fecal bacteria counts than the tributary streams.[33]

From 1990 to 1999, the Philadelphia Water Department reported water quality at the Baxter intake along the tidal Delaware River improved for phosphorus, ammonia, total organic carbon, and total suspended solids. Fecal coliform bacteria in the tidal Delaware River declined significantly during the 1990s at Philadelphia. Total phosphorus and nitrates decreased along tributaries such as the Lehigh River, Delaware River at Trenton, and Neshaminy Creek. Dissolved oxygen and fecal coliform levels improved along the Delaware Estuary at Philadelphia. In the largest tributary to the Delaware

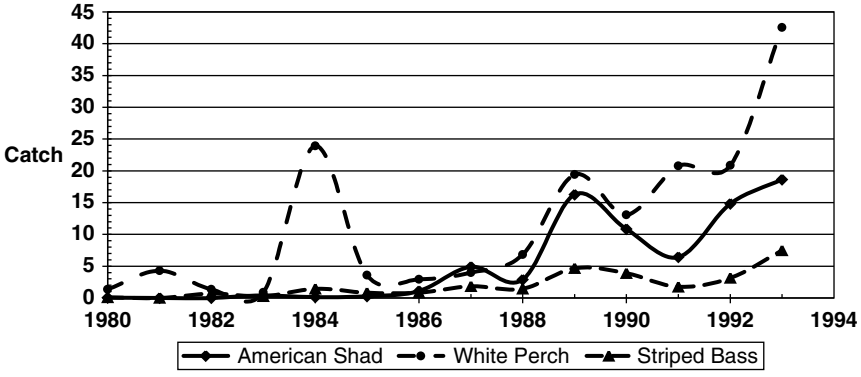

FIGURE 10: Catch per haul of fish species in the Delaware River from C and D canal to Trenton, NJ, 1980–1993. (Adapted from Weisberg et al. 1996.)

Estuary, ammonia decreased along the Schuylkill River at Philadelphia from 1970 to 2000.[34]

With improving water quality, over 29,000 shad were caught in the Delaware Estuary in 2002 as counted by the Delaware Division of Fish and Wildlife. Between 2001 and 2005 over 200,000 migrating shad were detected annually along the Delaware River at Lambertville, New Jersey (Figure 11).[35]

In 1998, the Atlantic States Marine Fisheries Commission declared that Delaware River striped bass stocks were restored. In 2005, striped bass were measured at high levels again by the Delaware Division of Fish and Wildlife as Delaware recreational anglers landed 20,000 striped bass weighing 250,000 pounds in the Delaware Estuary. In 1999, improved water quality drew over 70,000 anglers to the Delaware, a boost to the fisheries economy of over $3 million.

Acid mine drainage reclamation projects have improved water quality in the Schuylkill and Lehigh Rivers, the two largest tributaries to the Delaware. In 2002, one of the largest water pollution problems in the Schuylkill River was acid water from abandoned coal mines. Over 100 miles of stream miles in the Schuylkill Basin, the Delaware's largest tributary, were impaired by

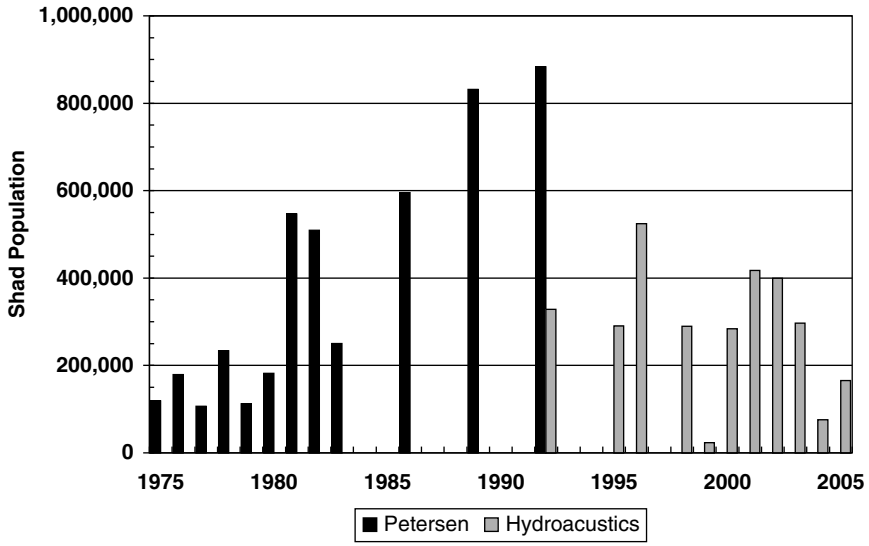

FIGURE 11: American shad spawning population in the Delaware River, Lambertville, NJ. (Adapted from NJDEP 2006.)

acid mine drainage. More than 16,000 acres of mines were reclaimed and 35 mines remained targeted for reclamation. In 2003 the Lehigh River, the second largest tributary to the Delaware, was "cleaner than it had been in the last 150 years." Mainly due to acid mine drainage cleanup programs, the water quality in the Lehigh River was good with few exceptions.[36]

In 2003, the DRBC reported that mean annual dissolved oxygen along the Delaware River at Philadelphia (RM 100) was just under 6 mg/l, up from 2.5 mg/l in 1980 and 2.0 mg/l in 1967 (Figure 12).

A 2004 U. S. Geological Survey assessment of quality in the Delaware Basin reported that PCB concentrations in fish in 4 of six rivers had declined from the 1970s–1980s to the late 1990s. PCB concentrations in fish tissue sampled from the Delaware River at Trenton, Upper Delaware River, Brandywine Creek, and Upper Schuylkill River had declined over the previous 25 years.[37]

Non-tidal Delaware River water quality at nine stations between Portland and Trenton from 2000 to 2003 indicated dissolved oxygen was better than the New Jersey and Pennsylvania standard of 5 mg/l at all stations. Nitrate levels were better than the standard of 10 mg/l at all stations. Total phosphorus was better than the New Jersey standard of 0.1 mg/l at Portland and Belvidere and better except for high flow at the other seven stations. Total

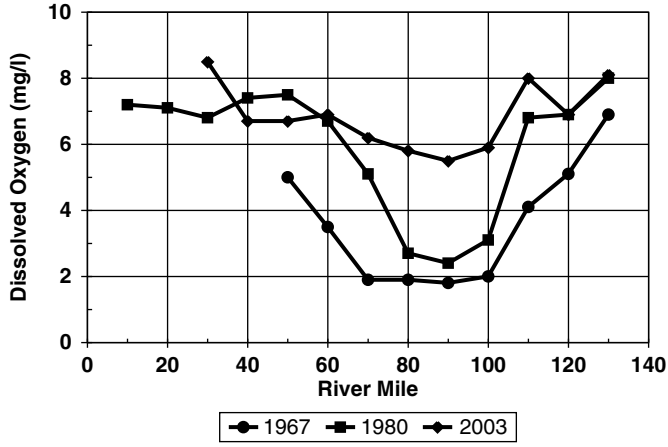

FIGURE 12: Mean annual dissolved oxygen along the Delaware River and Bay. Wilmington, Philadelphia, and Trenton are at river miles 70, 100, and 130, respectively. (Adapted from DRBC 2003.)

suspended solids were better than the New Jersey 40 mg/l standard at all nine stations.[38]

Along Pennsylvania streams in the Delaware Basin between 1995 and 2005, the Pennsylvania DEP found that five stations had improving nitrite plus nitrate nitrogen trends, twenty seven had no change in water quality, and four stations had degrading trends. For total phosphorus, twelve stations had improving trends, twenty four stations had no change, and zero stations had degrading trends.[39]

The Philadelphia Water Department reported in a source water assessment that tidal Delaware River water quality significantly improved over the past twenty years. Nitrate levels slightly increased over the past few decades while levels of dissolved oxygen and phosphorus have significantly improved due to reductions in agricultural runoff and improved wastewater treatment. The PWD reports: "the Delaware River is a much healthier river now than it was over the past century. The periods of the river smelling of raw sewage, covered in sheens of oil or foaming with detergent bubbles are now gone, resulting in improvements in fish, wildlife, and water quality over the past 20 years". The PWD report attributed improvements in Delaware River quality to decline of the coal industry, decline of manufacturing industry (steel, paper, textiles, glass), increased cost of oil, construction of sewers and sewage treatment plants, Federal Clean Water Act of 1972, regulations limiting phosphorus in detergents, and toxic chemical regulations.

By 2008, dissolved oxygen improved since 1971–1975 along all river and bay monitoring stations (Figure 13). Since 2000, dissolved oxygen levels have rarely dipped below 4 mg/l, the fishable standard in the Delaware Estuary and DO has improved markedly along the tidal Delaware River at Ben Franklin Bridge in Philadelphia (Figure 14). Water quality as measured by DO has also improved along the Delaware River at Trenton, Lehigh River, and Schuylkill River (Figures 15 and 16).

Water quality has improved with increased forested land and decreased agriculture even though the population of the Delaware Basin has doubled from 4 million in 1920 to 8 million by 2010. The Delaware Basin remains heavily wooded in the upper half of the watershed as primarily due to replacement of timber as a fuel source, forest and wetland area increased to 60% of the basin by 2000, double the area of wooded area recorded in 1930 and a growth rate equal to 100 acres per day. Agricultural land decreased from 65% of the basin in 1930 to 25% of the basin by 2000 as agricultural conservation programs instituted by the U. S. Department of Agriculture after the

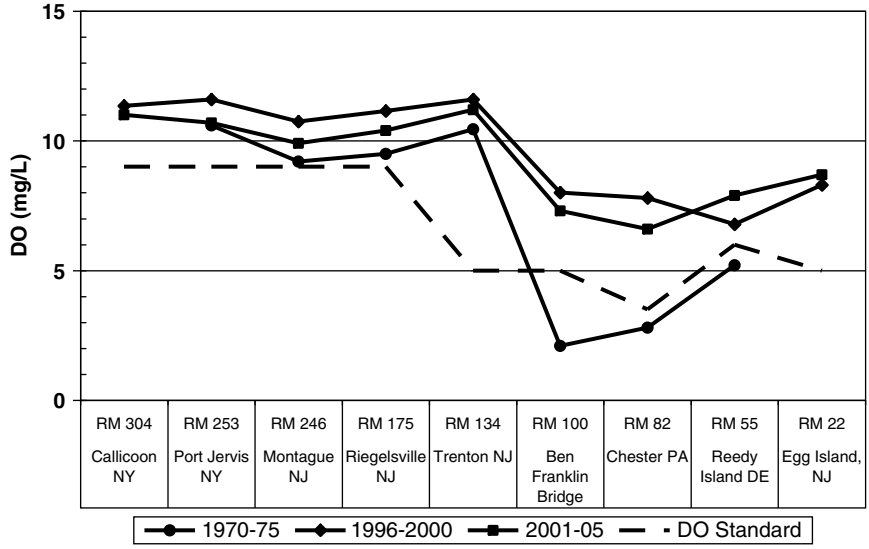

FIGURE 13: Dissolved oxygen along the Delaware River and Bay. (Adapted from DRBC 2009.)

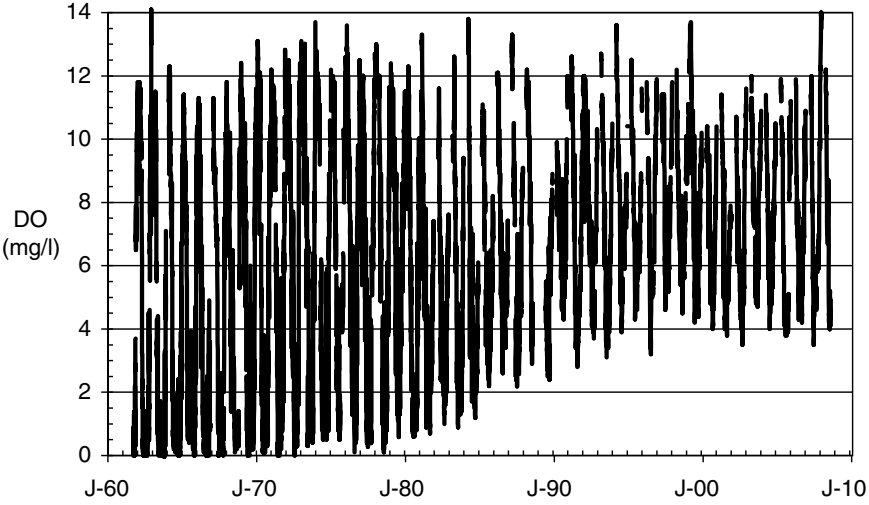

FIGURE 14: Dissolved oxygen along the Delaware River at Ben Franklin Bridge in Philadelphia. (Adapted from USGS 01467200, 2008.)

1930s Dust Bowl years of the Great Depression have measurably reduced soil erosion from agricultural stormwater runoff.

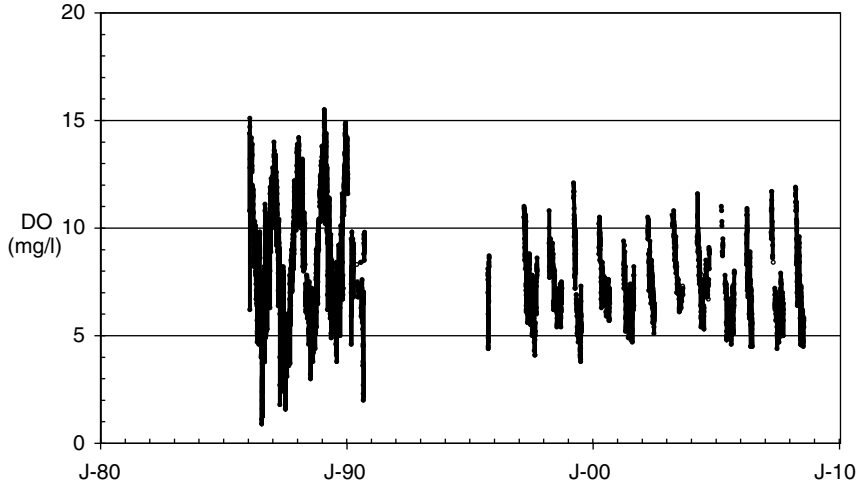

FIGURE 15: Dissolved oxygen along Schuylkill River at Linwood, Pa. (Adapted from USGS 1472104, 2008.)

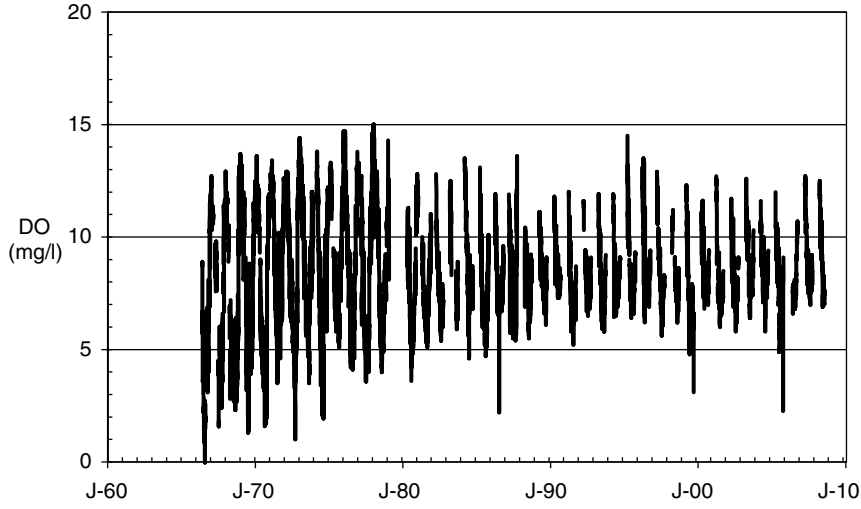

FIGURE 16: Dissolved oxygen along the Lehigh River at Easton, Pa. (Adapted from USGS 1454720, 2008.)

The deindustrialization of the Delaware Valley and associated abandonment of river discharges have contributed to improved water quality in the Delaware River. During the 19th century, the Philadelphia metropolitan area was the

greatest industrial center in the nation fueled by inexpensive coal from nearby mines in the Lehigh and Schuylkill watersheds to the northeast. By the turn of the twentieth century, Philadelphia housed major industries such as the Baldwin Locomotive company, Pennsylvania Railroad, and the Bethlehem Iron Company. By the 1930s textiles employed 35% of the city's workers and contributed more to the economy that any other industry. The post-war highway and commuter train transportation boom led to urban flight and by the 1990s only 3000 industries were left in Philadelphia, down from over 50,000 before the Second World War. In 1995 the Bethlehem Steel Works in the Lehigh Valley closed after 100 years and by 1991, U. S. Steel in Fairless Hills, Pennsylvania closed operations at a plant that had employed 7,000 people along the Delaware River since 1952.

Crude oil spills remain a great environmental threat along the Delaware River, the largest freshwater oil port in the world. Oil spills occur once every 8 to 10 years and have occurred on Jan 31, 1975 (11,000,000 gallons spilled from *Corinthos*), Sep 28, 1985 (435,000 gallons spilled from *Grand Eagle* at Marcus Hook), Jun 24, 1989 (306,000 gallons spilled from *Presidente Rivera* at Claymont). and November 26, 2004 (265,000 gallons spilled from *Athos 1* near Paulsboro).

A River Revival

The Delaware River revival coincided with an environmental era spurred by the enactment of water quality laws by governments. Water quality improvements occurred congruently with a five-decade evolution of watershed environmental programs administered by Federal and state governments, the Delaware River Basin Commission, and Partnership for the Delaware Estuary.

In 1961, John F. Kennedy signed the DRBC Compact that led in 1968 to waste load allocations to almost ninety dischargers in the basin, requiring them to cut back effluent loads to levels more stringent than required by the Clean Water Act passed four years later. In 1970, the year that America first observed Earth Day, Richard M. Nixon signed a bill creating the U. S. Environmental Protection Agency. With the birth of the USEPA in 1970, the Governors and state legislatures created comparable environmental agencies such as the New York State DEC, New Jersey DEP, Pennsylvania DEP, and Delaware DNREC.

Congress passed the Federal Water Pollution Control Act Amendments of 1972 and 1977 known as the Clean Water Act. The CWA set limits on the amount of pollutants that could be discharged to waterways, funded sewage treatment plants, and set aggressive goals for fishable and swimmable waters by 1985. By 1990 using $1.5 billion in CWA funding, all dischargers in the Delaware Basin completed secondary wastewater treatment improvements. In 1996, the USEPA created the Delaware Estuary program furthering the impetus to protect and restore the tidal and most industrialized portion of the Delaware River. By 2000, the USEPA issued regulations requiring states to list impaired waters and pass watershed load limits to restrict the amount of pollutants that could enter a stream without violating a state's water quality standards.

After nearly decades of improved water quality and cleaner water, shellfish and anadromous fish such as the American shad and striped bass have returned to the Delaware River in numbers not recorded in 100 years. (Figures 17 and 18). Blue crabs, a $7 million shellfishery, are increasingly abundant in the Delaware Estuary (Figure 19).

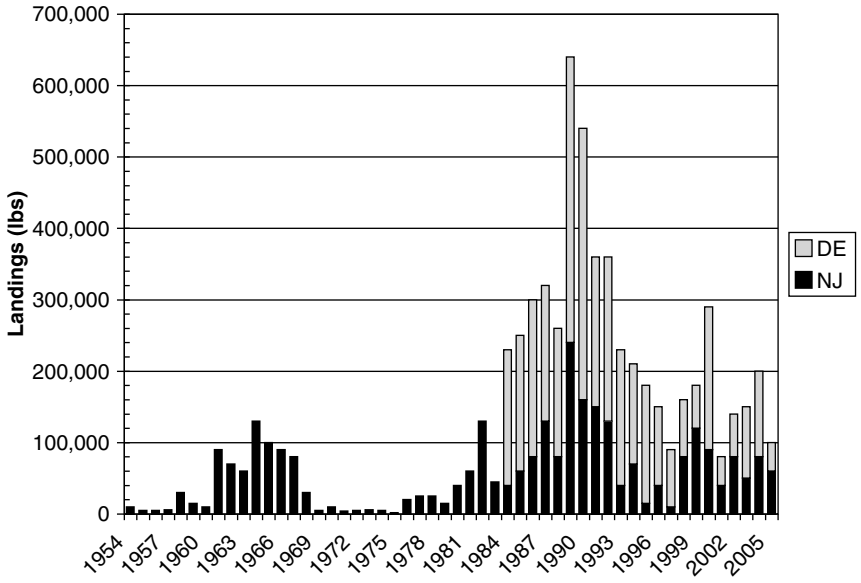

FIGURE 17: Commercial landings of American shad in the Delaware River Basin. (Adapted from NJDEP, DNREC 2006.)

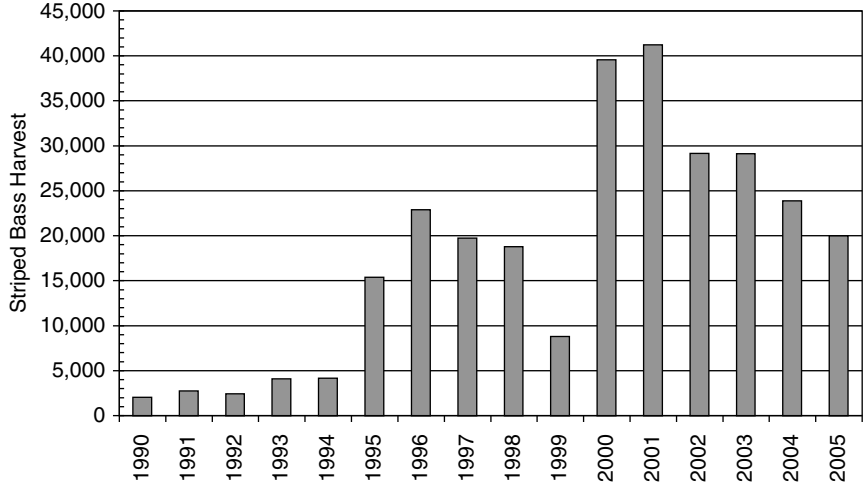

FIGURE 18: Recreational striped bass harvest in the Delaware Estuary. (Adapted from DNREC 2006.)

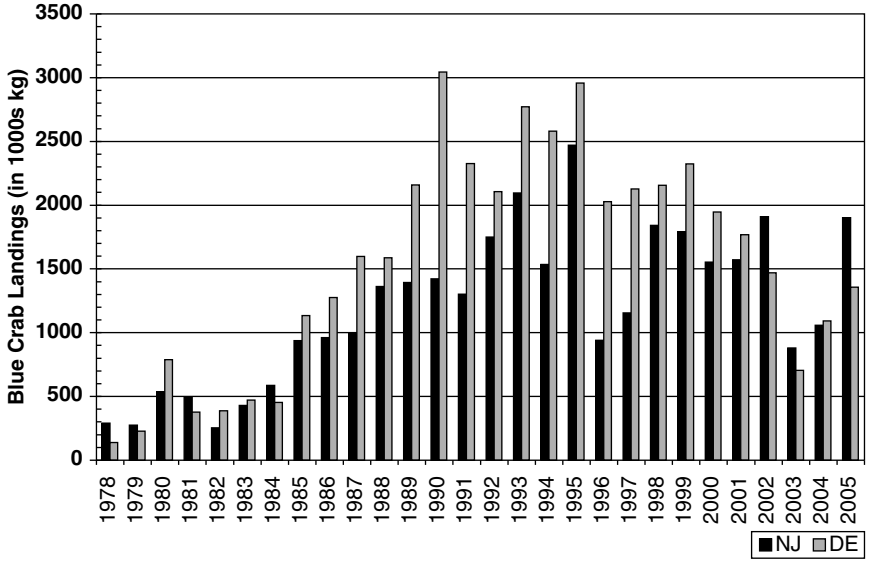

FIGURE 19: Blue crab landings in the Delaware Estuary, 1978–2005. (Adapted from NJDEP, DNREC 2005.)

In September 2009, for the first time in 50 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 water of the recovering Delaware River.[40]

The bald eagle returned to the Delaware River Basin in impressive numbers. Cleaner water, the government ban on DDT in 1980, Federal endangered species protection, and habitat preservation along the Delaware Bay contributed to the growth in bald eagle numbers. In 2007, a bald eagle nest was even sighted in South Philadelphia at the mouth of the Schuylkill River, one of the most urban places in the USA. In the Delaware Basin, the four states reported that ninety six bald eagle nests were observed in 2004, more than double the total of forty four in 2001 (Figure 20).

While water quality and fisheries have improved, downbeat trends remain regarding the health of the Delaware River. Phosphorus levels have improved but are still high and exceed standards in the Delaware Estuary due to fertilizer application in neighborhoods and farm fields. Legacy pollutants from the electric power industry such as PCBs in fish tissue have declined over 25 years but PCBs were still detected in 84% of fish samples in the basin.

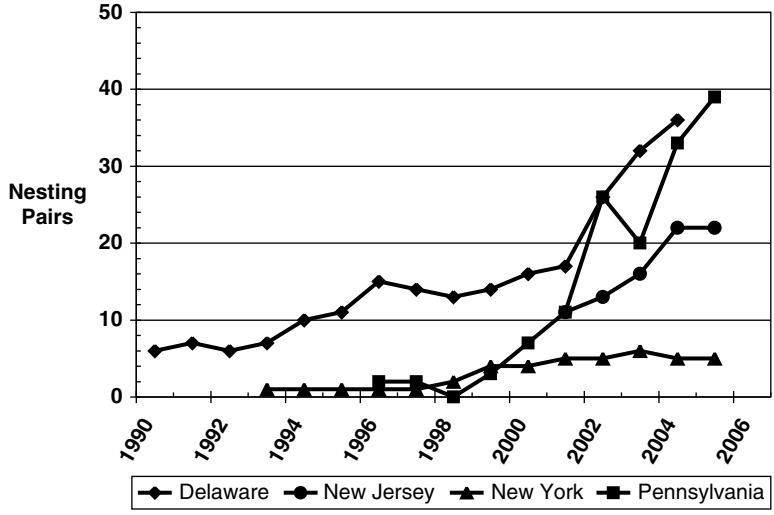

FIGURE 20: Bald eagle nesting pairs in the Delaware River Basin. (Adapted from DNREC, Pa. Game, NYSDEC, NJDEP.)

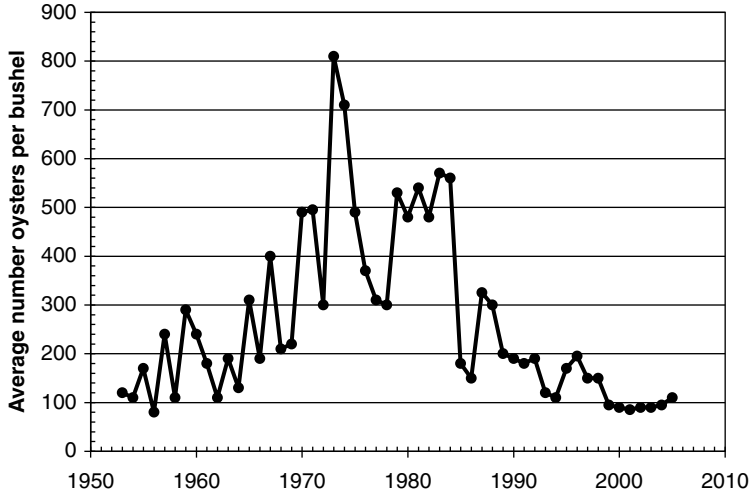

FIGURE 21: Oyster harvest in the Delaware Bay. (Adapted from Bushek et al. 2006.)

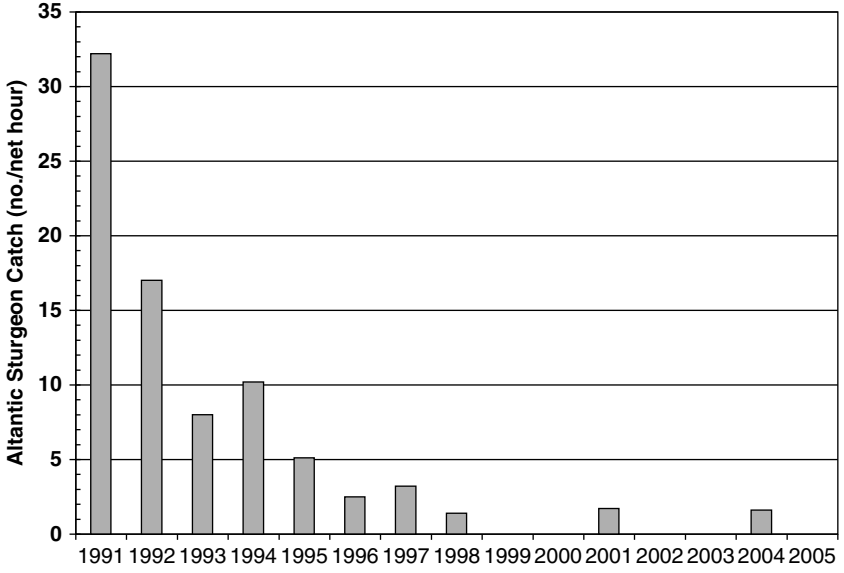

FIGURE 22: Annual catch rates of Atlantic sturgeon collected in the Delaware River. (Adapted from DNREC 2006.)

Fish consumption advisories from mercury levels from coal fired power plant emissions remain on 1,000 stream miles in the Delaware Basin. Common pesticides atrazine (from agriculture) and metolachlor (from urban/suburban applications) have been detected in eight of ten streams in the Delaware Basin. About 10% of basin tributaries are declared impaired by the USEPA and the states. Due to disease caused by rising salt water levels, oyster catches have dropped to 100,000 bushels per year in the bay (Figure 21), down from over 700,000 bushels harvested twenty years earlier. The Atlantic sturgeon is teetering on extirpation due to habitat destruction from dredging (Figure 22), only 2 fish per haul were caught by DNREC in the Delaware in 2004, none in 2005. The habitat of the brook trout, the state fish of New Jersey, New York, and Pennsylvania, is extirpated in 15% of the basin due to climate change, acid mine drainage, and watershed urbanization.[41]

Concluding Remarks

Federal, state, and regional governments initiated environmental programs that resulted in a Delaware River revival. The DRBC, an agency that predated USEPA by nearly a decade, was feted as one of the early actors responsible for restored water quality in the United States. In 1968, Stewart Udall, Secretary of the Interior who originally advised JFK to oppose the DRBC due to unconstitutionality stated: "Only the Delaware among the nation's river basins is moving into high gear in its program to combat water pollution." In 1996, William D. Ruckelshaus, Nixon's first Administrator of the USEPA remarked: "Looking back, the DRBC was the vanguard in the Johnny-come-lately march to manage water resources on a watershed basis."

Water quality in the Delaware River has improved due to water pollution control actions that extend back to George McGovern's guidance of the Clean Water Act through Congress in 1972, JFK's signature on the DRBC compact in 1961, and as far back as the original Delaware River watershed agency, INCODEL, when America was on the edge of war after the Great Depression. The health of the Delaware River has come a long way from the time when Ben Franklin complained about animal carcasses in Dock Creek and nineteenth century industries built privies directly over the creeks. JFK had the right idea when he changed his mind and signed the DRBC compact in 1961 as the best way to manage the interstate Delaware River watershed. One of his wisest public policy moves was appointing the Governors as

DRBC commissioners, thus ensuring that water resources are being addressed at the highest levels in state government. While the Delaware will never again be as pristine as when Henry Hudson found it four hundred years ago, recent history indicates the Delaware River and tributaries can continue their recovery using the cooperative watershed approach embraced by the Federal government and the four states through the comity of the Delaware River Basin Commission and the Partnership for the Delaware Estuary.

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