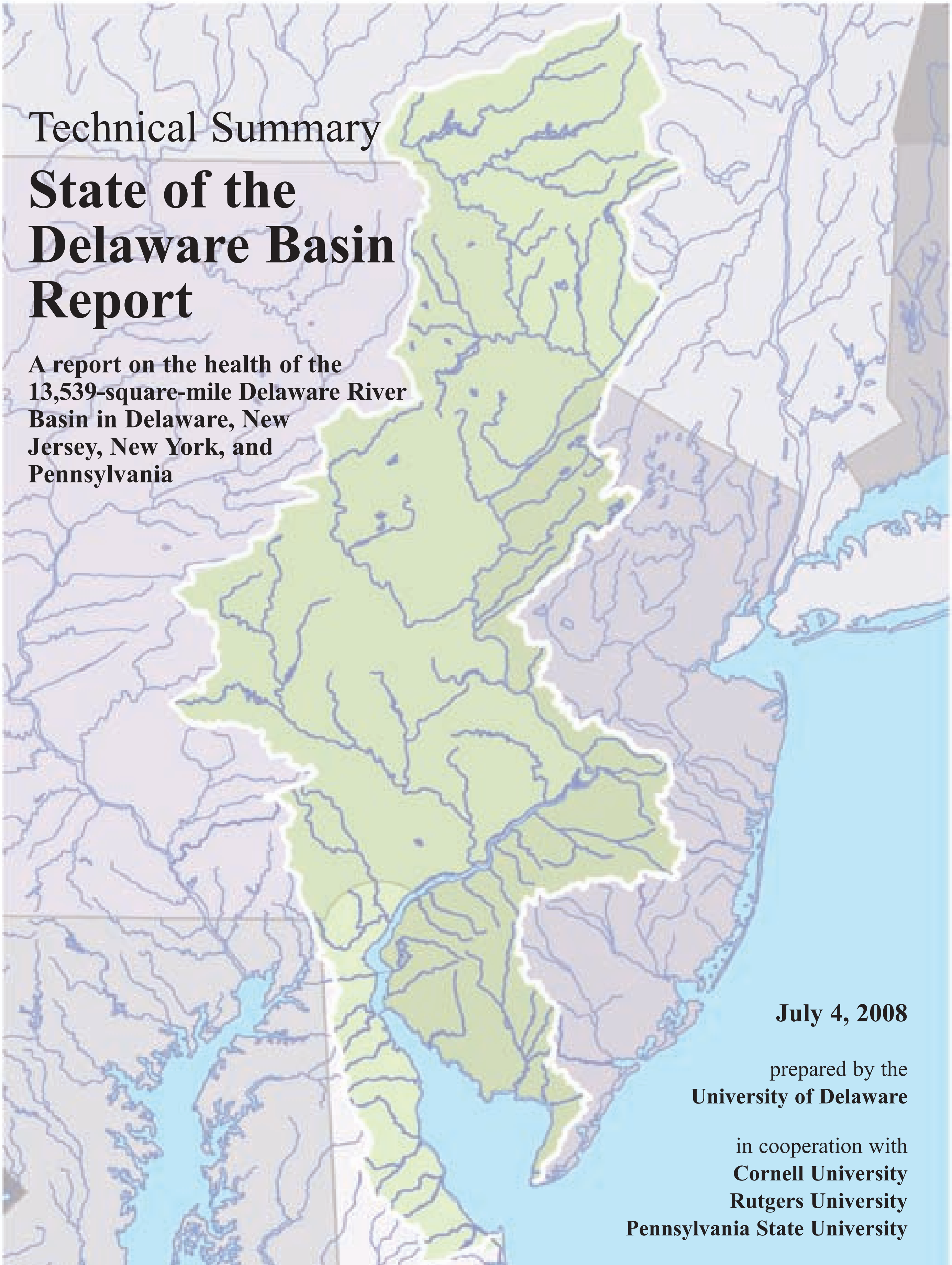

Technical Summary

State of the Delaware Basin Report

A report on the health of the 13,539-square-mile Delaware River Basin in Delaware, New Jersey, New York, and Pennsylvania

July 4, 2008

prepared by the
University of Delaware

in cooperation with
Cornell University
Rutgers University
Pennsylvania State University

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July 4, 2008

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Submitted to
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West Trenton, New Jersey

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Summary

This report defines environmental indicators for the State of the Delaware River Basin project. Indicator data were collected by a collaboration among the Delaware River Basin Commission, Partnership for the Delaware Estuary, U.S. Environmental Protection Agency (USEPA), U.S. Geological Survey, and a consortium of the four land-grant universities that represent the states in the basin—Cornell University, Pennsylvania State University, Rutgers University, and University of Delaware.

For many environmental indicators, the health of the Delaware River Basin has improved or at least remained stable in many watersheds, even in the face of an industrial legacy, increased land development, a growing population, and rising thirst for water supplies. Water quality as measured by dissolved oxygen, phosphorus, lead and zinc levels is improving or constant in a majority of the watersheds and main stem waters since 1990. Delaware and New Jersey are partnering on an oyster-restoration project, which involved planting 500,000 shells on reefs in the bay. Watershed groups are removing dams that have been an impediment to fish migration. Many of the 1,600 Federal Superfund sites are being cleaned up and remediated. Blue crab landings are up, resulting in a $7 million economy. Bald eagles, an endangered species that relies on clean streams for its fish-laden diet, are returning to the basin in growing numbers. Black bears are returning to the mountain forests in the headwaters of the basin. Shad and striped bass are swimming upstream again. There are more forests in the basin then there were in the 1930s, although there was a decline between 1996 and 2001. More than 400 miles of rivers in the basin are now protected as part of the National Wild and Scenic River program. These improvements were prompted by environmental programs administered by Federal, state, and local governments, the DRBC, PDE, and USEPA.

On the other hand, there are certain troublesome trends. The common pesticides atrazine and metolachlor have been detected in at least 80 of 100 streams in the basin. Fish-consumption advisories are imposed on almost 4,000 miles of streams in the Delaware Basin. About 10% of the streams in the basin are declared impaired by the USEPA and the states. Oyster catches have dropped to 100,000 bushels per year in the bay. The red knot, a shore bird that depends on Delaware Bay horseshoe crab eggs for food, is closer to extinction. The habitat of the brook trout—the state fish of New Jersey, New York, and Pennsylvania—is declining and extirpated in 15% of the basin although habitat remains in 50% of the basin. The Atlantic sturgeon is teetering on extinction, only two fish per haul were caught in the Delaware in 2004, none in 2005. The Louisiana water thrush, an upland bird species, is declining. Impervious cover in suburbanizing watersheds is increasing with more development and population growth. The Delaware Basin has lost 18 mi^2 of agriculture, 4 mi^2 of wetlands, 48 mi^2 of forests, and gained 70 mi^2 of urban/suburban land between 1996 and 2001. Three major floods occurred along the Delaware River in 2004, 2005, and 2006, damaging hundreds of homes in the river floodplain. These are all declines that are worth reversing.

Since the 1960s and 1970s, Federal, state, and regional governments initiated environmental programs that resulted in water-quality improvements and reduced water pollution in the Delaware River Basin. The Delaware River Basin Commission has been cited as one of the first actors responsible for restored water quality in the Delaware River and Estuary:

In 1968, Stewart Udall, Secretary of the U. S. Department of the Interior from 1961-1969, stated, *"Only the Delaware among the nation's river basins is moving into high gear in its program to combat water pollution."*

In 1968, the Federal Water Pollution Control Administration noted, "*The Delaware River Basin is the only place in the country where water-quality standards and waste-load-allocation procedures were being followed."*

In 1982, the Western Governor's Association Report wrote, *"The DRBC's framework for regional coordination under the Federal-interstate compact mechanism appears unrivaled by any existing or proposed institutional arrangement."*

In 1996, William D. Ruckelshaus, Administrator of the USEPA from 1970-1973 and 1983-1985 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 Basin has improved due to water pollution–control actions that extend back to Richard Milhouse Nixon's consent to the Clean Water Act 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 in 1940.

The Delaware River Basin Commission plans to update the State of the Basin Report at five-year intervals. In the next half-decade, emphasis should be placed on programs to reverse the decline of those indicators of poor health. Recent history indicates that environmental health can be improved using the cooperative watershed approach espoused by the Federal government and the four states through the comity of the Delaware River Basin Commission and the Partnership for the Delaware Estuary.

Gerald J. Kauffman, Director July 4, 2008
University of Delaware
Institute for Public Administration
Water Resources Agency

Delaware River Basin Indicator	Report Card	Trend
Landscape		
Population	Delaware Basin population projected to exceed 8,000,000 by 2010, an 800,000 increase from 7,200,000 in 1990.	▼
Land Use	The Delaware Basin gained 70 mi^2 of developed land between 1996 and 2001, a rate of 25 acres per day.	▼
Impervious Cover	Impervious cover is increasing with new development. Watersheds near Philadelphia exceed 10% impervious cover.	▼
Tidal Wetlands	20% of Delaware Bay watersheds covered by tidal wetlands.	▲
Tidal Wetland Buffers	35% of Delaware Bay watersheds covered with tidal wetland buffers	▲
Total Wetlands	The Delaware Basin has lost 4 mi^2 of wetlands between 1996 and 2001, a rate of 1.4 acres per day.	▼
Forest	The Delaware Basin lost 48 mi^2 of forest between 1996 and 2001,a rate of 17 acres per day. There are more forests now (54% in 2001) than 1930 (32%).	▼
Superfund Sites	USEPA identified 1,600 Federal Superfund sites in the Delaware Basin, many are being cleaned up and being remediated.	▲
Riparian corridor condition	Riparian areas along streams contain 1 to 4 miles of roadway per mi^2 of buffer.	●
National Wild and Scenic Rivers	EB/WB, Hancock, NY (73 mi), Del. Water Gap (40 mi), Maurice R. (35.4 mi), Lower Del. River, PA (38.9 mi), White Clay Creek in DE, PA (190 mi).	▲
Water Quality		
Dissolved Oxygen	DO has improved or remained constant since 1990 at 11/12 stations along main stem and at 14/20 tributary stations.	▲
Nitrogen	N has remained constant since 1990 at 7/7 stations along the river and bay and at 15/16 tributary stations.	●
Phosphorus	P has improved or remained constant since 1990 at 7/7 stations along the river and bay and at 20/20 tributary stations.	▲
Total Suspended Sediment	TSS has remained constant since 1990 at 5/6 stations along the river and bay and at 19/19 tributary stations.	●
Copper	Cu has remained constant since 1990 at 5/5 stations along main stem and at 19/19 tributary stations.	●
Lead	Pb has remained constant since 1990 at 2/2 stations along main stem and improved or remained constant at 19/19 tributary stations.	▲
Zinc	Zn has improved or remained constant since 1990 at 5/5 stations along main stem and at 18/18 tributary stations.	▲
Mercury	Hg improved at Delaware R. at Trenton and EB/WB Delaware River and Neversink subwatersheds. Miles of Hg fish consumption advisories.	●
PCBs	PCBs detected in 84% of fish samples. PCBs in fish tissue declined over 25 yrs in basin.	●
Atrazine,	95 of 100 streams in Delaware River Basin had detectable levels of Atrazine.	▼
Metolachlor	83 of 103 streams in Delaware River Basin had detectable levels of Metolachlor.	▼
Water Temperature	Water temperatures constant since 1990 at 10/13 stations. Summer median and peak water temperature declined in EB/WB and Neversink River.	●
Fish Consumption Advisories	3,935 miles (17%) of Delaware River Basin streams have full/limited fish consumption advisories in 2006.	▼
Sec 303(d) Designated Uses /Impaired Streams	2,493 miles (11%) of Delaware River Basin streams are impaired according to the USEPA in 2004.	▼
Salt Line (chlorides)	Salt line fluctuates annually in the Delaware River between the mouth of the Schuylkill at Philadelphia and the Christina River at Wilmington.	●

Delaware River Basin Indicator	Report Card	Trend
Water Quantity and Hydrology		
Water Supply and Demand	8,264 mgd of peak surface water withdrawals in 1996,	●
Streamflow	Little or no changes in peak or low flow streamflows since 1990.	●
Groundwater quantity	In the Delaware Basin: 4,645 mgd groundwater available, 423 mgd withdrawn, 9% of groundwater used.	●
Flooding	Three major floods occurred along the Delaware River in 2004, 2005, and 2006.	▼
Dams (hydrologic impairment)	Dams removed or fish ladders installed along Schuylkill, Lehigh R., and Pennypack Creek. Dam removals proposed along Brandywine Creek.	▲
Living Resources		
Macroinvertebrates	Macroinvertebrate health ranges from good to poor.	●
Oyster Beds	500,000 bushels of shell planted in 2005 for Delaware Bay oyster restoration project.	▲
Eastern Oyster	Oyster landings in bay down to 100,000 bushels from 500,000 bushels during 1980s.	▼
Horseshoe Crab	Spawning index constant since 1990 at 0.8. although ISA declining along the DE side of the bay. DE/NJ have horseshoe crab harvest moratoriums.	▼
Blue Crab	DE/NJ blue crab landings at 2 to 5 million, up from 1 million during 1970s. Most lucrative shellfishery in bay. Value of harvest = $ 7 million.	▲
Freshwater Mussels	23% of native freshwater mussels are federally endangered and 7% are extinct.	▼
Zebra Mussels	Invasive mussel only detected in Lehigh River watershed near Easton so far. Numerous sightings in adjacent basins of Hudson and Susquehanna.	●
American Shad	Almost 200,000 migrating shad detected along Delaware River at Lambertville. Shad counted along the Schuylkill and Lehigh Rivers.	●
Brook Trout	The state fish of NJ, NY, and PA, about 15% of native brook trout habitat extirpated in Delaware River Basin with habitat remaining in 50% of Basin.	▼
Striped Bass	20,000 fish caught in 2005 and 40,000 in 2000 up from less than 5000 striped bass caught in 1990.	▲
Atlantic Sturgeon	In danger of extinction, only 2 fish caught in 2004, none in 2005. Atlantic sturgeon is on the DE endangered species list.	▼
Weakfish	Weakie abundance down to 50 per mile from at or above 150 fish per mile during 1990s.	▼
Summer Flounder	Fluke biomass at 50,000 metric tons in 2005, up from 30,000 tons in 2000.	▲
Louisiana Water Thrush	Breeding bird survey habitat down by more than 3% in much of the Delaware River Basin.	▼
Red Knot	The Delaware Bay red knot stopover population has declined since 1997. Peak numbers of over 100,000 in the 1980s have fallen to 13,455 in 2006 .	▼
Bald Eagle	Bald eagle nests have increased significantly in all four states in the Delaware as 96 nests spotted in the basin in 2004, up from 44 in 2001.	▲
Black Bear	Close to 5,000 black bear were spotted in NJ, NY, and PA up from 4,200 in 2002.	▲
Amphibians/Reptiles Bog Turtle	Bog turtle wetland habitat is declining as the reptile is a Federally endangered species and is on the NJ, NY, and PA state protected lists.	▼
Endangered Species	Almost 180 species on the DE, NJ, NY, and/or PA endangered species lists.	●

Recommendations

Jonathan Farrell (2007), graduate student in forest resources at Pennsylvania State University, wrote about DRBC's State of the Delaware River Basin Report for his master's thesis and filed these recommendations.

1. Systematically evaluate scientific and policy issues relevant to the DRBC to guide selection of indicators. The DRBC should associate defined assessment goals (water quality, river ecosystems, etc.) with specific indicators to provide an organized format to revise the basin-report design.

2. Initiate a formal indicator-development process and reduce the number of indicators to focus on those with best data availability, proven scientific validity, and relevance to policy. Indicator selection should be based on data availability across the basin.

3. Evaluate the basin-report indicators to ensure their compatibility with the goals outlined in the 2004 DRBC Water Resources Plan.

4. Use the indicator data as baselines for future basin reports using similar data collection and processing methods and consider stressor and condition indicators to define reference conditions.

5. Assign qualitative and significant ratings such as *good*, *fair*, and *poor* to the indicators as an index and fundamental step to establish reference conditions.

6. Integrate indicators into an Index of Environmental Integrity for the Delaware River Basin to establish a systematic framework for assessment.

7. The DRBC should compile a "wish list" of indicators where more data are needed and initiate and sponsor new data-collection and -inventory efforts in a coordinated fashion across state boundaries within the basin. Indicators where more data are needed include bioindicators such as fish and mussel species, mammals, birds, reptiles, and amphibians.

8. Indicator-data collection across state boundaries should be more compatible and better coordinated by the Federal, state, and local governments in the river basin. For instance, land use data are not integrated among states in the basin because each jurisdiction relies on imagery from different years (1997, 2002 in DE; 2000, 2005 in PA; 1996, 2001 from NOAA, 1992, 2001 from USGS). Land use should be flown in half-decade intervals (2010, 2015, etc.) to be compatible with U.S. Census data. Each of the four states monitors macroinvertebrates using four methodologies.

9. Analyze correlation and relationship between/among indicators through statistical methods. Conduct small-scale research to compare results of different indicators in various landscapes in the Delaware River Basin to evaluate how condition indicators (e.g., oysters) respond to stressors (e.g., salt line).

10. Include existing regional environment assessments such as the Consortium for Atlantic Regional Assessment (CARA) and the EPA MAIA as source data for DRBC indicators.

11. Compile environmental-indicator data and mapping from the four basin states into a publically viewable Web site.

Chapter 1 – Introduction

The Interstate Commission on the Delaware River Basin (1940) once called the tidal Delaware River below Trenton at Philadelphia and Camden *"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. Army and Navy pilots were instructed to ignore the stench of the river as they flew overhead (Albert 1988). By the 1950s, the urban Delaware Estuary was noted as one of most polluted stretches of river in the world with zero oxygen levels during the summer. American shad were unable to migrate through the zero oxygen barrier at Philadelphia leading to near extirpation of the species with genetic origins in the basin (Chittendon 1971). In 1973, three years after USEPA was created, a study concluded the Delaware Estuary would never achieve fishable designated uses (USEPA 2000).

Since then, environmental actions initiated by governments have led to a Delaware River revival. In 1961, JFK signed the law creating the Delaware River Basin Commission, the first Federal-state water resources compact (DRBC 2004) In 1972, Richard Milhous Nixon signed the Clean Water Act which led to amendments in 1977 and 1987 (Cech 2003). Phosphate detergent bans by New York in 1973 and Pennsylvania in 1990 along with a 1994 halt on manufacture (Litke 1999) prompted phosphorus declines by over 25% in many Basin streams. Richard C. Albert (1988), DRBC supervising engineer and historian of the Delaware River Basin, recognized in an rticle in *Estuaries* 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 5 mg/l, the fishable water quality standard in the river. Migratory shad and striped bass returned to the river in numbers not recorded since the early 20th century (PDE 2002). Bald eagles, a protected species that relies on a fish laden diet, returned to the cleaner waters of the Delaware Estuary in growing numbers, even nesting in South Philadelphia in March 2007 (Associated Press 2007).

1.1. Approach

This Technical Summary - State of the Delaware River Basin Report is a collaborative effort between the Delaware River Basin Commission, Partnership for the Delaware Estuary, and four state land - grant universities to describe the health of the basin, the river, the estuary, and its tributary watersheds. The water resources institutes of the land grant universities in New York, Pennsylvania, New Jersey, and Delaware – Cornell, Penn State, Rutgers, and Delaware - were responsible for collection and analysis of basin - wide water resource data, land use, and socioeconomic which was transmitted to the DRBC and PDE.

The DRBC Water Resources Plan (2004) recommended developing a set of indicators to assess baseline conditions and measure progress toward objectives to be published in a state of the basin report. The Delaware Estuary Comprehensive Conservation and Management Plan (PDE 1996) recommended regular updates to the 2002 State of the Estuary Report, (PDE 2002). The PDE published their State of the Delaware Estuary 2008 report for public consumption during Summer 2008. The DRBC to plans publish their 80 – page State of the Delaware River Basin Report during October 2008. The DRBC and PDE plan to update the state of the Delaware Basin and Estuary reportsat five – year intervals.

1.2. Scope of Work

This universities gathered environmental indicator data in accordance with the following scope of work:

1. Report Coordinating Team – Assemble a coordinating team consisting of faculty,staff, and graduate and undergraduate students from the following organizations:

- Delaware River Basin Commission and Partnership for the Delaware Estuary
- Federal Government (U. S. Geological Survey and U. S. Environmental Protection Agency)
- University of Delaware, Delaware Water Resources Center and Water Resources Agency - Newark, DE
- Cornell University, New York State Water Resources Institute - Ithaca, New York.
- Rutgers University, New Jersey Water Resources Institute - New Brunswick, New Jersey.
- Penn State University, PA Water Resources Center, Center for Watershed Stewardship - State College, PA.

2. Progress Meetings –UDWRA chaired monthly coordinating team meetings at the four universities or in West Trenton and conducted teleconference calls. DRBC commissioners were briefed at commission meetings.

3. Watershed Regions - As a reporting framework, the coordinating team utilized the hierarchy of the 4 regions and 10 watersheds outlined in the 2004 DRBC Water Resources Plan:

- Upper Region East/West Branch watershed
  Lackawaxen watersheds
  Neversink-Mongaup watershed
- Central Region Upper Central watersheds
  Lehigh Valley
  Lower Central watersheds
- Lower Region Schuylkill Valley
  Upper Estuary watersheds
  Lower Estuary watersheds
- Bay Region Delaware Bay watersheds

The team further segmented the 10 watersheds into 21 subwatersheds based on physiographic province, land use, stream order, and hydrologic network criteria.

4. Measurable Indicators – From a list of over 200 watershed indicators utilized by groups throughout North America, the team selected a set of 50 indicators most appropriate to assess the conditions of the Delaware Basin. The team grouped indicators into 4 categories: landscape, water quality, water quantity/hydrology, and living resources and designed a reporting methodology to present data and trends on a basin, region, watershed, and subwatershed basis. During the indicator selection process, the team considered these goals listed in the 2004 Delaware Basin Water Resources Plan:

- Water quality for human and instream/ecological use
- Water supply adequacy
- Riparian corridor function and condition
- Flood warning and mitigation
- Aquatic and wildlife habitat
- Public health (recreation, consumption advisories, etc.)
- Water quantity and flow regime
- Land use and water resource linkages

5. Watershed Data – The 4 land grant universities collected indicator data available for subwatersheds in their state (Table 1.1). When subwatersheds included more than one state, the institute partners assembled data that crossed political boundaries and jurisdictions.

Table 1.1. University data collection assignments.

State	Institution	Land Area (mi^2)	% of Basin Area
Delaware	University of Delaware	1,012	8%*
New Jersey	Rutgers University	2,969	23%
New York	Cornell University	2,362	18%
Pennsylvania	Penn State University	6,524	51% **
	Total	12,867	100%

* Includes 8 square miles in Maryland. ** The UD assisted in southeastern PA watersheds.

6. Watershed Trends – The coordinating team defined baseline environmental conditions and trends for each of the subwatershed reporting units. The team developed spatial trends (i.e. differences in land uses between subwatersheds) and temporal trends (i.e. changes in water quality over time).

7. Technical Report – The universities compiled draft report graphics and narratives and submitted these documents to the Delaware River Basin Commission. Upon the receiving the data, the DRBC and the Partnership for the Delaware Estuary prepared 50 – page, full color reports, one for the basin and one for the estuary, in reader friendly formats suitable for the public, elected officials, and stakeholders in the Delaware River Basin.

Chapter 2 – The Delaware River Basin

2.1. Basin Overview

The DRBC oversees water resources management in parts of four states - Delaware, Pennsylvania, New Jersey, and New York. John F. Kennedy signed a federal law in 1961 creating the DRBC as the first federal – state water resources partnership. The DRBC is led by five commissioners representing the Governors and Federal government designee. The DRBC executive director and deputy director manage 48 staff at headquarters in West Trenton, New Jersey.

The Delaware Estuary (Figure 2.1) - the tidal reach of the Delaware River below Trenton – is one of 28 members in the National Estuary Program, a project set up by the USEPA Federal Water Quality Act of 1987 to protect estuarine systems of national significance (PDE 2002). The Partnership for the Delaware Estuary formed in 1996 and is managed by an executive director and staff with headquarters along the tidal Delaware River at Wilmington, Delaware.

The Delaware is the longest undammed river east of the Mississippi, extending 330 miles from the east and west branches at Hancock, New York to the mouth of the Delaware Bay. The river is fed by 216 tributaries, the largest being the Schuylkill and Lehigh Rivers in Pennsylvania (Figure 2.2). Including the bay, the basin contains 13,539 square miles, draining parts of Pennsylvania (51%), New Jersey (23%), New York (18%), and Delaware (18%).

The Delaware Basin consists of five physiographic provinces (Figure 2.3). These include the rocky Appalachian Plateau north of the Delaware Water Gap, the Valley and Ridge north of Easton, and the New England and Piedmont provinces north and west of the fall line which runs through Trenton, Philadelphia, and Wilmington (USGS, 2004). The flat, sandy Coastal Plain is situated south of the estuary and below the fall line in southern New Jersey and Delaware.

Over 7.5 million people live in the Delaware Basin. Nearly 15 million people (5% of the nation's population) rely on the Delaware River Basin for drinking and industrial use, 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 gets 50% of its water from three reservoirs in the headwaters of the Delaware.

Three-quarters of the non-tidal Delaware River are National Wild and Scenic Rivers including 73 miles from Hancock, NY to Milford, PA., 40 miles from Port Jervis, NY to the Delaware Water Gap, 39 miles from the Delaware Water Gap to Washington Crossing, PA, the Maurice River (NJ), and 190 miles in the White Clay Creek (PA and DE).

The Delaware River is the largest freshwater port in the world and generates $19 billion in annual economic activity. The river is the third largest petrochemical port as well as 5 of the largest East Coast refineries. Nearly 42 million gallons of crude oil are moved on the Delaware River daily. It is the largest North American port for steel, paper, and meat imports and largest importer of cocoa and fruit on the East Coast. Over 65% of Chilean fruits imported into the USA arrive at the tri-state port complex. Wilmington is the largest U.S. banana port, importing over 1 M tons annually.

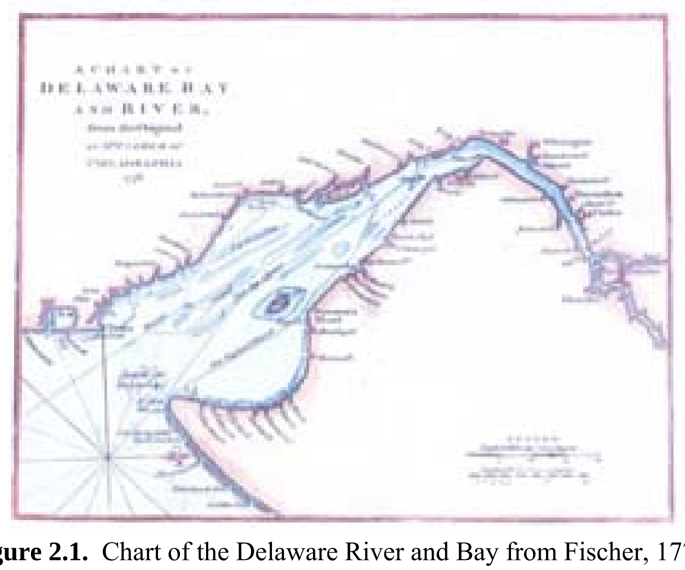


Figure 2.1. Chart of the Delaware River and Bay from Fischer, 1776.

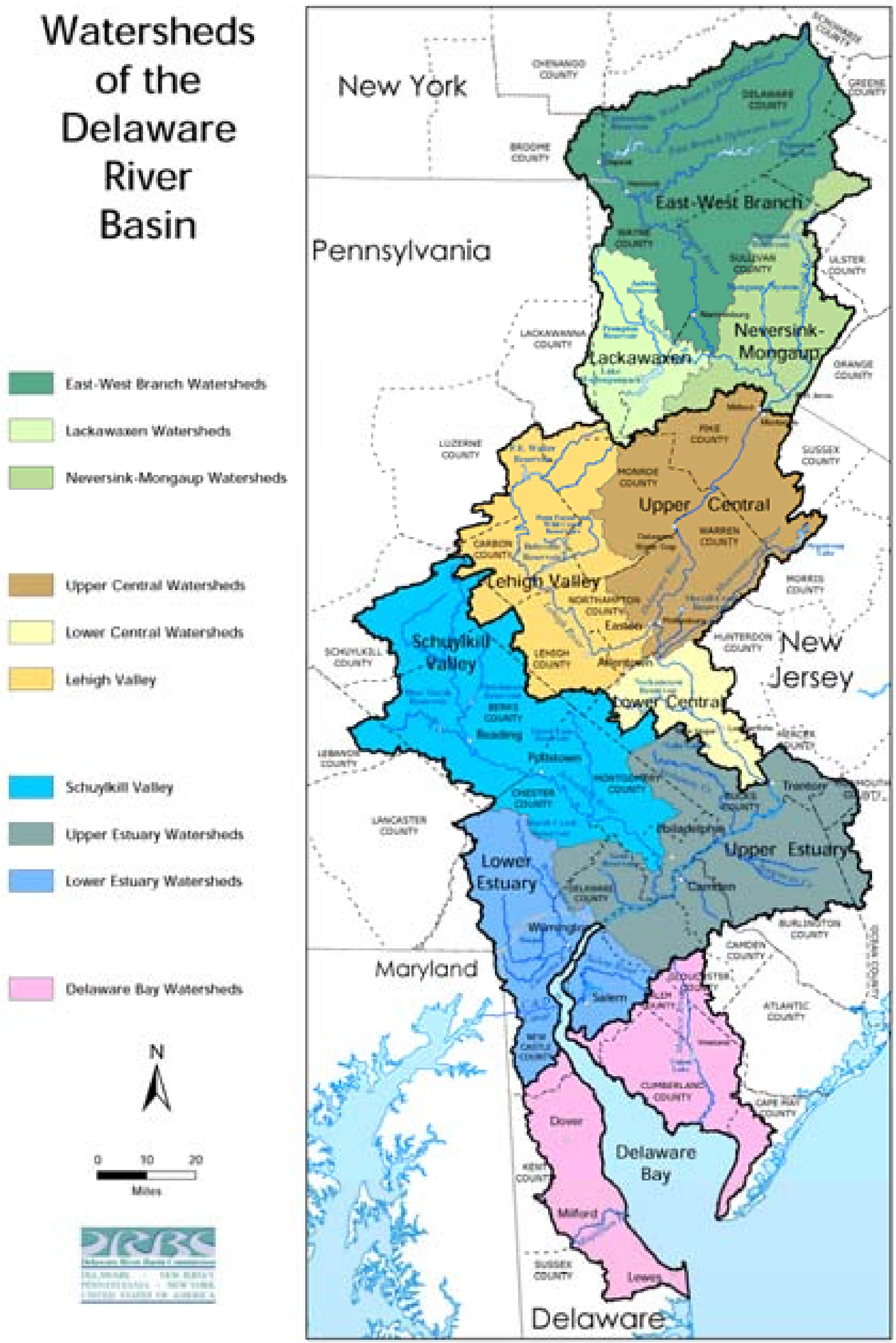


Figure 2.2. The Delaware River Basin. (DRBC 2007)

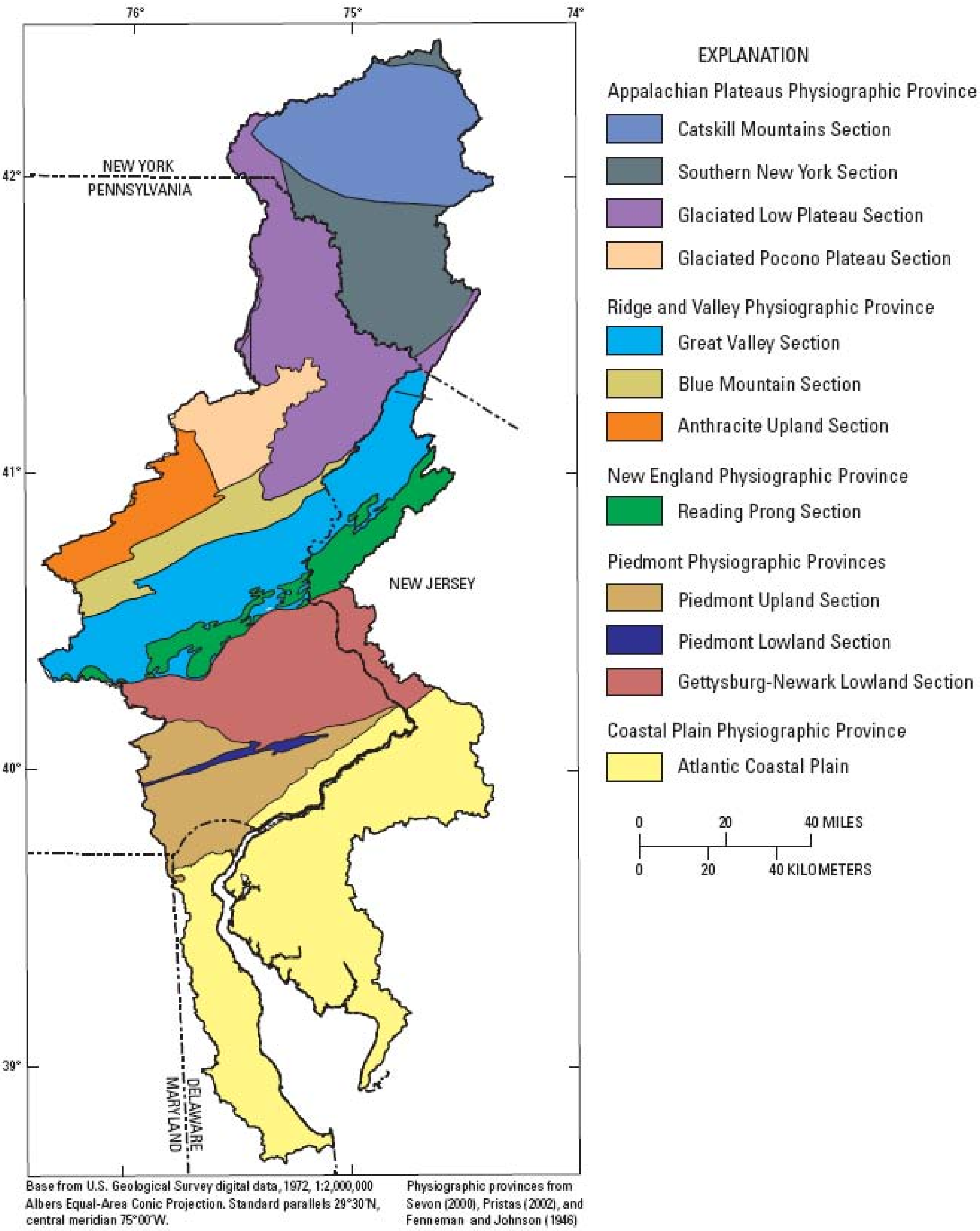


Figure 2.3. Physiographic provinces in the Delaware River Basin. (USGS 2004)

2.2. Basin Chronology

The literature and water quality records were reviewed to trace water quality change in the Delaware River and Estuary and tributaries. Over the centuries, water quality along the Delaware River and tributaries changed from pristine, to polluted, to partially restored as discussed in the following chronology as cited from Brandt 1929, INCODEL 1940, Tyler 1955, DRBC 1975, DRBC 1981, Albert 1988, Albert and Albert 2002, Sutton, O'Herron, and Zappalorti 1996, Dale 1996, USEPA 2000, and others as cited.

Indigenous Peoples (600 – 1609 A.D.): By 600 A. D., the Lenni - Lenape lived in the Delaware Valley, part of the land they called *Lenapehoking*. As noted by the first European visitors 10 centuries later, these indigenous peoples of America found vast populations of fish and fowl in the pristine waters along the forested Delaware River and Estuary.

Colonial Expansion (1609 - 1776): In 1609, Henry Hudson's *Half Moon* sailed to the mouth of Delaware Bay. Hudson called the body of water "South River" which was marked on early maps. A year later, British Captain Samuel Argall visited the bay and named the cape after Lord De La Warre, governor of the Jamestown Colony. In 1638, Swedes aboard the *Kalmar Nyckel* established a colony at Fort Christina at the confluence of the Brandywine and Christina Rivers, the first permanent European settlement in the Delaware Valley.

Captain Thomas Young filed one of the first water quality reports on the Delaware Estuary during the 1630s when he wrote: *"the river aboundeth with beavers, otters, 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 1655 the Dutch under Governor Stuyvesant of New Amsterdam sent seven vessels to the Delaware and forced surrender of the Swedes. In 1664 following the capture of New Netherlands from the Dutch, King Charles II of England named his James II, the Duke of York, as proprietor of the Atlantic coast from Canada to the Delaware River.

In 1682, English Quaker William Penn sailed up the Delaware River on the *Welcome* and founded Philadelphia, landing at Dock Street. By 1700, Philadelphia had 5,000 residents. Foreshadowing later water quality problems, in 1769 a visiting Englishman commented on the *"mess"* in the Delaware River at Philadelphia

Independence and Industry (1776 – 1880)*:* On July 4, 1776, the Declaration of Independence was signed in Philadelphia, the largest city in America. On Christmas Eve 1776, George Washington crossed the Delaware River from Pennsylvania to New Jersey on Christmas Eve and defeated the Hessians at Trenton, a turning point in the American Revolution.

Spring 1778 runs of shad, celebrated as the America's founding fish by Princeton author John McPhee (2002), migrated upstream from the Delaware and fed General Washington's starved troops at Valley Forge along the Schuylkill.

In 1799, the first American government pollution survey noted contamination entering the Delaware River from ships and sewers. By 1802, the DuPont family settled in Wilmington and established gunpowder mills along the falls of the Brandywine River serving as the origin of the petro-chemical business that now sprawls along the estuary.

In 1832, cholera caused by contamination of drinking water by human and animal waste killed over 900 people in Philadelphia. Due to pollution, fisheries declined and untreated drinking water supplies were contaminated resulting in disease outbreaks of typhoid.

Fisheries Boom and Collapse (1880 – 1900): By the end of the 19^{th} century, Delaware River water quality was declining but still sustained a fragile fishery (Dove and Nyman 1995). The Delaware River of the 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 (10 million kg) of oysters were harvested from the Delaware Bay. In 1896 over 14 million pounds (6.4 million kg) of shad were caught with a value of $400,000 ($10 million in 2008 dollars). In 1896, a fisheries report to the Pennsylvania governor cited the catch of a 76 lb (34 kg) striped bass above Gloucester, New Jersey. However, record harvests combined with declining water quality and low reproductive rates eradicated the Atlantic sturgeon population by the late 1800's (Fox, Simpson, Brown, Magowan, and Hightower, 2007). By the turn of the 20th century the American shad fishery had begun to collapse (Figure 2.4).

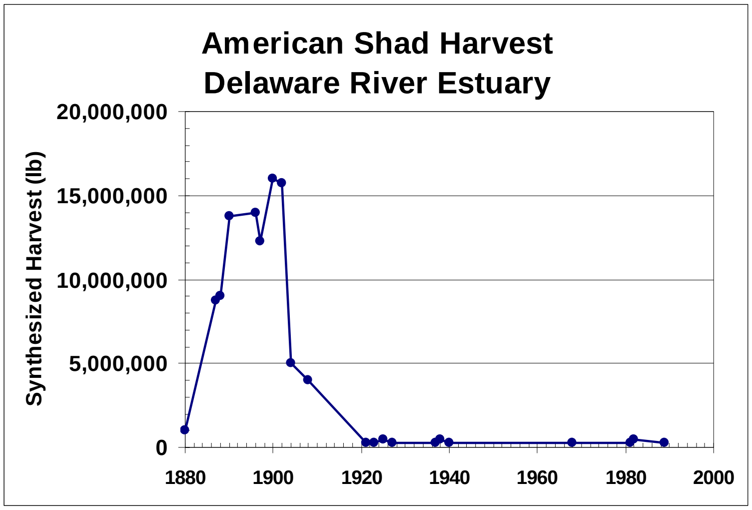


Figure 2.4. Synthesized American shad harvest in the Delaware Estuary. (Delaware Estuary Program 1996)

World War I (1900 – 1930): During the early 1900's, water treatment plants utilizing chlorine for disinfection were constructed along the Delaware River, cutting cholera and typhoid by 90%. By 1914, low dissolved oxygen levels approaching 1 mg/l were recorded along the Delaware Estuary near Philadelphia and Camden. During World War I, shipbuilding at the largest U.S. Navy base in the world accelerated along the "Clyde of America". Industries and cities dumped untreated wastewater and sewage into the river.

INCODEL (1930 – 1940): In May 1931, the United States Supreme Court authorized New York City to divert up to 440 mgd 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 flow in the Delaware River at Port Jervis, New York to protect downstream water supplies in Delaware, Pennsylvania, and New Jersey.

In 1936, New Jersey, New York, and Pennsylvania created the Interstate Commission on the Delaware River Basin to clean up pollution with Delaware joining in 1939. INCODEL initiated a water pollution control program to bring primary sewage treatment to communities along the Delaware River. By 1940, Trenton was the only city with a sewage treatment plant along the Delaware Estuary. 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".* The pollution came from raw sewage dumped into the river from the cities and untreated industrial waste. In the river between Chester and Burlington, "*more than 400 million gallons of untreated domestic sewage and industrial wastes are discharged daily".* Shad and herring were unable to migrate through the zero oxygen barrier along the Delaware Estuary at Philadelphia to upriver spawning grounds.

Second World War (1941 – 1946): Water pollution continued unabated during the Second World War as defense industries along the river churned around the clock to meet the war effort. Army and Navy pilots flying overhead commented on a rotten egg - like hydrogen sulfide stench from the Delaware River. President Roosevelt ordered an investigation in 1941 to determine if pollution was hampering the U. S. war effort. Water pollution was so bad that a newly painted hospital ship turned into the colors of a rainbow as it sailed out into the Delaware River. The U. S. Navy harbored ships in the Delaware Estuary because nothing would grow on the hulls in the polluted water

During the 1940s, up to 350 mgd of raw sewage poured into the Delaware River from Philadelphia alone. The river ran black and the stench of hydrogen sulfide gas was noticeable. Pollution from war industries resulted in a 1946 report by the U.S. Fish and Wildlife Service that recorded an all - time - worse anoxia condition from shore to shore.

INCODEL (1946 – 1960): After World War II, water quality conditions were very poor. Depleted DO levels were recorded due to wastewater loading from Philadelphia. During summer months in the 1940s and 1950s, DO levels were typically 1 mg/l or less over a 20 mile (32 km) section of estuary 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. During the 1950's the Philadelphia region of the Delaware River had essentially zero oxygen during the summer. In 1952, ichthyologist Edward Raney cited the Delaware as an *"outstanding example of destruction of (striped) bass habitat by industrial and domestic pollution"* (Raney 1952).

After World War II, extensive water pollution prompted INCODEL to revive wastewater controls started during the 1930s. In 1951, large cities 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 1950s after construction of primary sewage treatment plants by Philadelphia, Camden, and Wilmington between 1951 and 1954. The INCODEL water pollution abatement program increased the towns with sewage treatment from 63 municipalities in 1935 to 236 in 1959. More tolerant to low oxygen levels than other species, blue crabs thrived and landings in the Delaware Estuary increased during the 1950s (Figure 2.5).

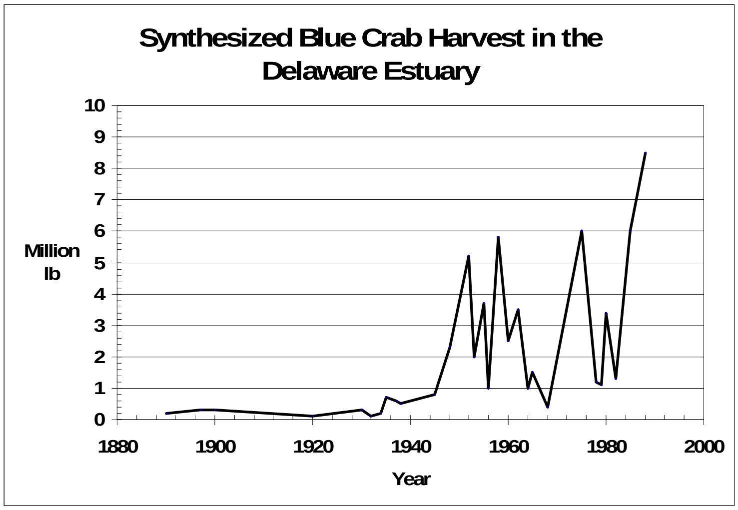


Figure 2.5. Synthesized blue crab harvest in the Delaware Estuary. (Killam and Richkus 1992)

On June 1954, the United States Supreme Court amended the 1931 decree to increase the diversion by New York City to 800 mgd (3,000 MLD) from Delaware Basin reservoirs at Cannonsville, Pepacton, and Neversink and release water to maintain 1,750 cfs (49 cms) in the Delaware River at Montague, NJ for downstream water interests.

In August 1955, Hurricanes Connie and Diane hammered the Delaware Basin causing killer floods and leaving an "*oily film of silt… and a terrible stench – an aroma of feces and rotting flesh."* During the late 1950s, MSX disease devastated oyster stocks in the Delaware Bay. Only a million pounds (455,000 kg) of oysters were taken during by 1960, down from over 15 million pounds (6.8 million kg) harvested during the 1930s (Figure 2.6).

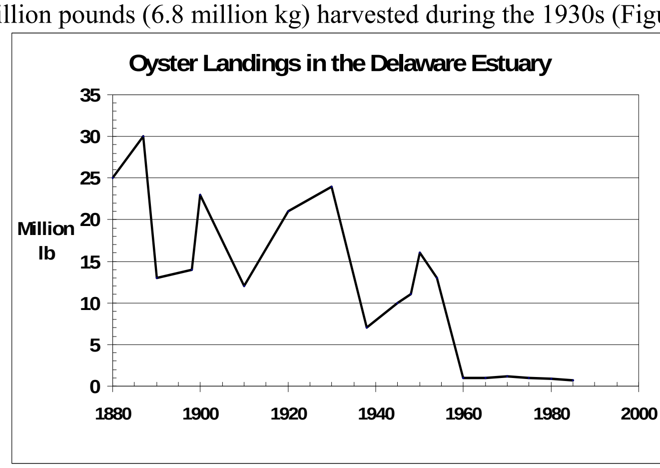


Figure. 2.6. Oyster landings in the Delaware Estuary. (University of Delaware Sea Grant Program 1988)

In 1958, water quality was good above the head of tide at Trenton and deteriorated to poor downstream in the tidal Delaware River (Smith, Haber, Kaplovsky, and Simpson 1959). In September 1958, dissolved oxygen declined from 95% saturated downstream from Trenton to 15% saturated at Philadelphia, rising to 50% saturated at Wilmington and

75% at the C & D Canal. Nitrate nitrogen increased from 0.01 ppm downstream from Trenton, to 0.14 ppm at Philadelphia to Marcus Hook, declining to 0.08 ppm at Wilmington, and 0.01 ppm at the C & D Canal (Figure 2.7).

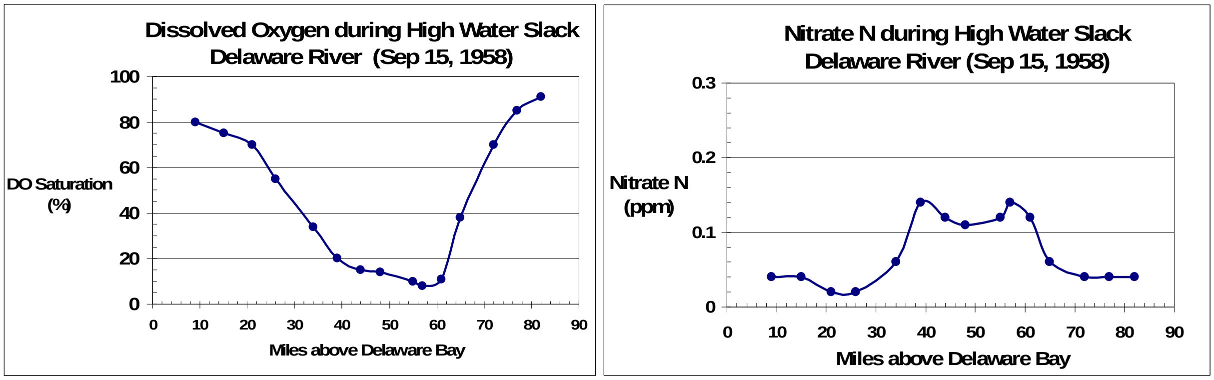


Figure 2.7. Dissolved oxygen and nitrate nitrogen levels along the tidal Delaware River. RM 9 = Reedy Island, RM 21 = New Castle, RM 55 = Philadelphia, RM 65 = Torresdale, and RM 82 = Fieldsboro. (Smith, Haber, Kaplovsky, and Simpson 1959).

DRBC 1961 – 1972: In 1961, INCODEL was replaced by the Delaware River Basin Commission, a federal – state compact with broad water resources management powers signed into law by John F. Kennedy, Jr. (DRBC 2004). When Congress voted in 1961 to approve the DRBC they stated: *"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 activiuties. 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 the multi-year drought of record, the driest spell since at least 1895. During the 1960s, with conditions exacerbated by the drought, dissolved oxygen in the Delaware River from Wilmington to Philadelphia commonly reached near zero from May through October mostly due to high ammonia levels from untreated wastewater (Figure 2.8).

A $1.2 million Delaware Estuary Comprehensive Study by the U. S. Public Health Service found nearly 100 cities and industries were discharging waste into the Delaware River. Seeking to restore water quality, the DRBC adopted a waste load allocation program in 1967 and with the four States started a basin wide point source pollution abatement program.

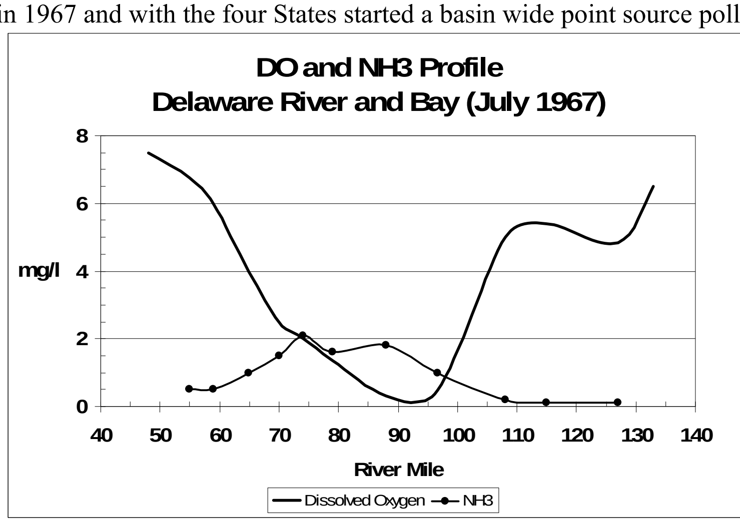


Figure 2.8. Dissolved oxygen and ammonia nitrogen profile along the Delaware River and Bay, July 1967. (Thomann 1972) RM = Liston Point, DE. RM 75 = Wilmington, DE. RM 100 = Philadelphia, PA. RM 133.4 = Trenton, NJ.

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. Figure 2.9 indicates substantial wastewater treatment upgrades to secondary standards resulted in an 89% decrease in chemical biochemical oxygen demand (CBOD) loading from municipal and industrial sources to the Delaware Estuary from 1,136,000 lb/day in 1958 to 128,000 lb/day by 1995 (DRBC 2000). By the end of the 1960s, mean oxygen levels along the Delaware River inched up to 2 mg/l, still too low to meet fishable water quality standards.

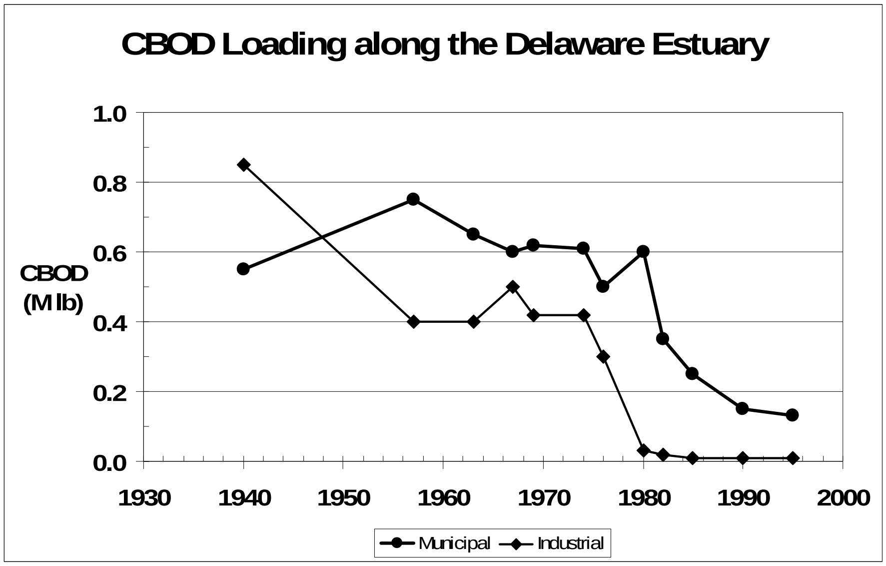


Figure 2.9. CBOD loading along the Delaware Estuary, 1940 – 1995. (USEPA 2000)

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, 20 times lower than in late 19th century when over 10 million pounds of shad were caught annually. The suspected cause of the shad fishery crash was overfishing and zero oxygen levels due to pollution in the Delaware River at Philadelphia that served as a block to the shad migrating upstream (Chittendon 1974). By 1971, near zero dissolved oxygen between Philadelphia and Wilmington and *"gross pollution of tidal freshwater had extirpated the striped bass from its historical chief spawning and nursery areas in the Delaware River"* (Chittendon 1971).

Clean Water Act (1972 – 1990): The environmental movement prompted Earth Day, celebrated on April 22, 1970. The same year, Richard Nixon signed the law creating the United State Environmental Protection Agency which absorbed the responsibilities of the U. S. Water Pollution Control Administration. In 1972, Mr. Nixon and Congress passed the Clean Water Act which set goals for returning the nation's waterways to fishable and swimmable status.

In June 1972, an early hurricane caused 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 along the Delaware River from the headwaters to Trenton and extremely poor in the Delaware Estuary in the Philadelphia area. Water quality recovered to good to excellent near the entrance of the Delaware Bay (Thomann 1972). In 1973, a USEPA study concluded the Delaware Estuary would never achieve designated uses definable by fishable standards.

New York became the first state in the Delaware River Basin to ban phosphate detergent in 1973 followed by Pennsylvania in 1990. By 1994, manufacturers stopped producing phosphate detergent (Litke 1999).

In 1974, water quality in the Delaware Estuary above Wilmington was improving but still poor as Chittenden asserted that due to water quality concerns and the threat of a Tocks Island dam, "*extirpation of the remnant (shad) runs is a distinct possibility"*. In 1975, dissolved oxygen levels along the Delaware Estuary were 1.7 mg/l at Philadelphia, 1.2 mg/l at Chester, and 3.1 mg/l at Wilmington, less than the 4 mg/l fishable water quality standard (DRBC 1975).

Rutgers Professor William Whipple called for better regional planning in the Delaware River and was one of the first to warn of pollution caused by stormwater runoff. He reported that a two-inch storm in the Delaware Estuary drainage area would generate 530,000 lbs (240,000 kg) of BOD in urban runoff. Dissolved oxygen in the Delaware Estuary would decrease by 2 mg/l after a storm and take over a week for DO to recover to pre-storm levels (Whipple 1975).

By 1981, dissolved oxygen levels in the Delaware Estuary near Philadelphia were rising but still did not meet the fisheries standard of 4 mg/l. Wastewater treatment plants at Philadelphia, Camden, and Trenton had not yet met standards set by the USEPA NPDES and DRBC waste load allocation program (DRBC 1981). 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 and improvements to old sewage treatment facilities along the Delaware River and tributaries between Wilmington, Philadelphia and Trenton. Improvements to wastewater treatment 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 annual DO levels improved from 3 mg/l in 1968, to 3.5 mg/l in 1981, to 8 mg/l by 1987.

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

By 1988, an article in *Estuaries* observed that the Delaware Estuary had better water quality than at any time in the century due to pollution abatement programs conducted over 50 years (Albert 1988). 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, Delaware County (PA) and Wilmington constructed secondary wastewater treatment plants which treat over 700 mgd of sewage before discharge into the Delaware Estuary.

Watershed Era (1990 – Present): During the 1990's, the USEPA re-emphasized basin planning of the sort practiced by the DRBC since 1961 and encouraged States to adopt the watershed approach to clean up waterways. Water quality in the Delaware River continued to improve with the close of the 20th century. In 1991, the Middle Delaware Scenic and Recreational River between Port Jervis and Stroudsburg near the Delaware Water Gap had high water quality which exceeded standards (Breidt, Boes, Wagner, and Flora, 1991). In 1993, University of Delaware scientists concluded: "*During the last 30 years, there has been a fourfold decrease in TP concentrations in the tidal river of the Delaware Estuary".* Total phosphorus reached peak levels in the Delaware Bay in the high turbidity zone near the C & D Canal and decreased to minimum concentrations at the mouth of the bay (Lebo and Sharp, 1993).

In 1994, DRBC reported of 866 square miles in the Delaware Estuary, 96% had good, 3% had fair, and 1% had poor water quality. The recovery of shad and striped bass were linked to water quality improvements (USEPA 2000).

Between the 1980s and 1995, water quality in the Delaware Estuary improved significantly (USEPA 2000). Mean annual DO in the Delaware River at Philadelphia improved from 1 mg/l in 1958 to 5 mg/l by 1995. Nitrogen in the Delaware Bay near the C & D Canal was 4 mg/l during 1968 - 1970 and decreased to 2.5 mg/l by 1988 - 1990. Phosphorus along the Delaware River at Philadelphia decreased from 0.45 mg/l during 1968 - 1970 to 0.15 mg/l during 1988 – 1990. At Marcus Hook, phosphorus declined from 0.8 mg/l in 1966 to 0.1 mg/l by 1995 and ammonium N declined from 1.4 mg/l to 0.2 mg/l during the same period (Figure 2.10). Increased landings of American shad, striped bass, and white perch between 1980 and 1993 correlated with improved water quality in the Delaware Estuary

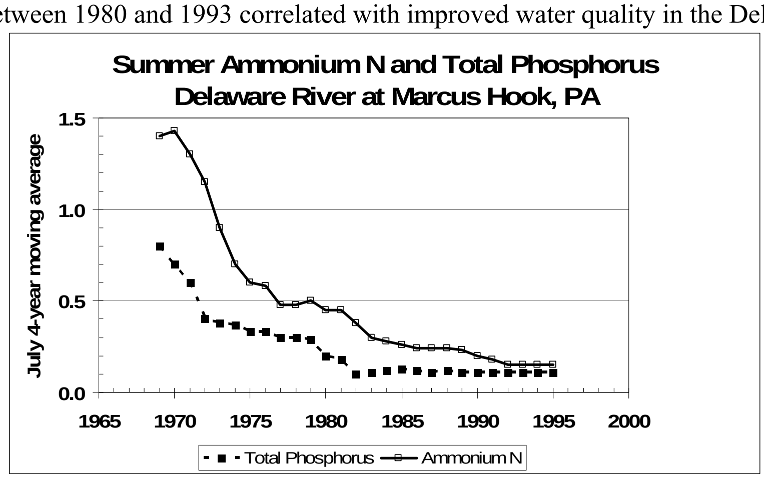


Figure 2.10. Ammonium N and total phosphorus in the Delaware River at Marcus Hook, PA. (USEPA 2000, from Santoro 1998)

In 1996, water quality still did not meet bacteria standards for swimming at Philadelphia and Camden along the Delaware River. Total phosphorus dropped dramatically during the early 1970's and remained constant through 1996. By 1995, 99 major dischargers were permitted along the Delaware Estuary, most in compliance with DRBC water quality standards. By 1996, over 90% of the Delaware Estuary met fishable and swimmable goals of the Clean Water Act (USEPA 2000).

By 1996, water quality in the Delaware Estuary improved dramatically over the last several decades (Weisberg, Himchak, Baum, Wilson, and Allen, 1996). Areas near Philadelphia that were once anoxic and formed a pollution block to migratory fish passage now rarely experienced dissolved oxygen concentrations less than 3 mg/l. During a beach seine survey conducted annually from 1980 – 1993, the number of fish species captured increased and the increase was greatest in areas of the Delaware Estuary downstream from Philadelphia where water quality had improved the most. Juvenile striped bass and American shad abundance, migratory species that are susceptible to water quality problems, both increased 1000-fold over the past decade (Figure 2.11). The increase in fish abundance in the tidal Delaware River relates closely to improving water quality conditions.

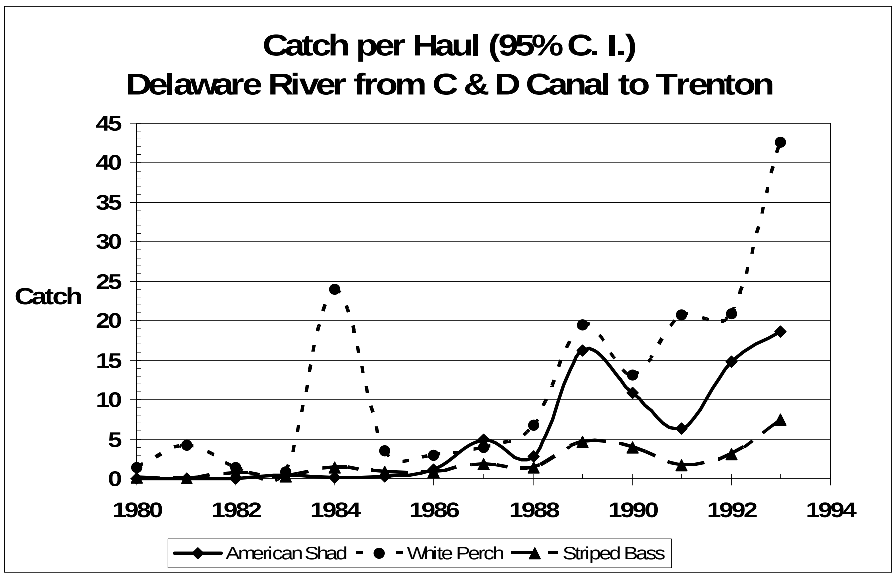


Figure 2.11. Catch per haul of fish species in the Delaware River. (Weisberg, Himchak, Baum, Wilson, and Allen 1996)

In 1996, the USEPA and Delaware, New Jersey, and Pennsylvania formed the Delaware Estuary Program and adopted a Comprehensive Conservation and Management Plan (CCMP). By 1996, levels of dissolved oxygen increased to meet the 4 ppm fishable standard for the tidal Delaware Estuary.

The Delaware Estuary Program reported in 1996 that there have been *"dramatic improvements in water quality since the 1960s"* (Sutton, Herron, and Zappalorti 1996). 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 fecal coliform bacteria levels improved since 1987 (DRBC 2001). The Delaware River had lower fecal bacteria counts than the tributary streams. Other relatively bacteria free waters included the Lehigh River, Tohickon Creek, and Paulins Kill.

During 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 (Crockett 2008). Total phosphorus and nitrates decreased along Estuary 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 Estuary, ammonia decreased along the Schuylkill River at Philadelphia from 1970 to 2000. (Interlandi and Crockett 2003).

In 2002, over 29,000 shad were caught in the Delaware Estuary as counted by the Delaware DNREC, Division of Fish and Wildlife (DNREC, 2002). Figure 2.12 indicates between 2001 and 2005, , over 200,000 migrating shad were detected annually on the average along the Delaware River at Lambertville, New Jersey (NJDEP 2006).

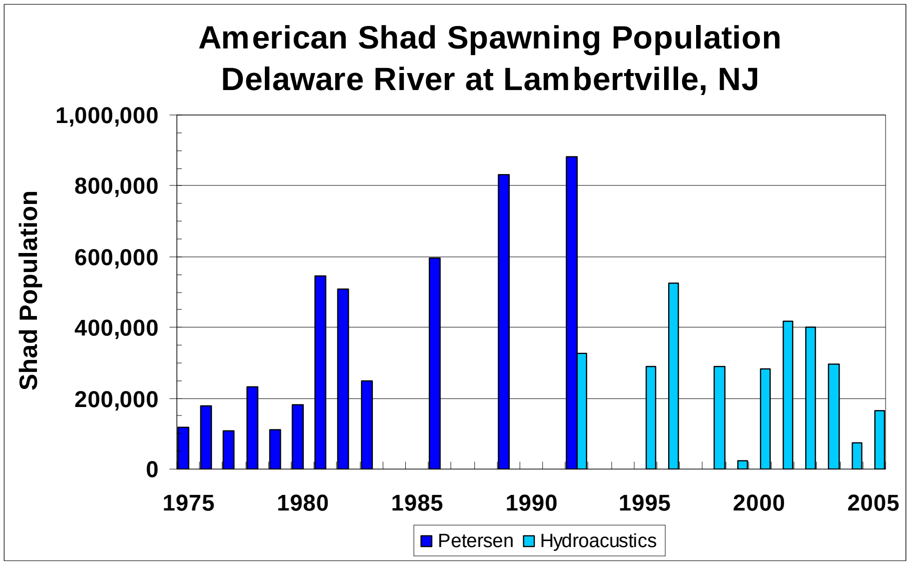


Figure 2.12. American Shad spawning population in the Delaware River at Lambertville, New Jersey. (NJDEP 2006)

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 totaling a combined weight of 250,000 pounds (114,000 kg) in the Delaware Estuary

In 2003, the Lehigh River (second largest tributary to the Delaware Estuary) was "*cleaner than it had been in the last 150 years.*" The water quality in the Lehigh River was as good with few exceptions (Wildlands Conservancy, 2003).

In 2003, the DRBC reported that mean annual dissolved oxygen along the Delaware Estuary at Philadelphia (RM 100) was recorded at just under 6 mg/l, up from 2.5 mg/l in 1980 and 2.0 mg/l in 1967 (Figure 2.13).

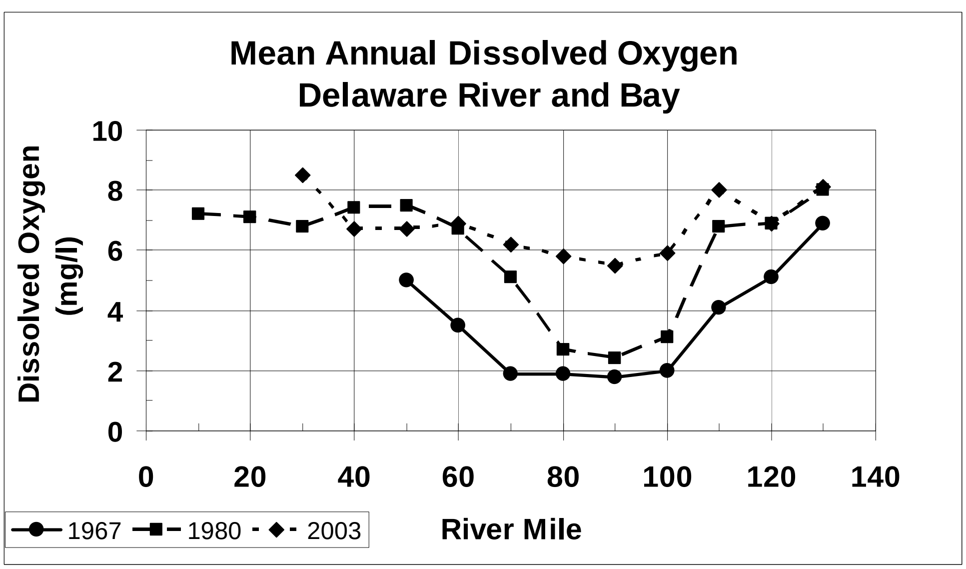


Figure 2.13. Mean annual dissolved oxygen levels along the Delaware River and Bay. Wilmington, Philadelphia, and Trenton are situated at river miles 70, 100, and 130, respectively. (DRBC 2003)

The assessment of PCB water quality in the Delaware Basin reports (USGS 2004): *"Concentrations of PCBs in fish from some rivers have markedly declined from the 1970s or 1980s to the late 1990s, but this decline was not seen in two of the six rivers studied. PCB concentrations in fish tissue from the Delaware River at Trenton have declined over the last 25 years. Declines were also seen on the Upper Delaware River, Brandywine Creek, and Upper Schuylkill River. Declines were not as apparent on the lower Schuylkill and lower Lehigh Rivers"*

Non-tidal Delaware River water quality at 9 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 7 stations. Total suspended solids were better than the New Jersey 40 mg/l standard at all nine stations (DRBC 2004)

Along Pennsylvania streams in the Delaware Basin between 1995 and 2005, 5 nitrite plus nitrate nitrogen stations had improving trends, 27 had no change, and 4 stations had degrading trends (Figure 2.14). For total phosphorus, 12 stations had improving trends, 24 stations had no change, no stations had degrading trends (PADEP 2005).

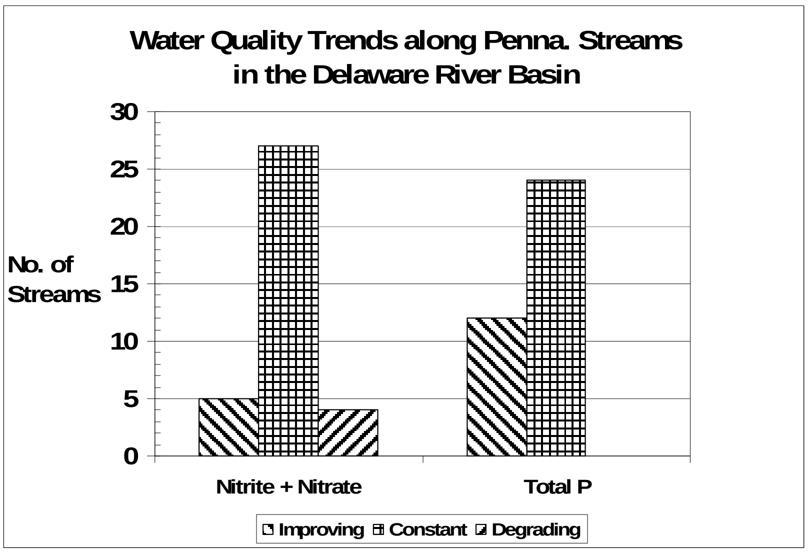


Figure 2.14. Water quality trends along Pennsylvania streams in the Delaware River Basin. (PADEP 2005).

In 2006, along RM 0 to RM 133 in the Delaware Estuary (Figure 2.15), 394 of 790 sq mi (1,000 of 2,000 sq km) support aquatic life, 790 sq mi (2,000 sq mi) have limited or full fish consumption advisories, 643 of 693 sq mi (1,650 of 1,780 sq km) support shellfishing, and 514 of 769 sq mi (1,300 of 1,970 sq mi) support primary contact recreation (swimming).

The Philadelphia Water Department reported in a source water assessment that tidal Delaware River water quality significantly improved over the past 20 years (Crockett 2008). 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.

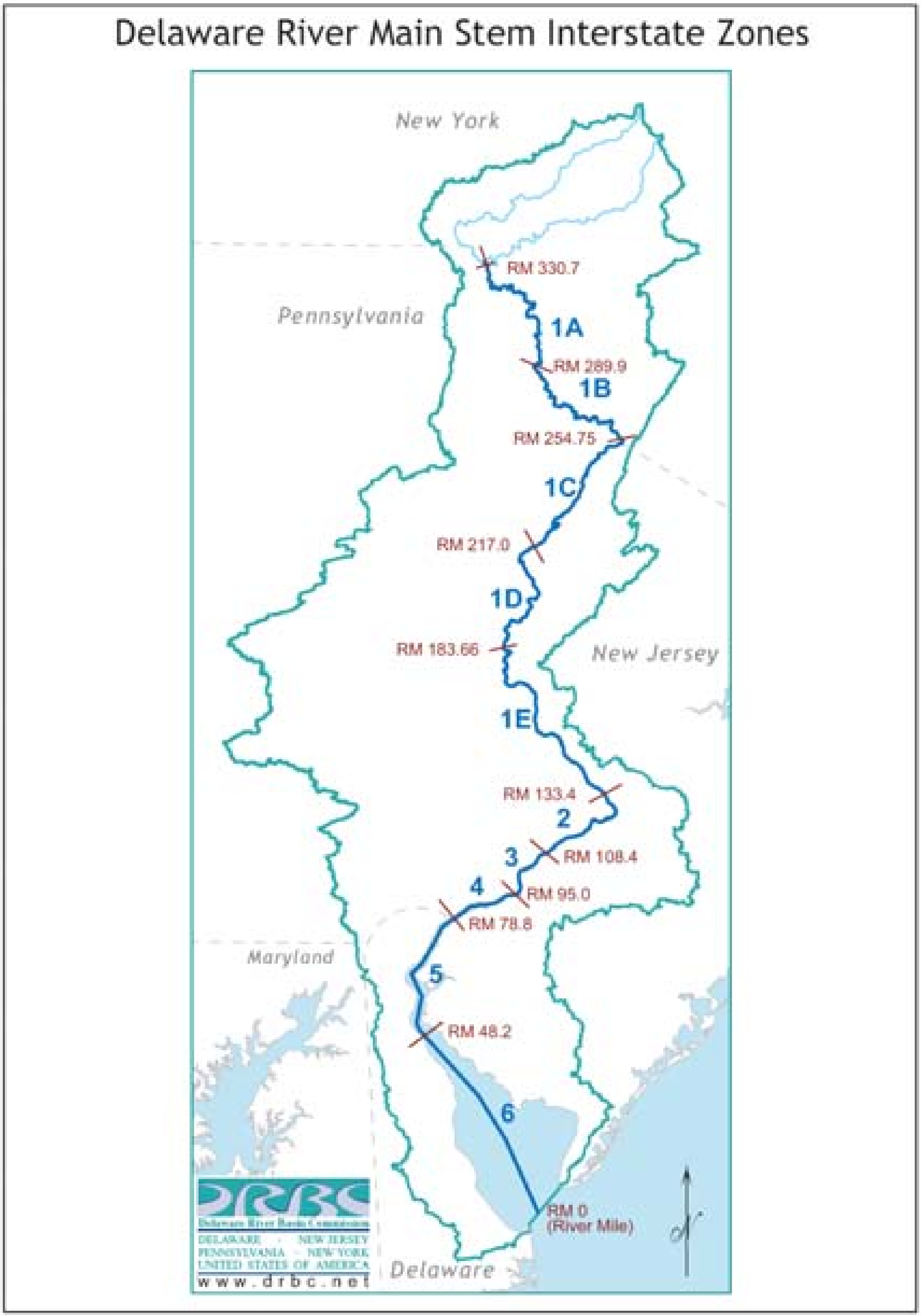


Figure 2.15. Delaware River Basin interstate water quality zones.

Chapter 3 – Watershed Regions

3.1. Watershed Hierarchy

The Delaware Basin subdivides into 21 subwatersheds based on the following criteria (Figure 3.1 and Table 3.1).

- Hydrology at the confluences of major river branches such as the subdivision of the West and East Branch of the Delaware River in New York into subwatersheds EW1 and EW2.

- Population density changes above and below major cities and suburbs. A logical subwatershed divide along the Schuylkill is above the heavily populated City of Philadelphia and suburbs.

- Land use change. The Lehigh River splits into 3 subwatersheds: forested/mining in the Appalachian plateau (LV1), agriculture in the Ridge and Valley above Allentown (LV2), and suburban above Easton (LV3).

- Physiographic province/topography along the boundaries of the Appalachian Plateau, Ridge and Valley, New England, Piedmont, and Coastal Plain hydrogeologic provinces (Figure 3.2).
-
- USGS stream gages such as the Delaware River at Port Jervis (Figure 3.3).

Table 3.1. Subwatersheds in the Delaware River Basin.

	Region		Watershed		Subwatershed	
	mi^2	km^2	mi^2	km^2	mi^2	km^2
Upper Region Subbasin (NY and PA)	3,435	8,794				
EW · East/West Branch watersheds			2,023	5,179		
EW1 West Branch					666	1705
EW2 East Branch					834	2,135
EW3 Mainstem Hancock to Narrowsburg					523	1,339
LW1 · Lackawaxen watersheds			597	1,528	597	1,528
NM1 ·Neversink-Mongaup watersheds			815	2,086	815	2,086
Central Region Subbasin (PA and NJ)	3,337	8,543				
UC ·Upper Central watersheds			1,523	3,899		
UC1 Pocono Mountains, PA tributaries					778	1,992
UC2 Highlands of NJ tributaries					745	1,907
LV ·Lehigh Valley			1360	3482		
LV1 Lehigh River above Lehighton					451	1,155
LV2 Lehigh River above Jim Thorpe					430	1,101
LV3 Lehigh River Bethlehem and Easton					479	1,226
LC1 Lower Central subwatershed above Trenton			454	1162	454	1,162
Lower Region Subbasin(PA, NJ and DE)	4,654	11,914				
SV ·Schuylkill Valley			1,891	4,841		
SV1 Schuylkill above Reading					342	876
SV2 Schuylkill above Valley Forge					656	1,679
SV3 Schuylkill above Philadelphia					893	2,286
UE ·Upper Estuary watershed			1,743	4,462		
UE1 Pennsylvania Fall Line					701	1,795
UE2 New Jersey Coastal Plain					1042	2,668
LE ·Lower Estuary Watersheds			1,020	2,611		
LE1 Christina/Brandywine Rivers					603	1,544
LE2 C & D Canal, DE					155	397
LE3 Salem River, NJ					262	671
Bay Region Subbasin (DE and NJ)	1,423	3,643				
DB ·Delaware Bay watershed (NJ and DE)			1,423	3,643		
DB1 Delaware Bay tributaries, DE					634	1,623
DB2 Delaware Bay tributaries, NJ					789	2,020
Basin	12,856	32,911	12,856	32,911	12,856	32,911

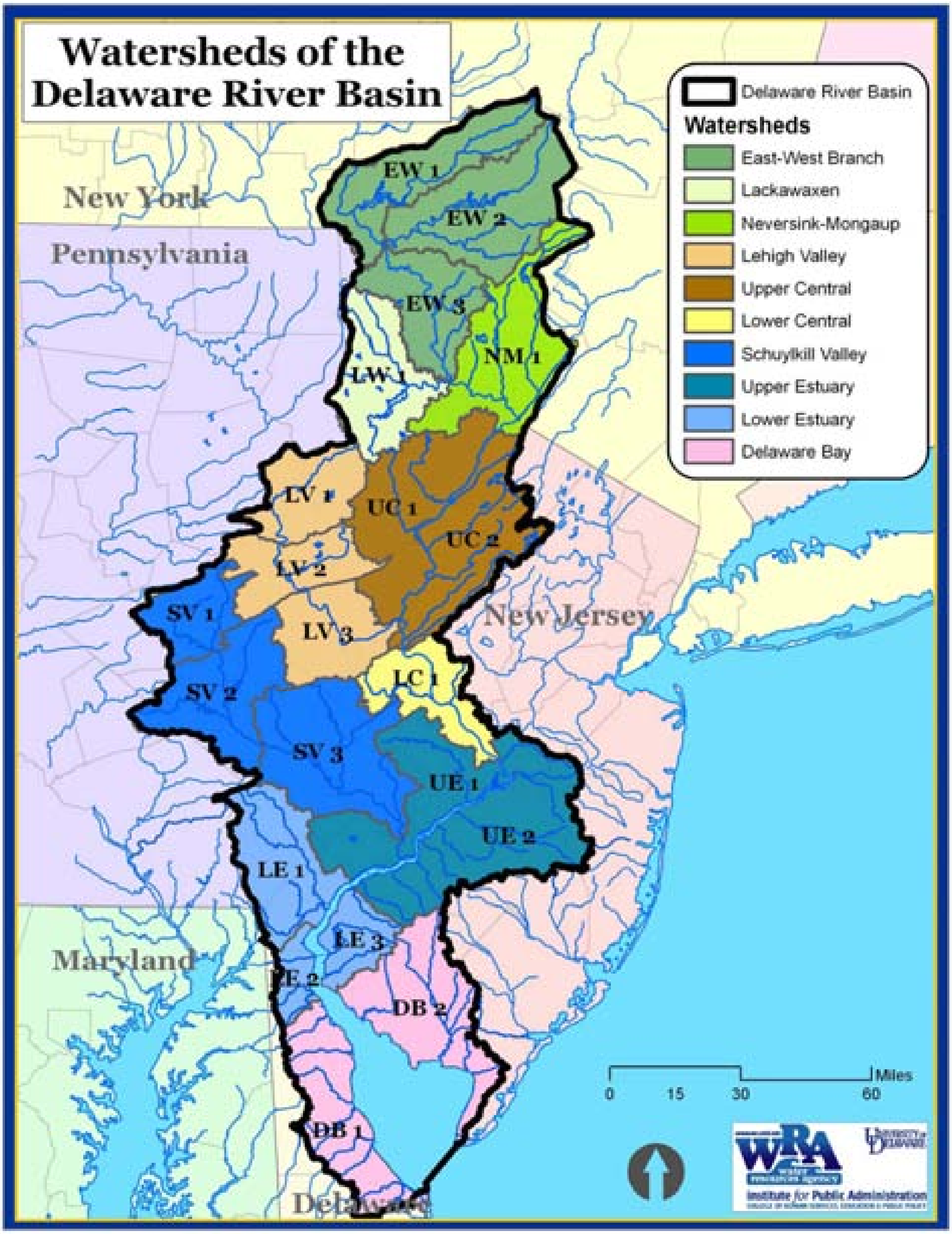


Figure 3.1. Delaware River Basin watershed map. (UDWRA 2007)

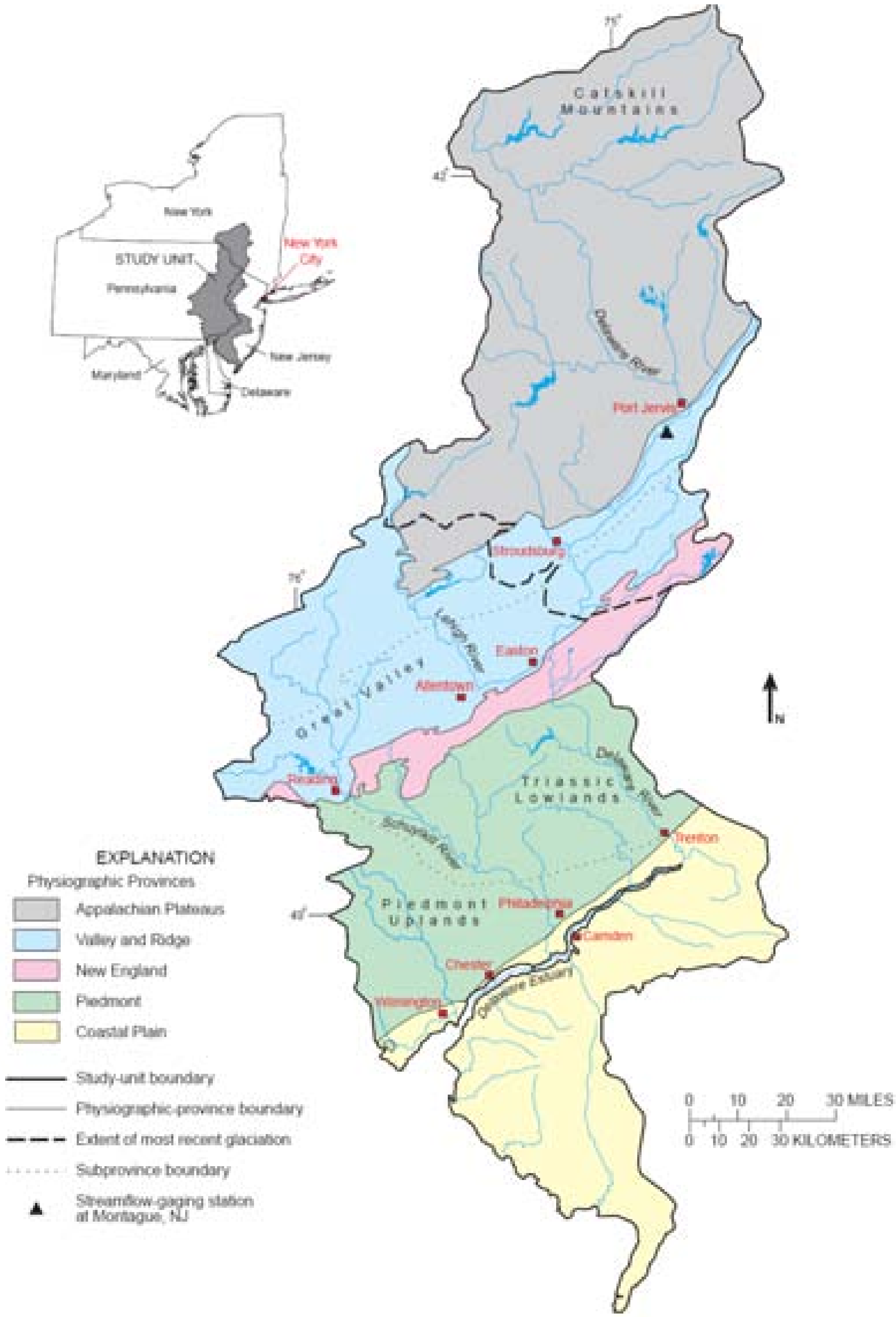


Figure 3.2. Physiographic provinces in the Delaware River Basin. (USGS 2004)

Figure 3.3. Stream gages in the Delaware River Basin. (DRBC and USGS)

3.2. Upper Region Subbasin (NY and PA)

The Delaware River Basin's headwaters originate in the Catskill Mountains, New York and provide good water quality to the main stem Delaware River. Four subwatersheds drain through the West and East Branches of the Delaware River, the Callicoon Creek, and the Mongaup and Neversink Rivers in New York, with contributions from streams in Pennsylvania. The Delaware River serves as New York's border with Pennsylvania, and travels southeasterly for approximately 79 miles before exiting New York at Port Jervis. Since these watersheds are mostly forested, most of the main stem of the Delaware and tributaries streams exhibit very good to exceptional water quality. The largest export of water from the entire Delaware River Basin at approximately 650 million gallons per day is to New York City, from the Cannonsville Reservoir (EW1), Pepacton Reservoir (EW2) and Neversink Reservoir (NM1).

Subwatersheds EW1, EW2 and EW3 are partially managed under two existing programs working in concert to maintain the region's high quality of water. The Memorandum of Agreement (MOA) is a landmark watershed agreement between the residents living in the region and the New York City Department of Environmental Protection (NYC DEP). Signed in 1997 by the New York State Governor, the New York City Mayor, the Coalition of Watershed Towns (representing thirty-four towns, nine villages and five counties west of the Hudson River), the US Environmental Protection Agency (EPA) and members of the environmental community, the MOA was conceived for the long-term protection of its unfiltered water supply serving approximately nine million people. EPA accepts this watershed agreement as an alternative to its requirement that public water supplies be filtered.

EW1 West Branch: The 666 mi^2 West Branch of the Delaware River subwatershed originates in the Catskill Mountains of upstate New York in the Appalachian Plateau and includes Cannonsville Reservoir, which provides drinking water to New York City. The largest town along the river is Deposit, New York part of Delaware County. This headwaters subwatershed is largely rural with 73% forests and 22% agriculture, mainly dairy farms. The relatively unpopulated subwatershed has a population of 23,000 people or a population density of only 35 people per mi^2. Many of the tributaries are clean enough to support year-round populations of wild trout.

EW2 East Branch: The East Branch of the Delaware River flows through the Appalachian Plateau from Pepacton Reservoir joining the Delaware River at Hancock, New York in Delaware County. Approximately 90% of the subwatershed is forested, the most heavily wooded in the Delaware Basin. Around 19,000 people live in the 840 mi^2 subwatershed, a density of only 23 people per mi^2. Most streams in the East Branch exhibit exceptional water quality.

EW3 Mainstem Hancock to Narrowsburg: This 524 mi^2 subwatershed includes the main stem of the Delaware River from Hancock, New York as it cuts the gorge through the Appalachian Plateau and flows through Callicoon to Narrowsburg, mostly in Sullivan County. The rural watershed is 80% forest and 17% agriculture. Only 20,000 people live in this rural subwatershed accounting for a population density of 38 people per mi^2. The relatively pure water of the main stem of the Delaware River supports a thriving canoe, kayak, and rafting ecotourism and recreation industry.

LW 1 Lackawaxen watersheds: The Lackawaxen River is tributary to the Delaware River at the town of Lackawaxen, Pennsylvania and north of Matamoras, New York. The watershed drains Lake Wallenpaupack where flow is controlled for hydropower, recreation and flood control. This stream is located in the heavily forested (76%) and glaciated Poconos low plateau region of Pennsylvania. From 1990 to 2000 as more people relocated from the New York City suburbs, population in the LW1 subwatershed increased by 25% to 50,000 people, the 4th largest population increase among the 21 Delaware Basin subwatersheds. The Pocono Mountain forests and lakes support seasonal tourism and recreation with more people are choosing to live year round and commute to jobs in New York City and North Jersey. .

NM1 Neversink-Mongaup watersheds: This 815 mi^2 subwatershed has a population of 77,960 with approximately 96 people per mi^2 in year 2000. Outdoor recreational activities and proximity to New York City attract a significant influx of population during the summer months. The subwatershed includes the Neversink and Mongaup and Delaware Rivers near Matamoras, Pennsylvania and Port Jervis, New York. About 90% of the watershed is covered by forests in and near the Upper Delaware River National Wild and Scenic River. Thus, water quality is very good. With improvements in water quality and increases in public open space, species such as bald eagles and black bears are returning to their forested, mountainous habitats where the three states join together near the Delaware River at Port Jervis.

3.3. Central Region Subbasin (PA and NJ)

The Central Region of the Delaware River Basin in New Jersey and Pennsylvania represents a very complex set of physiographic conditions that vary along a gradient from the uplands to the lowlands. The upper regions are part of the Appalachian Plateau physiographic province that has been glaciated and has numerous small lakes. This region is steeply dissected by valleys cutting through glacial till and sedimentary sandstone and shale bedrock. The major stream within this region is the Lehigh River which flows south to southeast to its confluence with the Delaware River at Easton. The Lehigh Valley extends south from the Appalachian Plateau Province into the Anthracite Upland Section of the Ridge and Valley Province, cutting through the Blue Mountain Section and flows from there to its terminus largely within the eastern end of the Great Valley Section. Within the Great Valley Section a mix of shale, slate, carbonate, and crystalline metamorphic rocks can be found. Numerous small watersheds with streams that flow directly into the Delaware River also exist between the Lehigh Valley and the main stem of the Delaware River.

Land cover and land use in the upper regions of the Pennsylvania part of this Central Region is largely forest. Valleys to the south and at lower elevations were traditionally farmed. The region was once the heart of anthracite coal mining for the United States and an unwanted legacy of streams polluted by acid mine drainage was left behind in the middle portion of the Lehigh Valley. A zinc smelter was also operated at Palmerton in this region to take advantage of the availability of coal which polluted the air and soils downwind with metals. This region in generally is currently experiencing rapid urbanization in its northern regions for recreation and due to its proximity to large population centers in New Jersey and New York. Several older major industrial communities - Bethlehem, Allentown, and Easton - are located in the southern end of the Lehigh Valley. Suburban development still is occurring there. Most of the growth in urban areas appears to be occurring at the expense of forest land.

This area in northwestern New Jersey encompasses all of Warren County and the western half of Sussex County and includes two portions of the Valley and Ridge physiographic province, a region of tilted Paleozoic sedimentary rocks. The eastern portion includes the valley underlain by the Kittattiny Limestone; this region has supported agriculture since its settlement in the late 1700's. The western portion includes of the subwatershed is located on the steep topography of shales, sandstones and conglomerates that make up the Kittattiny Ridge. This portion is forested, with much of the area included in federally-protected land (Delaware Gap National Recreation Area) and state land (Worthington State Forest, Stokes State Forest, High Point State Park). It is intermediate among the set of subwatersheds in area, population, rate of population change, and population density. Increasing suburbanization in the Kittattiny valley accounts for much of the land use change.

This subbasin includes a small tongue of hilly terrain composed of Pre-Cambrian gneisses and schists of the New England Upland physiographic province along the northern edge of the area, with the rest being rolling topography of the shales and sandstones of the Piedmont physiographic province. The region is developing rapidly, experiencing a 10 percent increase in population over the past as agricultural land is converted to suburban housing.

UC1 Pocono Mountains, Pennsylvania tributaries: This rural and forested 779 mi^2 subwatershed is in the Pocono Mountains of Pike and Monroe Counties, Pennsylvania. The lake-filled landscape popular with tourists and vacationers is dominated by the double hump of the Kittatiny and Blue Mountain Ridges of the Appalachian Plateau near the Delaware Water Gap. Major trout streams include the Broadhead Creek and Bushkill Creek near Stroudsburg. Although still very rural with 74% forests and 16% agriculture, the subwatershed is urbanizing (8% developed) due to relocating workers that commute via I-80 to distant jobs in North Jersey and New York City. From 1990 to 2000, the population increased 27% to 208,500, a density of 268 people per mi^2. This population increase was the 3rd greatest among the 21 subwatersheds in the Delaware River Basin.

UC2 Highlands of New Jersey tributaries: On the other side of the Delaware Water Gap lies the 745 mi^2 highlands subwatersheds of New Jersey in the wrinkled Ridge and Valley Province. This largely rural subwatershed (64% forest and 28% agriculture) includes trout streams along the Flat Brook, Paulinskill, and Musconetcong River in Sussex and Warren Counties. The subwatershed is protected along the spine of the Appalachian Trail,part of the Delaware Water Gap National Recreation Area and Worthington, Stokes, and High Point State Parks. Over 218,000 people live in the subwatershed bisected by I-80. Population density is 294 people per mi^2 , a 9% increase from 1990 to 2000.

LV1 Lehigh River above Lehighton: This 451 mi^2 headwaters subwatershed of the Lehigh River lies north of the Blue Mountain ridge in the glaciated Pocono Plateau and Anthracite Uplands of the Ridge and Valley Province. The land of the Molly Maguires, this area in Monroe and Carbon counties near Palmerton, Pennsylvania is a center of coal mining.

Over 87% forested, the land is too rugged for farming (only 2% agriculture). Only 38,000 people (83 people per mi^2) live up on the Pocono Plateau or down in the anthracite valleys as this subwatershed is one of the most sparsely settled in the Delaware Basin. Some of the best brook trout habitat lies in the upper LehighValley although it is greatly reduced by acid drainage from the coal mines.

LV2 Lehigh River above Jim Thorpe: As the Lehigh River flows downstream into the Blue Mountain section of the Ridge and Valley, the 430 mi^2 subwatershed adopts a more agricultural character (17% cultivated) while still heavily forested (70%). This is coal country. The Molly Maguires, a group of Irish coal miners were jailed in Jum Thorpe, Pennsylvania in Carbon County near where the Lehigh cuts through the Blue Mountain gap. The subwatershed is becoming a center of ecotourism with river rafting and mountain biking concentrated near the "Little Switzerland" of Pennsylvania. The population density is around 200 people per mi^2, still rural in character.

LV3 Lehigh River Bethlehem and Easton: Downstream from the little water gap in the Blue Mountain, the 479 mi^2 subwatershed becomes more agricultural (45%) and developed (27%) and less forested (27%) as the Lehigh River flows by the steel mill towns of Allentown, Bethlehem, and Easton in Lehigh and Northampton Counties to the junction with the Delaware River. With almost 480,000 residents, this watershed has a density of 1000 people per mi^2, the 5th highest in the basin ranking only behind the subwatersheds near Philadelphia. Interstate Route 78 is a principal commuting route opening up the Lehigh Valley as a bedroom suburb of the edge cities in North Jersey near New York City.

LC1 Lower Central subwatershed above Trenton: These subwatersheds include the Tohickon Creek in Bucks County Pennsylvania and the Wichechoke Creek in Hunterdon County, New Jersey in the rolling pastoral hills of the Piedmont Province. Almost 42% of the 454 mi^2 subwatershed is agriculture interspersed with contiguous forests (45%). The land is attracting executive homes and weekend farmers where residents can commute to New York City or Philadelphia via train from Trenton. About 160,000 people live in the subwatershed amounting to a density of 352 people per mi^2, still somewhat rural. One of the most famous events in American history occurred here on a snowy Christmas Day in 1776 when George Washington crossed the Delaware from Pennsylvania to New Jersey and defeated the British and Hessions at Trenton.

3.4. Lower Region Subbasin (PA, NJ, DE)

The Lower Region of the Delaware River Basin is represented by watersheds in Pennsylvania, New Jersey and Delaware. The Pennsylvania portion is dominated by the Schuylkill River Basin and smaller watersheds that drain from Pennsylvania directly into the Delaware River in the vicinity of Philadelphia. The Schuylkill River originates in the Ridge and Valley Province (Blue Mountain Section and Great Valley Section) and flows southeast through the New England and Piedmont Provinces to merge with the Atlantic Coastal Province at Philadelphia. Most of the Blue Mountain Section uplands are underlain by sandstone and shale on the ridges and limestone/dolomite in the valleys. Uplands are heavily forested, but agricultural land uses have historically dominated the valleys. Anthracite coal mining also occurred in the uplands of the Schuylkill Valley and impacts of acid mine drainage are still in evidence today. The less steep Great Valley Section on lower portions of the watershed are underlain by softer shales and in the New England Province crystalline metamorphic rocks are found. The Piedmont contains limestone and dolomite bedrock. Lowlands on this basin in generally show mixed agricultural and forest land uses, rapid urbanization is occurring with growth of the metropolitan Philadelphia area. Land use changes are primarily increases of urban/suburban lands and surprisingly increases in agricultural lands in some regions , while the proportion of forest lands decreases. As much as 10% of land area was converted from forest land to urban and agricultural uses in Upper Estuary (UE1) subwatersheds over the period 1992-2001.

SV1 Schuykill above Reading: This 342 mi^2 subwatershed is situated north of the Blue Mountain ridge in the Anthracite and Blue Mountain sections of the of the Ridge and Valley Province in Schuylkill County, Pennsylvania. This area is mined for coal and is heavily forested (71%). Only 21% of the subwatershed is farmed and 6% is developed near the river towns of Pottstown and Reading. About 88,000 people live in the subwatershed, a density of 260 people per mi^2. The subwatershed has lost population between 1990 and 2000 due to the closure of industries.

SV2 Schuylkill above Valley Forge: Flowing south, the Schuylkill Valley in the Great Valley becomes more agricultural (52%) and developed (12%) and less forested (35%) as the river nears the Philadelphia suburbs. The 656 mi^2 subwatershed houses 321,000 people in Carbon County, an increase of 10% from 1990 to 2000.

SV3 Schuylkill above Philadelphia: With almost 1,100 people per mi^2, the 894 mi^2 lower Schuylkill subwatershed is the 4th most populous in the Delaware Basin as the river flows from the hilly Piedmont to the Coastal Plain at sea level in Philadelphia. Over 28% of the subwatershed is developed in suburban Montgomery and Chester Counties. Farming (36%) and forest (34%) diminishes as the Schuylkill flows closer to the head of tide at Philadelphia. William Penn chose the peninsula between the Delaware and Schuylkill as the site of Philadelphia in 1680 for his green country town.

UE1 Pennsylvania Fall Line subwatersheds: This 702 mi^2 network of tributaries between Trenton and Chester includes Neshaminy Creek, Pennypack Creek, and Darby Creek in Bucks, Philadelphia, and Delaware counties, Pennsylvania that cross the fall line from the Piedmont to the Coastal Plain province. This subwatershed includes dense Philadelphia neighborhoods and surrounding suburbs and at 3,700 people per mi^2 is by far the most densely populated in the Delaware River Basin. Over 59% is developed, only 15% is farmed, and 22% remains in forests.

UE2 New Jersey Coastal Plain subwatersheds: This 1,043 mi^2 subwatershed in Mercer, Burlington, Camden, and Burlington Counties in New Jersey is a fairly large area, located entirely within the Coastal Plain physiographic province. A small portion of the subwatershed, the upper reaches of the Rancocas River, are within the Outer Coastal Plain (New Jersey Pinelands), a region of extremely sandy unconsolidated sediments; the remainder of the region is within the Inner Coastal Plain, a region of more loamy but unconconsolidated, older sediments. The two stations chosen for analysis include Crosswicks Creek, a large basin which drains a partly agricultural and partly densely suburban region on the outskirts of the city of Trenton in the northern part of the sub-basin, and the North Branch Rancocas River in the middle of the subwatershed, which in part drains a large, protected forested area in the Outer Coastal Plain region (New Jersey Pinelands). The subwatershed has experienced moderate population growth (5.3% change from 1990 - 2000), and increased developed area (32%) with loss of forest and agricultural land.

LE1 Christina/Brandywine Rivers: The 603 mi^2 Christina and Brandywine Rivers subwatershed in Delaware and Pennsylvania is the only source of public surface water supply in Delaware as the streams provide 100 mgd to 400,000 people, 60% of the First State population. The subwatershed includes the Brandywine, Red Clay, White Clay, Christina, and Naamans Creeks – the only streams in the Delaware Basin which flow through at least two states. The Christina River flows from the hilly Piedmont in Pennsylvania entering Delaware at the arc and crossing through the fall line before flowing through the flat Coastal Plain meeting the Delaware River at sea level at Wilmington, site of the first permanent European colony in the Delaware Basin . About 30% of the subwatershed is developed, 32% is forested and 37% is agriculture. Close to job centers at Wilmington and Philadelphia, the subwatershed is suburbanizing and with 1,100 people per mi^2. The Christina/Brandywine has the 3rd highest population density in the Delaware River Basin. The Brandywine watershed is famous as the home of the original DuPont gunpowder mills, the Pyle and Wyeth schools of art, and epicenter of great American gardens such as Longwood and Winterthur. The White Clay Creek is a national wild and scenic river, one of only two in the nation designated on a watershed instead of river corridor basis.

LE2 C & D Canal, DE: The 155 mi^2 LE2 subwatershed includes the flat sandy Coastal Plain tributaries in Delaware draining to the Delaware River and upper Delaware Bay including Army Creek, Red Lion Creek, Dragon Run, Chesapeake and Delaware Canal, Augustine Creek, Appoquinimink River, Blackbird Creek, and Smyrna River (Duck Creek). The watershed is largely rural (20% forest and 47% farming) yet is rapidly suburbanizing (17% developed) in the flat country surrounding the towns of Middletown, Odessa, and Townsend in southern New Castle County, Delaware. With the construction of the Delaware Route 1 toll road, the watershed south of the Chesapeake and Delaware Canal has become an outlying bedroom suburb of Wilmington and for more adventurous commuters, Philadelphia. The LE2 subwatershed is the second most rapidly growing subwatershed in the entire Delaware River Basin with a population increase of 52% between 1990 and 2000.

The Delaware coastal plain watersheds are renowned for the vast coastal wetlands (10%) that lie between Route 9 and the Delaware Bay. The coastal tributaries and the bay support a lucrative blue crab fishery and the northern reaches of the bay oyster beds sit off the coast near Woodland Beach and Bombay Hook National Wildlife Refuge. Each May back in the late 1800s, the docks at Delaware City and Port Penn, Delaware, were jammed with Atlantic sturgeon along America's premier sturgeon river. The old Indian path between the Appoquinimink River draining to the Delaware and the Sassafras River flowing to the Chesapeake is the shortest land path between these two water bodies. Just to the north, 19th century engineers dug the Chesapeake and Delaware Canal in 1829 as one of the shortest points between the two estuaries. Odessa, Delaware was named after the great Russian port in 1855 and was once a major grain shipping center at the head of the Appoquinimink Creek. Nowadays, Odessa is famous as a restored colonial town in a association with the Winterthur museum, a "Williamsburg – like" recreation as it were without all the trappings. This fertile coastal plain watershed was once one of the most productive peach growing areas in the United States. In 1953 the peach blossom became Delaware's State flower. Today the Town of Middletown celebrates this agricultural heritage during the annual Peach Festival in August.

LE3 Salem River, NJ: This small 262 mi^2 subwatershed is located in the inner Coastal Plain. This is one of the subwatersheds that endow the Garden State with its nickname as it remains primarily agricultural (48%) and forested (25%) with relatively little development (only 9%). Almost 12% of the subwatershed is covered by tidal wetlands along the Delaware River and Bay. It experienced little population growth (less than 1%) over the past decade. Two small watersheds were selected for data acquisition: Oldman's Creek is a small watershed in the northern portion of the sub-basin, and Salem River is a small watershed in the southern portion of the area. The subwatershed still retains relatively low population density (207 people per mi^2), although it has experienced loss of forests and increase in developed land.

3.5. Bay Region Subbasin (DE and NJ)

DB1 Delaware Bay tributaries, DE: This heavily agricultural watershed includes the lazy, meandering, brackish Delaware coastal plain tributaries draining to the lower Delaware Estuary including Leipsic River, St. Jones River, Murderkill River, and Broadkill River. The DB1 subwatershed watershed covers 634 mi^2 with 53% farmed, 22% in forest and 17% in wetlands along the Delaware Bay. Approximately 60% of the subwatershed is in Kent County and 40% is in Sussex County. There are 781 farms located in the subwatershed. The average farm size is 257 acres with 5% of the farms between 500 and 1,000 acres and another 5% exceed 1,000 acres. There are 187,904 acres in farms in the watershed with 509 acres enrolled in the Conservation Reserve Program. Approximately 86% of the watershed or 161,600 acres is cropland. Corn, soybeans and wheat are the primary crops grown on about 85% of the acreage. Vegetables are grown on 14% of the acreage and hay and pasture account for the remaining one percent. Poultry is the dominant type of livestock operation in the watershed.

The DB1 watershed is world - famous as the home of the oyster beds in the Delaware Bay and as the integrated habitats of the horseshoe crab and red knot shorebirds. The oyster beds are situated in the bay shelf off the coast of Dover, Delaware. Each spring migratory shorebirds such as the red knot gorge on the horseshoe crab eggs as sustenance on their way north from southern Chile and Argentina to their summer grounds in the Arctic. In a complimentary relationship, each spring the largest concentration of horseshoe crabs in North America lay their eggs on the beaches at Woodland Beach, Bowers Beach, Slaughter Beach, Prime Hook, Broadkill Beach, Cape Henlopen.

The southern part of the DB1 subwatershed is developing rapidly as part of the summer resort influx close to the Atlantic Ocean towns of Lewes and Rehoboth Beach, Delaware. The subwatershed population grew by 17% between 1990 and 2000. By 2000 the population was 142,000. Cape Henlopen State Park is the northern-most Atlantic Ocean beach in Delaware and the closest beach in the state to Wilmington and points north. Due to low property tax rates (around a $1,000 per year), the towns in this watershed are becoming a nationwide magnet for retirees interesting in living near the Atlantic beaches with a pleasant, southern-like year round climate.

DB2 Delaware Bay tributaries, NJ: This 790 mi^2 subwatershed is largely occupied by the Maurice River, which drains from the Pinelands National Reserve to the Bay, plus a number of very small watersheds on the Cape May Peninsula. The entire subwatershed is on the Outer Coastal Plain, whose very sandy sediments both create waters with very low nutrients and suspended solids under undisturbed conditions but also readily allow pollutants from both urban and agricultural land-uses to rapidly move to surface waters. The subwatershed is developing rapidly (7% increase in population in the last decade), with losses of agricultural and forest land, and increases in urban and barren land. However, population density is still moderate at 300 people per mi^2, and the subwatershed is intermediate in rank in total forested area. Two stations on the Maurice River were used for water quality data, one including the upper drainages, and the other encompassing the lower basin. Bald eagles are returning to the forests (44%) and wetlands (17% of the subwatershed) along the bay. Shell planting and aquaculture programs seek to bring the oyster beds back to their once prodigious numbers that harken back to the days of boom towns like Shellpile and Bivalve, New Jersey.

Chapter 4 – Environmental Indicators

4.1. List of indicators

From a candidate list of 200 indicators drawn from watersheds in the National Estuary Program and throughout North America, the land grant university consortium and DRBC, PDE, USGS, and USEPA selected over 50 indicators to report trends in the Delaware River Basin (Table 4.1). The team culled the list of indicators by the following criteria:

- Utilize indicators already selected by the PDE as published in the 2002 *State of the Estuary Report*.
- Existing and abundant data must be available for the selected indicator. No new monitoring programs would be initiated to collect data for the selected indicators.
- Data should be available for each indicator throughout the Delaware Basin in all 21 subwatersheds. Fish may be a major category, with striped bass as the indicator in the estuary and brook trout in the nontidal streams.

The need for environmental indicators is discussed in the following reports issued by the USEPA, the U. S. Government Accountability Office, the Delaware River Basin Commission, and the Partnership for the Delaware Estuary.

4.2. USEPA Report

The USEPA (2002) compiled an index of watershed indicators to measure the health of aquatic resources in the USA.

Just as a physician might take your temperature and your blood pressure, check your pulse, listen to your heart beat and respiration, evaluate your weight compared to your height, etc., the Index looks at a variety of indicators that point to whether rivers, lakes, streams, wetlands and coastal areas are "well" or "ailing" and whether activities on the surrounding lands that affect our waters are placing them at risk.. The Index is based on the June 1996, Indicators of Water Quality in the United States, developed by EPA in partnership with States, Tribes, private organizations, and other Federal Agencies. The Indicators Report presents 18 indicators of the "health" of our water resources. The Index of Watershed Indicators evaluates a similar set of indicators for each of 2,111 watersheds, or " units" in the 48 states….

4.3. GAO Report

In 2005, the U.S. Government Accounting Office released a report that found some environmental data needed to monitor environmental conditions may be unavailable in the future (GAO 2005):

The GAO study was requested in October, 2003 by Science Committee Chairman Sherwood Boehlert (R-NY) and Environment, Technology, and Standards Subcommittee Chairman Vernon Ehlers (R-MI) in response to a landmark 2002 Heinz Center report that identified the key indicators necessary for monitoring ecosystem health and measuring the efficacy of environmental protection. The report, "The State of the Nation's Ecosystems," was released at a September 24, 2002 Science Committee hearing. Of the more than 100 key indicators it identified, the study found that high quality data sets existed for only half. For the remaining indicators, the study found that only partial or, in some cases, no data existed.

4.4. Delaware River Basin Water Resources Plan

The September 2004 Water Resources Plan for the Delaware River Basin discusses the need for environmental indicators to measure progress and assess the health of the Delaware River Basin.

Assessing a baseline condition means determining the status or condition of a resource attribute using a measure or indicator. In the context of the Basin Plan, a baseline is the condition or set of conditions at one point in time; the starting point against which conditions in succeeding years can be measured. A target or reference condition is aspired to, a condition which actions are intended to produce. For example, a degraded wetland might undergo restoration efforts to return it to a better or target condition, one closer to that of a "reference" or unimpaired wetland.

Much has been accomplished since the passage of pollution control and environmental legislation in the second half of the last century. States have established environmental protection and conservation agencies, adopted rules and standards to govern withdrawals from and discharge to their streams and rivers, and begun developing criteria for the protection of human and aquatic ecosystem health to their streams and rivers, and begun developing criteria for the protection of human and aquatic ecosystem health. Each state has developed programs and set priorities, making varied progress across an array of water resource issues. This plan sets a structure for taking stock of these achievements and for identifying areas still needing action.

Existing programs and plans form the foundation of progress already made in the water resource arena. We will build on this foundation, and measure progress from this baseline. Measuring progress toward achieving the Basin Plan's Goals and Objectives rests on the ability to:

- *Assess baseline conditions.*
- *Monitor and report on those critical indicators when combined signal the improvement or deterioration of conditions in the Basin's watersheds.*

4.5. White Paper Summary of the 2005 Delaware Estuary Science Conference

The White Paper Summary of the 2006 Delaware Estuary Science Conference discusses the need for environmental indicators to improve monitoring capabilities (Kreeger *et al.* 2006).

Improvement in our monitoring capabilities is a fundamental need. Environmental conditions in the Delaware Estuary are currently monitored with numerous programs….. For some aspects of water quality and living resources, we are fortunate in having long-term datasets for the Delaware Estuary; e.g., DRBC "Boat Run" and Rutgers oyster surveys, respectively. It is imperative that these programs be continued to maintain the integrity of long-term monitoring data, which is increasingly viewed as critical for assessing status and trends. Monitoring programs should be broad based, capturing functionally dominant components of the physical, chemical and biological ecosystem.

New indicators are needed that can be used to gauge the status and trends of ecologically significant species or critical habitats in the Delaware Estuary and watershed, such as riparian corridors, wetlands and reefs. Development of indicators and goals that capture the important elements of a commonly accepted conceptual framework and link to monitoring activities would have enormous value for environmental managers and education and outreach activities. This would also lead to improved State of the Estuary reports (e.g., DELEP 2003) that better link to scientifically meaningful measures of environmental condition. By emphasizing desired future conditions, this would also strengthen efforts to improve forecasting capabilities and link science to policy outcomes.

The 2006 White Paper lists the top ten technical needs for advancing science and management of the Delaware Estuary:

1. *Contaminants (forms, sources, fates & effects for different classes)*
2. *Tidal Wetlands (status, trends and relative importance of different types)*
3. *Ecologically Significant Species & Critical Habitats (benthos, reefs, horseshoe crabs)*
4. *Ecological Flows (effects of base and episodic flows on salt balance & biota)*
5. *Physical-Chemical-Biological Linkages (e.g., sediment budget effects on toxics & biota)*
6. *Food Web Dynamics (key trophic connections among functional dominant biota)*
7. *Nutrients (forms, concentrations and relative balance of macro- and micronutrients)*
8. *Ecosystem Functions (assessment and economic valuation of ecosystem services)*
9. *Habitat Restoration and Enhancement (science & policy)*
10. *Invasive Species (monitoring, management & control)*

Environmental indicators are typically defined as parameters, or values derived from measured parameters, that describe or provide information about an environmental phenomenon. In many cases, indicators are developed to answer specific management questions pertaining to relative changes in ecosystem states or environmental conditions. Indicators should be representative, easy to interpret, provide information on trends over time, and be responsive to changes imposed by humans (e.g., policy, restoration activities). Indicators should also be appropriate in terms of scientific and/or technical acceptability.

The Pressure-State-Response (PSR) framework … has been applied in many natural resource management indicator programs. This framework provides a conceptualization of how anthropogenic, or other, pressures potentially affect change in an environmental condition, resulting in a measurable state that invokes a human response. This framework provides the basis of conceptual models that can then be developed at appropriate scales to aid in the appropriate selection of environmental indicators.

4.6. Maryland Growing Smart List

The report *Maryland Growing Smart* lists the *Seven Things a Good Indicator Should Do (*Univ. of Maryland 2005):

1. *Measure something important – a condition that people accept as important to measure.*
2. *Measure an objective condition – a sound indicator that is value-free.*
3. *Measure what it claims to measure – an indicator should be defined with care so it cannot be misinterpreted.*
4. *Should be transparent and accurate – the average citizen should be able to understand its logic.*
5. *Capable of being measured at different geographic scales – from neighborhood to community to state.*
6. *Should reflect best practice – indicators that have been widely used in other jurisdictions and contexts or have endorsement from professionals are desirable.*
7. *Should have relationship to other indicators that can be grouped for greater context on being measured.*

Table 4.1. List of environmental indicators and metrics for the Delaware River Basin.

Indicator	Metrics and Template for Reporting Data
Land Use/ Landscape	
Population	Two basin wide maps showing (a) 2002 pop density per watershed and (b) population change from 1990 to 2000 .
Land Use	Map and table with area and % of watershed with: developed, forested, cultivated, wetlands, from NOAA Coastal Services Center (CSC) data. Compare land use change 1996 to 2001.
Impervious Cover	Basin wide map and bar chart and table comparing % impervious cover for each subwatershed for 2001 from USGS NLCD data.
Tidal Wetlands	Acreage by type provided by Battelle report draft 2006 to PDE.
Tidal Wetland Buffers	Acreage, types of land uses in wetland buffer provided by Battelle report draft 2006 to PDE.
Total wetlands	Tabulate area (mi) and % of watershed area in pie chart and bar chart with changes from 1996 to 2001 using NOAA CSC data.
Forest	Tabulate area (mi) and % of watershed area in pie chart and bar chart with changes from 1996 to 2001 using NOAA CSC data.
Federal/State Superfund Sites	Basin wide map, table, and bar chart comparing the number of Federal superfund sites per subwatershed for the entire basin.
Riparian corridor condition	Table and bar chart summarizing number of road miles in 50 m wide from either side of stream buffer per watershed area for each of 21 watersheds.
Wild and Scenic Rivers	Map of national wild and scenic rivers in the Delaware River Basin.
Water Quality	
Dissolved Oxygen	Scatter graph showing all samples (mg/l). Show trends with 5 - year medians starting in 1990. Delineate stream water quality standards on the graph. For all water quality parameters, plot data for station at the downstream most point of the largest watershed or the two largest watersheds if there are multiple large streams that flow into the Delaware River.
Nitrogen, Total	Scatter graph showing all samples (mg/l). Show trends with 5 - year medians starting in 1990. If Total N is not available, then use Nitrate N or others forms of N.
Phosphorus, Total	Scatter graph showing all samples (mg/l). Show trends by medians in 5 year increments starting in 1990. Delineate state stream water quality standard on the graph.
Total Suspended Sediment	Scatter graph showing all TSS samples (mg/l). Show trends by medians in 5 year increments starting in 1990. Delineate state stream water quality standard on the graph.
Metals (Cu, Pb, Zn, Hg, As)	Scatter graph showing all samples (ug/l). Show trends by medians in 5 year increments starting in 1990. Delineate acute and chronic stream water quality standards on the graph.

Indicator	Metrics and Template for Reporting Data
Organics (PCBs, Atrazine, Metalachlor)	Scatter graph showing all samples (ug/l). Show trends by medians in 5 year increments starting in 1970. Delineate state stream water quality standard on the graph.
Water Temperature	Scatter graph showing water temperature in deg C. Show trends by medians in annual and 5 year increments from data provided by USGS continuous stream gages.
Fish Consumption Advisories	Basin – wide map of stream segments (red = full fish consumption advisory or one meal per year, orange = partial advisory, blue or green = no advisory)..
Sec 303(d) Designated Uses /Impaired Streams	Basin - wide map showing streams impaired (red) and unimpaired or unassessed (blue) for N, P, DO, and bacteria. Table to list miles of streams impaired by subwatershed.
Salt Line (chlorides)	In the tidal Delaware River and Bay main stem only. Graph and map location of salt line (250 ppm chloride line) at furthest upstream river mile per year beginning in 1970.
Water Quantity/Hydrology	
Water Supply and Demand	Graph existing and projected peak water demands (mgd) for each of the 21 watersheds using data from the DRBC.
Streamflow	Graph 1 with annual mean flow (cfs/sq mi) and precipitation (in) by water year starting in 1945. Graph 2 with lowest daily mean flow and highest peak daily flow in the water year since 1945.
Groundwater quantity	Tabulate groundwater availability and withdrawals (mgd) by subwatershed provided in report from USGS.
Flooding	Number of repeat claims per watershed area (1974 through 2006) to be provided by DRBC using data from FEMA.
Dams (hydrologic impairment)	Numbers of dams per watershed area map and table using USACOE National Dam Inventory see http://crunch.tec.army.mil/nid/webpages/nid.cfm. Integrate with Battelle report to the PDE.
Living Resources	
Macroinvertebrates	Basin-wide map showing streams with state rankings coded good (green), fair (orange), poor (red), not monitored (blue).
Oyster Beds	Map the areas of oyster beds and reefs using the Rutgers Haskins lab report 2005.
Eastern Oyster	Bar charts of oyster abundance (oysters/bushel), spat (oysters/bushel), and oysters harvested from seed beds (oysters per year) for Delaware Estuary utilizing the Rutgers Haskins lab report 2005.
Horseshoe Crab	Plot line graphs of habitat suitability index for DE and NJ shorelines. Supplement with Battelle report to PDE.
Blue Crab	Bar chart plotting blue claw crab landings for DE and NJ in Delaware Estuary 1978 – 2005. Discuss economic value.
Freshwater Mussels	Table listing species, watershed, county, river/stream, date, abundance using data from PDE.
Zebra Mussels	Use basin –wide map from USGS Jun 2005 of confirmed sightings in eastern US. One sighting in Lehigh River watershed in the DRB.
American Shad	Graph 1, bar chart showing annual spawning population 1991 – 2005 at Lambertville, NJ using 4 different sampling methods. Graphs 2 and 3, Shad population and netting effort.
Brook Trout	Basin –wide table and map showing location and condition of native brook trout habitat.
Striped Bass	Bar chart plotting annual abundance for Delaware Estuary 1990 – 2005
Atlantic Sturgeon	Bar chart plotting annual abundance for Delaware Estuary 1990 – 2005
Weakfish	Bar chart with annual counts since 1990.
Summer Flounder	Line graph showing flounder abundance since 1990.
Louisiana Water Thrush	Basin – wide map showing habitat change by subwatershed with breeding bird index.
Shorebirds (red knots)	Two line graphs from DNREC and NJDEP bar chart with number of bird sightings annually starting in 1990 - 2005.
Bald Eagle	Line graph and table listing annual number of nesting pairs by each state in the Delaware Basin.
Black Bear	Line graph and table listing annual population in each state in the Delaware Basin.
Amphibians/Reptiles Bog Turtle	Map showing range of bog turtle habitat in the Delaware Basin.
Endangered Species	Endangered and threatened species list for each of the 4 states in the Delaware Basin.

Chapter 5 – Landscape

5.1. Population

Watersheds with large population densities usually have poor water quality due to increased runoff and pollutant loads. U.S. Census data provide population for 1990 and 2000 for the 21 subwatersheds in the Delaware River Basin. Population data were tabulated for each census tract and then projected for each subwatershed (Table 5.1).

Population in the Delaware River Basin has doubled since 1920 and was at 7,800,000 in the year 2000 (Figure 5.1). The population increase between 1990 and 2000 was 600,000 people. Extrapolating, population in the basin may exceed 8,000,000 by 2010. Population density in the 13,000 mi^2 basin is just over 600 people per mi^2.

Population density varies considerably from 40 p/ mi^2 in the forested EW watersheds in New York to over 1,200 p/ mi^2 in the UE1 subwatershed at Philadelphia (Figure 5.2). In 2000, subwatersheds with the highest population density exceeding 350 people per mi^2 were in the Philadelphia metropolitan area including UE1, UE2, LV3, SV3, and LE1.

According to Figure 5.3, subwatersheds with the greatest population change (over 10%) from 1990 to 2000 were: LE2 in southern Delaware (51.9%), LV1 in the upper Lehigh Valley (46.2%), UC1 in the Pocono Mountains (27.3%), and LW1 in the Pocono Mountains (25.4%).

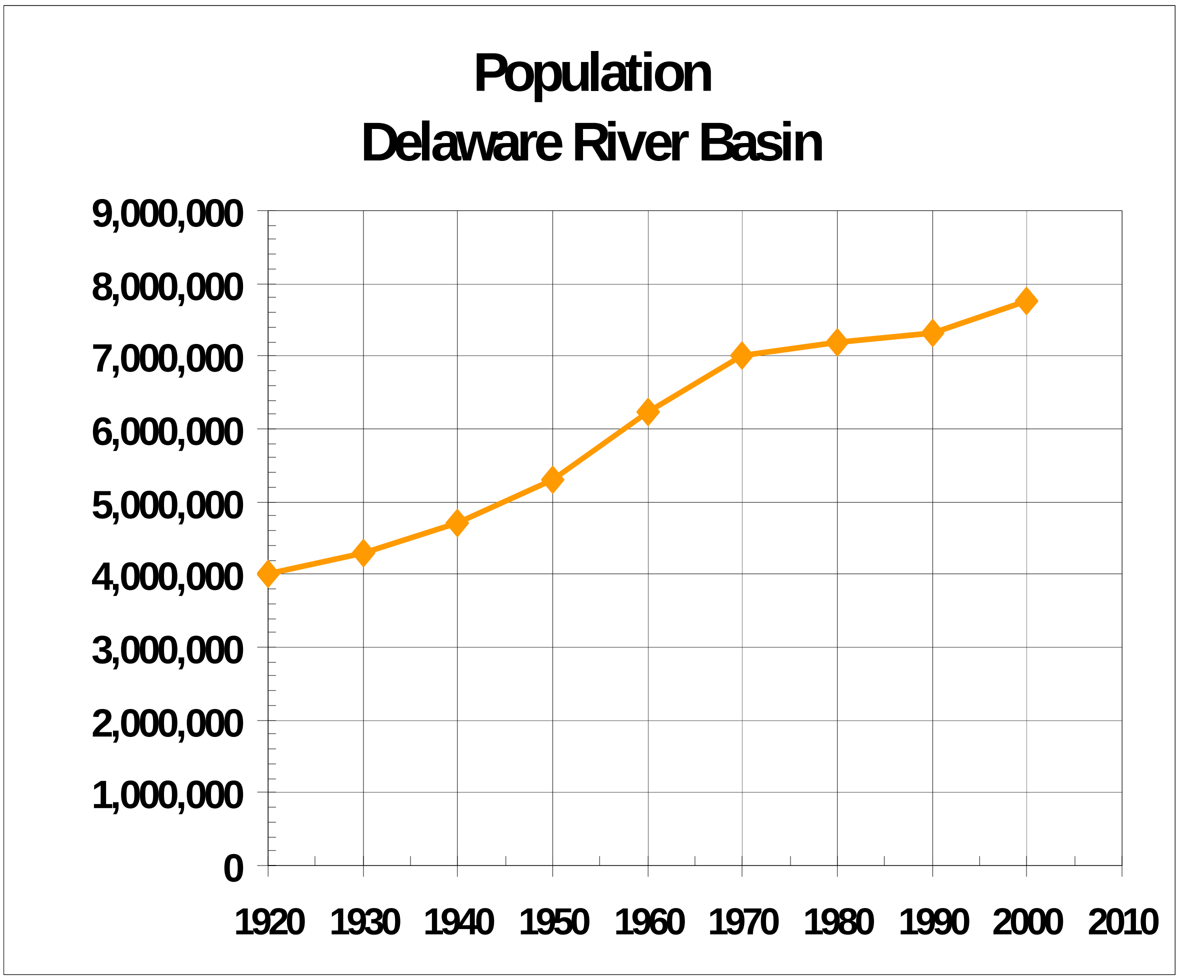


Figure 5.1. Population of the Delaware River Basin. (U. S. Census Bureau)

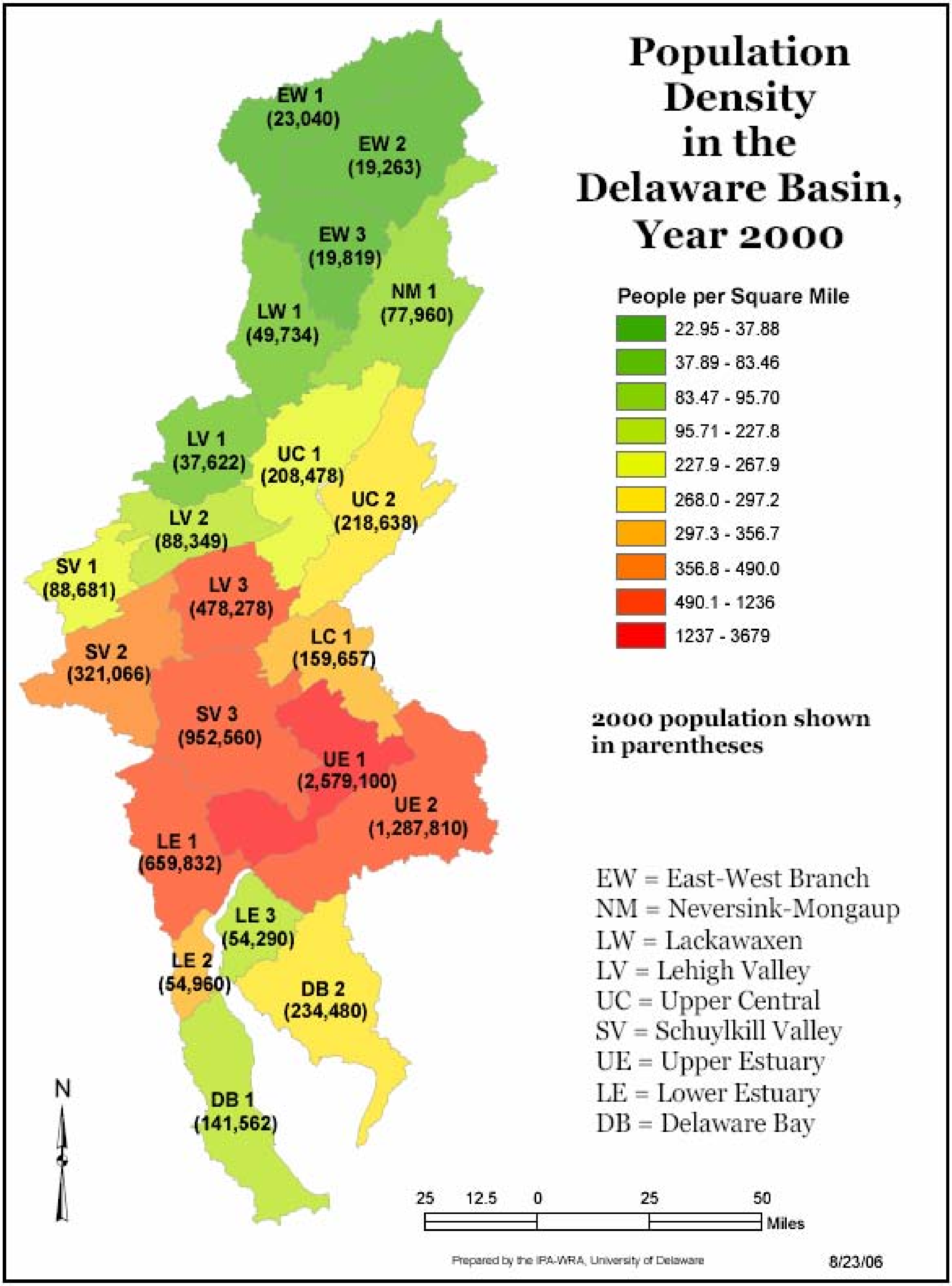


Figure 5.2. Population density in the Delaware River Basin.

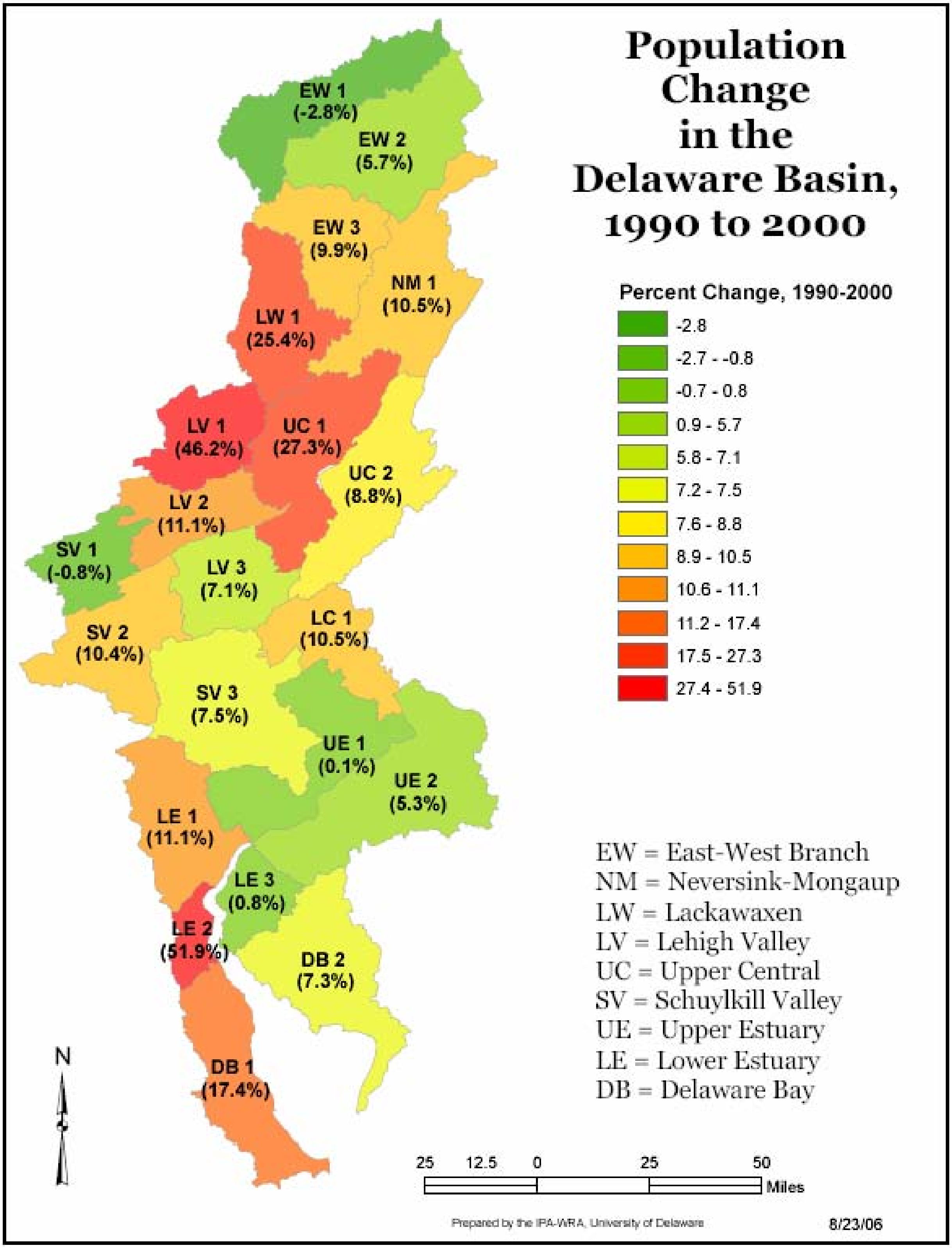


Figure 5.3. Population change in the Delaware River Basin.

Table 5.1. Population of Delaware River Basin subwatersheds.

	Area (mi^2)	1990 (pop.)	1990 (pop/ mi^2)	2000 (pop.)	2000 (pop/ mi^2)	% change 1990-2000
Upper Region (NY and PA)						
EW · East/West Branch						
EW1 West Branch (Cannonsville)	666	23,704	36	23,040	35	-2.8
EW2 East Branch (Pepacton)	840	18,216	22	19,263	23	5.7
EW3 Mainstem (abv Narrowsburg)	523	18,039	34	19,734	38	9.9
LW · Lackawaxen	597	39,673	66	49,734	83	25.4
NM ·Neversink-Mongaup	814	70,525	87	77,960	96	10.5
Central Region (PA and NJ)						
UC ·Upper Central watersheds						
UC1 Pennsylvania tributaries	778	163,773	210	208,478	268	27.3
UC2 New Jersey tributaries	745	200,886	270	218,638	294	8.8
LV ·Lehigh Valley						
LV1 Above Lehighton	451	25,734	57	37,622	83	46.2
LV2 Above Jim Thorpe	430	79,504	185	88,349	205	11.1
LV3 Above Easton	479	446,402	931	478,278	998	7.1
LC ·Lower Central (above Trenton)	454	144,433	318	159,657	352	10.5
Lower Region (PA, NJ and DE)						
SV ·Schuylkill Valley						
SV1 Above Reading	342	89,394	262	88,681	260	-0.8
SV2 Above Valley Forge	656	290,735	444	321,066	490	10.4
SV3 Head of tide at Philadelphia	894	885,775	992	952,560	1,066	7.5
UE ·Upper Estuary (Phila, Camden)						
UE1 Pennsylvania piedmont	701	2,576,370	3675	2,579,100	3,679	0.1
UE2 New Jersey coastal plan	1042	1,223,530	1,174	1,287,810	1,236	5.3
LE ·Lower Estuary Watersheds						
LE1 Christina River	603	594,092	986	659,832	1,096	11.1
LE2 C and D Canal, DE	154	36,170	235	54,960	357	51.9
LE3 Salem River, NJ	262	53,858	205	54,290	207	0.8
Bay Region						
DB ·Delaware Bay (NJ and DE)						
DB1 Delaware coastal plain	634	120,555	194	141,562	228	17.4
DB2 New Jersey coastal plain	789	218,427	277	234,480	297	7.3
Delaware River Basin	12,858	7,200,000	560	7,800,000	607	8.3 %

5.2. Land Use

The University of Delaware - Water Resources Agency delineated land use in the Delaware River Basin using NOAA Coastal Service Center (CSC) data for 1996 and 2001 (Figure 5.4). Several areas of the Lehigh River and Pocono Mountain watersheds in Pennsyvania were not mapped by NOAA so the UDWRA estimated land use proportions here using data from the USGS. In 2001, the Delaware Basin was covered by 14% developed land, 26% agriculture, 55% forest, and 5% water/wetlands or other (Figure 5.5).

Table 5.2 compares land uses in the Delaware River Basin for 1930 (INCODEL 1940), and 1996 and 2001 (NOAA CSC). Developed land gained 70 mi^2 from 1996 to 2001 and covers 14% of the basin, up from 3% in 1930. Agriculture lost 19 mi^2 between 1996 and 2001 and occupies 26% of the basin, down from 62% in 1930. Forests have decreased by 49 mi^2 between 1996 and 2001. But forests have increased to 55% in 2001, up from 32% in 1930. Wetlands have lost 4 mi^2 between 1996 and 2001 but have increased to 5% of the basin from 3% in 1930.

Land use varies widely ranging from over 70% forested in mountainous watersheds in the headwaters of the Catskill and Pocono Mountains (EW1, EW2, EW3, LW1, NM1, LV1, LV2, UC1, SV1), to over 20% developed in Philadelphia and suburbs (SV3, UE1, UE2, LE1), to over 10% wetlands and over 25% agriculture along the Delaware Bay (LE2, LE3, DB1, DB2) to the south.

Table 5.2. Land use in the Delaware River Basin for 1930, 1996, and 2001.

Land Use	**1930**	**1996**	**2001**
	INCODEL (mi^2)	NOAA (mi^2)	NOAA (mi^2)
Developed	386	1790	1860
Agriculture	7980	3361	3342
Forest	4117	7093	7044
Water/Wetlands	386	572	568
Developed	3%	14 %	14%
Agriculture	62%	26 %	26%
Forest	32%	55 %	55%
Water/Wetlands	3%	5 %	5%

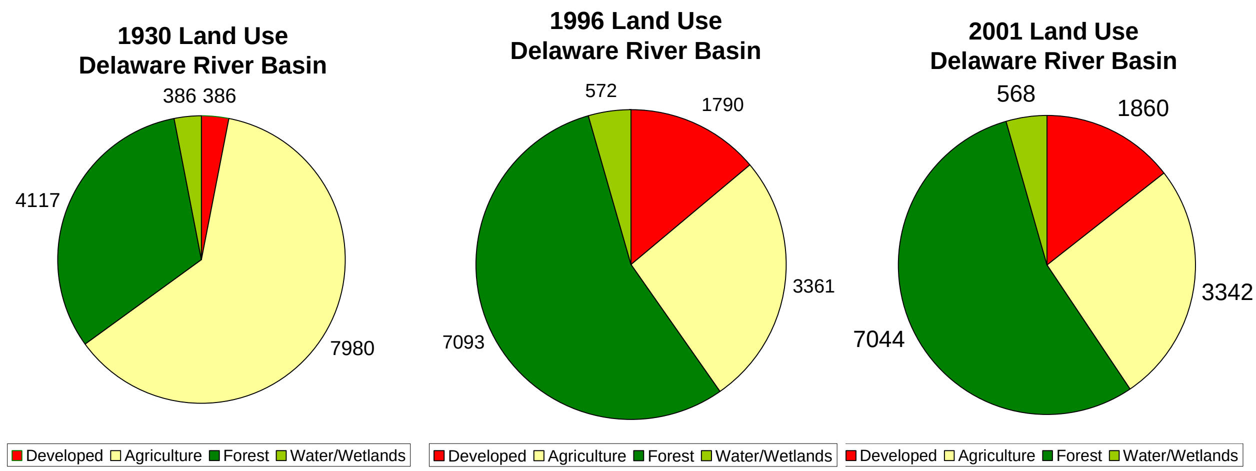


Figure 5.4. Land use in the Delaware River Basin, 1930, 1996, and 2001. (INCODEL, NOAA CSC)

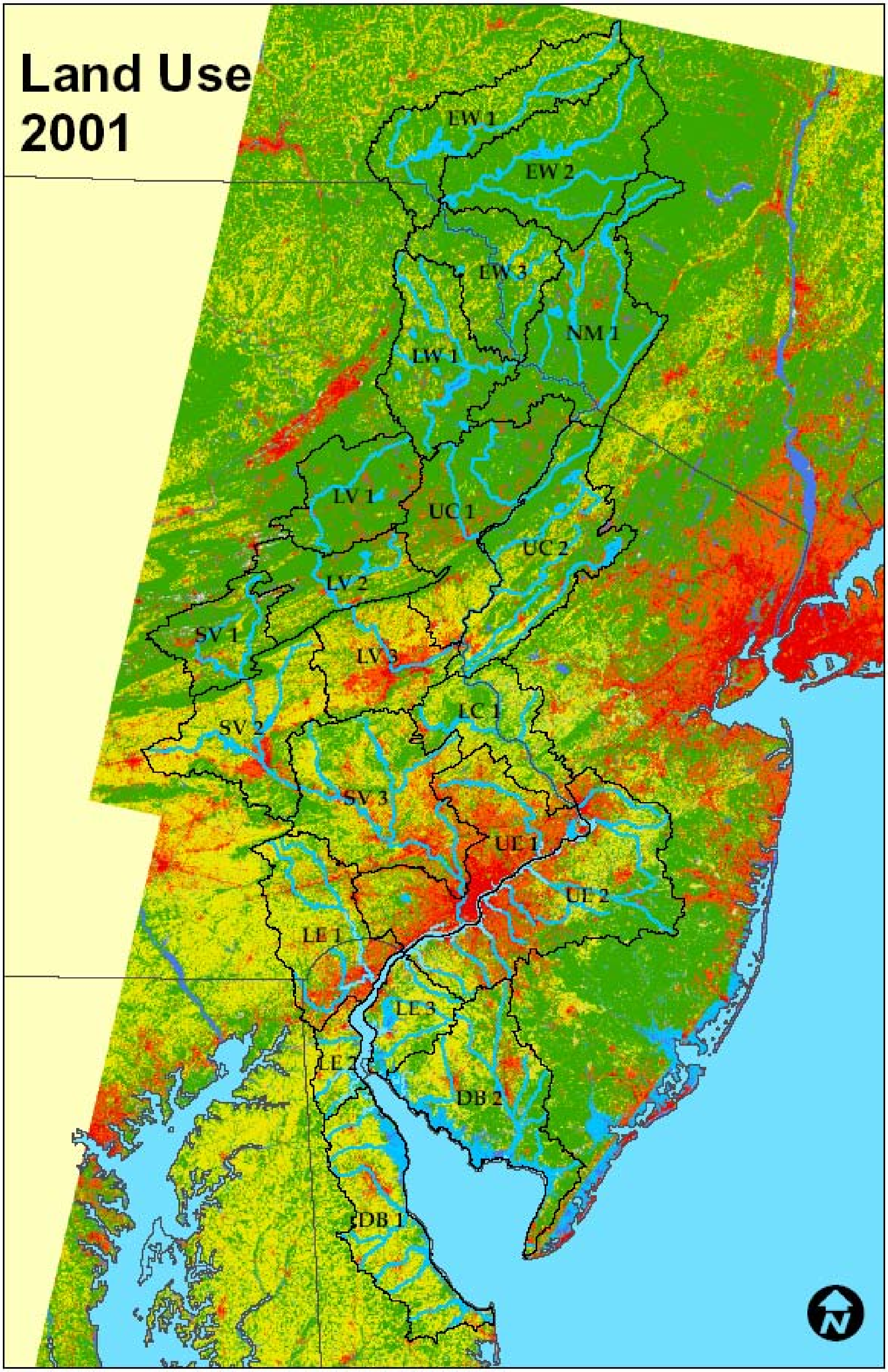


Figure 5.5. Land use in the Delaware River Basin, 2001. (NOAA CSC)

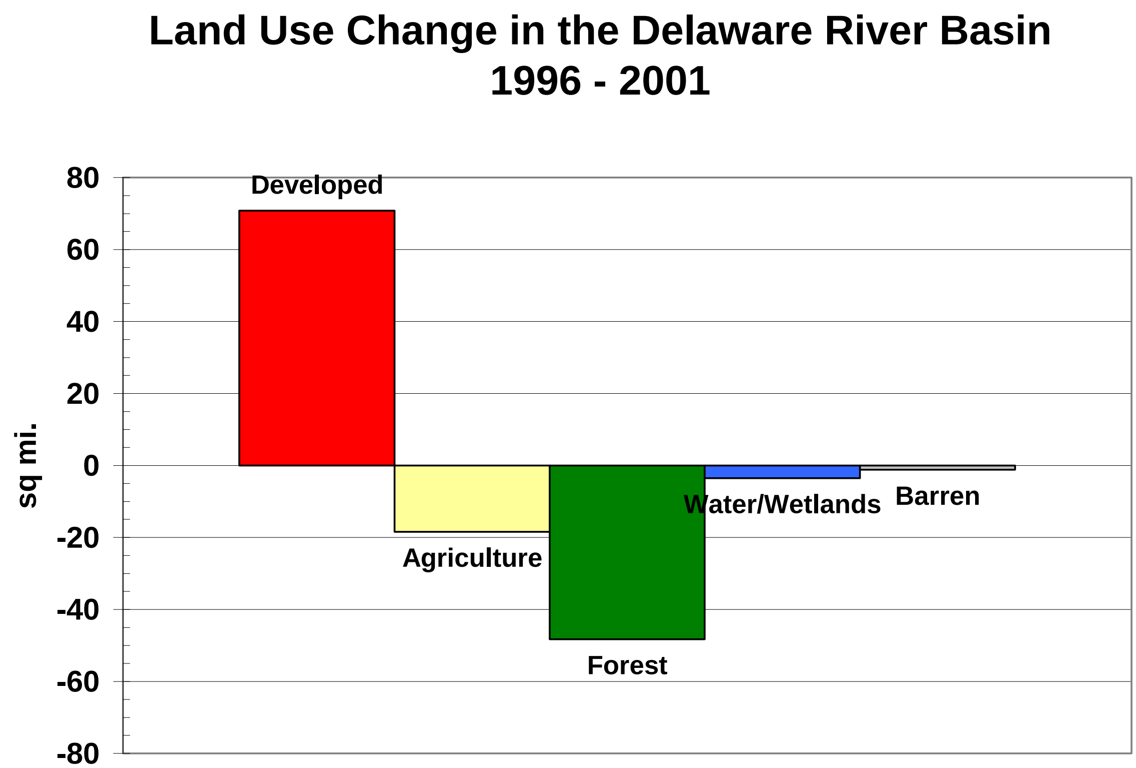


Figure 5.6. Land use change in the Delaware River Basin, 1996 - 2001. (NOAA CSC)

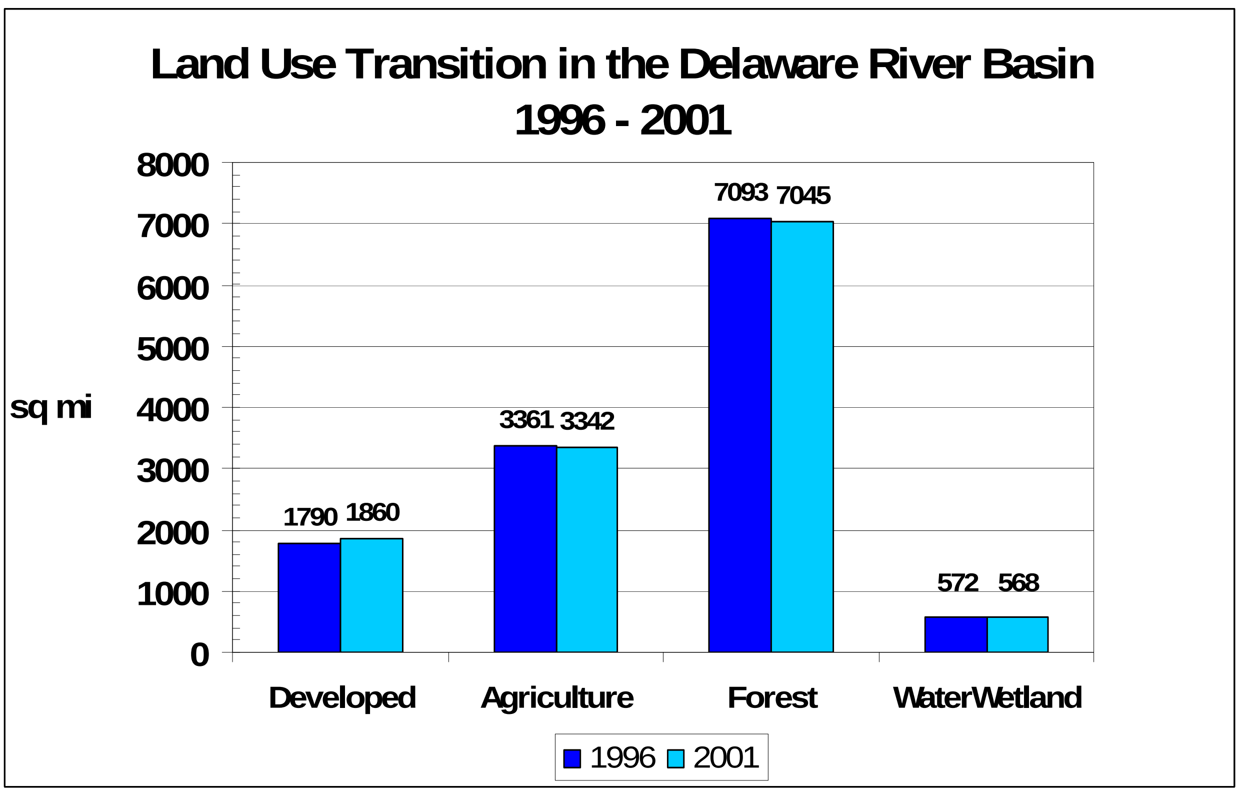
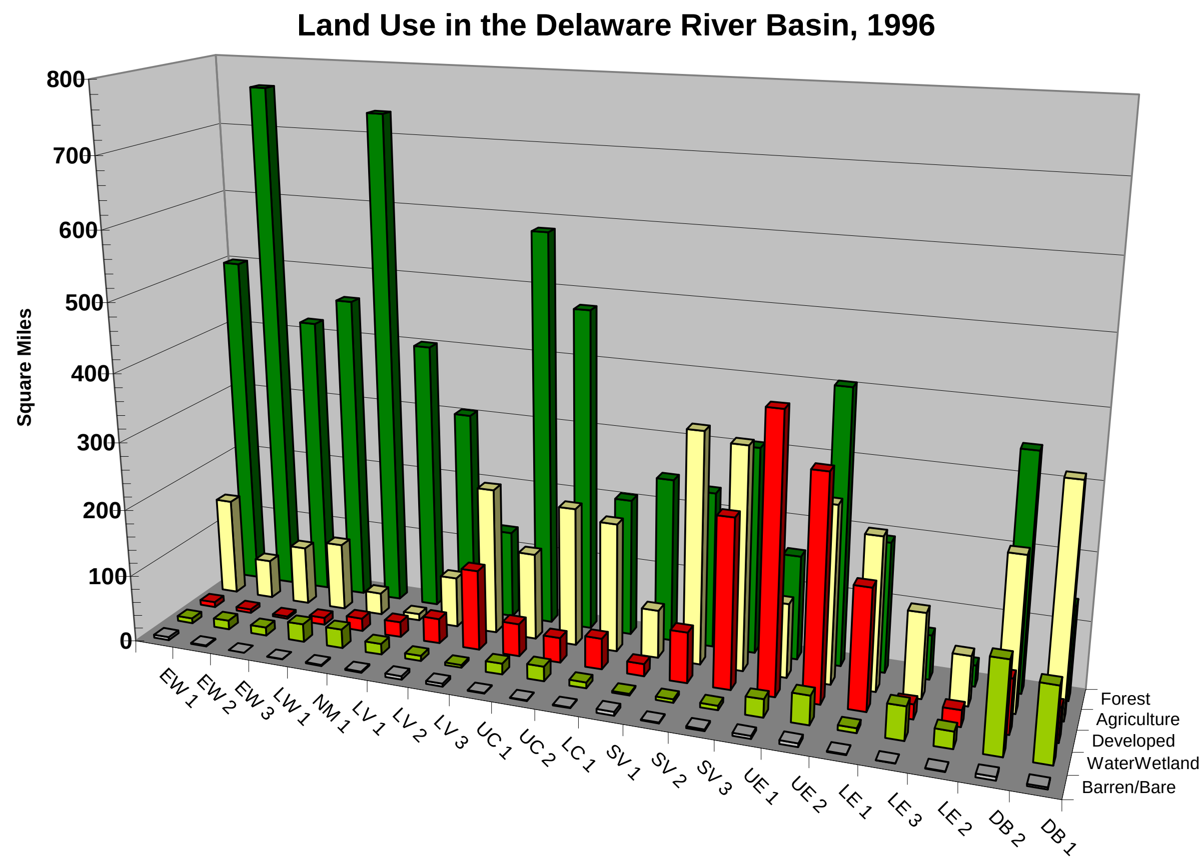


Figure 5.7. Land use transition in the Delaware River Basin, 1996 – 2001. (NOAA CSC)



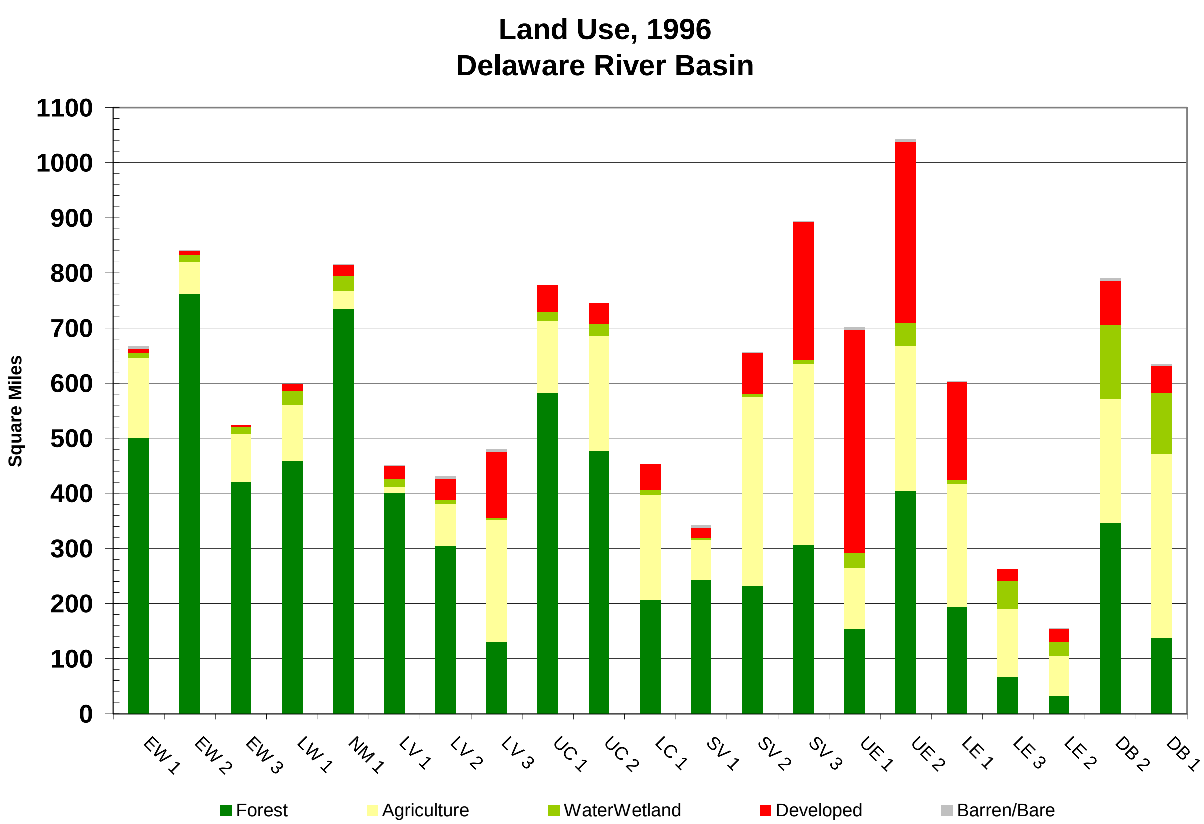
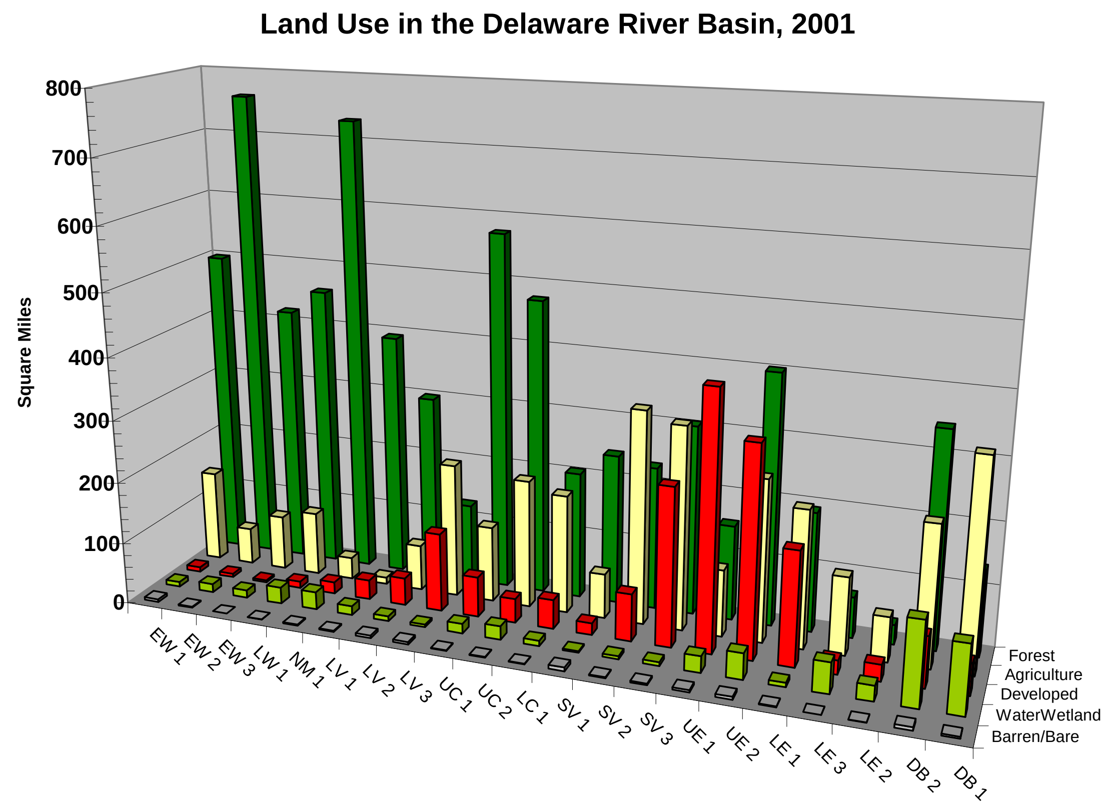


Figure 5.8. Land use area in the Delaware River Basin, 1996. (NOAA CSC)



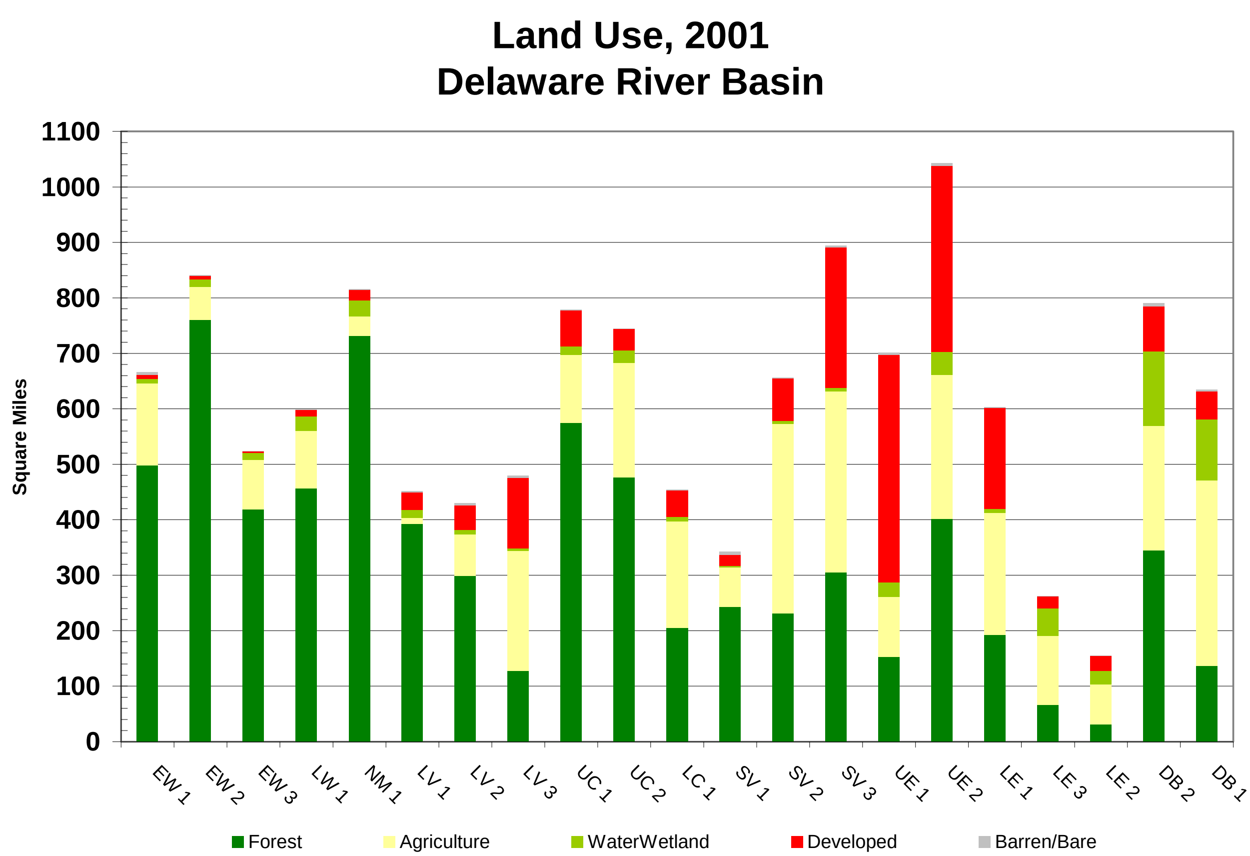


Figure 5.9. Land use area in the Delaware River Basin, 2001. (NOAA CSC)

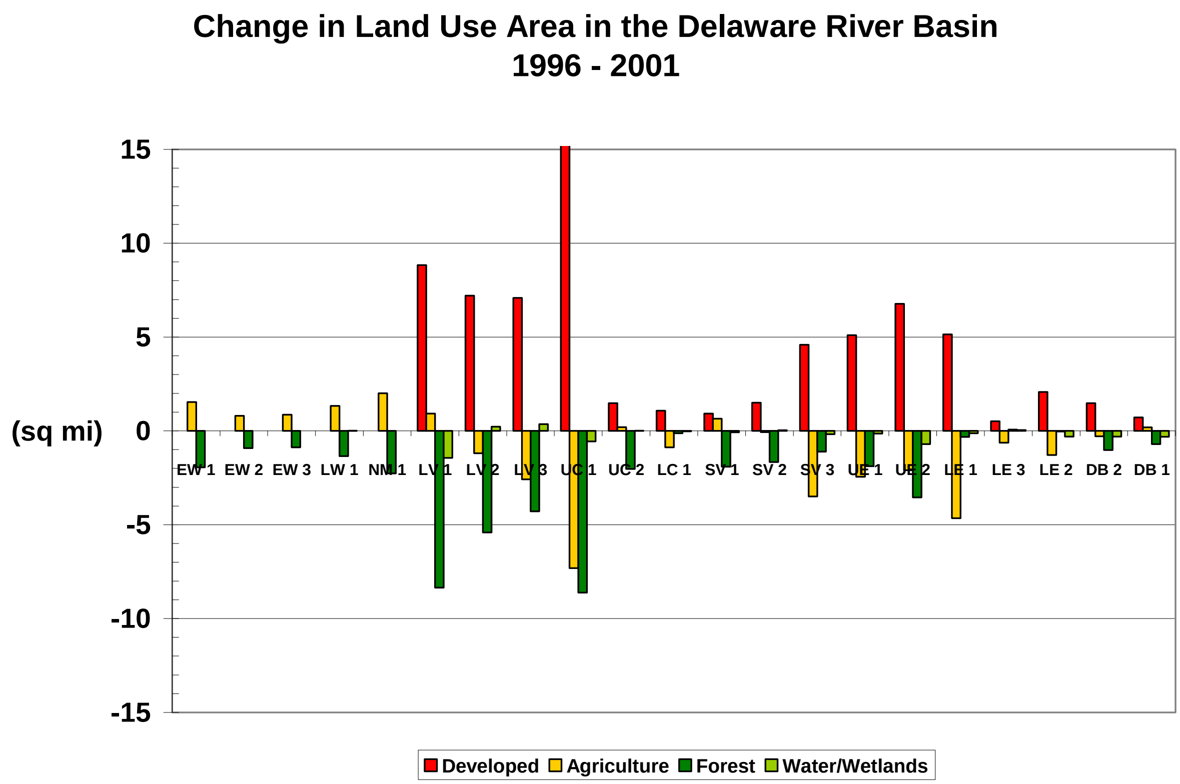


Figure 5.10. Land use change in Delaware River Basin subwatersheds, 1996 - 2001. (NOAA CSC)

Table 5.3. Land use change in the Delaware River Basin, 1996 - 2001. (NOAA CSC)

Watershed	N-S Order	WRA_ID	Developed (mi^2)	Cultivated (mi^2)	Forest (mi^2)	Wetland + Water (mi^2)	Other (mi^2)	Area (mi^2)
EW 1	1	7	0.00	1.57	-1.57	0.00	0.00	666
EW 2	2	6	0.00	0.81	-0.81	0.00	0.00	841
EW 3	3	10	0.01	0.86	-0.87	0.00	0.00	524
LW 1	4	5	0.00	1.34	-1.35	0.01	0.00	598
NM 1	5	13	0.00	2.02	-2.04	0.00	0.01	816
LV 1	6	14	8.83	0.92	-8.35	-1.44	0.11	451
LV 2	7	15	7.21	-1.19	-5.41	0.22	-0.78	430
LV 3	8	17	7.09	-2.58	-4.29	0.36	-0.59	480
UC 1	9	18	16.25	-7.31	-8.62	-0.56	0.24	779
UC 2	10	1	1.48	0.21	-2.03	0.01	0.33	745
LC 1	11	8	1.08	-0.88	-0.12	-0.03	-0.05	454
SV 1	12	19	0.92	0.65	-1.91	-0.07	0.41	342
SV 2	13	21	1.50	-0.07	-1.66	0.03	0.19	656
SV 3	14	16	4.58	-3.49	-1.11	-0.18	0.20	894
UE 1	15	12	5.10	-2.44	-1.88	-0.15	-0.63	702
UE 2	16	11	6.77	-2.10	-3.54	-0.70	-0.42	1043
LE 1	17	9	5.15	-4.65	-0.33	-0.12	-0.04	603
LE 3	18	3	0.51	-0.63	0.07	0.04	0.01	262
LE 2	19	20	2.07	-1.29	-0.04	-0.31	-0.44	155
DB 2	20	4	1.48	-0.29	-1.02	-0.30	0.14	790
DB 1	21	2	0.72	0.20	-0.70	-0.32	0.11	634
Change			70.77	-18.36	-47.58	-3.49	-1.21	12867

Table 5.4. Land use in the Delaware River Basin, 1996. (NOAA CSC)

Watershed	N-S Order	WRA_ID	Developed (mi^2)	Cultivated (mi^2)	Forest (mi^2)	Wetland + Water (mi^2)	Other (mi^2)	Area (mi^2)
EW 1	1	7	7.78	146.64	499.85	7.71	4.47	666
EW 2	2	6	5.46	58.71	761.52	13.60	1.55	841
EW 3	3	10	3.55	88.12	419.56	12.35	0.08	524
LW 1	4	5	10.78	101.91	458.05	26.90	0.27	598
NM 1	5	13	19.05	33.53	733.67	28.48	1.71	816
LV 1	6	14	22.93	9.50	401.22	16.12	1.72	451
LV 2	7	15	37.52	75.48	304.59	7.80	5.00	430
LV 3	8	17	120.12	219.61	131.41	3.94	4.57	480
UC 1	9	18	48.82	129.67	583.21	16.16	1.04	779
UC 2	10	1	37.59	206.84	478.04	22.01	0.87	745
LC 1	11	8	46.22	192.32	205.55	8.90	1.09	454
SV 1	12	19	18.29	71.74	244.07	2.57	5.51	342
SV 2	13	21	74.87	342.65	232.26	5.09	1.27	656
SV 3	14	16	249.26	329.62	306.19	6.38	2.48	894
UE 1	15	12	405.39	109.98	155.22	26.63	4.35	702
UE 2	16	11	328.48	261.30	405.35	42.53	5.27	1043
LE 1	17	9	177.34	225.15	192.72	6.84	1.35	603
LE 3	18	3	21.92	125.31	65.99	48.99	0.25	262
LE 2	19	20	24.37	73.39	31.54	24.76	0.90	155
DB 2	20	4	79.85	225.06	345.58	134.38	5.01	790
DB 1	21	2	49.94	334.37	137.57	109.64	2.90	634
Total			1789.53	3360.90	7093.16	571.77	51.67	12867

Table 5.5. Land use in the Delaware River Basin, 2001. (NOAA CSC)

Watershed	N-S Order	WRA_ID	Developed (mi^2)	Cultivated (mi^2)	Forest (mi^2)	Wetland + Water (mi^2)	Other (mi^2)	Area (mi^2)
EW 1	1	7	7.79	148.21	498.28	7.71	4.47	666
EW 2	2	6	5.46	59.52	760.71	13.60	1.55	841
EW 3	3	10	3.55	88.98	418.69	12.35	0.08	524
LW 1	4	5	10.79	103.24	456.70	26.91	0.27	598
NM 1	5	13	19.05	35.55	731.64	28.49	1.72	816
LV 1	6	14	31.77	10.42	392.87	14.68	1.83	452
LV 2	7	15	44.73	74.29	299.18	8.02	4.22	430
LV 3	8	17	127.20	217.04	127.12	4.30	3.98	480
UC 1	9	18	65.08	122.36	574.59	15.60	1.28	779
UC 2	10	1	39.07	207.05	476.01	22.03	1.20	745
LC 1	11	8	47.30	191.45	205.43	8.87	1.03	454
SV 1	12	19	19.21	72.39	242.16	2.49	5.92	342
SV 2	13	21	76.37	342.59	230.60	5.12	1.46	656
SV 3	14	16	253.84	326.12	305.08	6.20	2.68	894
UE 1	15	12	410.49	107.53	153.34	26.48	3.72	702
UE 2	16	11	335.25	259.20	401.81	41.83	4.85	1043
LE 1	17	9	182.48	220.49	192.39	6.72	1.31	603
LE 3	18	3	22.43	124.69	66.06	49.03	0.26	262
LE 2	19	20	26.45	72.10	31.50	24.45	0.46	155
DB 2	20	4	81.33	224.77	344.56	134.08	5.15	790
DB 1	21	2	50.66	334.57	136.87	109.33	3.01	634
Total			1860.30	3342.54	7045.58	568.29	50.46	12866

Table 5.6. Percentage of land use in the Delaware River Basin, 1996. (NOAA CSC)

Watershed	N-S Order	WRA_ID	Developed (%)	Cultivated (mi^2)	Forest (mi^2)	Wetland + Water (mi^2)	Other (mi^2)	Area (mi^2)
EW 1	1	7	1%	22%	75%	1%	1%	666
EW 2	2	6	1%	7%	91%	2%	0%	841
EW 3	3	10	1%	17%	80%	2%	0%	524
LW 1	4	5	2%	17%	77%	4%	0%	598
NM 1	5	13	2%	4%	90%	3%	0%	816
LV 1	6	14	5%	2%	89%	4%	0%	451
LV 2	7	15	9%	18%	71%	2%	1%	430
LV 3	8	17	25%	46%	27%	1%	1%	480
UC 1	9	18	6%	17%	75%	2%	0%	779
UC 2	10	1	5%	28%	64%	3%	0%	745
LC 1	11	8	10%	42%	45%	2%	0%	454
SV 1	12	19	5%	21%	71%	1%	2%	342
SV 2	13	21	11%	52%	35%	1%	0%	656
SV 3	14	16	28%	37%	34%	1%	0%	894
UE 1	15	12	58%	16%	22%	4%	1%	702
UE 2	16	11	31%	25%	39%	4%	1%	1043
LE 1	17	9	29%	37%	32%	1%	0%	603
LE 3	18	3	8%	48%	25%	19%	0%	262
LE 2	19	20	16%	47%	20%	16%	1%	155
DB 2	20	4	10%	28%	44%	17%	1%	790
DB 1	21	2	8%	53%	22%	17%	0%	634
Total			14%	26%	55%	4%	1%	12867

Table 5.7. Percentage of land use in the Delaware River Basin, 2001. (NOAA CSC)

Watershed	N-S Order	WRA_ID	Developed (%)	Cultivated (mi^2)	Forest (mi^2)	Wetland + Water (mi^2)	Other (mi^2)	Area (mi^2)
EW 1	1	7	1%	22%	75%	1%	1%	666
EW 2	2	6	1%	7%	90%	2%	0%	841
EW 3	3	10	1%	17%	80%	2%	0%	524
LW 1	4	5	2%	17%	76%	5%	0%	598
NM 1	5	13	2%	4%	90%	3%	0%	816
LV 1	6	14	7%	2%	87%	3%	0%	451
LV 2	7	15	10%	17%	70%	2%	1%	430
LV 3	8	17	27%	45%	27%	1%	1%	480
UC 1	9	18	8%	16%	74%	2%	0%	779
UC 2	10	1	5%	28%	64%	3%	0%	745
LC 1	11	8	10%	42%	45%	2%	0%	454
SV 1	12	19	6%	21%	71%	1%	2%	342
SV 2	13	21	12%	52%	35%	1%	0%	656
SV 3	14	16	28%	36%	34%	1%	0%	894
UE 1	15	12	59%	15%	22%	4%	1%	702
UE 2	16	11	32%	25%	39%	4%	0%	1043
LE 1	17	9	30%	37%	32%	1%	0%	603
LE 3	18	3	9%	48%	25%	19%	0%	262
LE 2	19	20	17%	47%	20%	16%	0%	155
DB 2	20	4	10%	28%	44%	17%	1%	790
DB 1	21	2	8%	53%	22%	17%	0%	634
Total			14%	26%	55%	4%	1%	12867

5.3. Impervious Cover

Research completed over the last 20 years shows increasing correlation between impervious coverage and watershed health. Watersheds with impervious cover above 10 to 20% exhibit increased flood peaks, lower stream flow during dry weather, degraded stream habitat, increased stream erosion, fragmented riparian forests, and decline in fish habitat.

New development requires construction of impervious area, which reduces the amount of groundwater recharge as compared to natural ground cover. Table 5.8 summarizes a 1993 USEPA water budget indicating that infiltration decreases with increased impervious cover. Infiltration decreases from 50% of total precipitation for a natural ground cover condition at zero impervious cover to 35% infiltration for a ground cover with 35 to 50% impervious cover.

Figure 5.11 depicts impervious cover patterns in Delaware Basin watersheds. Notice the progression of development along transportation routes radiating from the large cities like the spokes on a wheel.

Table 5.8. USEPA water budget model for impervious cover. (USEPA 1993)

Ground Cover	Infiltration	Runoff	Evapotranspiration
Natural, 0% impervious	50%	10%	40%
10 - 20% impervious	42%	20%	38%
35 - 50% impervious	35%	30%	35%
75 - 100% impervious	15%	55%	30%

Table 5.9. Impervious cover in the Delaware River Basin. (USGS NLCD)

Subwatershed	1996	2001	Increase
Upper Region (NY and PA)	(% imp.)	(% imp.)	(% imp.)
EW · East/West Branch			
EW1 West Branch (Cannonsville)		0.4	
EW2 East Branch (Pepacton))		0.2	
EW3 Mainstem (above Narrowsburg)		0.3	
LW · Lackawaxen		0.7	
NM ·Neversink-Mongaup		0.9	
Central Region (PA and NJ)			
UC ·Upper Central watersheds			
UC1 Pennsylvania tributaries		2.4	
UC2 New Jersey tributaries		1.9	
LV ·Lehigh Valley			
LV1 Above Lehighton		0.9	
LV2 Above Jim Thorpe		1.9	
LV3 Above Easton		9.5	
LC ·Lower Central (above Trenton)		2.2	
Lower Region (PA, NJ and DE)			
SV ·Schuylkill Valley			
SV1 Above Reading		2.7	
SV2 Above Valley Forge		4.6	
SV3 Head of tide at Philadelphia		7.6	
UE ·Upper Estuary (Phila, Camden)			
UE1 Pennsylvania piedmont		21.1	
UE2 New Jersey coastal plan		9.9	
LE ·Lower Estuary Watersheds			
LE1 Christina River		7.8	
LE2 C and D Canal, DE		3.6	
LE3 Salem River, NJ		2.3	
Bay Region			
DB ·Delaware Bay (NJ and DE)			
DB1 Delaware coastal plain		2.2	
DB2 New Jersey coastal plain		2.4	

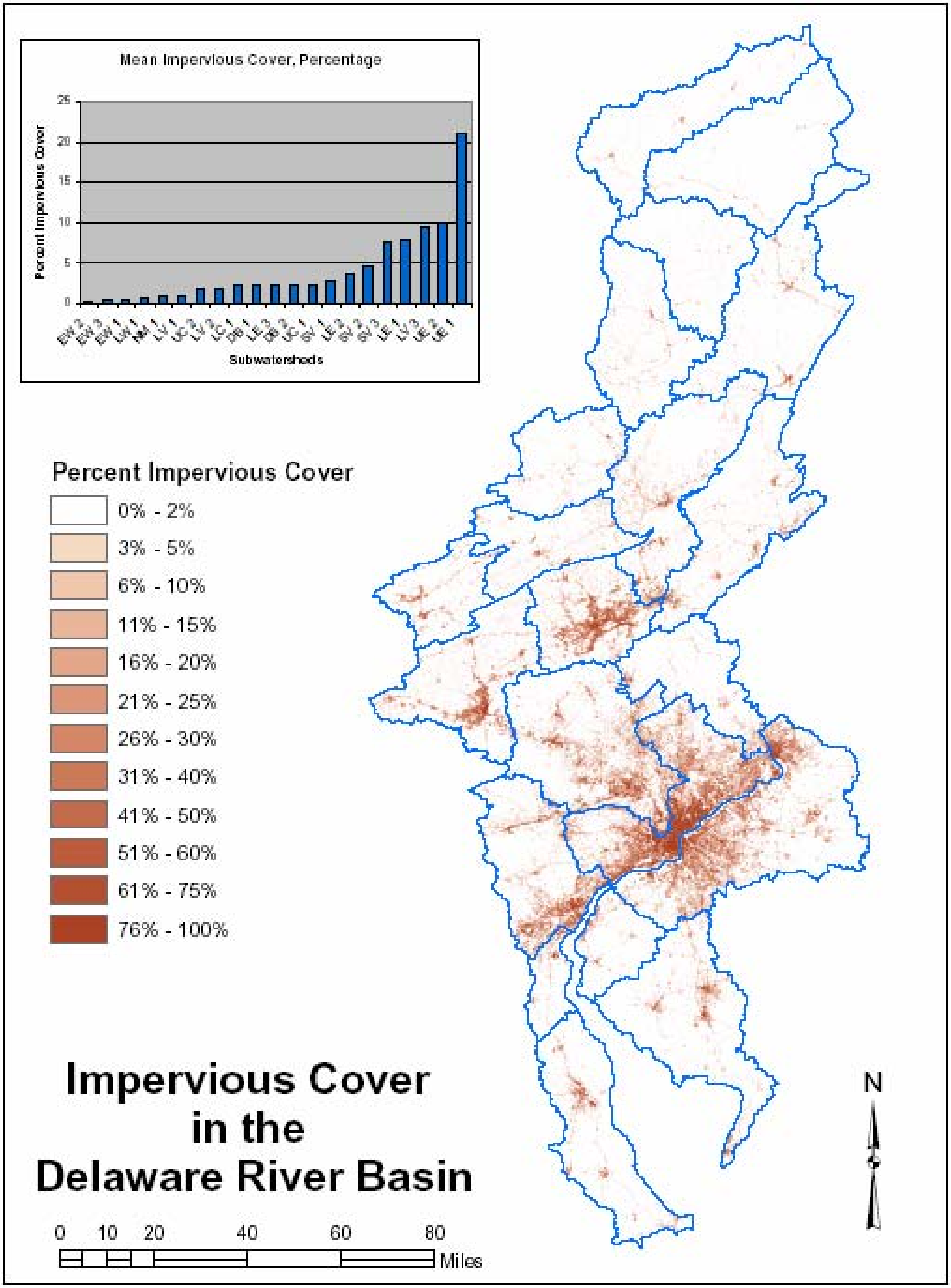


Figure 5.11. Impervious cover in the Delaware River Basin, 2001. (USGS NLCD)

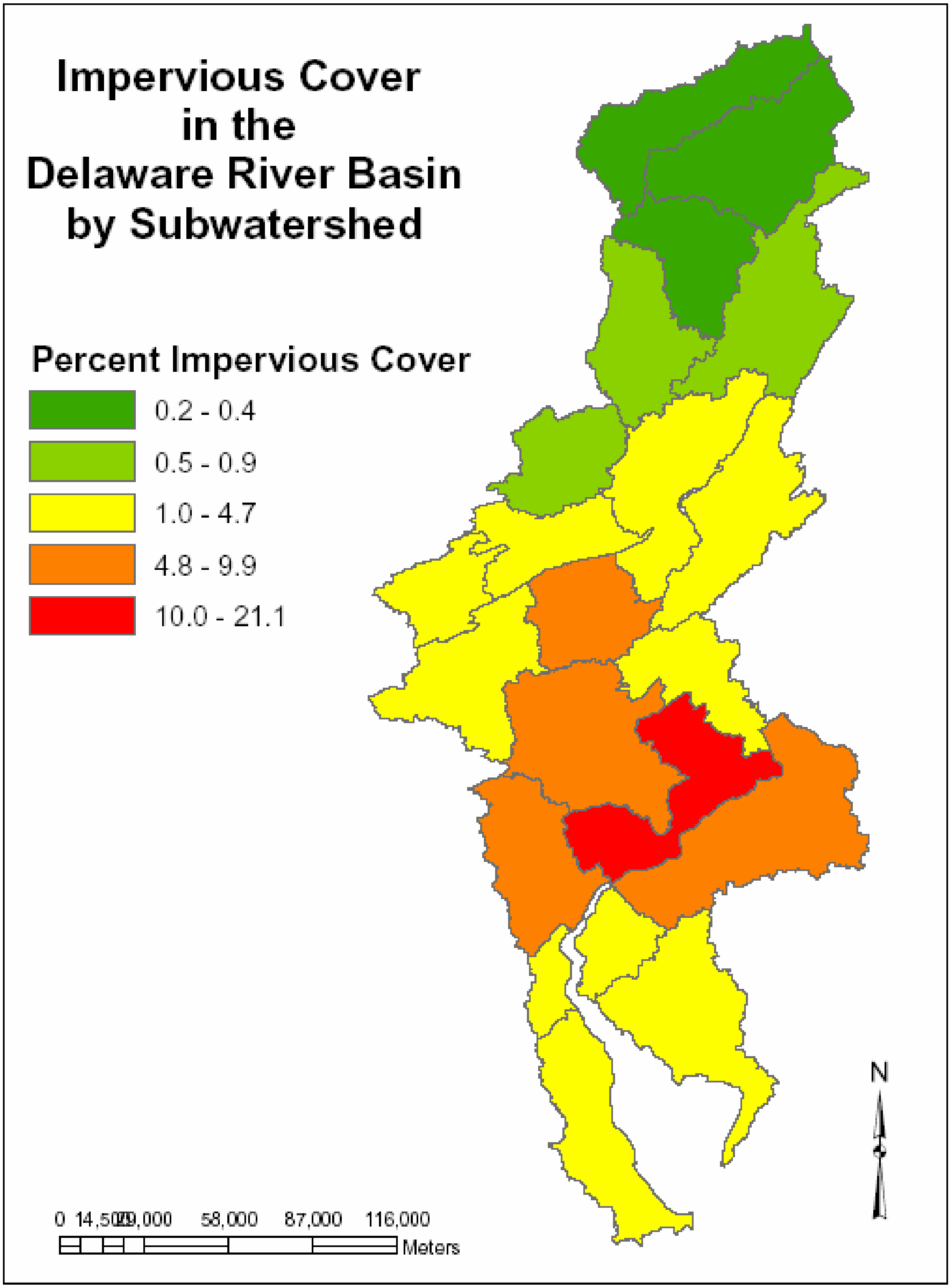


Figure 5.12. Impervious cover of Delaware River Basin subwatersheds, 2001. (USGS NLCD)

5.4. Tidal Wetlands

The Delaware Estuary is unique among large East Coast estuaries because of its fringe tidal marsh around nearly the entire perimeter, ranging from the mouth of Delaware Bay up near Wilmington. Delaware Bay is different from estuaries north and south of it - different in sediment loading and in the type of edge. In Delaware Bay, the silts and fines are abundant, resulting in less phytoplankton and little SAV compared to other estuaries, but there is more marsh and therefore more nursery habitat for commercial and recreational fishes.

The White Paper on Science in the Delaware Estuary (Kreeger *et al.* 2006) discusses tidal wetlands:
Historically, this contiguous fringe of tidal marsh extended farther up through the freshwater tidal system. Due to land conversion and degradation, less than 5 percent of the pre-settlement acreage of freshwater tidal marshes remains. Therefore, some marsh types are more imperiled than others.

One area of promise is to look landward and identify areas that tidal wetlands may be permitted to reclaim. As sea levels have risen in the past, tidal marshes have undergone a landward retreat, but existing developments and other impediments restrict this natural progression. Global warming and associated climate change is predicted to raise water temperatures and possibly alter gas exchange processes, and these effects could become more pronounced in exposed marshes and intertidal mud flats. To better protect the remaining system, it is essential to know the status and trends for the principal types of tidal wetlands, rates of marsh habitat loss/degradation/rehabilitation, the economic value of a fringe marsh, and whether the values differ among marsh types, dominant vegetation types, and/or geographical regions.

Even in areas that are not facing development pressure, tidal wetlands are expected to be increasingly imperiled due to sea level rise, land subsidence, sediment starvation, invasive species and other factors.

The Battele report to the Partnership for the Delaware Estuary (draft 2006) discusses tidal wetlands (tables 5.10-5.13):
The importance of tidal wetlands has been increasing over the decades and there are significant efforts to restore, enhance, and conserve these habitats. Although most of the loss tidal wetland habitat associated with coastal resource use and development occurred throughout the 1700s, 1800s, and early 1900s, these ecosystems continue to be vulnerable to deleterious effects of accelerated sea level rise, invasive and nuisance species, and other agents of change. These ephemeral habitats migrate with respect to the physical and biogeochemical states of their surrounding environments. For instance, as sea level rises, the tendency is for tidal wetlands to migrate shoreward along relatively gentle terrestrial slopes. The increase in coastal development in areas along existing coastal zone margins has resulted in losses of wetland buffer zone area, and thus, a decrease in potential future migrations.

A series of indicators and metrics have been developed to support the understanding of the spatial and temporal distribution of tidal wetlands in the Delaware Estuary watershed. The primary indicators associated with tidal wetlands in the Delaware Bay estuary region include spatial and temporal trends of wetland habitat, patterns and buffers, impacts associated with permitted activities, habitat or species "condition", conservation and restoration practices, and those related to sea level change. Data is based on the interpretation of aerial photography.

Table 5.10. Tidal wetland habitat within the Delaware River Basin. (Battele draft 2006)

Tidal Wetland (ha)	**DB1**	**DB2**	**LE1**	**LE2**	**LE3**	**UE1**	**UE2**	Total
Estuarine Subtidal	2,165	4,360	253	981	2,164	270	235	10,428
Estuarine Intertidal	24,057	26,887	574	4,493	7,199	22	127	63,359
Marine Subtidal	0	2	0	0	0	0	0	2
Marine Intertidal	6	9	0	0	0	0	0	15
Riverine Tidal	206	65	32	0	480	4,214	5,133	10,130
Total Tidal Wetlands	26,434	31,223	859	5,474	9,843	4,506	5,495	83,917
Tidal Wetland (mi^2)	**DB1**	**DB2**	**LE1**	**LE2**	**LE3**	**UE1**	**UE2**	Total
Estuarine Subtidal	8.4	16.8	1.0	3.8	8.3	1.0	0.9	40.3
Estuarine Intertidal	92.9	103.8	2.2	17.3	27.8	0.1	0.5	244.6
Marine Subtidal	0	0.01	0	0	0	0	0	0.01
Marine Intertidal	0.02	0.03	0	0	0	0	0	0.05
Riverine Tidal	0.8	0.2	0.1	0	1.8	16.3	19.8	39.1
Total Tidal Wetlands	102.1	120.5	3.3	21.1	37.9	17.4	21.2	324.0

Table 5.11. Tidal wetland change in the Delaware River Basin, 1981 to 1992. (Battele draft 2006)

Tidal Wetland (hectares)	DB1 1981	DB1 1992	DB1 % Change	LE2 1981	DB1 1992	DB1 % Change
Estuarine Subtidal Unconsolidated (E1UB)	809	1,779	+120%	14	878	+6,046%
Estuarine Intertidal Emergent (E2EM)	23,428	20,413	-13%	4,404	4,141	-6%
Estuarine Intertidal Forested (E2FO)	1	5	+302%	0	0	0
Estuarine Intertidal Scrub Shrub (E2SS)	248	1,373	+453%	5	35	+542%
Estuarine Intertidal Unconsolidated (E2US)	0	844	+	0	114	+
Marine Intertidal Unconsolidated Shore (M2US)	0	5	+	0	0	0
Riverine Tidal Emergent (R1EM)	3	44	+1,180%	0	68	+
Riverine Tidal Unconsolidated Bottom (R1UB)	0	225	+	0	66	+
Total Tidal Wetlands	24,489	24,688	+0.8%	4,423	5,302	+20%

Table 5.12. Land use within 100-m tidal wetland buffers in the Delaware Basin, 1992. (Battele draft 2006)

Land Use (mi^2)	DB1	DB2	LE1	LE2	LE3	SV3	UE1	UE2
Beaches	0.62	0.15						
Commercial and Services		0.73	3.04	0.98	2.11	0.07	9.36	9.80
Commercial Industries	3.53							
Confined Feeding Ops	0.03							
Cropland Pasture	136.88	41.73	1.39	31.81	48.54		1.54	17.85
Deciduous Forestland	7.82	4.54	1.34	2.65	4.05		2.50	2.55
Evergreen Forestland	0.44	10.10		0.20				0.47
Forested Wetland	7.70	7.45	0.16	0.80	4.24		0.97	6.97
Indust & Commercial		0.10	0.30				1.65	0.48
Industrial	0.74	1.03	4.56	1.28	2.15		12.43	7.43
Lakes	0.36	0.67	0.08	0.78	0.93		0.51	1.61
Mixed Forestland	19.92	36.23	0.29	1.89	1.91			3.71
Nonforested Wetland	29.66	12.48	3.62	4.80	8.96		3.16	9.24
Mixed Urban or Built-up							1.82	0.26
Orch, Grov, Vnyrd, Nurs, Orn	0.11	0.17		0.25	1.16			0.31
Other Agricultural Land	0.05			0.13	0.08			
Other Urban or Built-up	0.28	0.25	0.51	0.02	0.24	0.11	2.01	3.61
Reservoirs	2.56	1.81	0.07	0.10	0.19		0.43	0.96
Residential	14.42	17.96	8.33	1.79	8.41	0.20	13.26	37.13
Sandy Area (Non-Beach)	1.00	0.41						
Streams and Canals	0.29	0.39	0.15	0.57	0.07	0.05	2.86	2.10
Strip Mines	0.70	2.93	0.30	3.06	0.37			0.98
Trans, Comm, Util	0.20	1.13	2.31		1.28	0.13	6.18	4.09
Transitional Areas	0.21	0.08	1.64	0.42	0.15		2.82	
Total	227.44	140.35	28.13	51.53	92.57	0.56	61.51	79.36

Table 5.13. Tidal wetlands in Delaware River Basin. subwatersheds

Subwatershed (mi^2)	Area	1981 Tidal Wetlands	1981 Tidal Wetlands	1992 Tidal Wetlands	1992 Tidal Wetlands	Change Tidal Wetlands	1992 Wetland Buffer	1992 Wetland Buffers
UE1 PA Piedmont	702			17	3%		61	9%
UE2 NJ Coastal Plain	1042			21	2%		79	8%
LE1 Christina River	603			3	1%		28	5%
LE2 C&D Canal DE	154	17	11%	21	14%	+ 4	52	33%
LE3 Salem River, NJ	262			38	14%		93	35%
DB1 DE Del Bay	634	94	15%	102	16%	+ 8	227	36%
DB2 NJ Del Bay	789			121	15%		140	18%

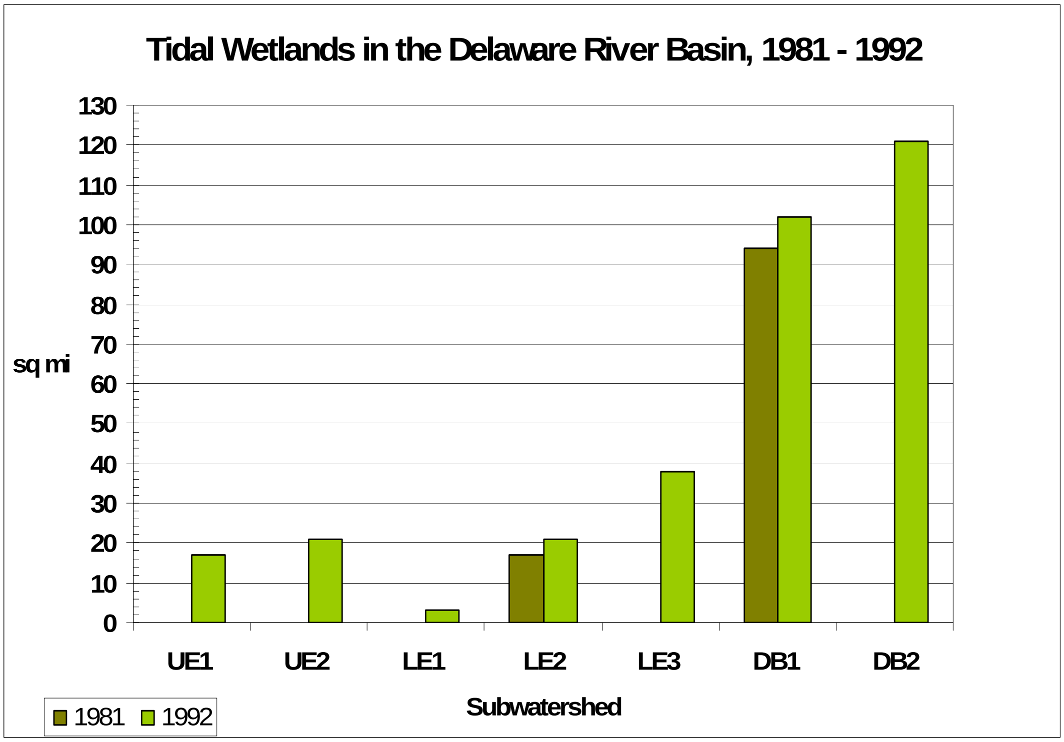


Figure 5.13. Tidal wetlands in the Delaware River Basin. (Battelle draft 2006)

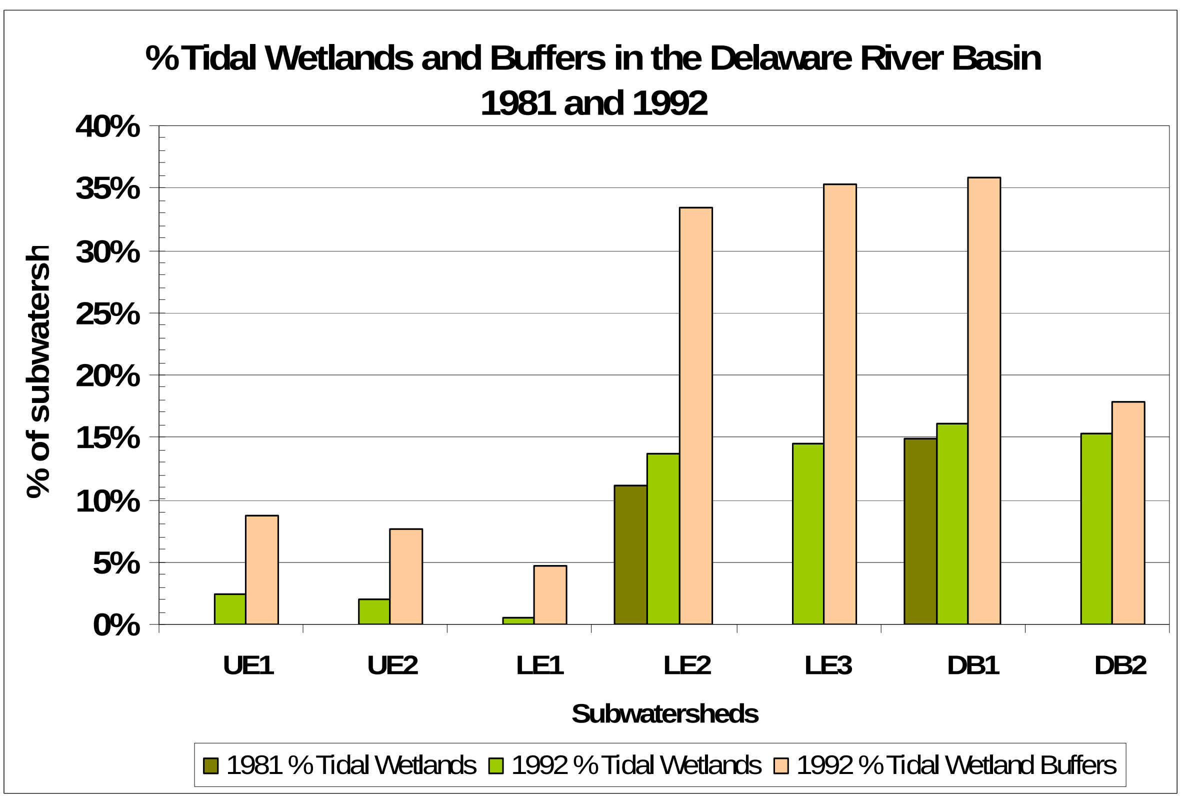


Figure 5.14. Tidal wetlands and 100 meter buffer areas in the Delaware River Basin. (Battelle draft 2006)

5.5. Wetlands

The USEPA defines wetlands generally as lands whose water saturation level is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. Under the Clean Water Act, the term wetlands means "*those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas.*" Wetlands have decreased in most watersheds of the Delaware Basin except for increases in the lower Lehigh Valley, LV2 and LV3. (Figures 5.15 and 5.16).

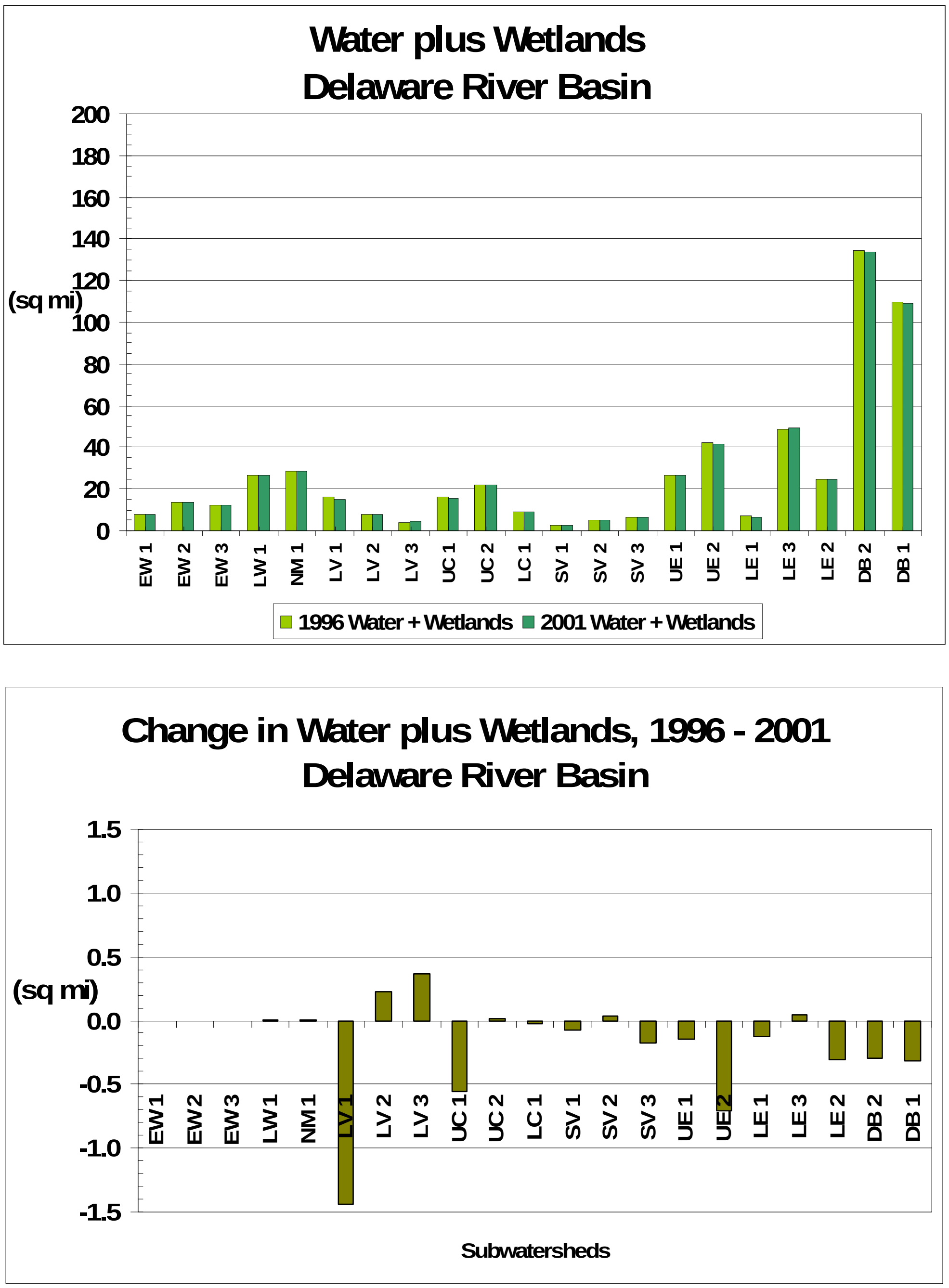


Figure 5.15. Water plus wetland change in the Delaware River Basin, 1996 to 2001. (NOAA CSC)

5.6. Forest Cover

The upper Delaware Basin is coated with forests (Figure 5.16) although most watersheds are losing forests (Figure 17). The basin had 7045 mi^2 of forest in 2001, down 48 mi^2 from 7093 mi^2 in 1996. Forests loss is 10 mi^2 per year.

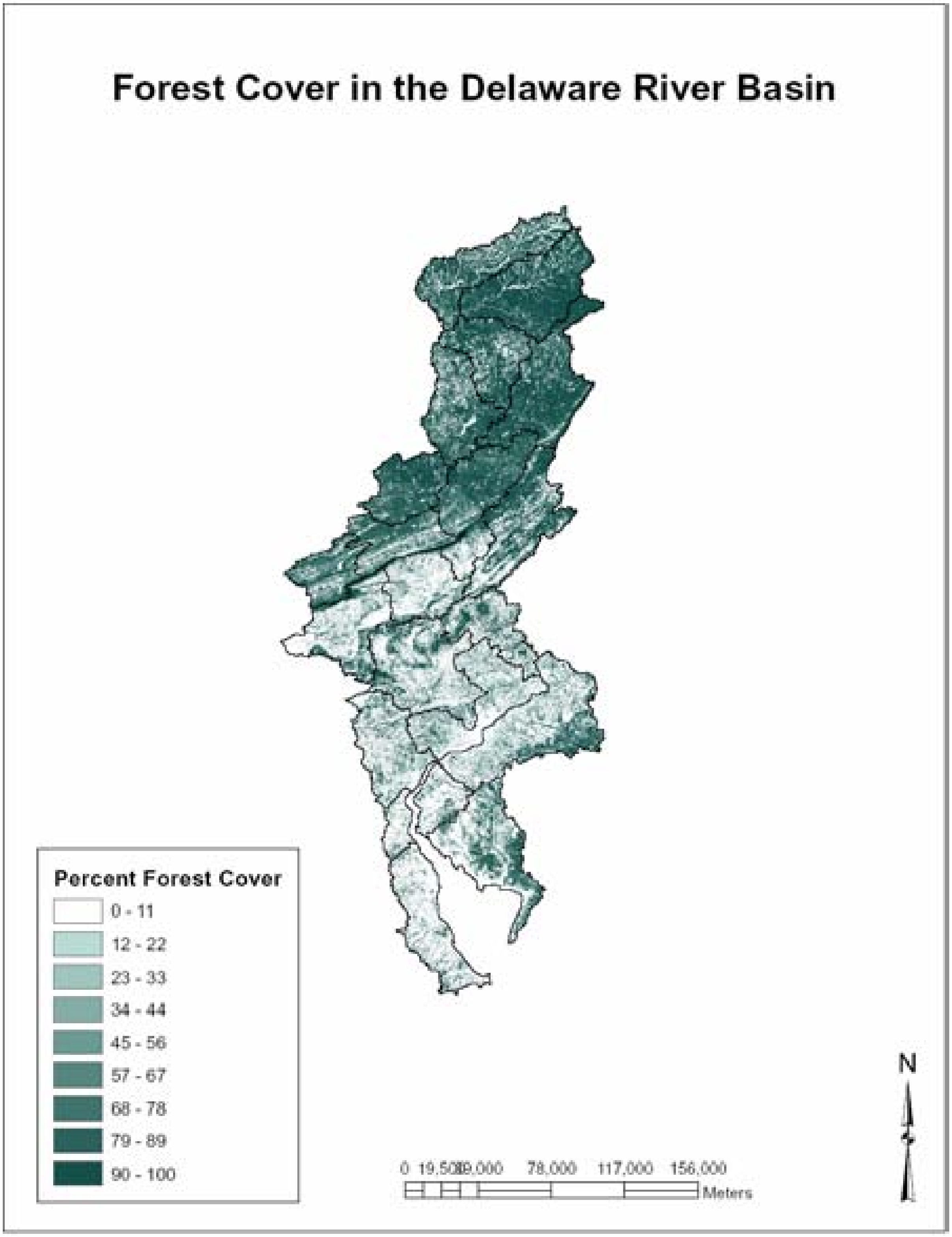


Figure 5.16. Forest cover in the Delaware River Basin. (NOAA CSC 2001)

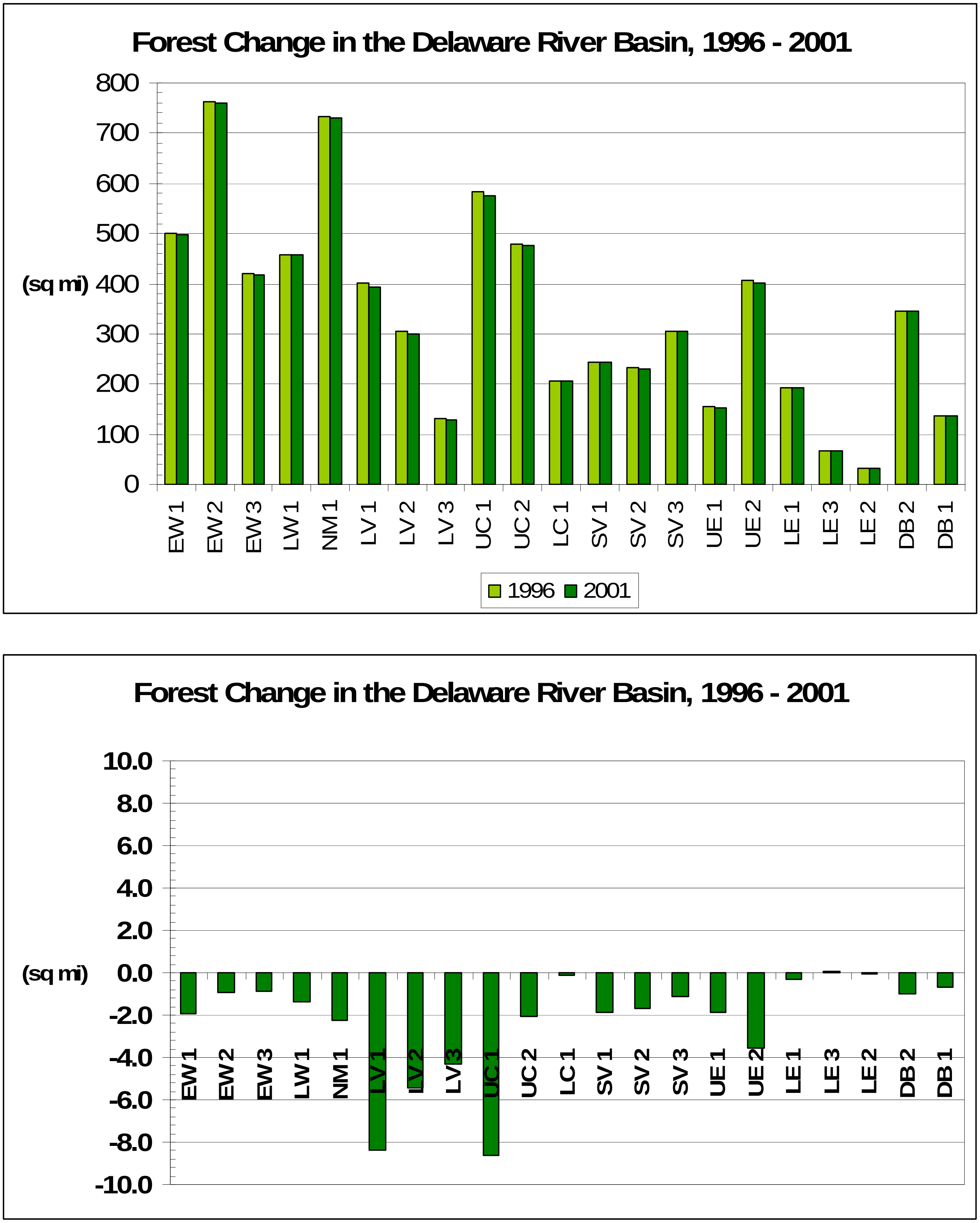
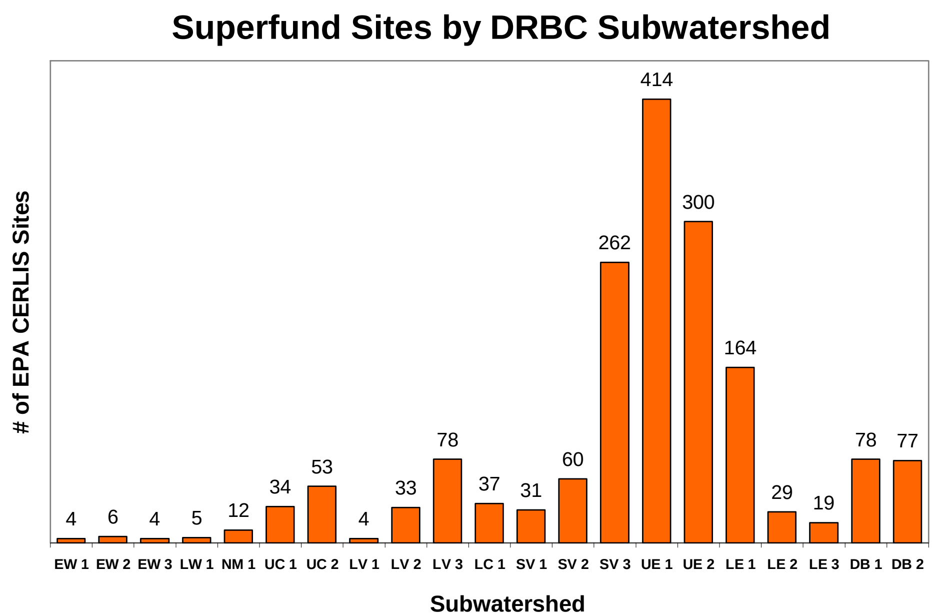


Figure 5.17. Forest change in the Delaware River Basin, 1996 – 2001. (NOAA CSC)

5.7. Superfund Sites

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund)is the Federal government's program to clean up the nation's uncontrolled hazardous waste sites. Every subwatershed in the Delaware River Basin contains at least one superfund site (Figure 5.18). Downstream watersheds contain higher numbers of superfund sites than the upstream watersheds. This pattern is especially apparent in the Lehigh and Schuylkill River Basins. Counts in the Lehigh increase from 4 to 33 to 78 from subwatersheds LV1 to LV2 to LV3. In the Schuylkill, counts increase from 31 to 60 to 262 from SV1 to SV2 to SV3. Subwatersheds in the lower Delaware, including UE1, UE2, SV3, and LE1, contain the highest number and density of superfund sites. Subwatershed UE1 contains the highest number and density of superfund sites in the Basin with 414 sites, nearly 0.6 sites per square mile, more than twice the density than that of the other three sub-watersheds with comparable numbers, UE2 (0.288, 300), SV3 (0.293, 262), and LE1 (0.272, 164). Subwatersheds LV3, LE2 and DB1 have the next highest densities of sites, at least a third of those in the Lower Delaware—SV2 and DB2 having similar counts of sites but lower densities when normalized by their areas.



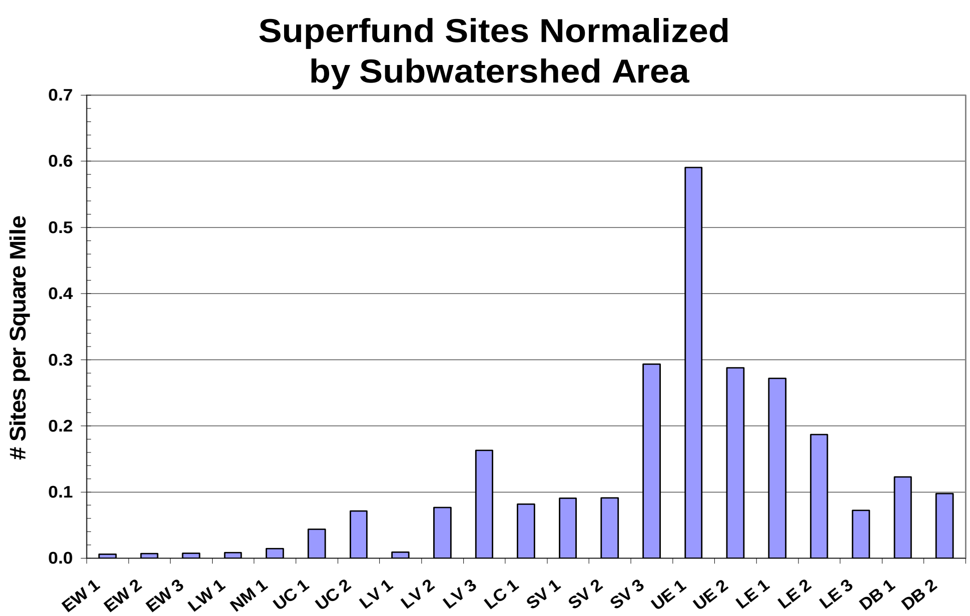
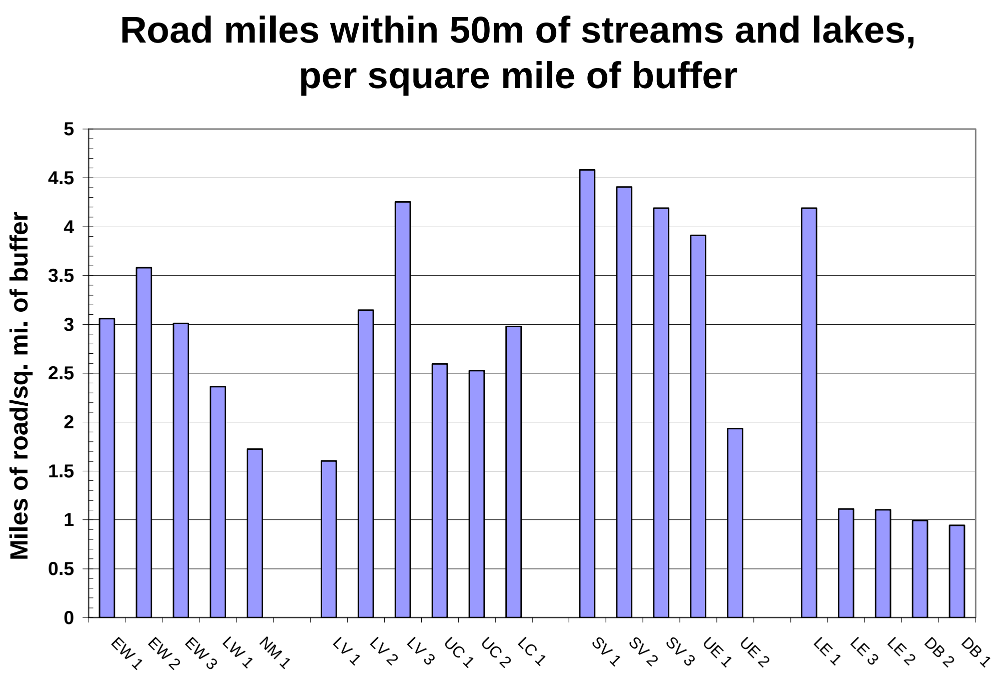


Figure 5.18. Federal superfund sites in the Delaware River Basin.

5.8. Riparian Corridor Health/Road Density

To assess riparian corridor health, road density was tabulated within a 50 - meter - wide stream buffer area measured from top of stream bank (Figure 5.19). Stream buffers with a high road length to buffer area ratio would have poor health and buffers with a low road to buffer area ratio would have better health. The number of roads within the stream buffer may be a function of urban land. In more rural areas, high road density could be due to roads that follow narrow winding stream valleys particularly in the hilly, mountainous northern areas of the Delaware River Basin.



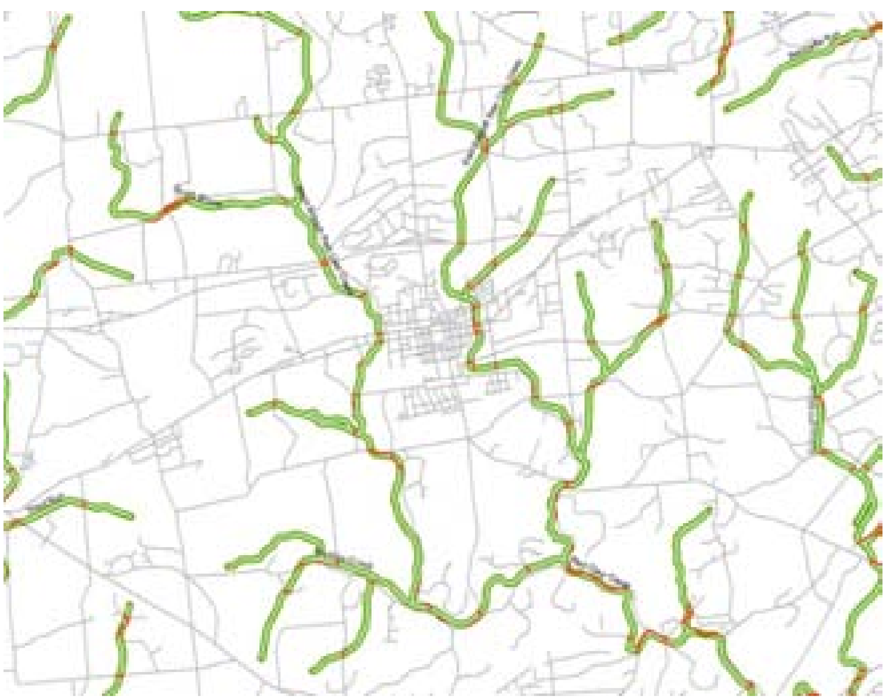


Figure 5.19. Road density within stream buffers in the Delaware River Basin.

5.9. Wild and Scenic Rivers

On October 2, 1968, President Lyndon B. Johnson and Congress signed the Natrional Wild and Scenic River Act. Three-quarters of the nontidal Delaware River are National Wild and Scenic Rivers including 73 miles from Hancock, NY to Milford, PA; 40 miles from Port Jervis, NY to the Delaware Water Gap; 39 miles from the Delaware Water Gap to Washington Crossing, PA; the Maurice River (NJ), and 190 miles in the White Clay Creek (PA and DE). Two streams in the Delaware Basin were added to the National Wild and Scenic Rivers System by Congress and President Jimmy Carter in 1978. One section extends 73 miles from the confluence of the river's East and West branches at Hancock, N.Y. downstream to Millrift, PA. The second covers about 40 miles from just south of Port Jervis, N.Y. downstream to the Delaware Water Gap near Stroudsburg, PA in the Delaware Water Gap National Recreation Area. In 1993, the Maurice River and several tributaries totaling 35.4 miles were added to the National Wild and Scenic Rivers System. In October 2000, Congress approved two bills that added a section of the lower Delaware River (39 miles) and the White Clay Creek (190 miles) to the National Wild and Scenic Rivers System. White Clay Creek is the first national wild and scenic river in the USA designated on a watershed basis instead of a river segement basis.

Figure 5.20. National wild and scenic rivers in the Delaware River Basin. (USNPS and DRBC)

Chapter 6 - Water Quality

6.1. Introduction

The State of the Estuary White Paper describes the need for water quality indicators to measure progress in restoring the Delaware River and Estuary (Kreeger *et al.* 2006).

As a former center for the Industrial Revolution in the New World and continuing as one of the top industrial regions in the United States, the greater Philadelphia region contains a pollutant legacy lasting more than 300 years. A TMDL process is underway in the tidal river and estuary to address the legacy of polychlorinated biphenyls (PCBs), and mercury levels in fish tissue. These necessitate consumption advisories for many edible estuarine and freshwater fish species. Although much of the present pollutant runoff can be attributed to past industry, the byproducts of numerous human activities continue to be problematic and new classes of pollutants are being recognized

To justify implementation of new policies and regulatory actions for contaminants, it is important to demonstrate the effectiveness of source reduction strategies. For example, decade-scale correlations are well-documented for the improvement of oxygen conditions in the upper estuary as a result of wastewater treatment and for the reduction in phosphorus loadings to the Estuary as a result of the ban on phosphorus detergents. Development of indicators and measurable goals related to water quality and contaminants is imperative. We must work now to identify and develop indicators that can be prepared from existing information, but we must also marshal resources to develop new indicators in the future that are cost-effective and that can strengthen the comprehensiveness of current assessments by filling crucial data gaps.

Data from the (DRBC) Boat Run and other programs have clearly documented that water quality has improved considerably with regard to the biological oxygen demand associated with upgrades in wastewater treatment over the past 50 years. More recently, improved conditions have also been reported for certain contaminants such as phosphorus and lead.

Nevertheless, many challenges remain. Legacy pollutants such as dioxin, PCB's, and mercury persist in our watershed, and existing monitoring programs may not be adequate enough to meet management and policy needs. Concentrations of these compounds in water and sediments often exceed standards for wildlife and human drinking water. Moreover, although concentrations in fish tissue also exceed guidelines for human consumption, many people continue to consume fish taken from contaminated areas.

An interesting feature of the Delaware Estuary is that eutrophication problems appear rare in relation to other large American estuaries that have similar high nutrient inputs. It appears that one important reason for this is high turbidity that may inhibit blooms of phytoplankton in the water column of the upper and middle Estuary. In other estuaries high turbidity is believed to be symptomatic of problems, such as high stormwater runoff and erosion in the watershed.

However in the Delaware Estuary, this high turbidity is thought to be a natural feature, partly because the Estuary is very well mixed and hydrodynamically active. This paradoxical phenomenon is an example of the importance of understanding how the physical, chemical, and biological features of the Estuary relate, and how they sometimes contribute to unexpected biological outcomes.

6.2. Water Quality

The university consortium collected water quality data based on each state's portion of the Delaware Basin: Delaware, 8% of basin (UD); New Jersey, 23% (Rutgers); New York, 19% (Cornell); and Pennsylvania, 50% (Penn State).

Water quality trends were defined along the Delaware River and tributaries according to the following methods:

1. Identify water quality stations along the Delaware River and subwatersheds with data reaching back to 1970.
2. Graph water quality data on scatter plots for dissolved oxygen, nitrogen, phosphorus, sediment, copper, lead zinc, mercury, arsenic.
3. Define short term (since 1990) and long term (since 1970) water quality trends by comparing the 50^{th} percentile (median) plotted for 5-year intervals from 1971 – 1975, 1976 – 1980… 2001 – 2005. In the future we plan to complete nonparametric statistical trend analyses using the Season Kendall trend test.
4. Characterize median 2001 - 2005quality of the DelawareRiver and tributaries as excellent, good, fair, or poor.

Water Quality Data

We plotted water quality data as a scatter plot for each parameter at each station as typically depicted in Figure 6.1. Scatter plots provide visual patterns of the statistical data such as sample size, min./max., range, variance, linearity/curvature . We defined short term (since 1990) and long term (since 1970) water quality trends by plotting the 5 – year median concentration of each parameter for half decade increments 1971 – 1975, 1976 – 1980…. 2001 – 2005. The median is prefered for statistical analysis of water quality central tendency as it is more resistant to outliers than the mean. Five –year increments provide a large sample (n> 4 per year) to calculate the median.

We defined water quality trend as a change in the 5-year median (2001 – 2005) measured against baseline years 1990 (short term) and 1970 (long term 1970). We describe trends as improved (median DO increases and N, P, TSS decreases), constant, or degraded (DO decreases and N, P, TSS increases). Comparison of medians for each time period provides a visual estimate of trend but the trend is not necessarily statistically significant.

Table 6.1 defines a water quality ladder to compare the health of the Delaware River/Bay and subwatersheds as good, fair, or poor. Table 6.2 and 6.3 summarize water quality standards set by the states and the DRBC. Dissolved oxygen standards range from 4.0 to 7.0 mg/l depending if waters support warm or cold water fish. Delaware defines total N target values below 1.0 mg/l as low for setting TMDLs. We used an N default value of 1.0 mg/l for the other states. Total phosphorus criteria range from 0.02 mg/l for New York cold water streams, to a target value of low 0.05 mg/l set by Delaware, and 0.1 mg/l set by the USEPA. In Pennsylvania we assigned a default level of 0.1 mg/l for P. New Jersey is the only state that sets total suspended sediment standards of 25 mg/l for cold water trout streams and 40 mg/l for non trout streams. We used the New Jersey TSS standard as default criteria for other states in the Delaware Basin.

Water Quality Monitoring Stations

Water quality monitoring stations are situated along the Delaware River/Bay and in 21 subwatersheds. Thirteen main stem stations are spaced along 304 river miles from the headwaters at Hancock, N. Y. to the mouth at Cape Henlopen, DE. Suitable monitoring stations have uninterrupted records dating back to 1970. Available Water quality data was accessed from data bases maintained by USEPA STORET, USGS (www.usgs.gov), DRBC, NYSDEP, PADEP, NJDEP, and DNREC. Table 6.4 summarizes the location, data source, and drainage area of the monitoring stations.

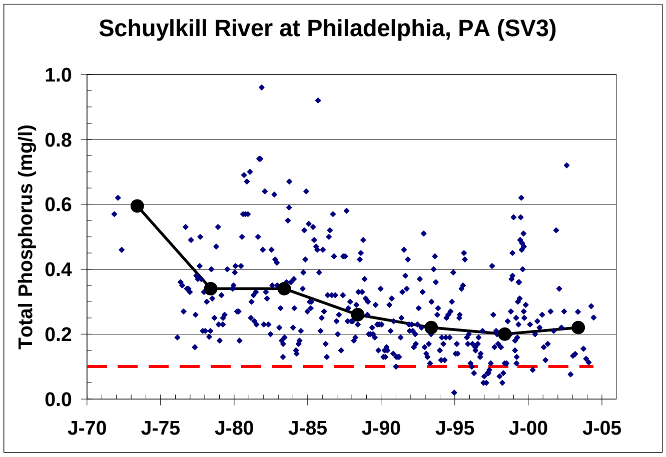


Figure 6.1. Total phosphorus along the Schuylkill River at Philadelphia (PADEP).

Table 6.1. Water quality ladder.

Water Quality	Description	DO (mg/l)	N (mg/l)	P (mg/l)	TSS (mg/l)
Good	Comfortably exceeds water quality standards	**> 8.0**	**< 0.5**	**< 0.02**	**< 25**
Fair	Just above water quality standards	**5.0 – 8.0**	**0.5 – 1.0**	**0.02 – 0.1**	**25 - 40**
Poor	Below stream water quality standards	**< 5.0**	**> 1.0**	**> 0.1**	**> 40**

Table 6.2. Water quality criteria in the Delaware River Basin.

Parameter	NJ	NY	PA	DE	USEPA
DO (mg/l)	4.0 non trout 5.0 trout maint. 7.0 trout prod.	4.0 non trout 6.0 trout 7.0 trout spwn	4.0 warm water 5.0 cold water 7.0 HQ cold	4.0 fresh water 5.0 cold water	
TN (mg/l)				< 1.0 low 1.0–3.0 med > 3.0 high	
TP (mg/l)	0.1	0.02		< 0.05 low 0.05–0.10 med > 0.1 high	0.1
TSS (mg/l)	25 trout 40 non trout				
Cu (ug/l)		200 water supply		see USEPA	13.0 acute 9.0 chronic
Pb (ug/l)	5.0	25		see USEPA	65.0 acute 2.5 chronic
Zn (ug/l)		25 non-aquatic		seeUSEPA	120 acute 120 chronic
Hg (ug/l)	0.144 resh water	0.0007 fish consumption		see USEPA	1.4 acute 0.77 chronic
Ar (ug/l)				see USEPA	
PCB (ug/l)				see USEPA	0.014 chronic 0.5drinking
Atrazine (ug/l)		7 water supply			3
Metolachlor (ug/l)					
Water Temp. (Deg F)	68 trout maint. 82 nontrout	70 trout	66 cold water 87 warm water	86 fresh water 75 cold water	

(NJDEP 2006, NYSDEC 1999, PADEP 2007, DNREC 2004 and 2007, USEPA, 2008)

Table 6.3. DRBC water quality criteria along the Delaware River and Estuary

Zone	RM	Description	DO (mg/l)	Nitrate (mg/l)	P (mg/l)	TSS (mg/l)
1A	330.7 – 289.9	Hancock – Narrowsburg, NY	5.0 min 7.0 trout 9.0 existing	0.293	0.029	4.0
1B, 1C	289.9 – 217.0	Narrowsburg – Tocks Island	4.0 min 9.0 existing	0.293	0.029	4.0
1D, 1E	217.0 – 133.4	Tocks Island – Trenton, NJ	4.0 min 9.2 existing	0.246	0.027	3.4
2	133.4 – 108.4	Trenton, NJ - Philadelphia	5.0 (24 hr)			
3, 4	108.4 – 78.8	Philadelphia – PA/DE line	3.5 (24 hr)			
5	78.8 – 48.2	PA/DE line – Liston Point	3.5 (RM 78.8) 4.5 (RM 70.0) 6.0 (RM 59.5)			
6	48.2 – 0.9	Liston Pt. – Atlantic Ocean	5.0			

Table 6.4. Water quality monitoring stations in the Delaware River Basin.

Subwatershed	Water Quality Station	D. A. (sq mi)	Designated Use
EW1 West Branch Delaware R. NY	West Br. at Hancock, NYS DEC St. 14041001	595	A(T)
EW2 East Branch Delaware R. NY	East Br. at Hancock, NYS DEC St. 14031001	784	C(T)
EW3 Hancock to Narrowsburg, NY	Cochecton Cr., NYS DEC St. 14010047		
LW1 Lackawaxen Watersheds, PA	Lackawaxen R. at Lackawaxen, SR0590 Br., WQN 147	589	HQ
NM1 Neversink-Mongaup R. NY	Delaware R. at Port Jervis, NYS DEC St. 1401001	3,070	A
UC1 Pocono Mountain tribs, PA	Brodhead Cr. at Del. Water Gap, SR2028 Br. WQN 137	259	TSF
UC2 Highlands tributaries, NJ	Paulins Kill at Blairstown, USGS Gage 1443500	126	FW-TM
LV1 Lehigh R. at Lehighton, PA	Lehigh R. at Stoddartsville, SR0115 Br. WQN 126	92	HQ
LV2 Lehigh R. at Jim Thorpe, PA	Lehigh R. at Walnutport, Main St. Br. WQN 125	889	TSF
LV3 Lehigh R. above Easton, PA	Lehigh R. at Glendon, Nazareth Br. WQN 123	1,359	WWF
LC1 Lower Central above Trenton	Wickecheoke Cr. at Stockton, USGS Gage 1461300	27	FW-TM-C
SV1 Schuylkill above Reading, PA	Schuylkill R. at Berne, Water St. Br. WQN 110	355	CWF
SV2 Schuylkill at Valley Forge	Schuylkill R. at Pottstown, Hanover St. Br. WQN 111	1,147	CWF
SV3 Schuylkill at Philadelphia	Schuylkill R. at Philadelphia, Falls Br. WQN 110	1,893	CWF
UE1 Pennsylvania Fall Line	Neshaminy Cr. at Langhorne, SR0213 Br. WQN 121	210	WWF
UE2 New Jersey Coastal Plain	N. Br. Rancocas Cr. Pemberton, USGS Gage 1467000	118	FW-NT
UE2 New Jersey Coastal Plain	Cooper River at Haddonfield, USGS Gage 01467150	17	FW-NT
LE1 Christina/Brandywine Rivers	Brandywine R. at Wilmington, Smith Br. DNREC 104051	300	ERES
LE2 C & D Canal, DE	Smyrna R. at Rte 9 Fleming's Landing, DNREC 201041	34	FW
LE3 Salem River, NJ	Salem R. at Woodstown USGS Gage 1482500	15	FW2-SE1
DB1 Delaware Bay tributaries, DE	Leipsic R. at Route 13, Leipsic, DE, DNREC 202021	105	FW
DB2 Delaware Bay tributaries, NJ	Maurice R. at Norma1 USGS Gage 411500	112	FW2-SE1
Delaware River and Bay	**Water Quality Station**	**D. A.**	**DRBC WQ**
RM304 Callicoon, NY	Delaware R. SR1020 Bridge Callicoon PADEP WQN0185	1,820	Zone 1B
RM253 Port Jervis, NY	Delaware R. at Port Jervis, NY USGS Gage 1434000	3,070	Zone 1B
RM246 Montague, NJ	Delaware R. at Montague, NJ USGS Gage 1438500	3,488	Zone 1C
RM145 Riegelsville, NJ	Delaware R. at Riegelsville, NJ USGS Gage 1457500	6,328	Zone 1E
RM134 Trenton, NJ	Delaware R. at Trenton, NJ USGS Gage 1463500	6,780	Zone 1E
RM100 Ben Franklin Br. Phila.	Del. R. Ben Franklin Br. USGS 1467200 DRBC 892071L	7,993	Zone 3
RM82 Chester, PA	Delaware R. at Chester, PA USGS Gage 1477050	10,300	Zone 4
RM73 Cherry Is. Wilmington, DE	Delaware R. at Cherry Is., DE DRBC 91011		Zone 5
RM66 New Castle, DE	Delaware R. at New Castle, DE DRBC 91008		Zone 5
RM61 Pea Patch Island., DE	Delaware R. at Pea Patch Is., DE DRBC 91005		Zone 5
RM55 Reedy Island, DE	Del. R. at Reedy Is., DE USGS 1482800 DRBC 91002	11, 200	Zone 5
RM22 Egg Island, NJ	Delaware Bay at Egg Is., NJ NJDEP 5700002420		Zone 6
RM10 Big Stone Beach, DE	Delaware Bay at Big Stone Beach, DE DNREC St. 401061		Zone 6

DRBC: Interstate water quality zones, DRBC Code, April 2001. DE: FW: Fresh Water, CWF: Cold Water Fishery, ERES: Waters of Exceptional Recreational and Ecological Significance (DNREC, 2004). PA: CWF: Cold Water Fish, WWF: Warm Water Fish, TSF: Trout Stocking, HQ: High Quality, EV: Exceptional Value. NJ: FW: Fresh Water, NT: Non-trout, TM: Trout maintenance, SE: Saline-estuarine. NY: Class A, Class C Fresh Surface Waters.

6.3. Dissolved Oxygen

Dissolved oxygen is one of the most primary water quality indicators necessary to sustain aquatic life. Healthy waterways have high DO levels. Polluted waterways have depleted DO levels usually caused by the oxygen demand of algae driven by high nutrient concentrations such as nitrogen and phosphorus from farm and lawn fertilizer, animal manure, human sewage and other chemicals. DO levels should remain above 6 mg/l to provide full support of aquatic life. However, levels of 4 or 5 mg/L are acceptable for brief periods."As DO in water drop below 5 mg/l, aquatic life is put under stress. Oxygen levels that remain below 1 to 2 mg/l for a few hours can result in large fish kills.

DO declines to low levels during the warm summer months and increases during the cold winter months. DO also fluctuates on a daily basis due to photosynthesis (from sunlight) of aquatic plants with the minimum daily DO found just before dawn and the maximum level detected just before sundown. Because there is less photosynthesis, forested and shady streams have higher DO than unforested and shadeless streams. Fishable standards of the Federal Clean Water Act are addressed by meeting DO criteria. Improved wastewater treatment plants and accelerated agricultural conservation have increased DO levels in the Delaware Basin since the mid 1980's, a real watershed success story.

The states in the Delaware River Basin have set minimum standards ranging from 4 to 5 mg/l to sustain the oxygen needs of warm water fish and 5 to 6 mg/l and higher for more sensitive cold water species such as trout.

The White Paper on the Delaware Estuary describes dissolved oxygen in context (Kreeger *et al*. 2006).
Among other factors, the amount of oxygen water can hold is dependent on temperature. The basic rule of thumb is colder water has the ability to hold higher amounts of dissolved oxygen than warmer water. During the summer months, warmer air temperatures and seasonal low flows raise the water temperature of lakes, streams, and rivers. As water temperature rises, the amount of oxygen the water can hold decreases. The presence of organic materials compounds this problem. Organic materials may be naturally occurring, such as leaves and branches, or they may originate from pollution such as stormwater runoff or poorly treated wastewater. Despite their origin, as organic materials decompose, dissolved oxygen supplies are depleted leaving less available for use by aquatic animals

A reduction in the supply of dissolved oxygen can lead to numerous changes in an aquatic ecosystem. Decreases in dissolved oxygen can cause changes in the types and numbers of aquatic species. Species which cannot tolerate decreases in dissolved oxygen include mayfly nymphs, stonefly nymphs, caddisfly larvae and beetle larvae. As dissolved oxygen levels decline, these pollution-intolerant organisms are replaced by pollution-tolerant, undesirable species of worms and fly larvae. Limited dissolved oxygen also decreases the feeding, reproductive, and spawning activities.

Dissolved oxygen levels have decreased along the Delaware Estuary and its major tributaries. Figure 6.2 illustrates median water quality along the Delaware River and Estuary at 5 - year intervals from 1971 -1975, 1996-2000, and 2001 – 2005. DO levels have improved since 1971-1975 along all river and bay monitoring stations. Above Trenton in the non-tidal Delaware River, DO levels increased to above 10 mg/l, indicative of good to excellent water quality. The most substantial improvements occurred in the tidal Delaware Estuary below Trenton where median DO levels now exceed 6 to7 mg/l, up from as low as 2 mg/l at Philadelphia during 1971 – 1975.

Mean daily dissolved oxygen levels recorded by the USGS have improved substantially markedly along the tidal Delaware River at Ben Franklin Bridge in Philadelphia (Figure 6.3). During the 1960s and 1970s, DO levels repeatedly reached near zero. Since 2000, the improvement in DO levels have been substantial as have rarely dipped below 4 mg/l, the fishable standard in the Delaware Estuary.

Along the Delaware River at Trenton, DO levels have been good and high since 1960 and rarely do excursions occur below 5 mg/l (Figure 6.4). Along the Lehigh River at Easton, mean daily DO levels rarely declined below 5 mg/l since 2000 whereas readings below 5 mg/l occurred quite frequently during the late 1960s and 1970s (Figure 6.5). Along the Schuylkill River at Linwood, PA, DO readings since 2000 have not declined below 4 mg/l compared to the late1980s, when DO frequently reached as low as 1 to 3 mg/l (Figure 6.6). Along the Brandywine Creek, mean daily dissolved oxygen levels have remained high and relatively unchanged since 1970 with only occasional excursions below 5 mg/l (Figure 6.7).

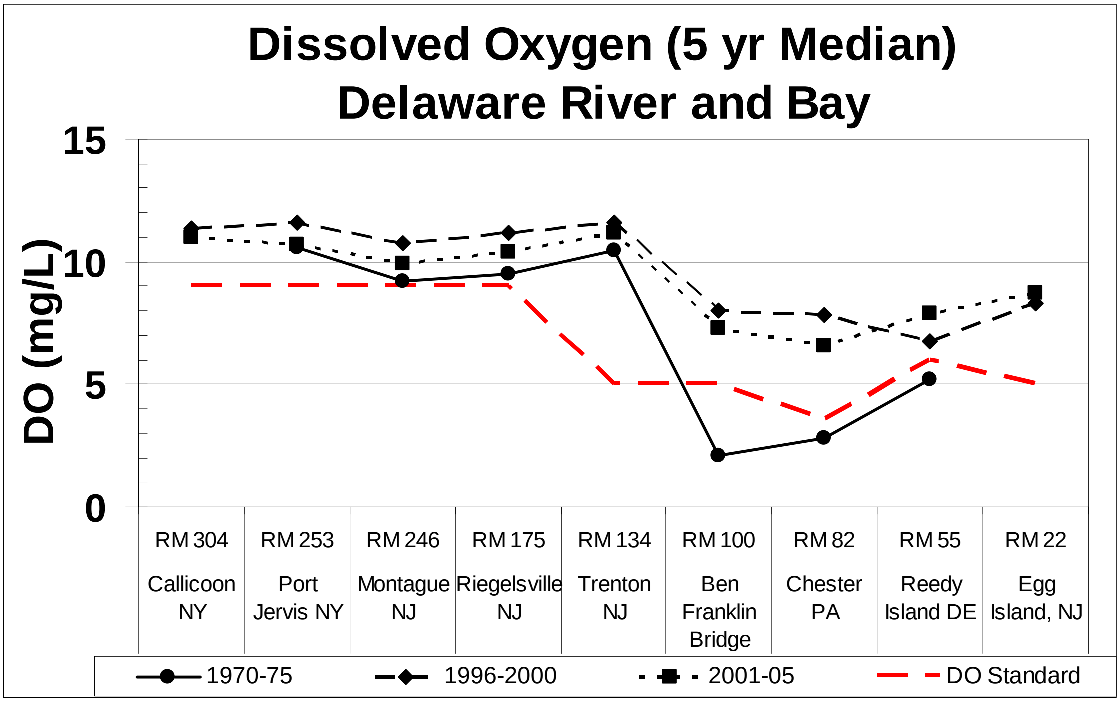


Figure 6.2. Dissolved oxygen levels along the Delaware River and Bay.

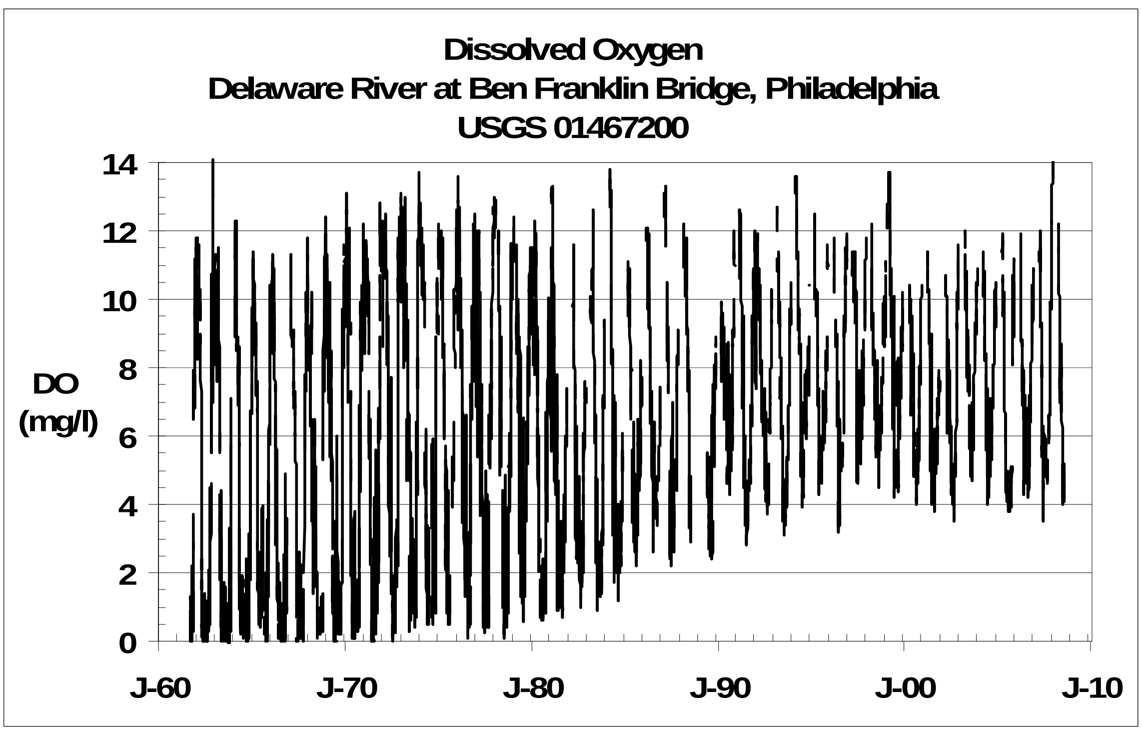


Figure 6.3. Mean daily dissolved oxygen along the Delaware River at Ben Franklin Bridge in Philadelphia. (USGS 2008)

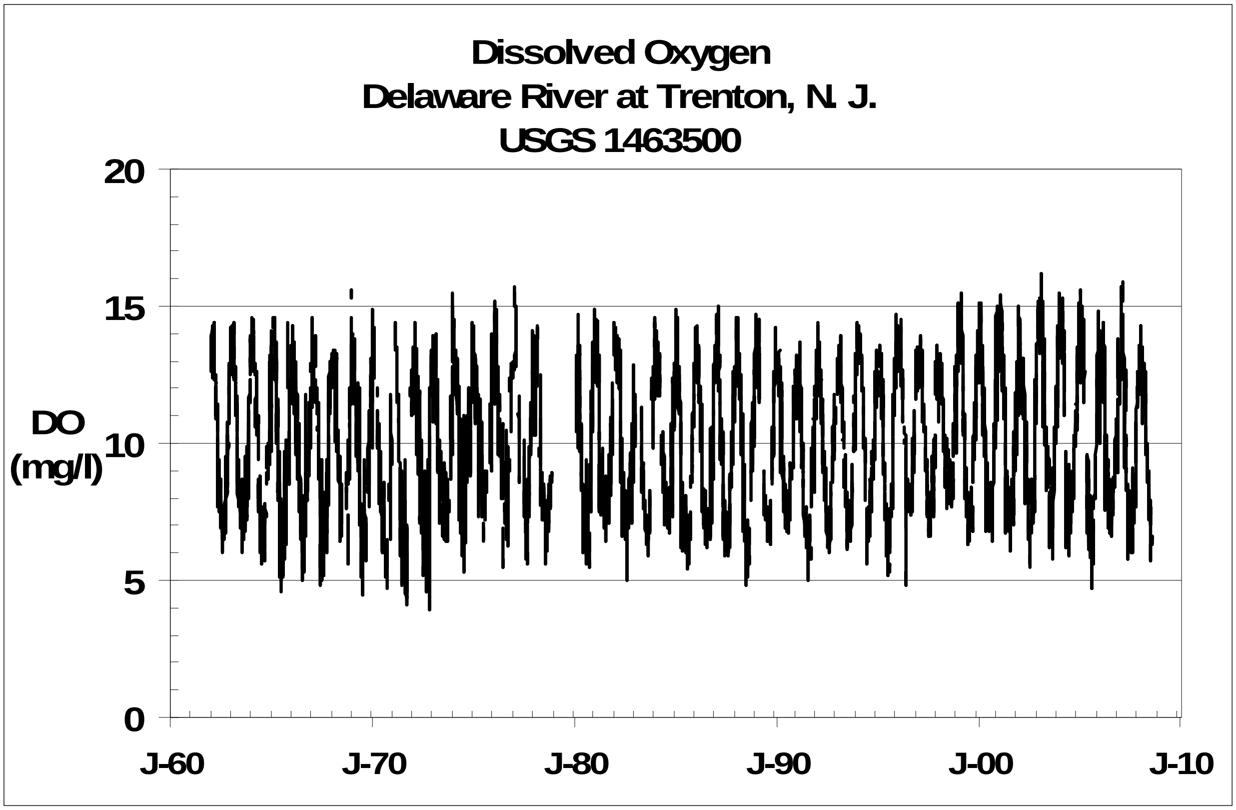


Figure 6.4. Mean daily dissolved oxygen along the Delaware River at Trenton, N. J. (USGS 2008)

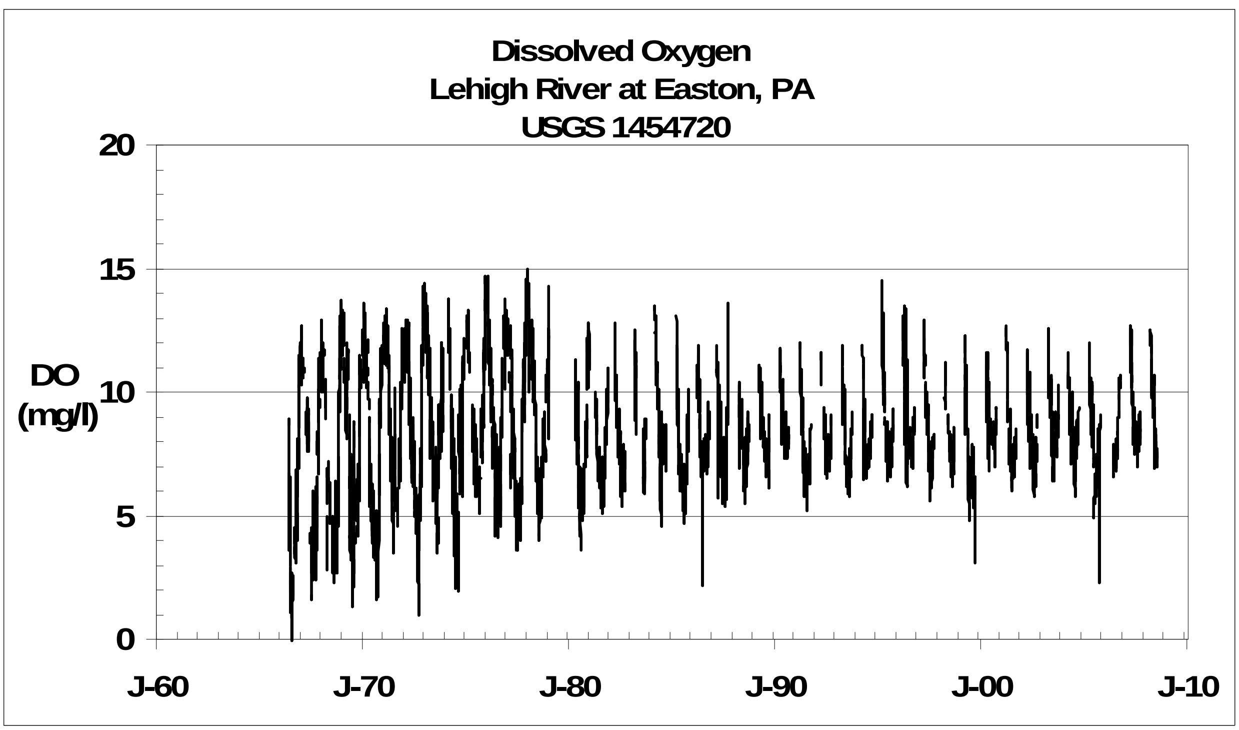


Figure 6.5. Mean daily dissolved oxygen along the Lehigh River at Easton, PA. (USGS 2008)

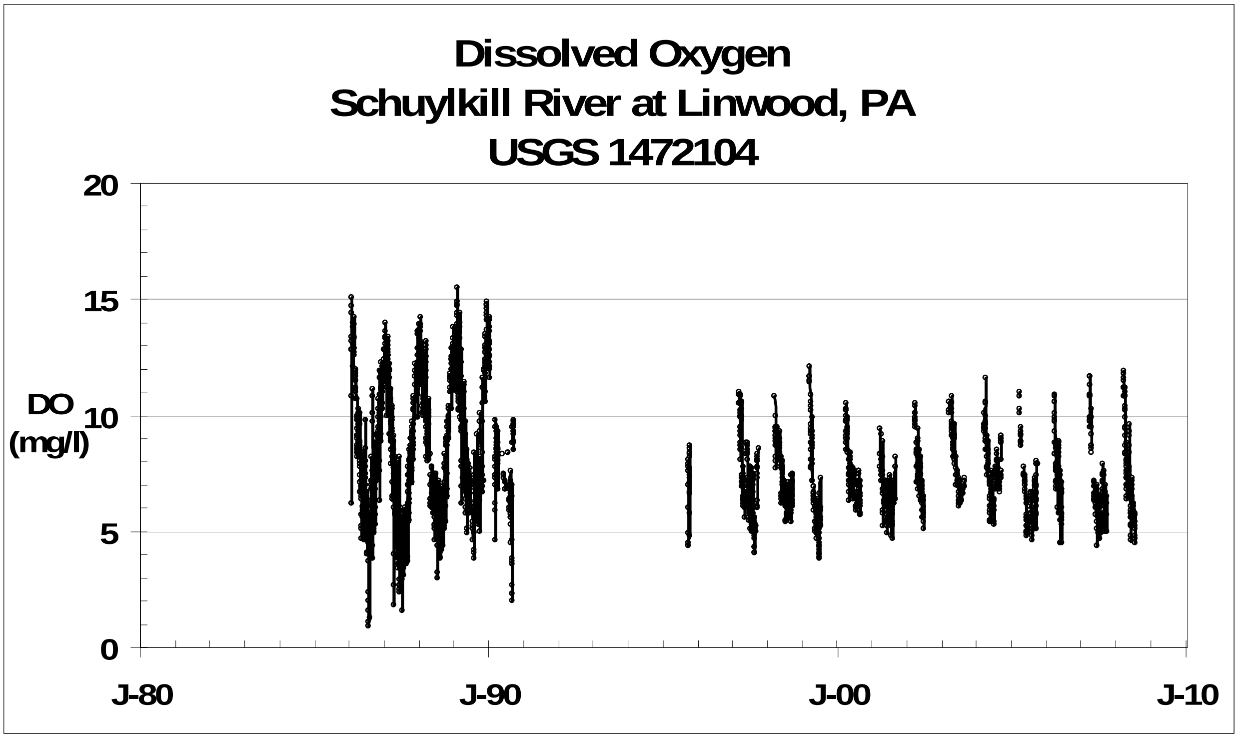


Figure 6.6. Mean daily dissolved oxygen along the Schuylkill River at Linwood, PA. (USGS 2008)

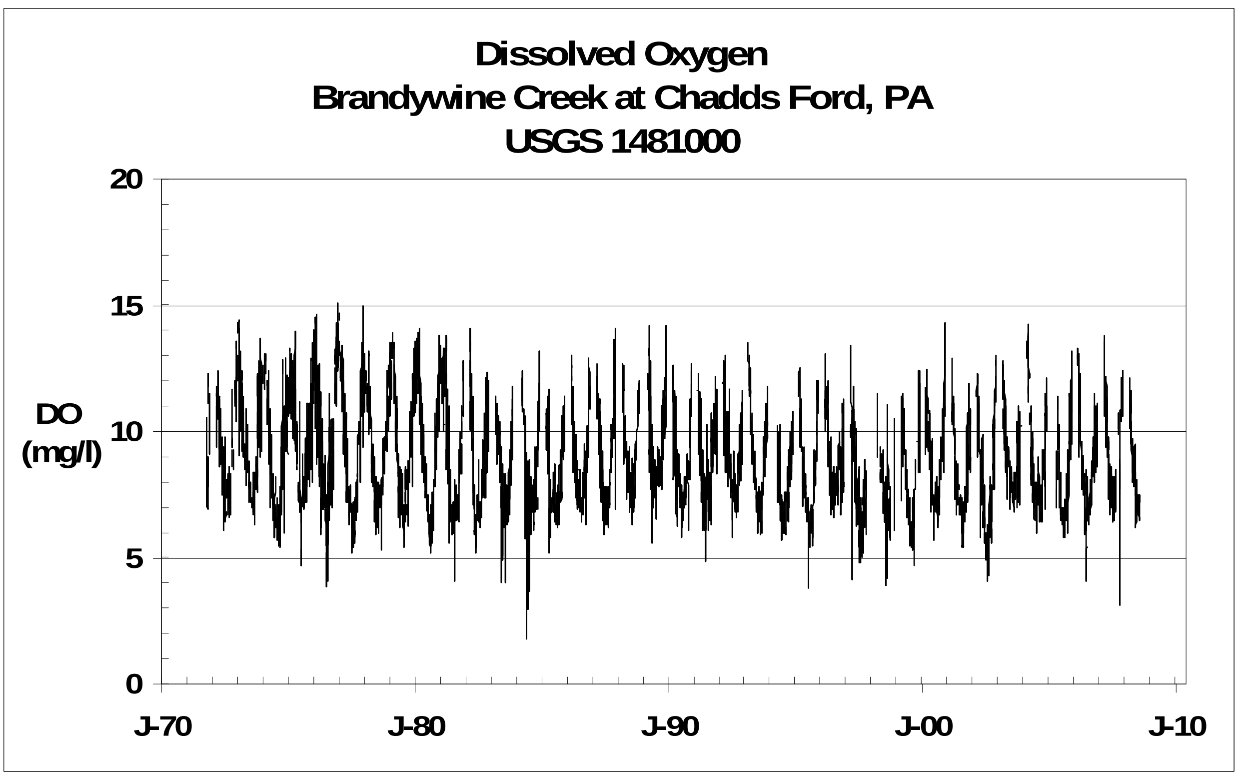


Figure 6.7. Mean daily dissolved oxygen along the Brandywine River at Chadds Ford, PA (USGS 2008)

Figure 6.8 depicts dissolved oxygen scatter plots and rolling median smoothing curves from monitoring data provided by the New Jersey Department of Environmental Protection, Pennsylvania Department of Environmental Protection, and Delaware Department of Natural Resources and Environmental Control. Visual examination of the data, while not statistically significant, indicates DO levels have remained constant since 1970 along the Delaware River at Trenton, improved along the Lehigh and Schuylkill Rivers, and declined along the Brandywine River until the mid 1990s then improved between 1995 and 2005. Water quality as represented by DO is good to excellent at the four stations as all but a few of the individual samples exceed a 5 mg/l standard.

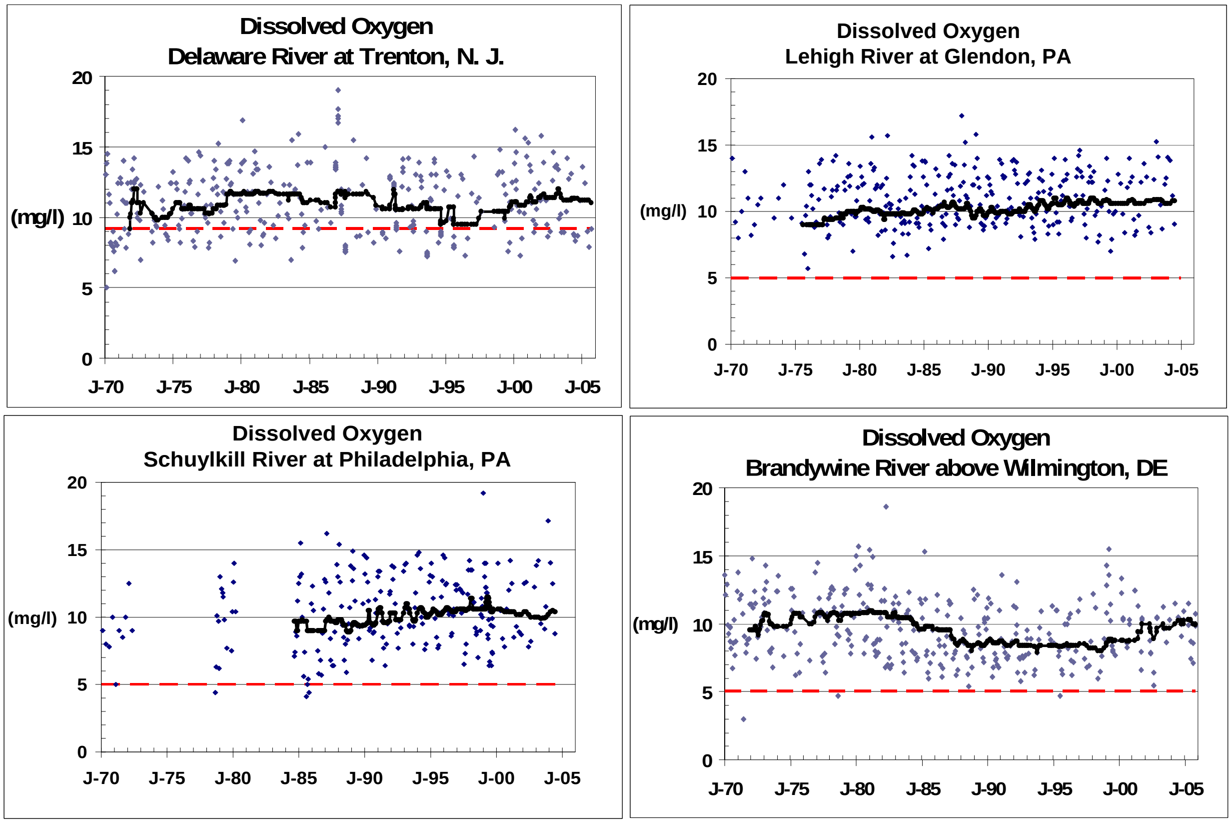


Figure 6.8. Dissolved oxygen along the Delaware, Lehigh, Schuylkill, and Brandywine Rivers. The smoothed line is a 50 - point rolling median. (PADEP, NJDEP, DNREC)

6.4. Nitrogen

One of the most abundant elements, about 80% of the air we breathe is nitrogen. The major routes of entry of nitrogen into bodies of water are, septic tanks, feed-lot discharges, animal wastes (including birds and fish) and discharges from. Bacteria in water quickly convert nitrites [NO2-] to nitrates [NO3-]. . High nitrogen levels cause eutrophication and algae blooms in streams and waterways resulting in depleted oxygen levels and high turbidity. Nitrogen levels higher than the natural background level of 1 mg/l are caused by excess amounts of lawn and farm fertilizers, unicipal /industrial wastewater animal manure, and car exhaust. The USEPA defines a stream aquatic life guidance level for total N at 1 mg/l. Drinking water containing forms of nitrogen higher than the Federal drinking water standard of 10 mg/l can lead to low levels of oxygen in the blood of infants causing blue baby synodrome. Nitrates below 0.5 mg/l seem to have no effect on warm water fish Federal and state water monitoring programs measure nitrogen in various forms such as total nitrogen, nitrate nitrogen, nitrite plus nitrate nitrogen, and Kjehdahl nitrogen.

From the White Paper on the Status and Needs of Science in the Delaware Estuary (Kreeger *et al.* 2006):
… ratios of various macronutrients (N, P) and micronutrients and minerals (silica, iron) are critically important for governing the structure and function of biological processes. Although nutrient-based TMDL's (total maximum daily loads) are being completed in some tributaries and eutrophication is not widespread in the Delaware Estuary, biological balance may be at risk in some areas due to localized eutrophication or to shifts in nutrient balance. Over the past 50 years, concentrations of nitrogen and phosphorus rose, but phosphorous was subsequently reduced as a result of the phosphorus detergent ban. Nitrogen inputs continue to rise. As a consequence, the relative balance of C, N and P appears to have undergone system wide shifts over time and may be tilting toward a high N:P ratio.

The 1998-2001 water quality assessment reports on nitrogen levels in the Delaware Basin (USGS NAWQA Program):

- *… total nitrogen in streams increased with the percentage of agricultural or urban land in a watershed.*
- *Nitrate was detected in more than 95 percent of the streams sampled. Concentrations of total nitrate ranged from nondetectable to 10.5 mg/l as N, with a median of 0.87 mg/l.*
- Median nitrate was highest in Piedmont streams (2 mg/l) where over 50% of the province is covered by agriculture and urban, followed by Valley and Ridge (1 mg/l) and Appalachian Plateau (0.2 mg/l) provinces.

6.5. Phosphorus

Phosphorus is naturally occurring and needed for the metabolism of living organisms but in high amounts is often the limiting nutrient leading to algae blooms and eutrophication of freshwater resulting in high turbidity, depleted oxygen levels, and fish kills. Phosphorus levels higher than the USEPA standard of 0.05 mg/l for streams that enter lakes and 0.1 mg/l for flowing waters are due agriculture, lawn fertilizers, manure, leaking septic systems, and under performing wastewater plants. Since the 1980's phosphorus levels declined due to (1) state bans on phosphate detergent, (2) phosphorus limits at wastewater plants, and (3) agriculture conservation plans since the 1972 Federal Clean Water Act.

One of the water quality success stories is the reduction in phosphorus loads due to the ban on phosphate laundry detergents and numerical P limits at wastewater plants in the 1980s (Litke 1999). Synthetic phosphate detergents (up to 15% phosphorus) were introduced after World War II and consumption peaked by the mid 1960's. In 1970, Congress became oncerned about phosphate detergent effects on water quality recommending that phosphorus detergent manufacture end by 1972. No federal ban ensued. The states banned phosphate laundry detergents including New York in 1973 – 1976 and Pennsylvania in 1990. Delaware and New Jersey did not ban phosphate detergents. By 1994, industry halted phosphate detergent production as it became unprofitable due to state - imposed bans.

Phosphate Detergent Ban Chronology

Post-WWII	Manufacturers begin producing synthetic phosphate detergent.
Mid 1960's	Phosphate detergent manufacture peaks.
1970	U.S. Congress recommends end of phosphate detergent by 1972. No Federal ban ensues.
1973	New York bans phosphate laundry detergent.
1990	Pennsylvania bans phosphate laundry detergent.
1994	Industry ends manufacture of phosphate laundry detergent.
2006	Many streams in Delaware Basin see measurable decline in P levels.

After the 1972 Clean Water Act, the Federal government funded over $200 billion for construction at wastewater treatment plants. Prior to 1972, few municipal wastewater plants had numerical phosphorus limits. By the 1980's and early 1990's the states began imposing numerical phosphorus limits at wastewater treatment plants. State NPDES wastewater permits reduced phosphorous effluent limits to 0.5 to 1.0 mg/l by tertiary treatment. TMDL provisions of the Federal Clean Water Act now restrict phosphorus loads to receiving streams from wastewater dischargers.

Wastewater Treatment Plant Phosphorus Removal Chronology

Pre 1972	Few municipal WWTPs with numerical P limits.
1972	Passage of Federal Water Pollution Control Act with $200 B in WWTP construction.
1980's	States impose numerical P limits at WWTPs through tertiary treatment.
2006	TMDLS require more restrictive limits on P loads from WWTPs.

Examination of the scatter plots and rolling median smoothing curves illustrated in Figure 6.9 indicate that total phosphorus levels have decreased substantially along the Delaware River at Trenton and along three of the rivers 3 largest tributaries: Lehigh River at Glendon (above Easton), Schuylkill River at Philadelphia, and Brandywine River above Wilmington. Except at Trenton, total P levels are still high with most individual readings above the 0.1 mg/l water quality standard.

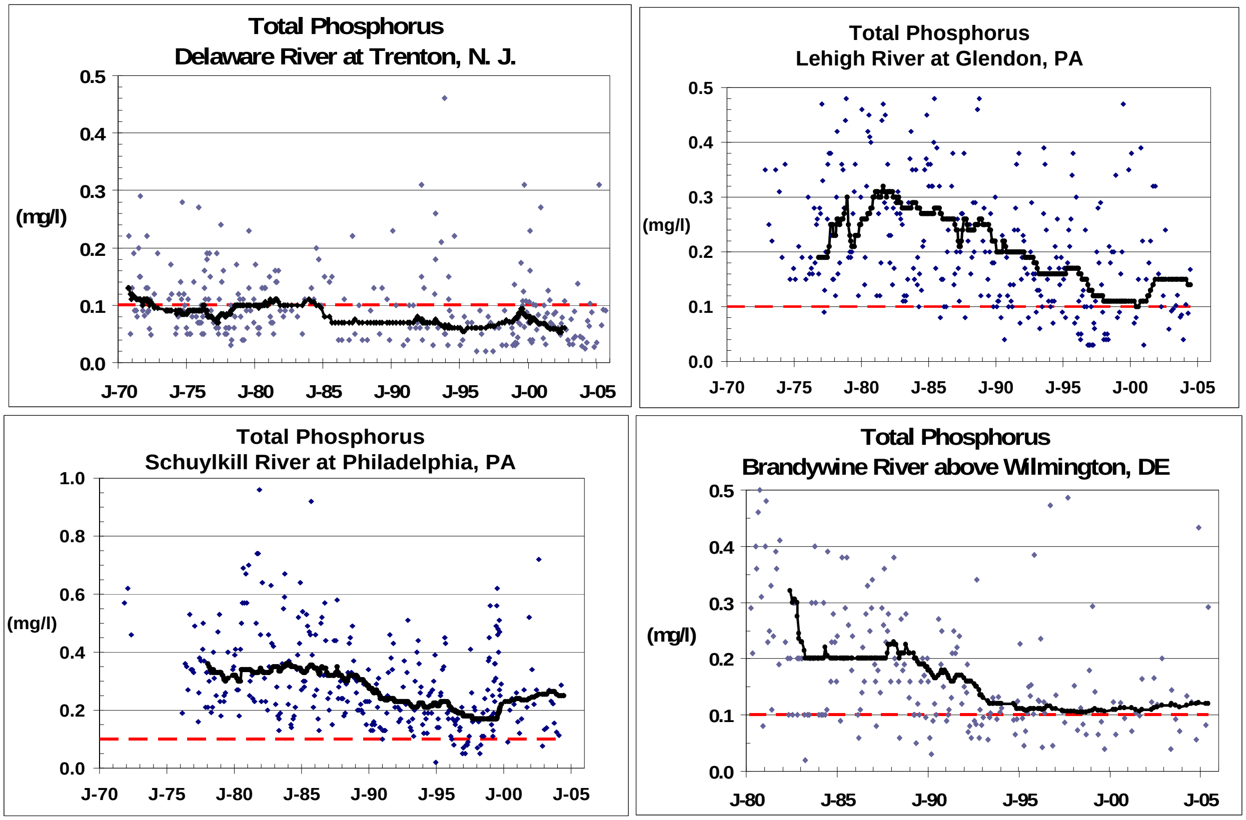


Figure 6.9. Total phosphorus along the Delaware, Lehigh, Schuylkill, and Brandywine Rivers. The smoothed line is a 50 - point rolling median. (PADEP, NJDEP, DNREC)

The USGS NAWQA Program (1998-2001) reports on the status of phosphorus in the Delaware River Basin.

- *Total phosphorus in stream samples ranged from nondetectable to 1.4 mg/l with a median of 0.068 mg/l.*
- *Concentrations commonly exceeded 0.1 mg/l, a goal established by USEPA for minimizing nuisance plant growth. For example, total phosphorus concentrations at 5 of 10 streams sampled throughout the year under all flow conditions exceeded this goal more than 50 percent of the time.*
- *Total P in streams increased with the percentage of agricultural or urban land in a watershed"* (Figure 6.10).

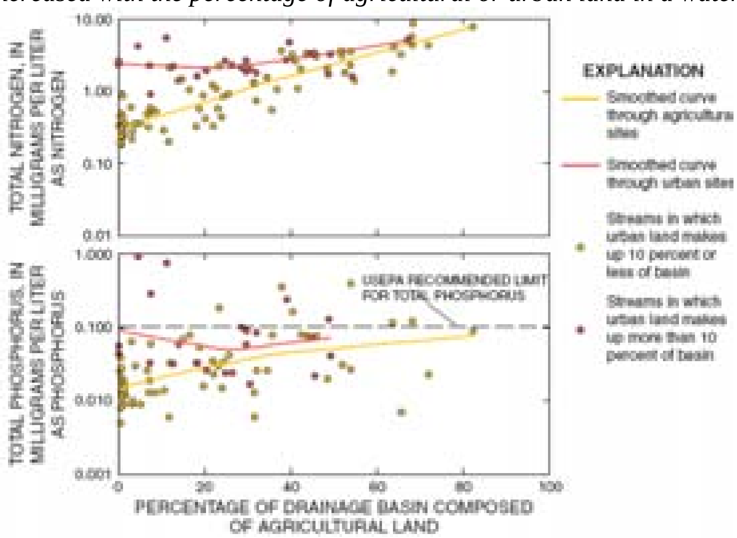


Figure 6.10. Nitrogen and phosphorus levels in agricultural watersheds in the Delaware River Basin. (USGS NAWQA Program)

6.6. Total Suspended Sediment

Total suspended sediment (or solids) refers to matter suspended in water and is related to specific conductance and turbidity. High TSS can block light from reaching submerged vegetation. As the light passing through the water is reduced, photosynthesis slows down. The decrease in water clarity caused by TSS can affect the ability of fish to see and catch food. Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. High levels of TSS cause waters to be murky or turbid resulting in poor stream and aquatic health. Large amounts of TSS block sunlight causing water plants to die, decreased DO levels leading to fish kills, and increased water temperature. TSS levels in many streams have declined markedly since the 1970s due to soil erosion and sediment controls imposed on new construction by local and state governments and agriculture conservation programs led by the USDA – Natural Resources Conservation Service and the county conservation districts. Control of TSS in streams is important because many other pollutants such as bacteria, nitrogen, phosphorus, pesticides and metals bind to the soil particles and are carried into the waterway. By controlling TSS, watershed managers can reduce the loads from many other pollutants in waterways.

Delaware, New Jersey, and New York do not have TSS stream water quality standards. New Jersey sets a maximum TSS level of 40 mg/l for warm water streams and 20 mg/l for cold water trout streams.

Total suspended sediment levels have improved along the Schuylkill and Lehigh Rivers, the two largest tributaries feeding the Delaware Estuary (Figure 6.11). Most recorded TSS readings are below a 40 mg/l TSS standard used by New Jersey for warm water streams.

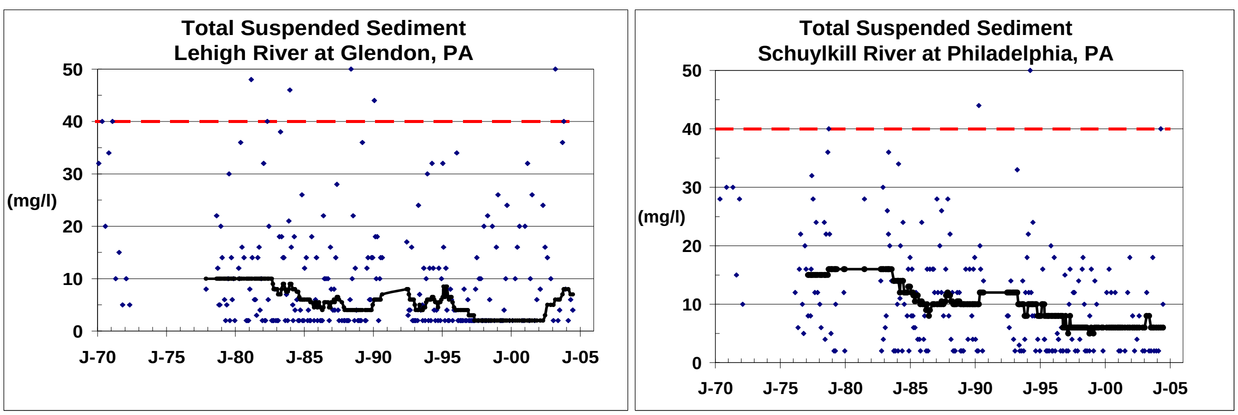


Figure 6.11. Total suspended sediment along the Lehigh and Schuylkill Rivers. The smoothed line is a 50 - point rolling median. (PADEP, NJDEP, DNREC)

Results

Table 6.5 summarizes water quality trends and five year medians from 2001 – 2005 in the Delaware River Basin. Figures 6.12, 6.13, 6.14, and 6.15 illustrate scatter plots with 5-year medians for DO, N, P, and TSS.

Median water quality levels in the Delaware River Basin have improved or remained constant at 89% of the stations examined over the short term since 1990 and 88% over the long term since 1970. Since 1990: dissolved oxygen levels have improved at 41%, remained constant at 37%, and degraded at 22% of the stations. Nitrogen levels have improved at 9%, remained constant at 87%, and degraded at 4% of the stations. Total phosphorus levels have improved at 56%, remained constant at 44%, and degraded at none of the stations. Total suspended sediment have improved at 8%, remained constant at 76%, and degraded at 16% of the stations.

Since 1970: DO has improved at 65%, remained constant at 27%, and degraded at 8% of the stations. N has improved at 37%, remained constant at 42%, and degraded at 21% of the stations. Total P has improved at 70%, remained constant at 19%, and degraded at 11% of the stations. TSS has improved at 55%, remained constant at 36%, and degraded at 9% of the stations. Water quality is good in the freshwater Delaware River and watersheds upstream from Trenton and declines to mostly fair and but some poor for N and P in the tidal estuary at Philadelphia and Wilmington.

Table 6.5. DO, N, P, and TSS water quality trends in the Delaware River Basin.

Station	DO (mg/l)	N (mg/l)	P (mg/l)	TSS (mg/l)	DO (mg/l)	N (mg/l)	P (mg/l)	TSS (mg/l)
	SHORT	TERM	SINCE	1990	LONG	TERM	SINCE	1970
EW1 West Br. Delaware R. Hancock, NY	10.4●	0.4●	0.01▲	6●	10.4●	0.4●	0.01▲	6●
EW2 East Br. Delaware R. Hancock, NY	9.9●	0.2●	0.01●	5●	9.9●	0.2●	0.01▲	5●
EW3 Hancock - Narrowsburg, NY								
LW1 Lackawaxen R. at Lackawaxen, PA	12.6▲	0.2●	0.02▲	6●	12.6▲	0.2▲	0.02▲	6▲
NM1 Delaware River at Pt. Jervis, NY	10.7▲	0.2●	0.02●	5●	10.7▲	0.2●	0.02●	5●
UC1 Brodhead Cr at Del. Water Gap, PA	12.0▲	0.5●	0.05▲	2●	12.0▲	0.5●	0.05▲	2▲
UC2 Paulins Kill at Blairstown, NJ	10.0●	1.0	0.02●	7●	10.0●	1.0●	0.02▲	7●
LV1 Lehigh River at Stoddartsville, PA	11.5▲	0.2●	0.01▲	4●	11.5▲	0.2▲	0.01▲	4●
LV2 Lehigh River at Walnutport, PA	12.1▲	0.7●	0.02▲	8▼	12.1▲	0.7▲	0.02▲	8▼
LV3 Lehigh River at Glendon, PA	11.2▲	2.1▼	0.11▲	9▼	11.2▲	2.1▼	0.11▲	9●
LC1 Wichechocke Creek at Stockton, NJ								
SV1 Schuylkill River at Berne, PA	10.5▼	1.0▲	0.02▲	6▼	10.5▲	1.0▲	0.02▲	6▲
SV2 Schuylkill River at Pottstown, PA	10.1●	3.0●	0.12▲	8●	10.1▲	3.0▼	0.12▲	8▲
SV3 Schuylkill R. at Philadelphia, PA	10.8▲	3.2●	0.23▲	2▲	10.8▲	3.2▼	0.23▲	2▲
UE1 Neshaminy Cr. at Langhorne, PA	10.7●	2.3●	0.18▲	6●	10.7▲	2.3▲	0.18▲	6▲
UE2 N. Br. Rancocas at Pemberton, NJ	7.1▼		0.05●		7.1●		0.05●	
UE2 Cooper River at Haddonfield, NJ	7.2▼	1.0●	0.23●	19●	7.2▲	1.0▲	0.23▲	19▲
LE1 Brandywine R. above Wilmington, DE	9.9▲	2.5●	0.12●	9●	9.9●	2.5▲	0.12▲	9●
LE2 Smyrna River at Route 9 bridge, DE	6.1▼	0.6●	0.21●	86▲	6.1▼	0.6	0.21●	86
LE3 Salem River at Woodstown, NJ	9.5▲	3.7	0.15●	17●	9.5●	3.7▼	0.15▼	17▲
DB1 Leipsic River at Route 13, DE	7.9▼	0.1▲	0.23●	20●	7.9▼	0.1▲	0.23▲	20
DB2 Maurice River at Norma, NJ	8.2▼	2.0	0.01●	3●	8.2●	2.0▼	0.01▼	3▲
Water Quality Trend: Improved ▲	9/20	2/16	10/20	2/19	11/20	8/18	15/20	9/17
Constant ●	5/20	13/16	10/20	14/19	7/20	5/18	3/20	7/17
Degraded ▼	6/20	1/16	0/20	3/19	2/20	5/18	2/20	1/17
Delaware River and Bay								
RM304 Callicoon, NY	11.0●	0.3●	0.01▲	2●	11.0	0.3	0.01	2
RM253 Port Jervis, NY	10.7▲	0.2●	0.02●	6●	10.7▲	0.2●	0.02●	6●
RM246 Montague, NJ	9.9▼	0.2●	0.02▲	2●	9.9▲	0.2●	0.02▲	2▲
RM145 Riegelsville, NJ	10.4●	0.3●	0.05▲	4●	10.4▲	0.3▲	0.05▲	4▲
RM134 Trenton, NJ	11.2▲	1.1●	0.07▲		11.2▲	1.1●	0.07▲	▲
RM100 Ben Franklin Bridge, Phila, PA	7.3▲	1.1●	0.10●	13●	7.3▲	1.1●	0.10▲	13
RM82 Chester, PA	6.6●				6.6			
RM73 Cherry Island Wilmington, DE	7.6●	1.7	0.14	24	7.6	1.7	0.14	24
RM66 New Castle, DE	7.4●	1.8	0.13	34	7.4	1.8	0.13	34
RM61 Pea Patch Island., DE	7.5●	1.6	0.15	44	7.5	1.6	0.15	44
RM55 Reedy Island, DE	7.9▲	1.5●	0.13▲	32▼	7.9▲	1.5●	0.13▼	32▼
RM22 Egg Island, NJ	8.6●	0.2	0.05	17	8.6	0.2	0.05	17
RM10 Big Stone Beach, DE							0.06●	
Water Quality Trend: Improved ▲	13/32	2/23	15/27	2/25	17/26	9/24	19/27	12/22
Constant ●	12/32	20/23	12/27	19/25	7/26	10/24	5/27	8/22
Degraded ▼	7/32	1/23	0/27	4/25	2/26	5/24	3/27	2/22

Five year median 2001 – 2005 level (mg/l): **8.0** = Good **6.0** = Fair **4.0** = Poor

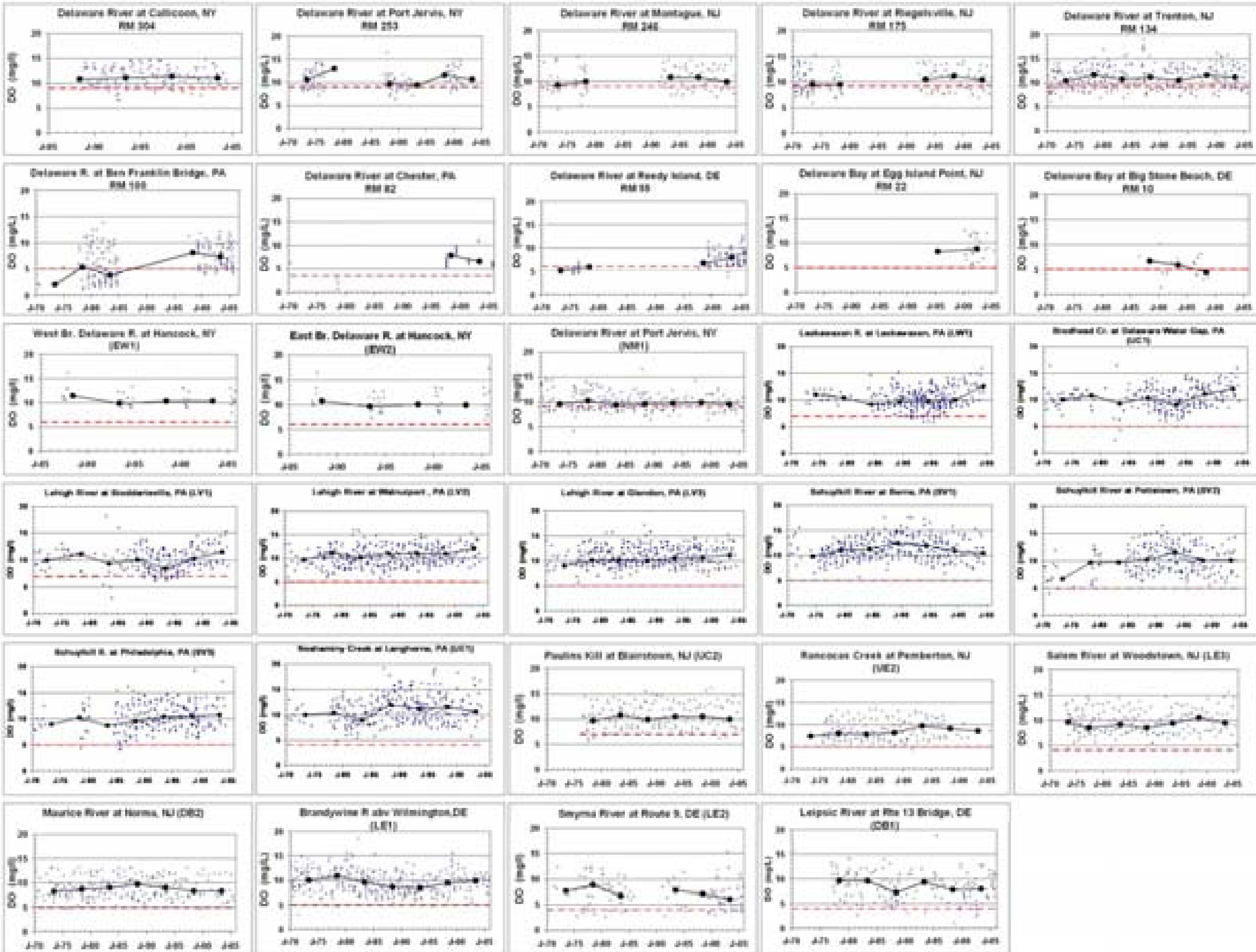


Figure 6.12. Dissolved oxygen trends in the Delaware River Basin.

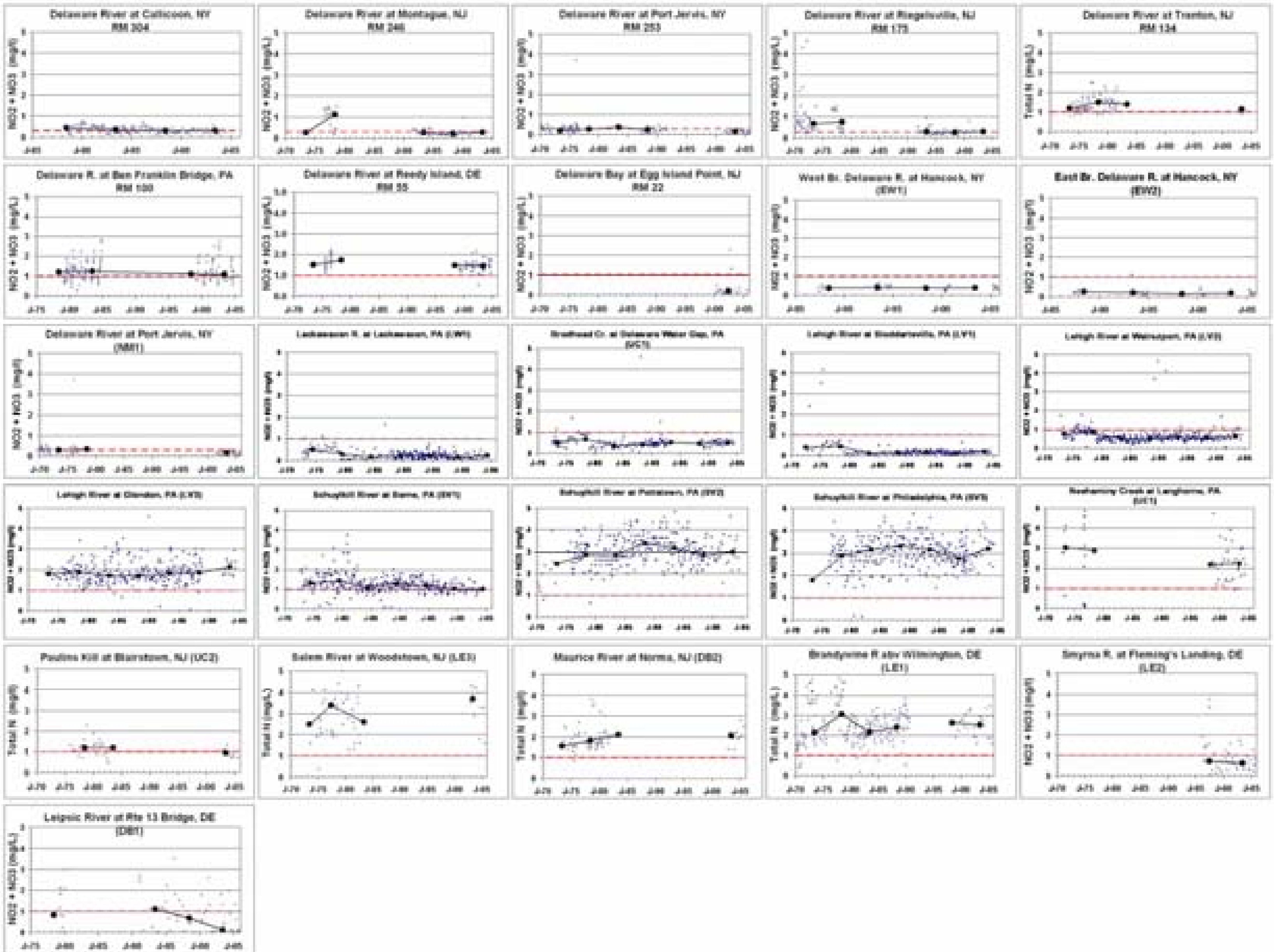


Figure 6.13. Nitrogen trends in the Delaware River Basin.

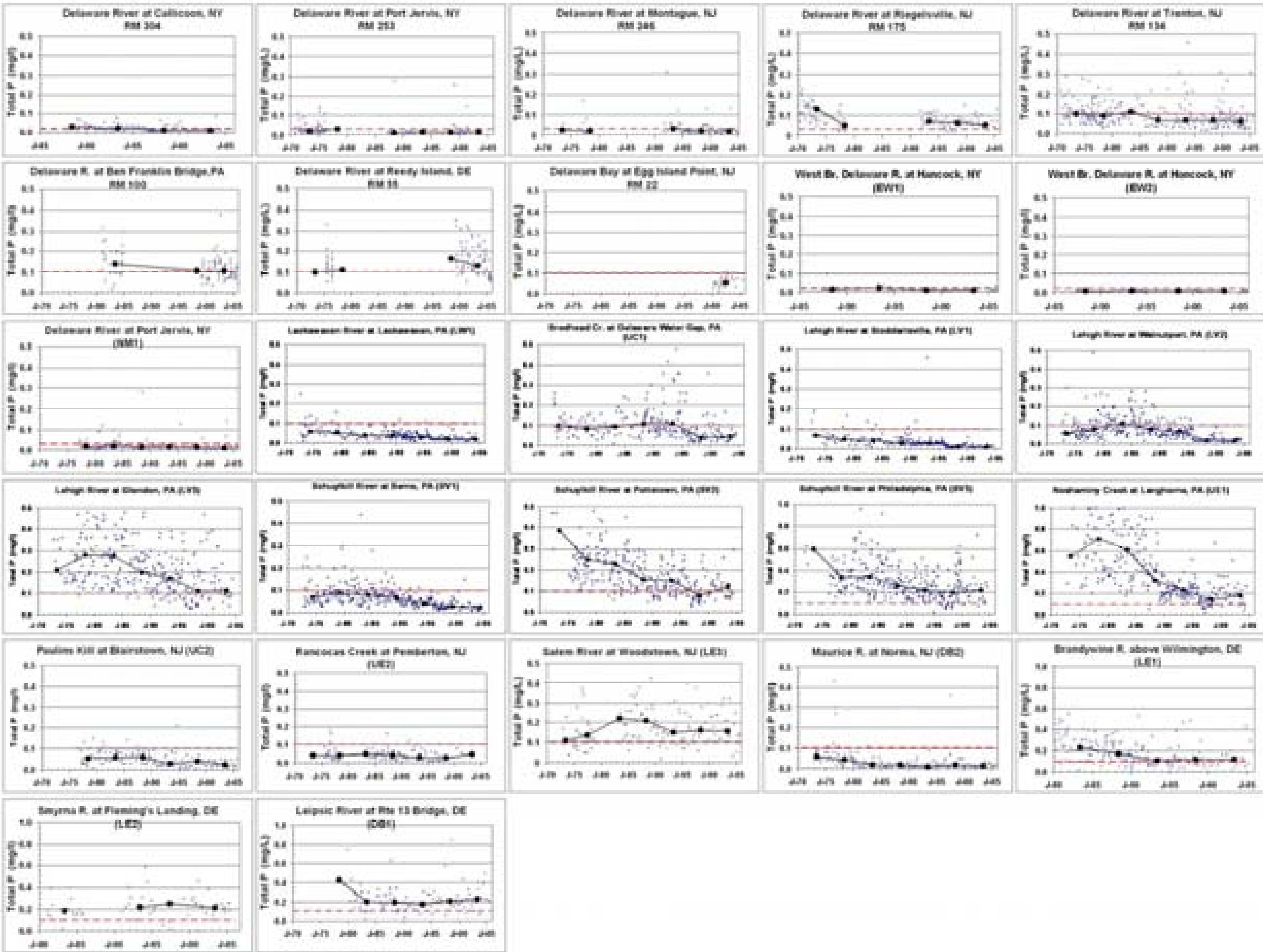


Figure 6.14. Phosphorus trends in the Delaware River Basin.

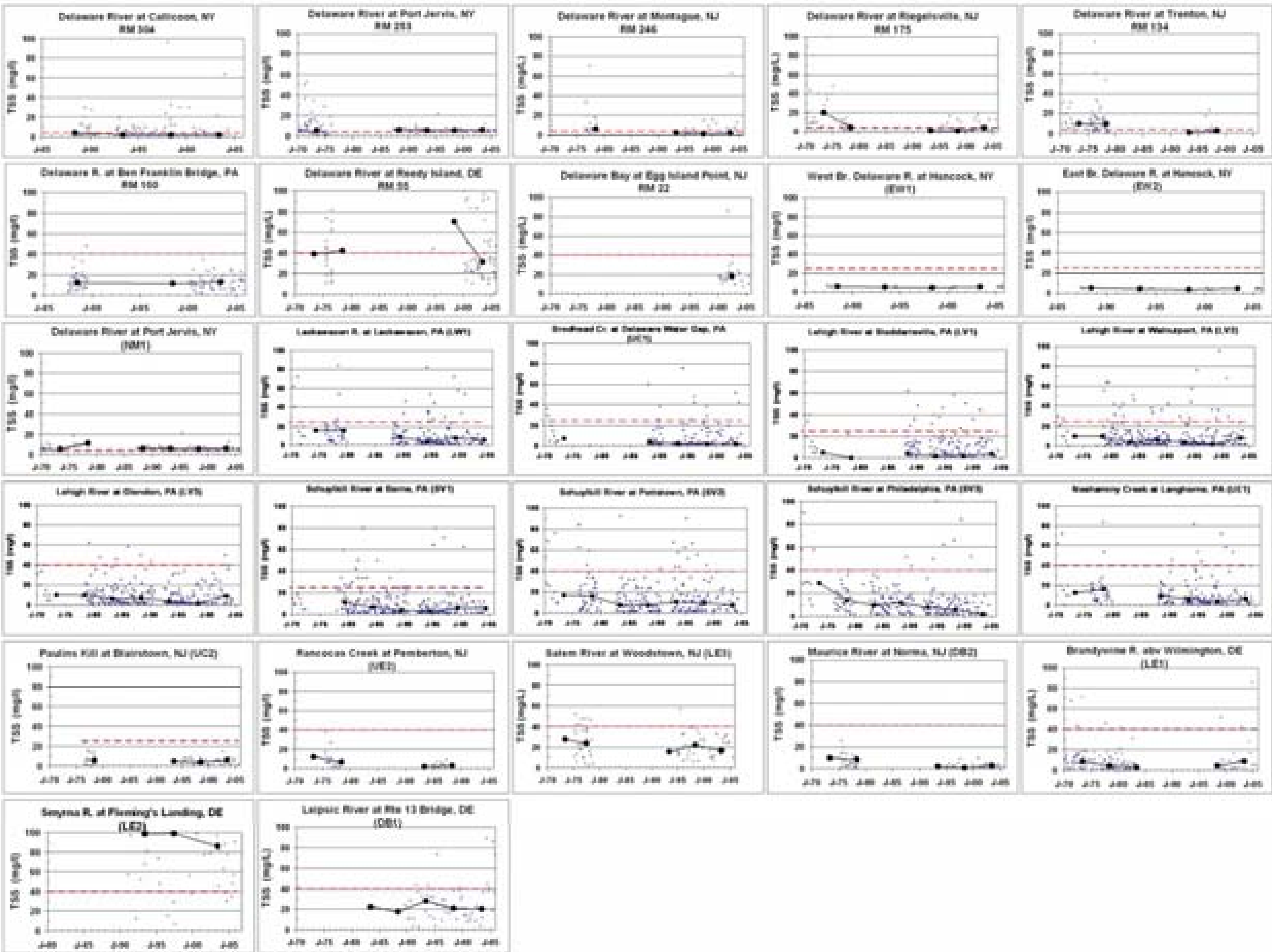


Figure 6.15. Total suspended sediment trends in the Delaware River Basin.

Delaware River and Bay

Water quality in the Delaware River and Bay has improved since 1970 and 1990. Most parameters indicate better or constant water quality now compared to 15 and 35 years ago (Figure 6.16). Since 1990; dissolved oxygen, nitrogen, phosphorus, and sediment levels improved at 4/12, 0/7, 5/7, and 0/6 stations, respectively. DO, N, P, and TSS levels remained constant at 7/12, 7/7, 2/7, and 5/6 stations, respectively. The Delaware River at Reedy Island (RM55) reported a degrading trend for sediment since 1990. Since 1970; DO, N, P, and TSS levels improved at 6/6, 1/6, 4/7, and 3/5 stations, respectively. DO, N, P, and TSS levels remained constant at 0/6, 5/6, 2/7, and 1/5 stations, respectively. Only the Delaware River at Reedy Island (RM55) reported degrading phoshorus and TSS trends since 1970.

Median 2001 – 2005 levels of DO, N, P, and TSS indicate water quality in the Delaware River is good above the Delaware Water Gap, fair to good above Trenton, and declines in the tidal estuary to fair for DO and TSS and poor for N and P (Figure 6.17). Downstream from Trenton in the tidal reach, water quality declines to lowest levels at Philadelphia, Chester and Wilmington. Downstream past Reedy Island and the C & D Canal into the bay, water quality improves as the cleaner tidal waters of the Atlantic Ocean begin to exert their influence on the intertidal mixing zone.

Water quality along the Delaware River above Trenton is fair to good and exceptional upstream from the Delaware Water Gap . At 5 stations between Trenton and Callicoon, median (2001 – 2005) DO levels exceed 9.8 mg/l, nearly double the fishable criteria of 5 mg/l. Median N levels are good at 4 of 5 stations above Trenton, ranging from 0.2 - 0.3 mg/l (less than the 1.0 mg/l criteria). Phosphorus levels meet the 0.02 mg/l criteria at 3 of 5 stations. Median TSS levels range from 2 - 6 mg/l, less than the 25 mg/l New Jersey cold water standard, at all 4 river stations above Trenton.

Water quality is mostly fair for DO and TSS and poor for N and P in the tidal Delaware Estuary below Trenton. DO ranges from 6 to 8 mg/l, above the 5 mg/l fishable criteria, at all 7 stations between Philadelphia and the C & D Canal. Nitrogen levels are poor in the Delaware Estuary (1.1 to 1.8 mg/l), above the 1 mg/l criteria, at all 6 stations between Trenton and the C & D Canal. Phosphorus levels in the estuary are fair between Trenton and Philadelphia and poor from Wilmington downstream to the C&D Canal. TSS levels are good from Philadelphia to Wilmington and fair between New Castle and the C&D Canal except for TSS levels which exceed 40 mg/l at Pea Patch Island, Delaware.

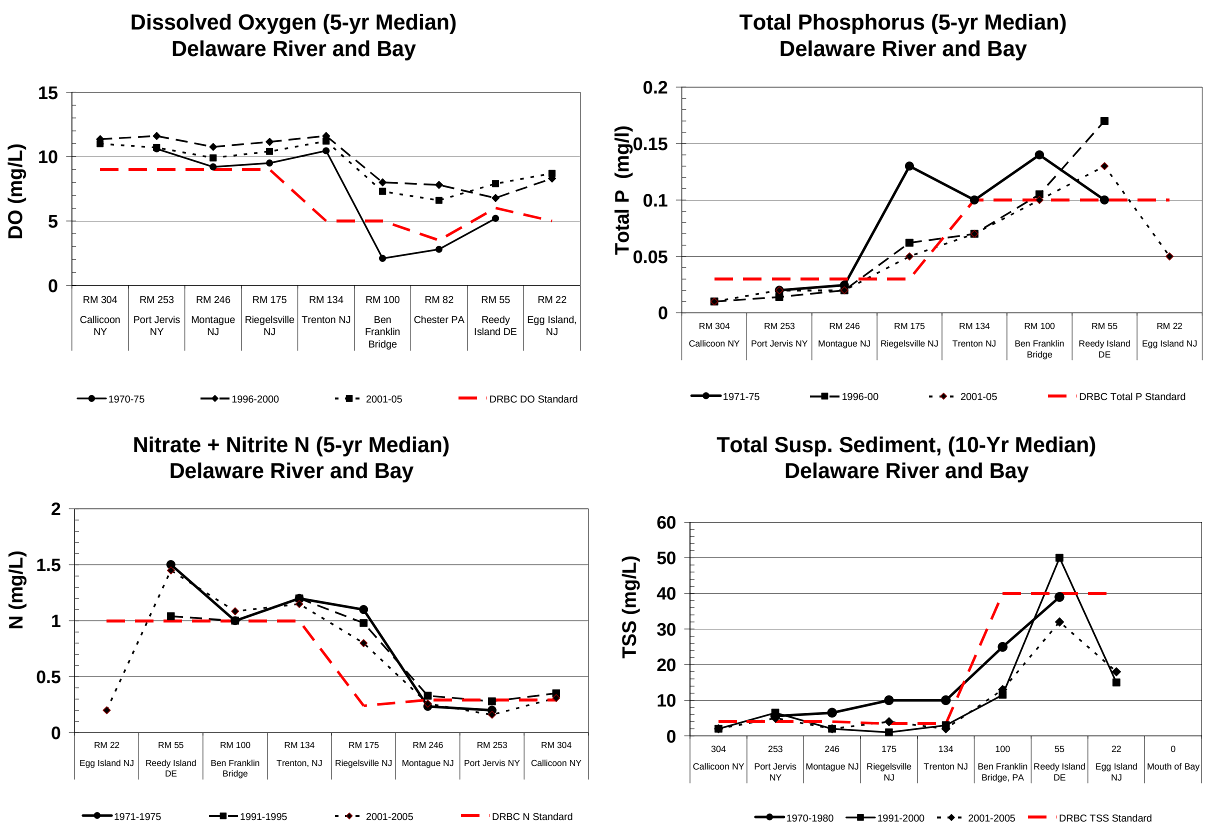


Figure 6.16. Spatial water quality trends along the Delaware River and Bay.

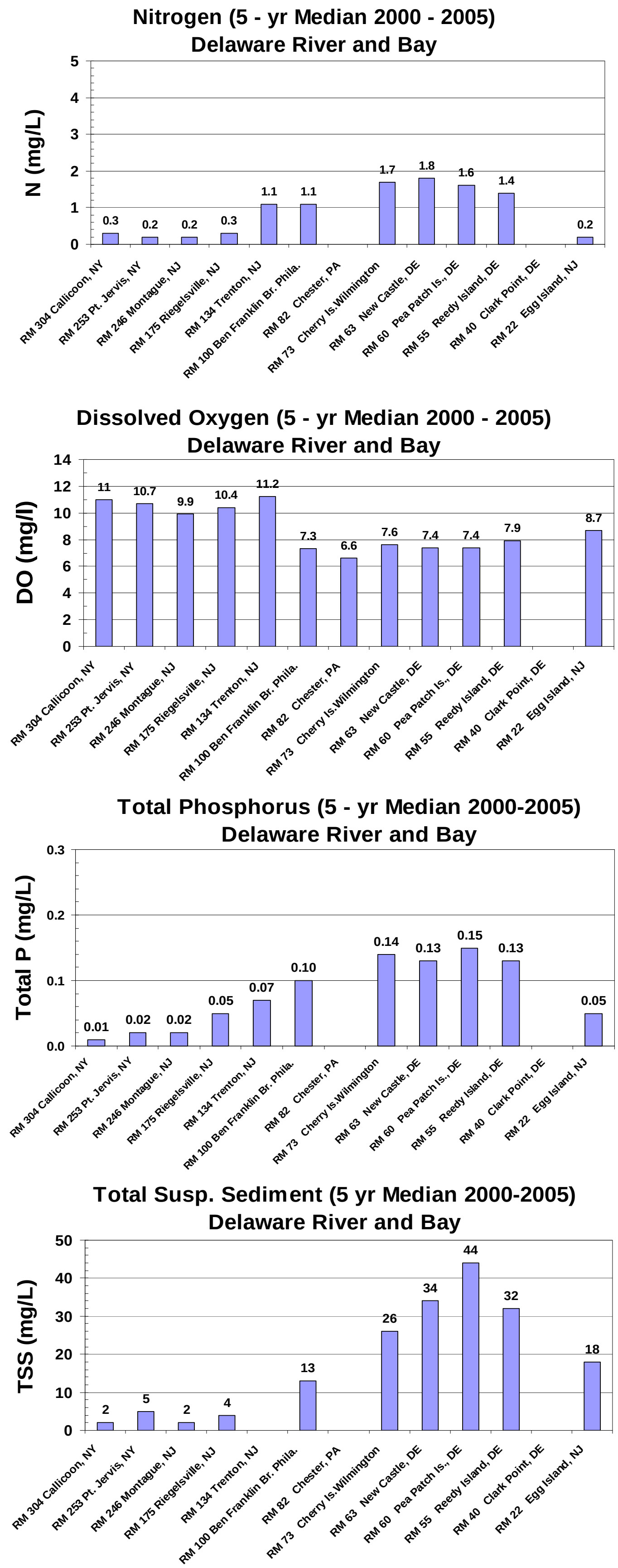


Figure 6.17. Median water quality levels along the Delaware River and Bay.

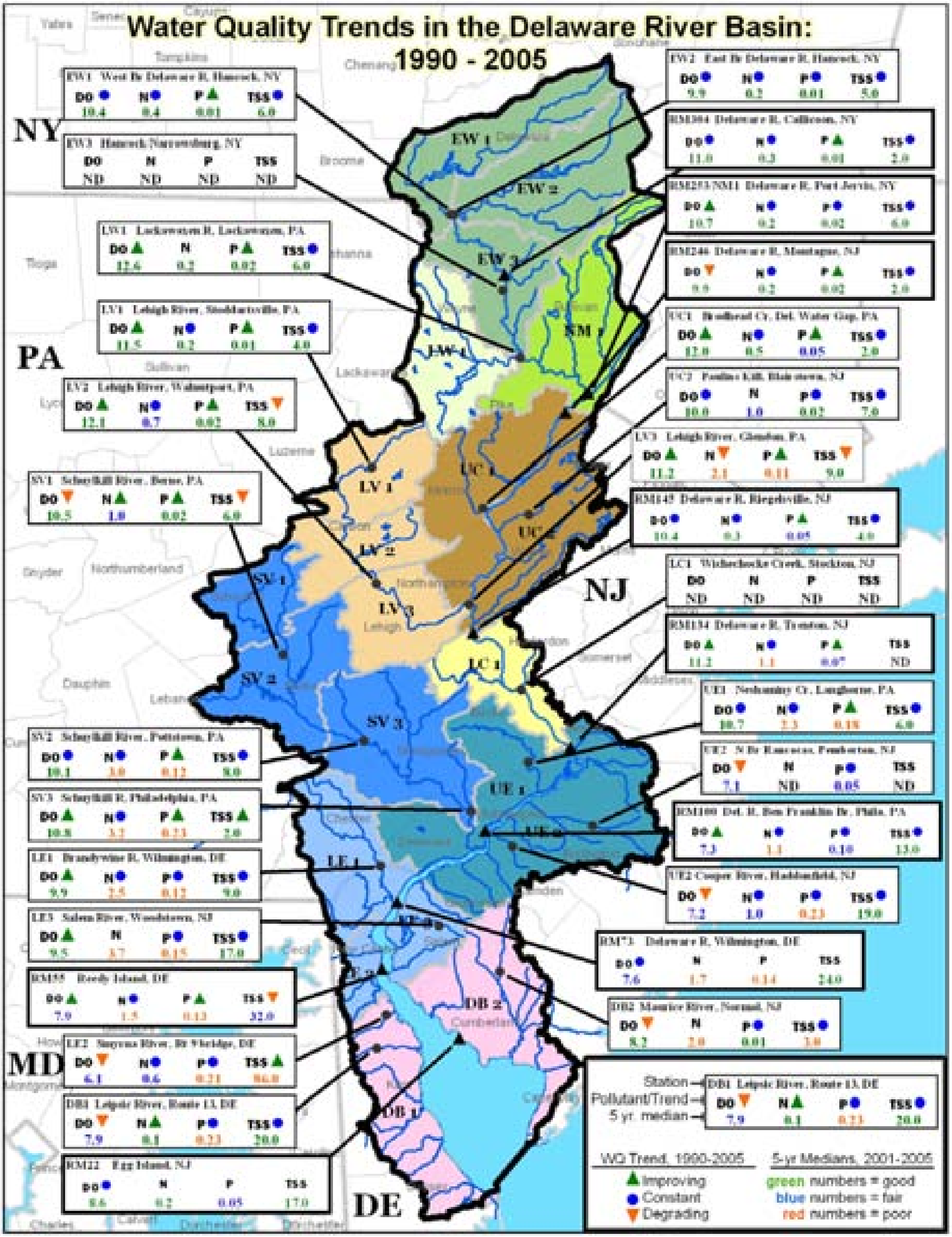


Figure 6.18. Median DO, N, P, and TSS trends in the Delaware River Basin since 1990. (UDWRA 2008).

Subwatersheds of the Delaware River Basin

Median DO, N, P, and TSS water quality levels in the subwatersheds of the Delaware River Basin have improved or remained constant at 65/75 (87%) of stations since 1990 and 65/75 (87%) of stations since 1970. Since 1990; 23 stations recorded improved water quality, 42 recorded constant water quality, and only 10 stations recorded degraded water quality levels. Since 1970; 43 stations recorded improved water quality, 22 recorded constant water quality, and only 10 stations recorded degraded water quality. Tables 6.6 and 6.7 summarize water quality trends in Delaware Basin subwatersheds as improved, constant, or degraded since 1990 and 1970.

Table 6.6. Short-term water quality trends in Delaware Basin subwatersheds since 1990.

Parameter	Improved	Constant	Degraded	Subtotal
Dissolved Oxygen	9	5	6	20
Nitrogen	2	13	1	16
Phosphorus	10	10	0	20
Suspended Sediment	2	14	3	19
Total No. of Stations	**23**	**42**	**10**	**75**

Table 6.7. Long-term water quality trends in Delaware Basin subwatersheds since 1970.

Parameter	Improved	Constant	Degraded	Subtotal
Dissolved Oxygen	11	7	2	20
Nitrogen	8	5	5	18
Phosphorus	15	3	2	20
Suspended Sediment	9	7	1	17
Total No. of Stations	**43**	**22**	**10**	**75**

In the Delaware Basin, most subwatershed stations indicate better or constant water quality compared to 15 and 35 years ago. Since 1990: dissolved oxygen, nitrogen, phosphorus, and sediment improved at 9/20, 2/16, 10/20, and 2/19 stations, respectively. DO, N, P, and TSS levels remained constant at 5/20, 13/16, 10/20, and 14/19 stations, respectively. We observed degrading DO trends since 1990 at the Schuylkill at Berne, Rancocas Creek, Cooper River, Smyrna River, Leipsic River, and Maurice River. Only the Lehigh River at Glendon recorded a degrading N trend since 1990. We noticed degrading TSS trends at two Lehigh River stations and the upper Schuylkill River at Berne.

Since 1970, dissolved oxygen, nitrogen, phosphorus, and sediment levels improved at 11/20, 8/18, 15/20, and 9/17 stations, respectively. Since 1970, DO, N, P, and TSS levels remained constant at 7/20, 5/18, 3/20, and 7/17 stations, respectively. Degrading DO trends since 1970 were recorded at the Smyrna River and Leipsic River stations. For nitrogen, the Lehigh River at Glendon, Schuylkill River at Pottstown and Philadelphia, Salem River and Maurice River stations recorded degrading trends since 1970. The Salem River and Maurice River recorded declining trends for phosphorus. We noticed a degrading TSS trend only at the Lehigh River at Walnutport station.

Spatially, water quality in the Delaware is mostly good in the forested subwatersheds from the Lehigh River north to mountain headwaters above Port Jervis, New York. Water quality declines from the Schuylkill River and downstream as subwatersheds become more populated toward the Philadelphia/Camden/Wilmington metropolitan area and then further south to the agricultural coastal plain tributaries to the Delaware Bay (Figure 6.20).

Water quality in the upper region subbasin above Port Jervis, New York is good for all stations and for all parameters. Water quality in the central region subbasin above Trenton is mostly good except for fair to poor for N and P in the lower Lehigh River. Water quality in the lower region subbasin below Trenton is good to fair for DO and TSS and mostly poor for N and P. All streams from Trenton south have DO levels that exceed 5 mg/l. All streams have TSS levels less than 25 mg/l. All streams from Trenton south have N levels that exceed the 0.1 mg/l criteria and P levels that exceed the 0.1 mg/l guidance level except for one segment. Only the headwaters of the Schuylkill at Berne have fair N levels of 0.1 mg/l and a good P level of 0.02 mg/l.

In the Delaware Bay region subbasin below Wilmington, water quality is fair to good for DO, good for TSS and mostly poor for nitrogen and phosphorus . Only the Smyrna River and Leipsic River in Delaware have fair or good N levels. The Rancocas Creek and Maurice River in New Jersey have fair and good P levels.

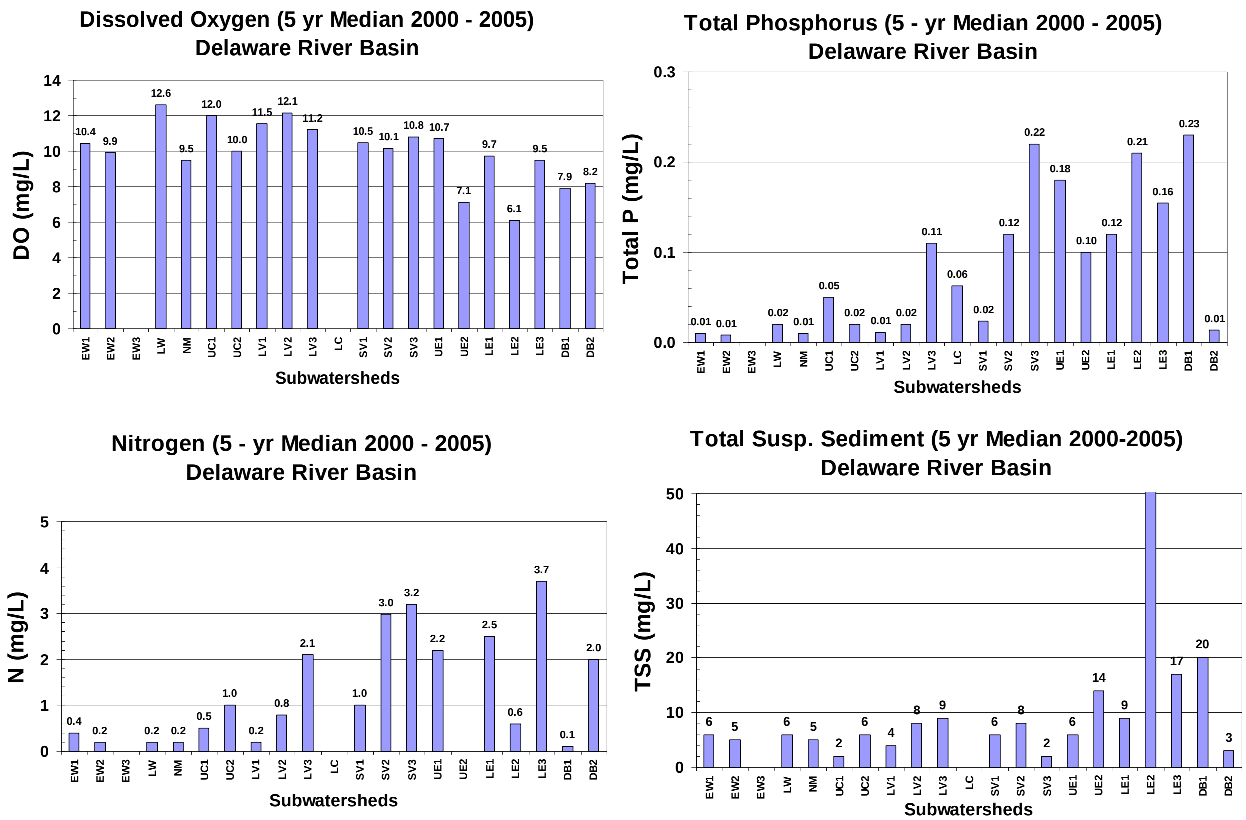


Figure 6.19. Median (2001-2005) water quality levels in Delaware River Basin subwatersheds.

Discussion

We found that water quality in the Delaware River Basin as measured by dissolved oxygen, nitrogen, phosphorus, and total suspended sediment improved or remained constant at 89% of the monitoring stations since 1990 and 88% of the stations since 1970. Overall, 32 % and 58% of the stations recorded improved water quality since 1990 and 1970, respectively. Only 11% and 12% of the stations recorded degraded water quality since 1990 and 1970, respectively. The number of improving water quality stations outnumbered the degrading stations by margins of 3:1 since 1990 and nearly 5:1 since 1970. The following water quality monitoring stations recorded significant (over 25%) improvements in water quality over the short term and the long term.

Dissolved Oxygen: Lackawaxen River, PA (30% improvement since 1990). Delaware River at Ben Franklin Bridge, PA (60% improvement since 1980). Brodhead Creek, PA (33% improvement since 1990).

Phosphorus: Delaware River at Trenton, NJ (40% improvement since 1980). Lehigh River at Stoddartsville, PA (300% improvement since 1980). Lehigh River at Walnutport, PA (350% improvement since 1980). Lehigh River at Glendon, PA (133% improvement since 1980). Schuylkill River at Berne, PA (350% improvement since 1980). Schuylkill River at Pottstown, PA (100% improvement since 1980). Schuylkill River at Philadelphia, PA (30% improvement since 1980). Neshaminy Creek at Langhorne, PA (235% improvement since 1980). Paulins Kill at Blairstown, NJ (25% improvement since 1980). Maurice River at Norma, NJ (200% improvement since 1980).

Nitrogen: Schuylkill River at Berne, PA (40% improvement since 1990). Cooper River at Haddonfield, NJ (800% improvement since 1970.

Total Suspended Sediment: Schuylkill River at Philadelphia, PA (400% improvement since 1990). Maurice River at Norma, NJ (100% improvement since 1970).

One of the more noticeable water quality success stories in the Delaware Estuary Basin occurred along the Cooper River at Haddonfield, New Jersey. The Cooper River flows from the urbanized New Jersey coastal plain into the Delaware Estuary at Camden. In 1972, the Camden County Municipal Utility Authority was formed to upgrade sewage treatment plants in accordance with the Federal Water Pollution Control Act and the DRBC pollution abatement program. Between 1981 and 1990, all wastewater discharges were removed from the Cooper River and sewage was delivered through a regional system to a new 80 mgd wastewater treatment plant No. 1 along the Delaware River at Camden. Coincident with these investments, water quality in the Cooper River improved significantly (Figure 6.20). Median DO levels improved from just above 5 mg/l during 1971-1975 to 10 mg/l by 2000 with a decline to near 7 mg/l by 2005. Total P dropped substantially from 1.0 mg/l during 1976-1980 to near 0.2 mg/l by 2001 – 2005.

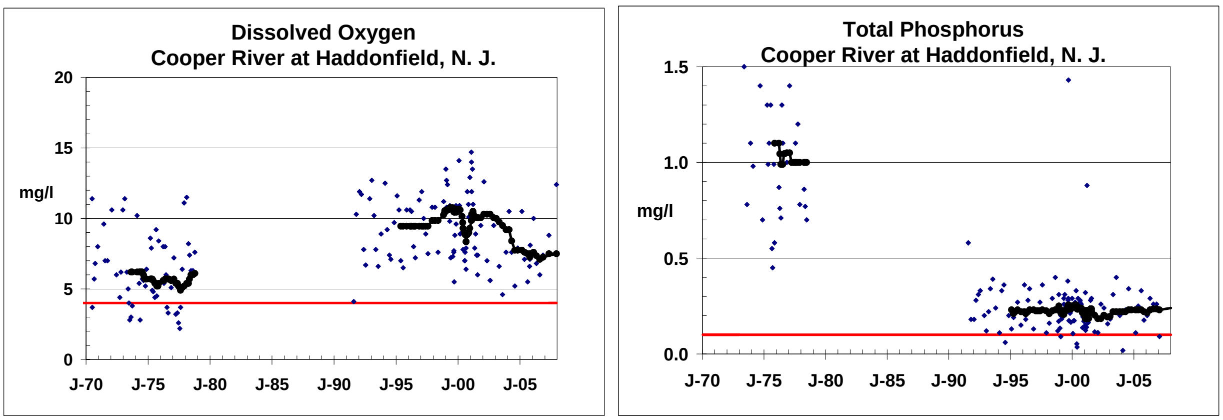


Figure 6.20. Water quality change along the Cooper River at Haddonfield, N. J. (NJDEP)
The smoothed line is defined by a 25 – point rolling median

6.7. Copper

Copper is occurs naturally in the environment and in plants and animals and low levels are essential for maintaining good health. Copper is released into the environment by mining, farming, and manufacturing operations and waste-water releases into rivers. Copper usually attaches to particles made of organic matter, clay, soil, or sand. Copper compounds break down into the air, water, and foods. Primary sources of copper to waterways are:

- Decomposed vehicle brake pads.
- Architectural copper such as roofs and downspouts.
- Copper pesticides for landscaping, wood deck preservatives, and pool algaecides.
- Industrial air emissions from gasoline fuel combustion, residential wood burning, and factories.
- Vehicle fluid leaks.
- Boat and marine antifouling coatings.

Leading copper control practices are introducing alternative materials in vehicle brake lining and utilizing non-copper based marine coatings. The USEPA copper stream water quality standards (which can vary with hardness) are 20 ug/l for acute and 9 ug/l for chronic levels. The Federal drinking water standard for copper is 13 ug/l.

6.8. Lead

Lead is the most abundant toxic heavy metal in the environment. The leading sources of lead in waterways are from wastewater discharges, lead - based paint, airborne deposition from industrial air emissions, and until 1986 emissions from leaded gasoline. In the last few decades, there was significant progress in reducing lead releases to the environment by restricting uses in paint, gasoline, pesticides and other products, promoting battery recycling, and prohibiting the use of lead shot in waterfowl hunting. Since the nationwide ban on lead shot use for waterfowl in 1991, lead poisoning in waterfowl has been greatly reduced. High levels of lead can occur in treated drinking water due to leaching of older lead based plumbing piping. The USEPA recommends stream water quality standards for lead at 65 ug/l for acute and 2.5 ug/l for chronic levels. The Federal drinking water standard for lead is 15 ug/L.

Lead levels in waterways have dropped considerably due to the ban of lead-based paint and the phase-out of leaded gasoline. In 1971, Congress passed the Lead-based Paint Poisoning Act. By 1994, a followup study indicated that U.S. blood levels (a proxy for the amount of lead in the environment) declined by 78% between 1978 and 1991.

A notable water quality success story results from the phase-out of leaded gasoline prompted by action of the Federal government. Since the 1980's, many streams and waterways have shown marked decreases in lead levels. Lead was originally added to gasoline to prevent engine knocking. The exhaust from no knock gas caused emissions with high lead levels. The leaded particulates settled from the air and ended up in waterways. The passage of the Federal Clean Air Act in 1970 presaged the phase-out of leaded gas. By 1972, the USEPA issued a notice of proposed phase-out of lead in gasoline. Industries began looking for unleaded gas alternatives because the lead contaminated the catalytic converters required by the Federal Clean Air Act. By 1982, President Reagan reversed earlier opposition to leaded gas phase-out in the United States. By 1986, refiners completed the primary phase-out of leaded gas in the USA.

Leaded Gas Phase-out Chronology (Kitman 2000)

1921	Thomas Midgley discovers that tetraethyl lead curbs engine knock.
1923	First DuPont tetraethyl lead plant opens along Delaware River in Deepwater, New Jersey.
1925	Yale's Yandell Henderson warns of breathing lead dust from auto emissions.
1936	90% of all gas sold in USA contains tetraethyl lead.
1965	Clair Patterson's study offers proof that high lead levels in industrial nations are man-made.
1970	Congress passes Clean Air Act. General Motors adds catalytic converters to meet law. Leaded gas found to contaminate catalytic converters.
1971	USEPA gives notice of proposed phase-out of leaded gasoline.
1976	USEPA leaded gas phase-out standards upheld by U.S. Court of Appeals.
1980	National Academy of Sciences labels leaded gas as greatest source of lead in air pollution.
1982	President Reagan reverses his opposition to USEPA rules on lead phase-out.
1986	Refiners complete primary phase-out of leaded gas in USA.
1994	U.S. blood-levels of lead declined by 78% from 1978 to 1991.
2000	European Union bans leaded gasoline.

6.9. Zinc

Zinc is found naturally in many rock-forming minerals. Because zinc is used in the vulcanization of rubber tires, it is generally found at higher levels near highways. It is used to galvanize steel, and is found in batteries, plastics, wood preservatives, antiseptics and in rat and mouse poison (zinc phosphide). Some fish can accumulate zinc in their bodies and bioaccumulate up the food chain. Zinc is the fourth most consumed metal in the world after iron, aluminum and copper. The USEPA recommends stream water quality standards for zinc to be 120 ug/L for acute and 120 ug/L for chronic levels. The Federal drinking water standard for zinc is 5 mg/L. Zinc in waterways originates from:

- Rust-resistant galvanized coating and paint for iron and steel.
- Manufacture of brass and bronze.
- Household items, including utensils, cosmetics, antiseptics and astringents, paints, varnishes, linoleum, rubber.
- Manufacture of parchment papers, glass, automobiles tires, television screens, dry cell batteries, electrical apparatus, agricultural fertilizers, insecticides, hardeners in cement and concrete, wood preservatives;
- Smoke bombs used for crowd dispersal, fire fighting exercises.
- Medicine in the treatment of zinc deficiency, various skin diseases, wounds, and sickle cell anemia patients.

When interpreting zinc trend data over time, the British Columbia Ministry of Environment cautions:
Historical zinc concentrations should be viewed with caution. Results from cleaner laboratory analytical methods with lower detection limits show that background zinc concentrations are lower than previously thought. Older high values may be the artifacts of high detection limits and artificial contamination during measurement.

6.10. Mercury

Mercury was well known as an environmental pollutant for several decades. Mercury is used in the manufacture of dry-cell batteries, fluorescent light bulbs, and electrical switches Human health concerns arise when fish and wildlife from these ecosystems are consumed by humans. Methylmercury is the biologically active form of mercury and is a potent neurotoxin to humans and wildlife. Consumption of contaminated fish is a primary source of methylmercury ingestion by humans.   Like many environmental contaminants, mercury undergoes bioaccumulation, the process by which organisms (including humans) can take up contaminants more rapidly than their bodies can eliminate them, thus the amount of mercury in their body accumulates over time. In 2001, the USEPA lowered the maximum advisable concentration of mercury in fish and shellfish to 3 ug/l per gram of edible fish tissue to protect consumers.

Mercury in even the smallest amounts can bioaccumulate and is poisonous to humans (causing kidney damage), plants and animals. Fish and shellfish can convert mercury to methylmercury, a highly toxic form of the element, which is dangerous if consumed by humans. Many streams in the Delaware Basin have fish consumption advisories set due to accumulation of mercury in fish tissue because of the potential health risk it poses to humans. Mercury is unique among metals because it can evaporate when released to water. Microbes convert inorganic mercury to organic forms which can accumulate in toxic amounts by aquatic life. The USEPA stream water quality standards for mercury are 1.4 ug/L for acute and 0.77 ug/l for chronic levels. The drinking water standard for mercury is 2 ug/l.

.Large amounts of mercury are emitted to the air from coal fired power plants and fossil fuels emissions. The USEPA estimates that coal-burning power plants are the largest human-caused source of mercury emissions to the air in the United States, accounting for over 40% of all domestic human-caused mercury emissions.

The Delaware Basin is downwind from the major coal fired plants in the middle west and is prone to the heaviest airborne deposition of mercury exceeding 20 micrograms/sq meter as the winds blow from the west (Figure 6.21). The USEPA proposes to reduce mercury emissions from coal-fired power plants through the March 15, 2005 Clean Air Mercury Rule using a cap-and-trade approach to reduce mercury emissions by 33 tons (70%). In June 2006, 16 states including all four Delaware Basin states - Delaware, New Jersey, New York, and Pennsylvania - filed a petition in federal court challenging the final Clean Air Mercury Rule published by the USEPA which establish a “cap-and-trade” system for regulating harmful mercury emissions from power plants. More than 20 states, including the four basin states, have adopted or are moving to adopt, stringent rules to reduce mercury emissions.

In Delaware, the Secretary of DNREC continued an initiative to reduce mercury emissions by issuing an order to Claymont Steel to clean up mercury emissions at its steel mini-mill in New Castle County, and encouraged salvage dealers to remove mercury switches from vehicles before they are crushed and shredded.

The USGS NAWQA Program (1998-2001) reports on the status of mercury in the Delaware River Basin.

- *Elevated concentrations of mercury were found in fish fillets throughout the Delaware River Basin (Figure 6.22). Concentrations of total mercury exceeded the human health citerion of 3 ug/g set by the USEPA (2001) at 22 percent of the 31 sites sampled and exceeded the 0.1 ug/g guideline set by the U.S. Fish and Wildlife Service for protecting fish-eating wildlife.*

- *Concentrations of total mercury in water and sediment were lowest in forested settings…. And highest in urban settings; however, the methylation efficiency (concentration of methylmercury divided by total mercury) was higher in forested settings than the urban settings (Figure 6.23).*

- *Mercury concentrations in fish fillets in the Delaware River Basin ranked eighth highest among concentrations measured in 20 NAWQA Study Units that were sampled as part of a National pilot program.*

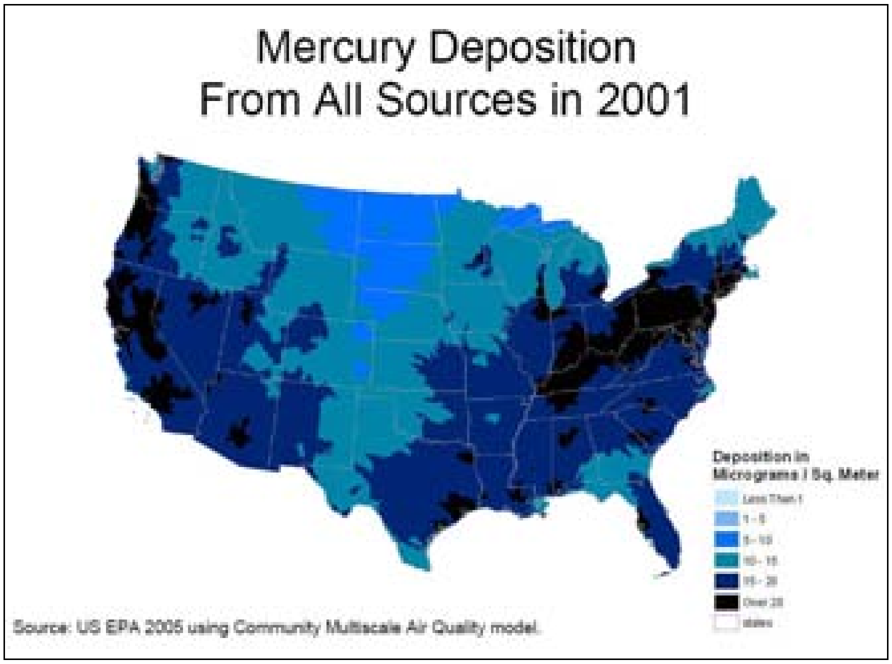


Figure 6.21. Mercury deposition from all sources in 2001. (USEPA)

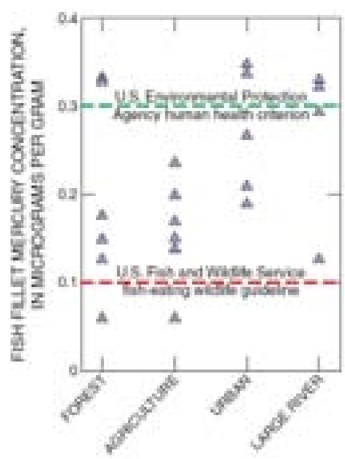


Figure 6.22. Mercury concentrations in smallmouth bass in the Delaware River Basin. (USGS NAWQA Program)

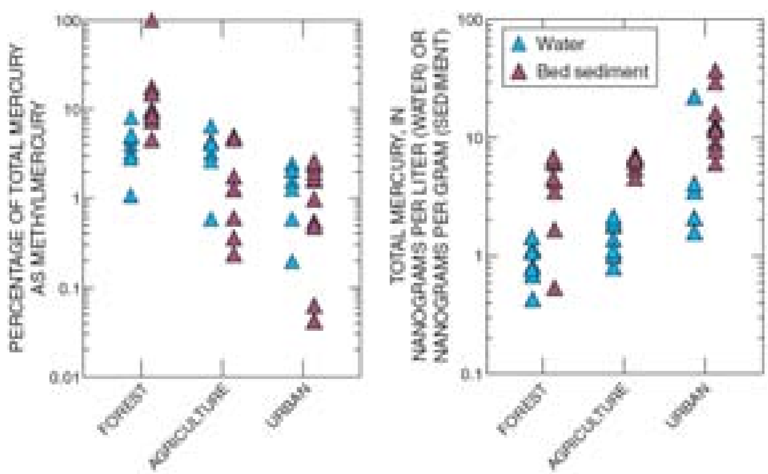


Figure 6.23. Methylmercury formation and total mercury in the Delaware River Basin. (USGS NAWQA Program)

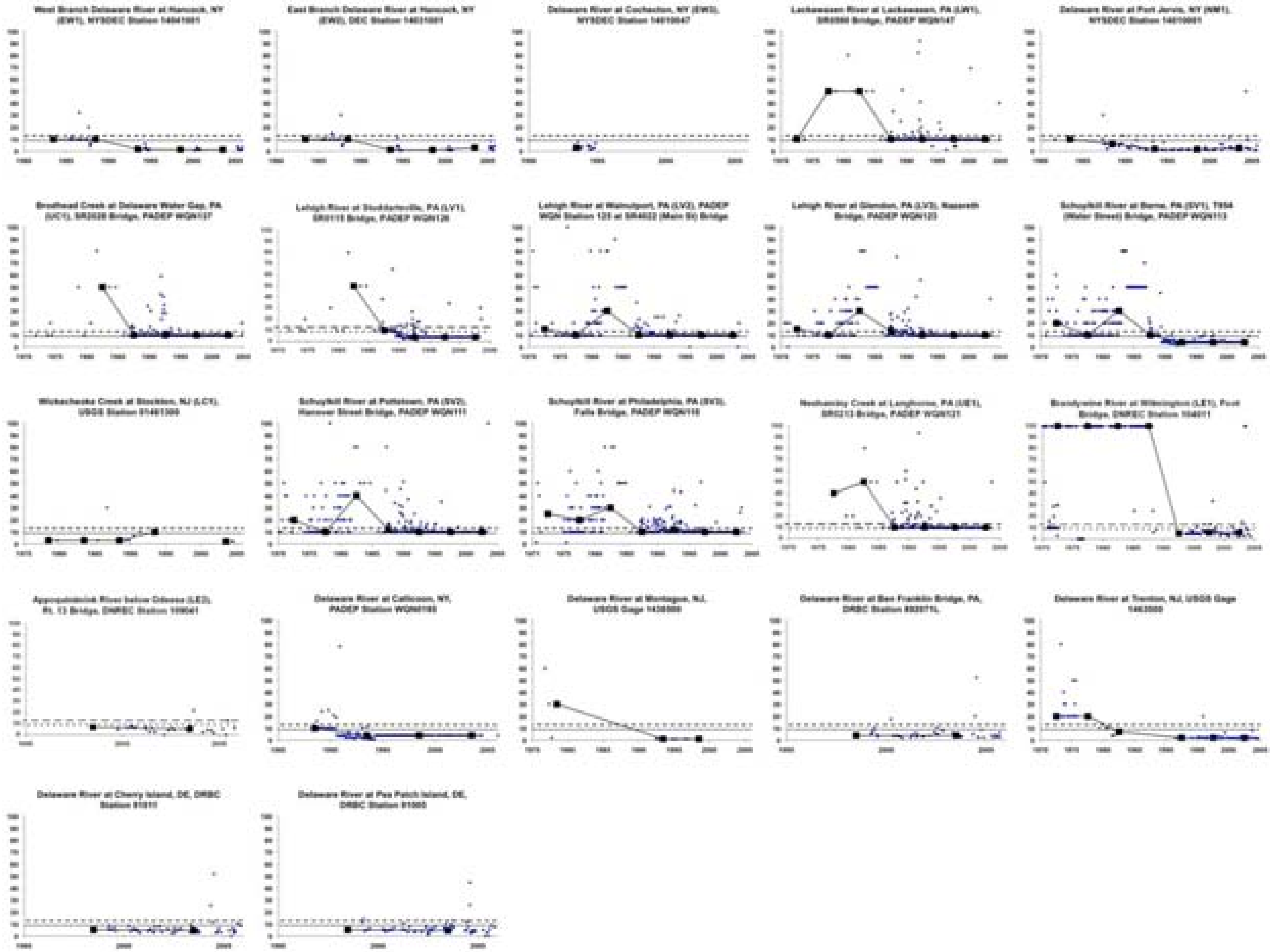


Figure 6.24. Copper water quality in the Delaware River Basin.

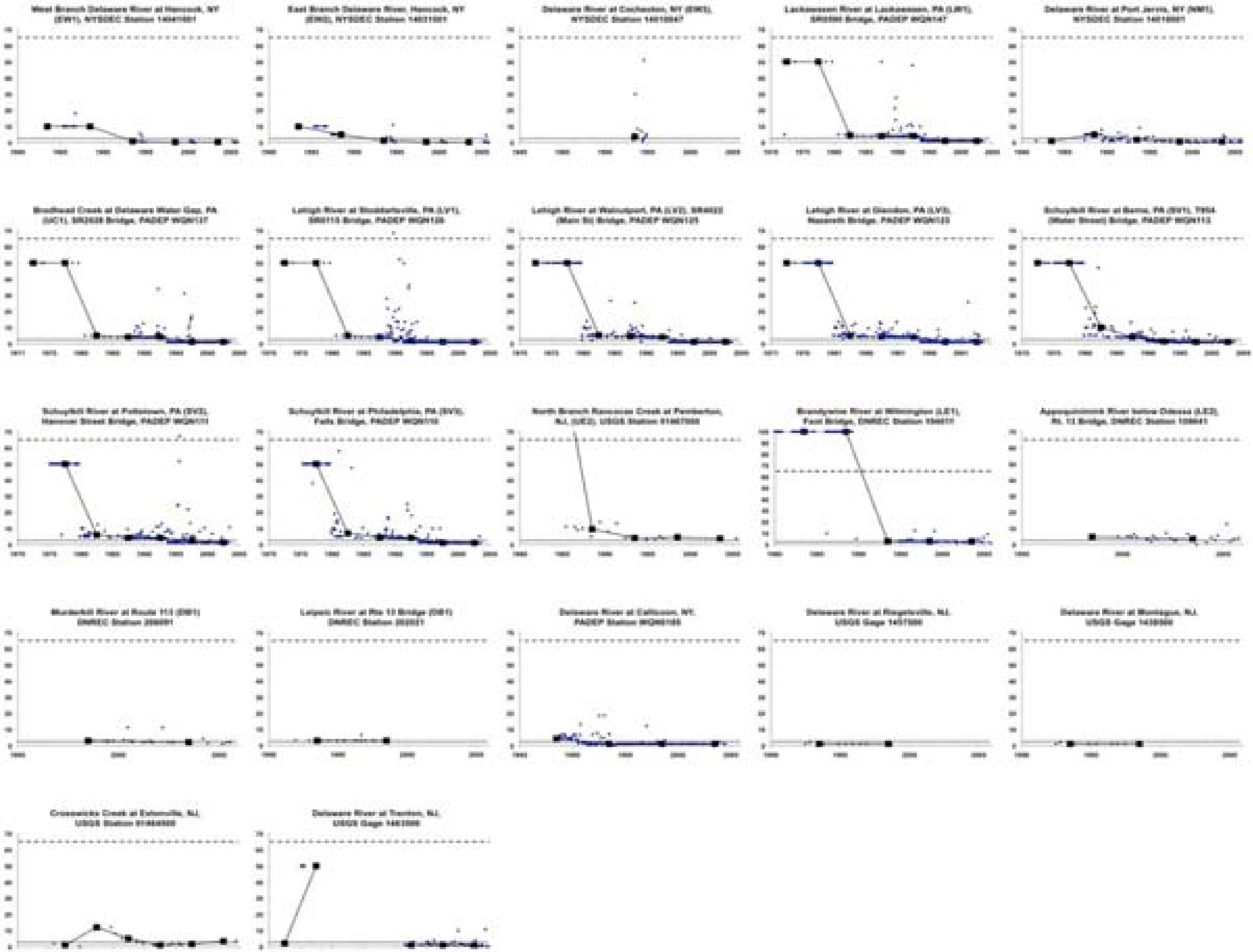


Figure 6.25. Lead water quality in the Delaware River Basin.

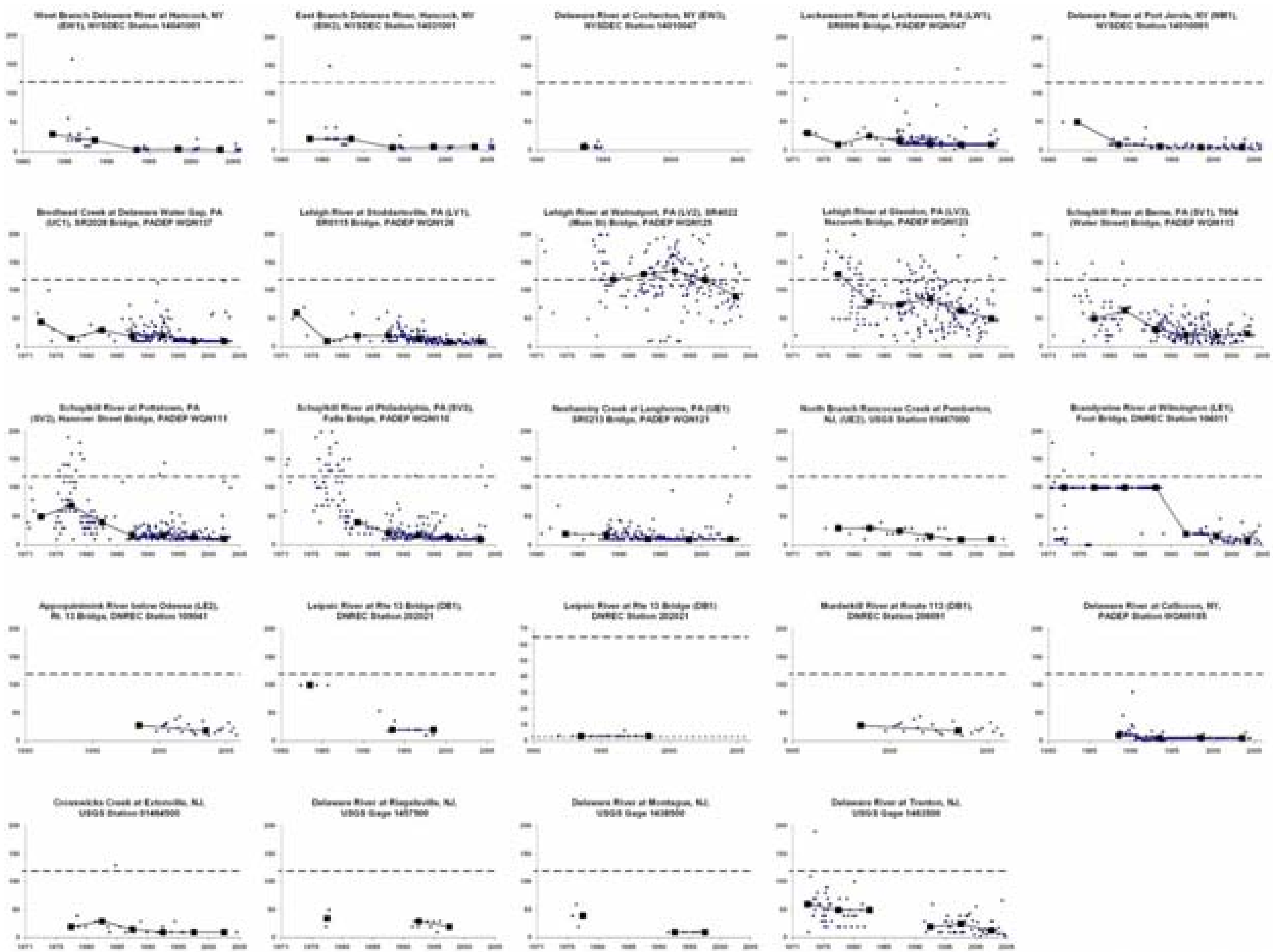


Figure 6.26. Zinc water quality in the Delaware River Basin.

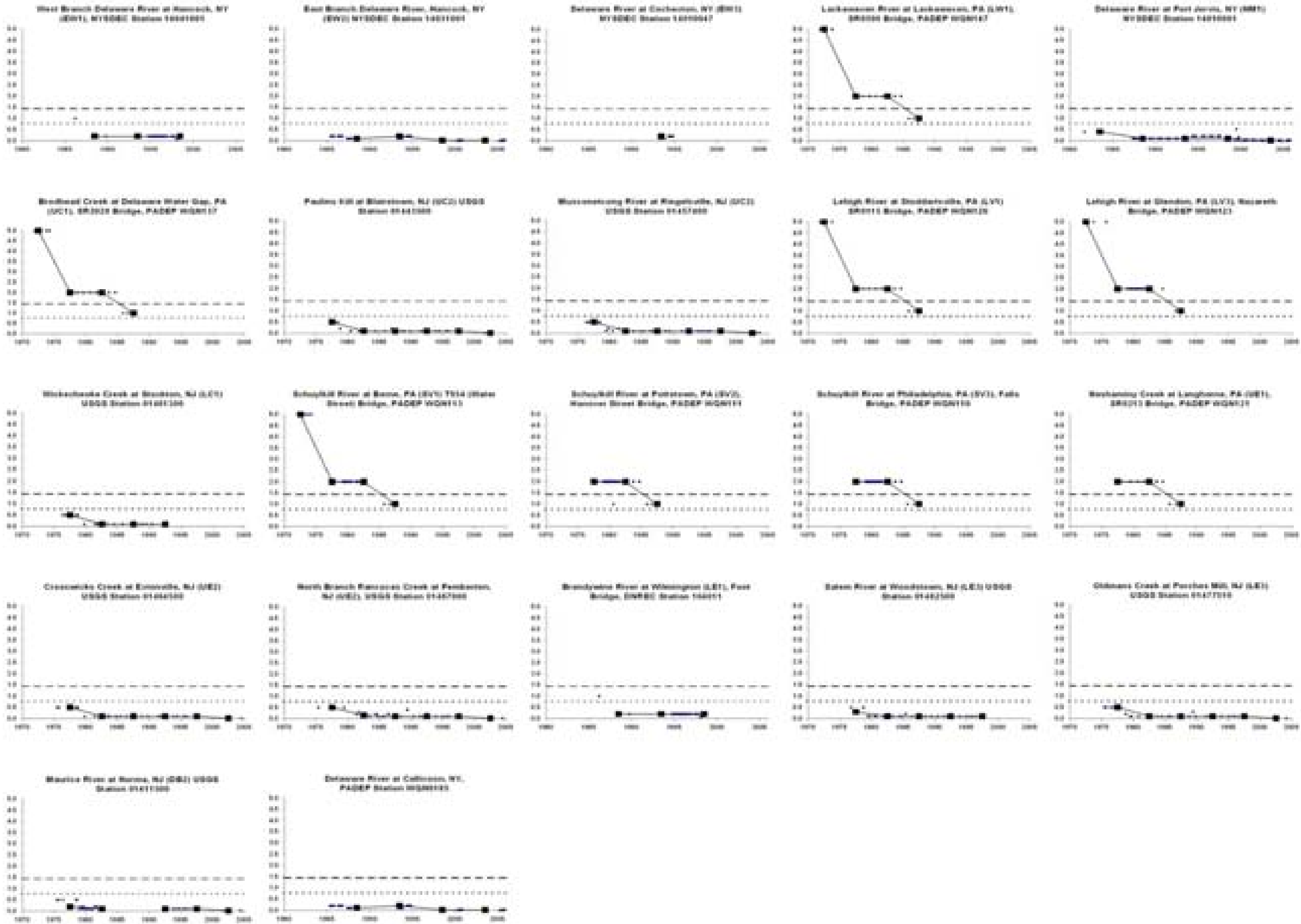


Figure 6.27. Mercury water quality in the Delaware River Basin.

Table 6.8. Cu, Pb, Zn, and Hg trends in the Delaware River Basin since 1990.

Station	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	Hg (ug/l)
Water quality standards	13.0 acute 9.0 chronic	65 acute 2.5 chronic	120 acute, chronic	1.40 acute 0.77 chronic
EW1 West Br. Delaware R. Hancock, NY	1.2 ▲	0.3 ▲	4.3 ▲	
EW2 East Br. Delaware R. Hancock, NY	2.9 ●	0.2 ▲	6.2 ●	0.01 ▲
EW3 Hancock - Narrowsburg, NY				
LW1 Lackawaxen R. at Lackawaxen, PA	10.0 ●	1.0 ▲	10.0 ●	
NM1 Delaware River at Pt. Jervis, NY	2.4 ●	0.6 ▲	4.7 ●	0.01 ▲
UC1 Brodhead Cr at Del. Water Gap, PA	10.0 ●	1.0 ▲	10.0 ▲	
UC2 Paulins Kill at Blairstown, NJ	2.2 ●	1.0 ●	5.0 ▲	0.01 ●
LV1 Lehigh River at Stoddartsville, PA	4.0 ▲	1.0 ▲	8.9 ▲	
LV2 Lehigh River at Walnutport, PA	10.0 ●	1.0 ▲	89.5 ▲	
LV3 Lehigh River at Glendon, PA	10.0 ▲	1.0 ▲	50 ▲	
LC1 Wichechocke Creek at Stockton, NJ				
SV1 Schuylkill River at Berne, PA	4.0 ●	1.0 ●	23.3 ●	
SV2 Schuylkill River at Pottstown, PA	10.0 ●	1.3 ▲	11.5 ▲	
SV3 Schuylkill R. at Philadelphia, PA	10.0 ▲	1.0 ▲	10.0 ▲	
UE1 Neshaminy Cr. at Langhorne, PA	10.0 ●	1.0 ▲	11.0 ●	
UE2 N. Br. Rancocas at Pemberton, NJ	2.2	3.7	11.0	0.2 ●
UE2 Cooper River at Haddonfield, NJ				
LE1 Brandywine R. above Wilmington, DE	5.5 ●	2.8 ●	8.9 ▲	0.2 ●
LE2 Smyrna River at Route 9 bridge, DE	5.2 ●	3.5 ●	18.4 ●	
LE3 Salem River at Woodstown, NJ	2.0 ●	1.5 ●	6.0 ●	0.01 ●
DB1 Leipsic River at Route 13, DE	5.0 ●	2.1 ●	11.8 ●	
DB2 Maurice River at Normal, NJ	0.7 ●	1.0 ●	6.5 ●	0.02 ●
Delaware River and Bay				
RM304 Callicoon, NY	4.0 ●	1.0 ●	5.0 ●	
RM253 Port Jervis, NY				
RM246 Montague, NJ				
RM145 Riegelsville, NJ				
RM134 Trenton, NJ	1.8 ●	1.0 ●	13.0 ▲	
RM100 Ben Franklin Bridge, Phila, PA	4.0 ●		12.7 ●	
RM82 Chester, PA				
RM73 Cherry Island Wilmington, DE	4.7 ▲		15.1 ●	
RM66 New Castle, DE				
RM61 Pea Patch Island., DE	5.2 ▲		17.1 ▲	
RM55 Reedy Island, DE				
RM22 Egg Island, NJ				
RM10 Big Stone Beach, DE				
5.0 = 5-yr median 2001 – 2005 Water Quality Trend	Improved ▲	Constant ●	Degraded ▼	

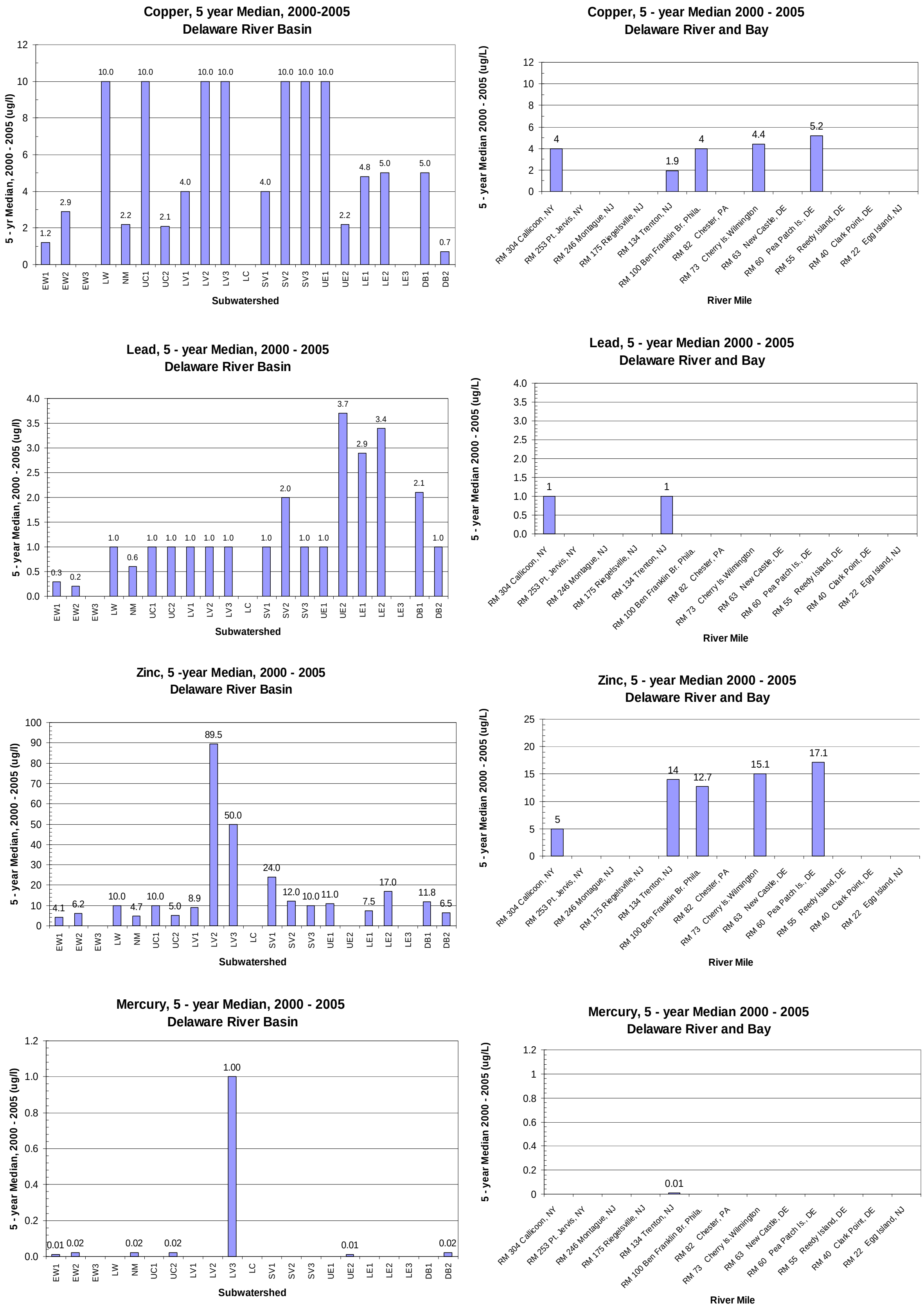


Figure 6.28. Water quality of metals in the Delaware River Basin.

6.11. Arsenic

The U.S. Department of Health and Human Services - Public Health Service (2005) and USEPA describe arsenic: *Exposure to higher than average levels of arsenic occur mostly in the workplace, near hazardous waste sites, or in areas with high natural levels. At high levels, inorganic arsenic can cause death. Exposure to lower levels for a long time can cause a discoloration of the skin and the appearance of small corns or warts. Arsenic has been found in at least 784 of 1,662 National Priority List sites identified by the U. S. Environmental Protection Agency (EPA).*

Arsenic is a naturally occurring element widely distributed in the earth's crust..Copper chromated arsenic (CCA) is used to make "pressure-treated" lumber. CCA is no longer used in the U.S. for residential uses; it is still used in industrial applications. Organic arsenic compounds are used as pesticides, primarily on cotton plants.

The following impacts occur when arsenic enters the environment:

- *Arsenic occurs naturally in soil and minerals and it therefore may enter the air, water, and land from wind-blown dust and may get into water from runoff and leaching.*
- *Arsenic cannot be destroyed in the environment. It can only change its form.*
- *Rain and snow remove arsenic dust particles from the air.*
- *Most of arsenic can dissolve in water in water or will ultimately end up in soil or sediment.*
- *Fish and shellfish can accumulate arsenic; most of this arsenic is in an organic form called arsenobetaine that is much less harmful.*

USEPA has set a limit of 0.01 mg/l (10 ug/l) for arsenic in drinking water and a stream aquatic life standard of 340 ug/l acute and of 150 ug/l chronic. Community water systems must comply with the drinking water standard by January 23, 2006, providing additional protection to an estimated 13 million Americans. USEPA estimates that roughly 5%, or 3,000 community water systems serving 11 million people, will have to take corrective action to lower the current levels of arsenic in their drinking water.

The 1998-2001 water quality assessment reports on arsenic in the Delaware Basin (USGS NAWQA Program):

- *Arsenic was detected in more than 70% of the domestic wells sampled in the Piedmont … aquifer and in only 20 and 6% of the wells in the Valley and Ridge clastic-rock and glaciofluvial aquifers, respectively.*

- *The median concentration for arsenic was 2.8 ug/l in samples from the Piedmont clastic-rock aquifer and less than 1.0 ug/l in the Valley and Ridge clastic-rock aquifer and glaciofluvial aquifers.*

- *Arsenic concentrations in samples from two domestic wells in the Piedmont exceeded the 10 ug/l drinking water standard. Arsenic in the clastic rocks of the Piedmont is from natural sources.*

6.12. Polychlorinated Biphenyls (PCBs)

The U.S. Public Health Service (2000) describes PCBs as: … *a mixture of individual chemicals which are no longer produced in the United States, but are still found in the environment. Health effects that have been associated with exposure to PCBs include acne-like skin conditions in adults and neurobehavioral and immunological changes in children. PCBs are known to cause cancer in animals. PCBs have been found in at least 500 of the 1,598 National Priorities List sites identified by the Environmental Protection Agency (EPA).*

The 1998-2001 assessment of water quality reports on PCBs in the Delaware Basin (USGS NAWQA Program):

- *Concentrations of PCBs in fish from some rivers have markedly declined from the 1970s or 1980s to the late 1990s, but this decline was not seen in two of the six rivers studied.*

- *PCBs were detected in 84% of the fish samples but in only 21 percent of the stream-bed sediment samples.*

- *Concentrations of PCBs in whole fish exceeded guidelines developed for protection of fish-eating wildlife..... at 52 percent of the sites.*

- *PCBs in fish from the four large-river sites (Lehigh River near Glendon, PA; Schuylkill River at Philadelphia, PA; and the Delaware River at Trenton, NJ and at Port Jervis, NY) exceeded fish-eating guidelines, …*

- *PCB concentrations in fish tissue from the Delaware River at Trenton have declined over the last 25 years. Declines were also seen on the Upper Delaware River, Brandywine Creek, and Upper Schuylkill River. Declines were not as apparent on the lower Schuylkill and lower Lehigh Rivers.*

- **Figure 6.29** indicates that 14 of 39 stations (36 percent) in the Delaware River Basin have detected PCBs above the NOAA bed sediment guideline.

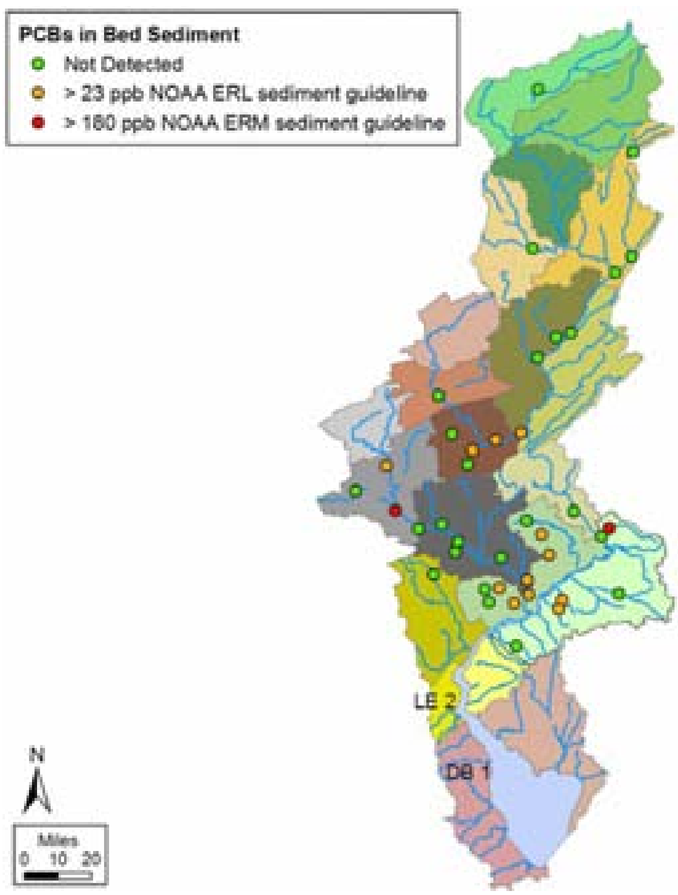


Figure 6.29. PCB in bed sediments in the Delaware River Basin. (USGS NAWQA Program)

6.13. Atrazine

Atrazine is one of the most frequently detected pesticides in ground and surface water (USGS NAQWA Program and USEPA, 1992-2001). In the Delaware River Basin, atrazine was the most frequently detected pesticide in agricultural and urban watersheds (USGS NAWQA Program).

Over 76 million pounds of atrazine were applied to U.S. lands in 2003 (USEPA 2001). Atrazine is a pre-emergent herbicide that works by being applied to soil where it can be taken up by target plants to inhibit photosynthesis. Atrazine is designed to remain in soil for several months during the growing season for continuous weed control. Due to its persistence and mobility from soil and solubility in water, atrazine surface water concentrations are highest in runoff from agricultural fields, especially following major runoff events occurring within a few weeks of application. Ground water concentrations are highest in areas with a long history of agricultural land use, particularly corn, and where surface and ground water systems are connected sufficiently to allow infiltration of the chemical downward.

The USEPA has set a drinking water standard for atrazine at 3 ug/l. New York has set an atrazine water supply standard of 7 ug/l. None of the other states in the Delaware River Basin have set an atrazine standard. The World Health Organization has set an atrazine standard at 2 ug/l.

The 1998-2001 water quality assessment reports on atrazine in the Delaware River Basin (USGS NAWQA Program):

- *The most commonly detected pesticides in surface water and in ground water were the herbicides atrazine, metolachlor, and simazine (Figure 6.30).*

- *Atrazine and metolachlor, two of the most heavily applied pesticides in agricultural areas of the basin, were detected in more streams (almost 30 percent) and wells (almost 30 percent) than any other pesticide.*

- *Streams in agricultural areas had higher concentrations of atrazine and metolachlor than streams in urban areas because these pesticides were applied to crops. Concentrations of atrazine increased from about 0.001 ug/l in a watershed with minimal to no agricultural land to about 1.00 ug/l in a basin with 70 percent agricultural land.*

- The median concentration of atrazine in the Delaware River Basin was almost 0.05 ug/l for urban watersheds and 0.12 for agriculture watersheds .

- *Concentrations of atrazine and metolachlor generally were lowest in the northern part of the basin, where agriculture development is least intense.*

- *Concentrations of atrazine in streams were highest during the growing season (May, June, July) when most pesticides are applied.*

- Figure 6.31 indicates 95 out of 100 of stations (95 percent) in the Delaware River Basin have detectable levels of atrazine in surface waters.

- Figure 6.32 indicates heavily agricultural subwatersheds such as the Lehigh River above Jim Thorpe and Easton (LV2 and LV3), Lower Central above Trenton (LC1), Schuylkill River above Valley Forge and Philadelphia (SV2 and SV3), and Christina/Brandywine Rivers (LE1) have the highest median concentrations of atrazine in the Delaware River Basin.

Table 6.9. Atrazine concentrations in Delaware Basin subwatersheds. (USGS NAQWA Program)

Subwatershed	Median Atrazine ug/l	% Agriculture 2001
LV3 Lehigh River above Easton	0.233	43
LE1 Christina/Brandywine River	0.158	45
SV2 Schuylkill above Valley Forge	0.111	49
LV2 Lehigh River above Jim Thorpe	0.080	16
LC1 Lower Central above Trenton	0.063	42
SV3 Schuylkill above Philadelphia	0.047	40

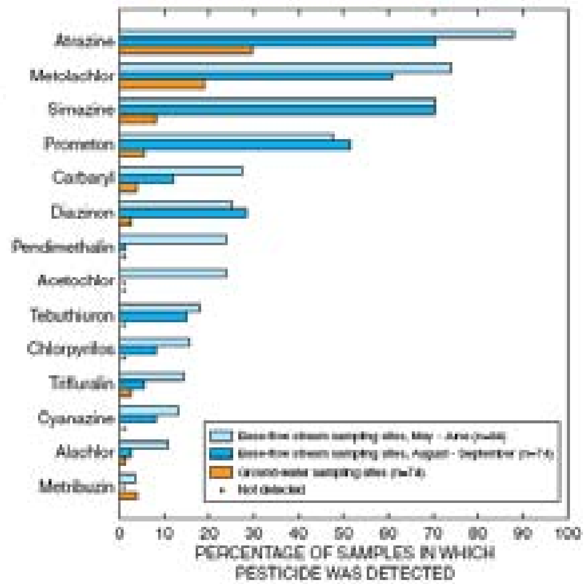


Figure 6.30. Frequency of pesticide detection in the Delaware Basin. (USGS NAQWA Program)

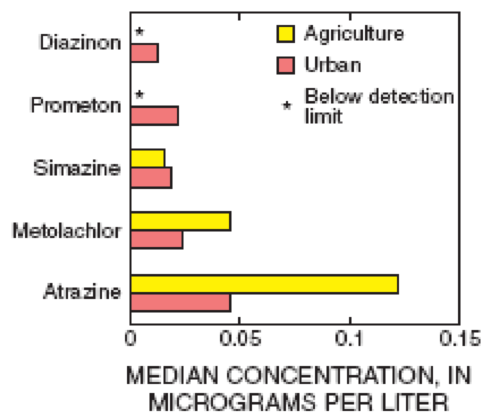


Figure 6.31. Median concentration of pesticides in the Delaware Basin. (USGS NAWQA Program)

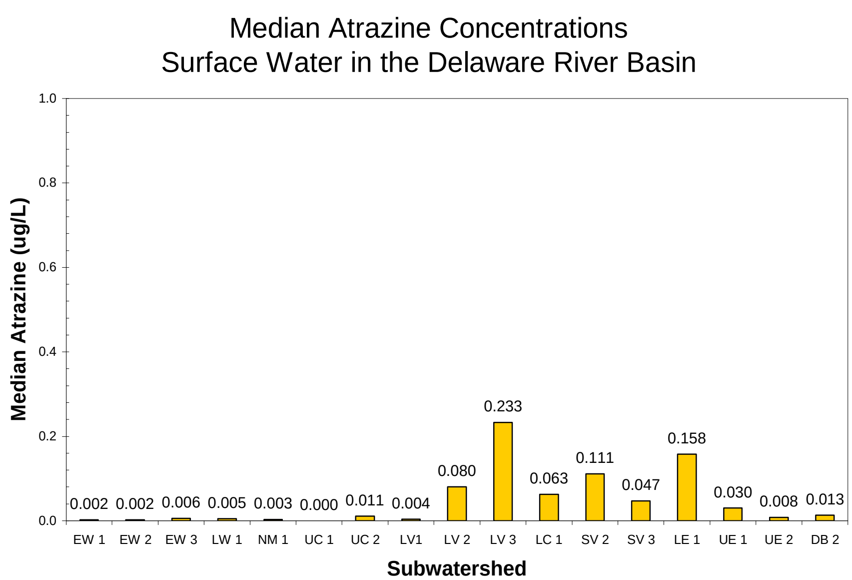


Figure 6.32. Median atrazine concentrations in Delaware Basin subwatersheds. (USGS NAWQA Program)

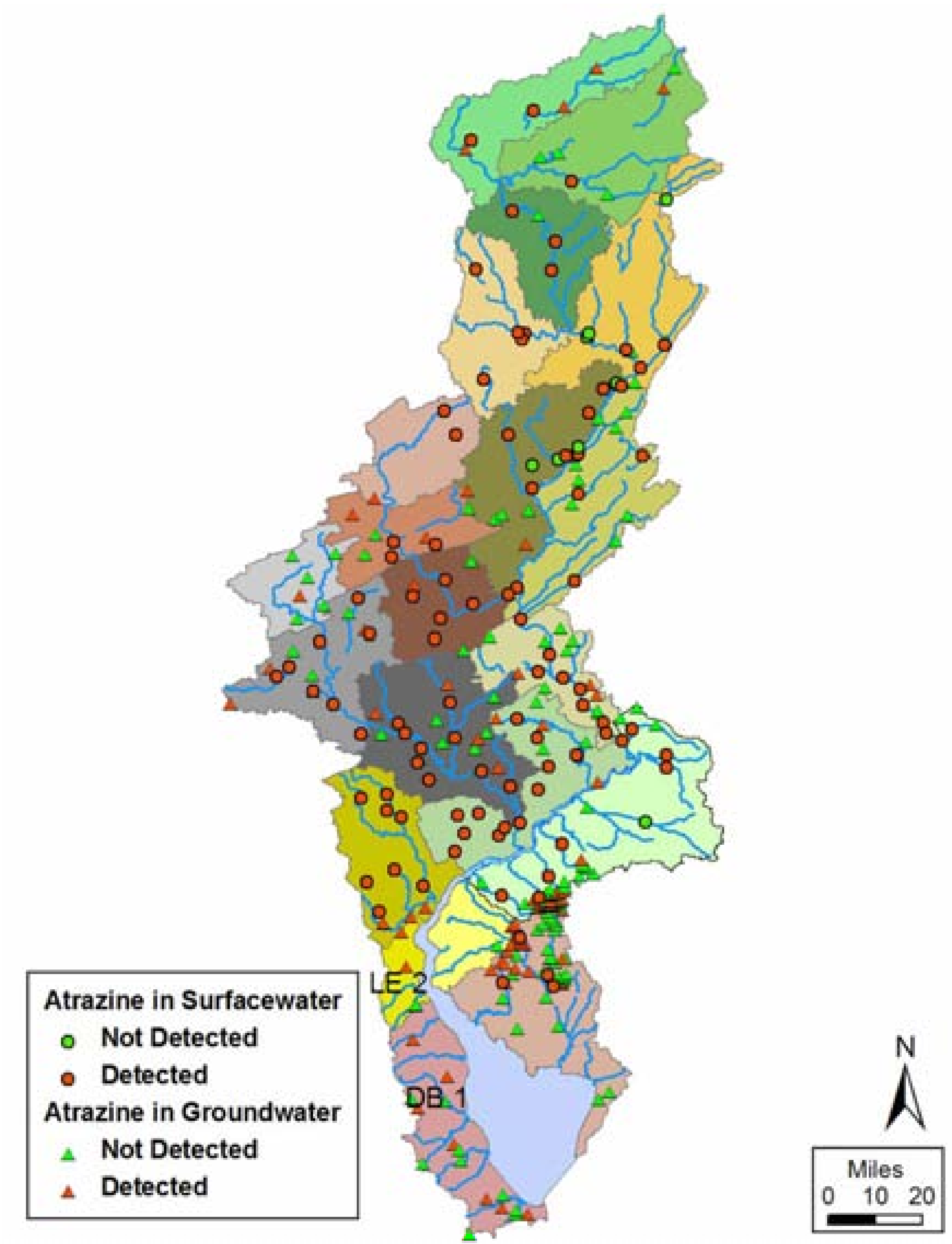


Figure 6.33. Atrazine detection in surface and groundwater in the Delaware Basin. (USGS NAWQA Program)

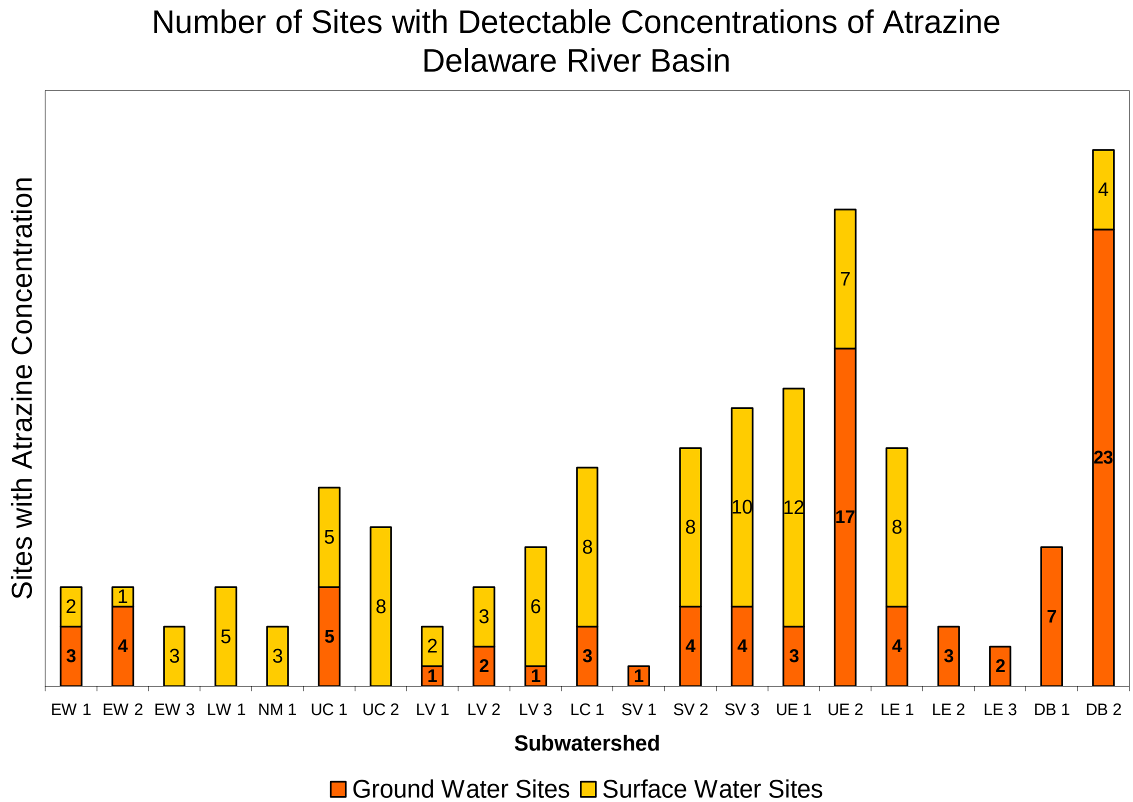


Figure 6.34. Sites with detectable concentrations of atrazine in the Delaware Basin. (USGS NAWQA Program)

6.14. Metolachlor

Metolachlor is the 2nd - most frequently detected pesticide in the Delaware River Basin (USGS NAWQA Program). Metolachlor was synthesized in 1972 by a Swiss chemical company and registered as an herbicide in the U.S. in 1977. Metolachlor is primarily used in the Delaware River Basin for weed control in the production of corn, soybean, and woody ornamentals. It is sometime used in formulations with other pesticides such as atrazine, cyanazine, and fluometuron. In 1997, between 60 and 65 million pounds of metolachlor are used in the United States annually.

Metolachlor is classified by the USEPA as a general use pesticide and is generally slightly less toxic to the environment than atrazine. Like atrazine, metolachlor is a selective herbicide that is typically applied to soil before planting for weed control throughout the growing season. It works by being taken up by plants and inhibiting protein synthesis after germination. Metolachlor can migrate from the soil into surface and ground water where it can remain in its active form for over 200 days before degrading through hydrolysis. None of the Delaware Basin states or USEPA have set a metolachlor standard. The World Health Organization has set a metolachlor standard at 10 ug/l. Canada has set an interim maximum acceptable concentration for metolachlor in drinking water at 50 ug/l.

Figure 6.35 indicates that 83 out of 103 stations (81 percent) in the Delaware River Basin have detectable levels of metolachlor in surface waters. Figure 6.36 indicates agricultural subwatersheds such as the Lehigh River above Easton (LV3), Christina/Brandywine Rivers (LE1), and Delaware Bay tributaries in New Jersey (DB2) have the highest median concentrations of metolachlor in the Delaware River Basin.

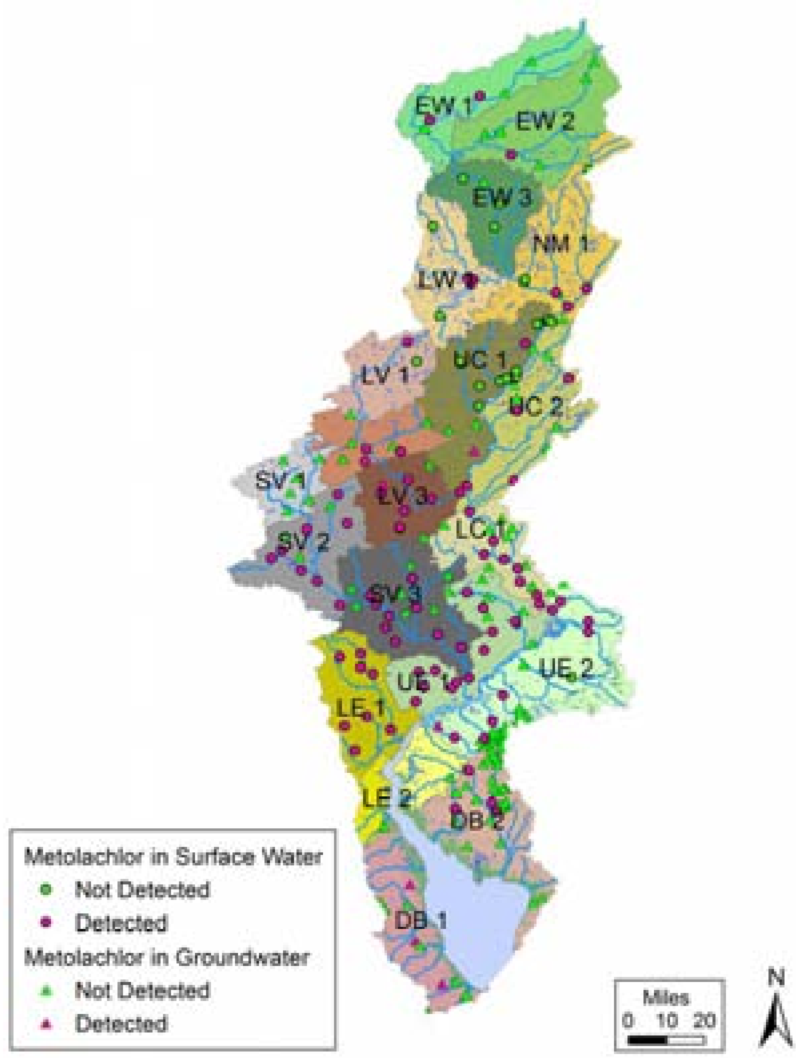


Figure 6.35. Metolachlor detection in surface and ground water in the Delaware Basin. (USGS NAWQA Program)

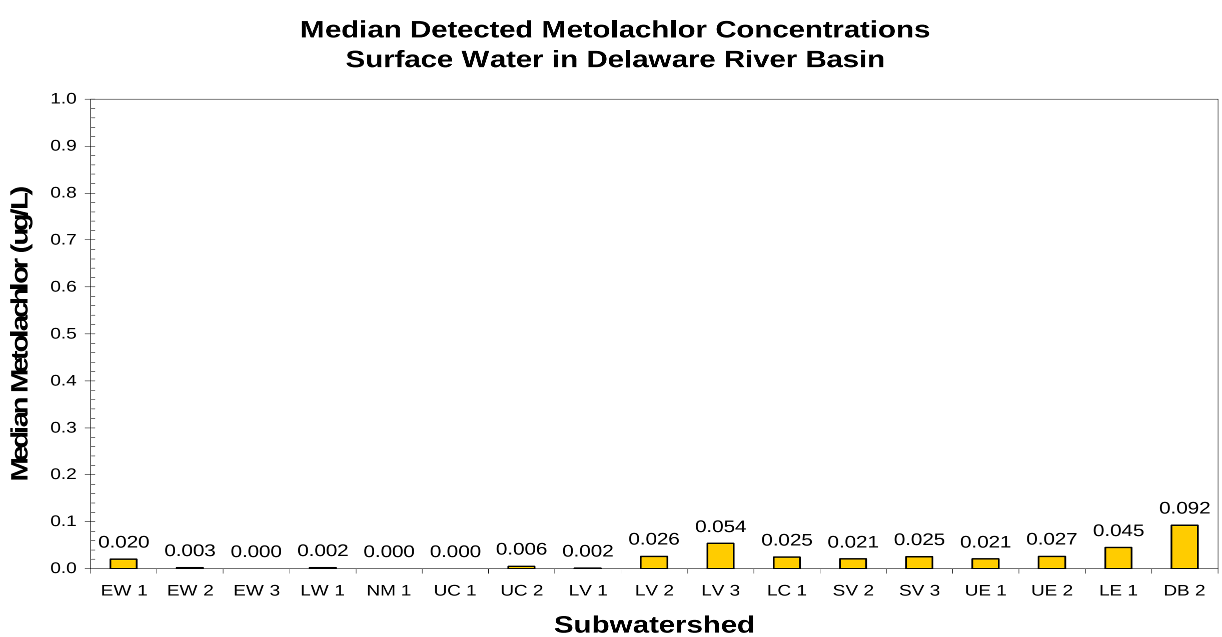


Figure 6.36. Metolachlor concentrations in surface water in the Delaware Basin**.** (USGS NAWQA Program)

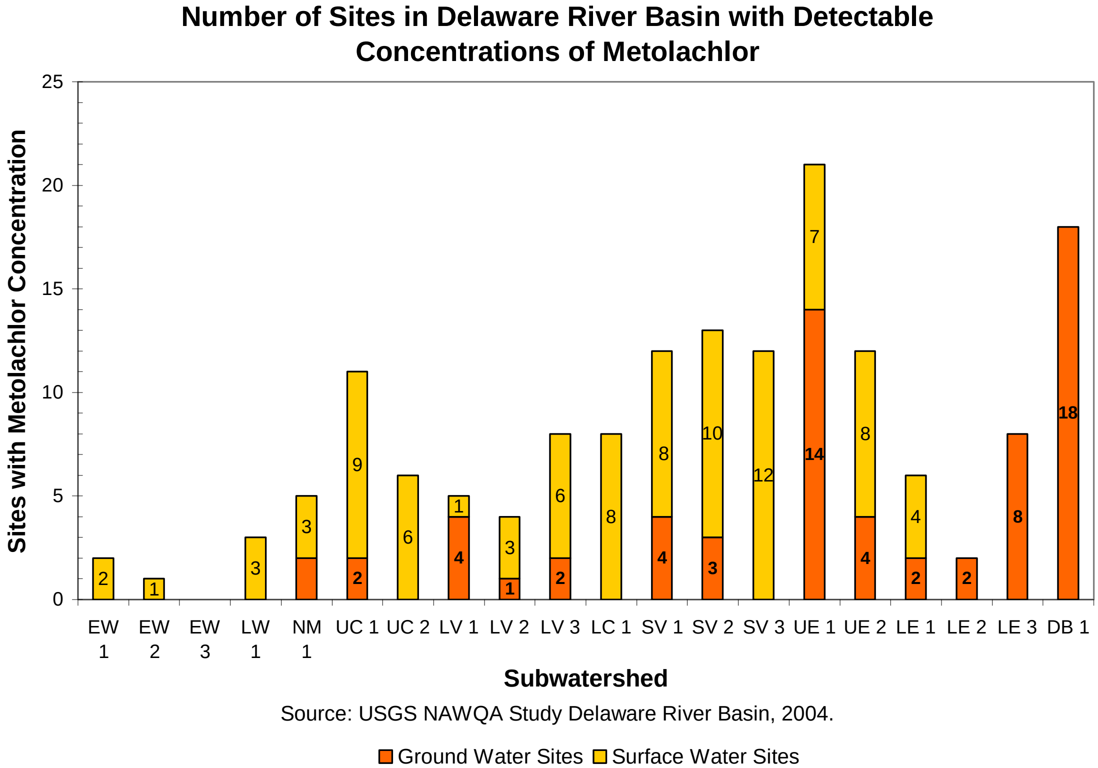


Figure 6.37. Sites with detectable concentrations of metolachor in Delaware River Basin.

Table 6.10. Median PCB, atrazine, and metalachlor levels in the Delaware River Basin.

Subwatersheds	PCB ug/l	Atrazine ug/l	Metalachlor ug/l
Upper Region (NY and PA)			
EW1 West Branch (Cannonsville)		0.020	0.020
EW2 East Branch (Pepacton)		0.002	0.003
EW3 Mainstem (above Narrowsburg)		0.006	0.000
LW1 Lackawaxen		0.005	0.004
NM1 ·Neversink-Mongaup		0.004	0.002
Central Region (PA and NJ)			
UC1 Pennsylvania tributaries		0.001	0.011
UC2 New Jersey tributaries		0.011	0.007
LV1 Lehigh River above Lehighton		0.004	0.002
LV2 Lehigh River above Jim Thorpe		0.080	0.026
LV3 Lehigh River above Easton	46	0.233	0.054
LC1 Lower Central (above Trenton)		0.063	0.025
Lower Region (PA, NJ and DE)			
SV1 Schuykill River above Reading			
SV2 Schuykill River abv Valley Forge	180	0.111	0.021
SV3 Schuylkill River above Phila.	125	0.047	0.025
UE1 Pennsylvania piedmont	115	0.030	0.021
UE2 New Jersey coastal plan	74	0.009	0.027
LE1 Christina River	7.5	0.158	0.045
LE2 C & D Canal, DE			
LE3 Salem River, NJ			
Bay Region			
DB1-Bay Region			
DB2 New Jersey coastal plain		0.013	0.092

6.15. Water Temperature

Water temperature affects aquatic species that live in the streams of the Delaware River Basin. Cold-blooded fish and macroinvertebrates have an optimum water temperature range. Most cold water fish such as trout can not spawn productively if the water temperature exceeds 68 deg F (20 deg C). The states in the Delaware River Basin have the following maximum water temperature criteria:

Delaware	86 deg F freshwater streams (warm water) 75 deg F cold water fisheries, put and take trout streams
New Jersey	68 deg F (20 deg C) FW2 trout maintenance/trout production (TM/TP) 82 deg F (27.8 deg C) FW2 nontrout small mouth bass and yellow perch
New York	70 deg F trout streams
Pennsylvania	66 deg F cold water fishery (CWF) 87 deg F warm water fishery (WWF) 87 deg F trout stocking fishery (TSF)

Water temperature also affects water chemistry as chemical reactions and biological activity increase at higher temperatures. Warm water holds less oxygen than cold water therefore dissolved oxygen levels are higher during the fall, winter and spring. Cooler streams generally have better water quality. Water temperature may be artificially raised by thermal pollution such as stormwater runoff from heated pavement and loss of shade trees. Wastewater discharges from industries and municipalities almost always artificially heat waterways. Water temperatures may be increasing due to warming air temperatures from the effects of global warming.

Water temperature varies due to seasonal fluctuations in air temperatures, changing stream velocities, and the expanse of forests in a watershed. Water temperatures are cooler in mountainous, steeply sloped, forested watersheds due to cooler air at higher altitudes, high velocity waters, and shading by the forests.

The United States Geological Survey monitors and records water temperature on a continuous basis at stream gages along the main stem and tributaries in the Delaware River Basin (Table 6.11).

Table 6.11. USGS water temperature monitoring stations in the Delaware River Basin.

USGS Gage	Stream	Period of Record
1426500	West Branch Delaware River at Hale Eddy, NY	1967-2007
1417500	East Branch Delaware River at Harvard, NY	1987-2006
1421000	East Branch Delaware River at Fish Eddy, NY	1967-2007
1427510	Delaware River at Callicoon, NY	1975-2007
1428500	Delaware River above Lackawaxen River near Barryville, NY	1967-2007
1463500	Delaware River at Trenton, NJ	1953-2007
1467200	Delaware River at Ben Franklin Bridge at Philadelphia, PA	1960-2007
1477050	Delaware River at Chester, PA	1961-2007
1482800	Delaware River at Reedy Island Jetty, DE	1970-2007
1420500	Beaver Kill at Cooks Falls, NY	1988-2006
1436690	Neversink River at Bridgeville, NY	1992-2007
1429000	West Branch Lackawaxen River at Prompton, PA	1987-2004
1454720	Lehigh River at Easton, PA	1967-2007
1481000	Brandywine Creek at Chadds Ford, PA	1968-2007

Table 6.12 summarizes annual median, annual summer median, annual maximum water temperatures for 2005 recorded at USGS stream gages in the Delaware River Basin. Annual maximum water temperatures are the highest recorded in a given year. Annual summer median water temperatures are calculated for June, July, and August of each year. Water temperature trends since 1990 are also reflected in the table.

Water temperatures are cooler in the forested, mountainous northern headwaters of the basin and decline as the Delaware River and tributaries flows downstream toward Trenton. Water temperatures have remained constant since 1990 at 11 of 14 stations except in the East Branch and West Branch of the Delaware and along the Neversink where summer and annual maximum temperatures have declined. Only the East Branch and West Branch of the Delaware, main stem at Callicoon, Neversink River, Beaverkill, and Lackawaxen River have summer median temperatures that remain near or below 20 deg C (68 deg F), a threshold necessary to sustain year - round cold water trout populations.

Table 6.12. Water temperature along the Delaware River and tributaries.

Station (deg C)	Annual Median 2005	Summer Median 2005	Annual Maximum 2005
West Branch Delaware River at Hale Eddy, NY	10.0 →	15.0 ↑	23.5 ↓
East Branch Delaware River at Harvard, NY	10.0 →	18.0 ↓	22.0 ↓
East Branch Delaware River at Fish Eddy, NY	11.5 →	23.0 ↓	27.0 ↓
Delaware River at Callicoon, NY	9.5 →	23.0 →	28.0 →
Delaware R. above Lackawaxen R. near Barryville, NY	11.0 →	28.0 →	32.0 →
Delaware River at Trenton, NJ	12.8 →	28.7 →	32.4 →
Delaware River at Ben Franklin Bridge at Philadelphia, PA		26.9 →	29.3 →
Delaware River at Chester, PA	22.1 ↑	27.9 →	30.8 →
Delaware River at Reedy Island Jetty, DE	14.9 →	27.5 →	30.7 →
Beaver Kill at Cooks Falls, NY	10.0 →	24.0 →	31.5 →
Neversink River at Bridgeville, NY	11.0 ↑	21.0 ↓	24.5 →
West Branch Lackawaxen River at Prompton, PA	15.8	19.5	22.4
Lehigh River at Easton, PA		25.3 →	28.1 →
Brandywine Creek at Chadds Ford, PA		25.0 →	29.0 →

10.0 = 2005 water temperature (deg C) Water temperature trends since 1990:
↑= increasing → = constant ↓ = decreasing

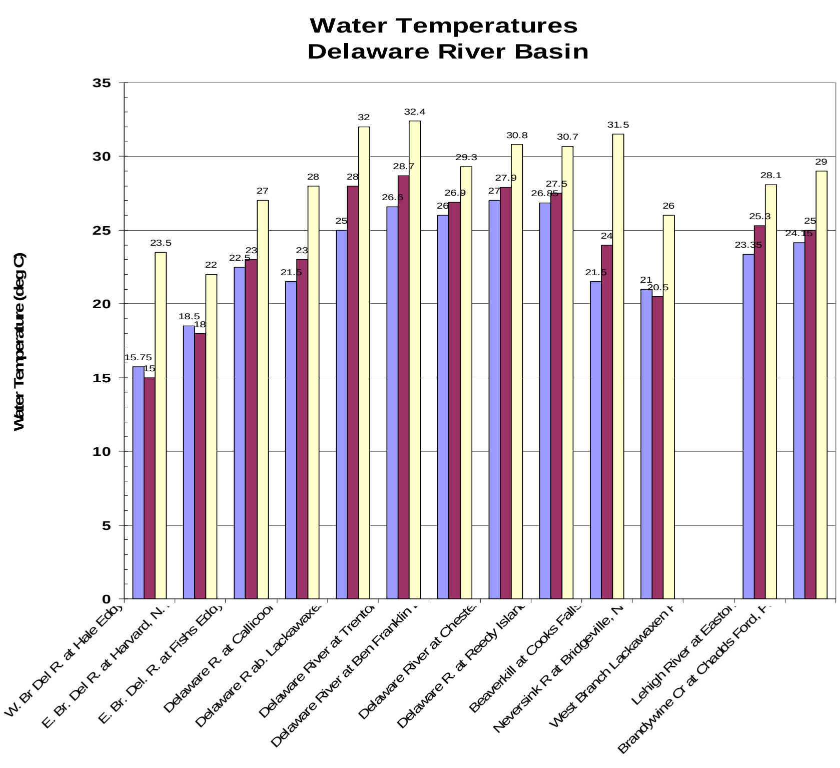


Figure 6.38. Median water temperatures in the Delaware River Basin.

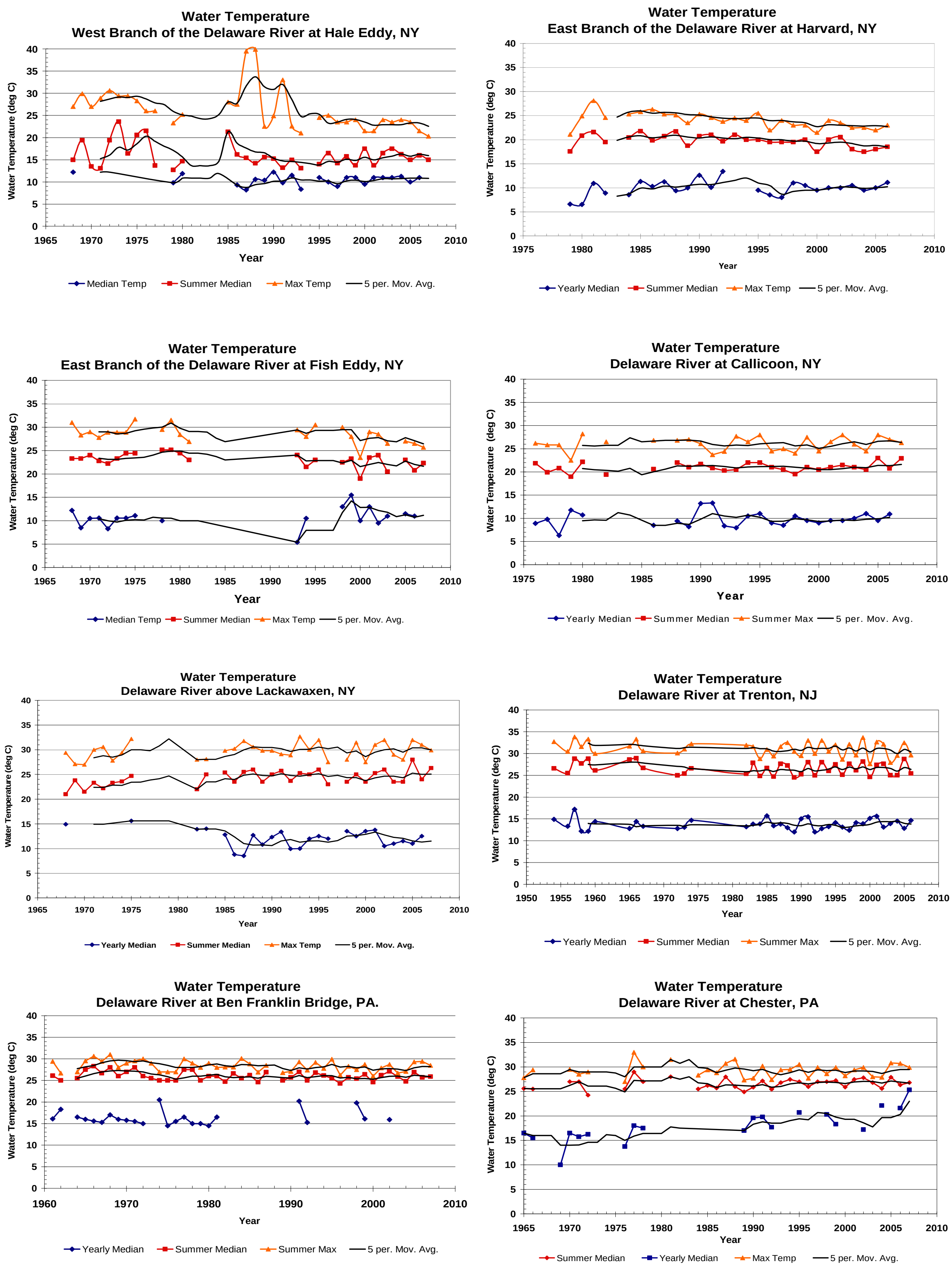


Figure 6.39. Water temperatures along the Delaware River and tributaries.

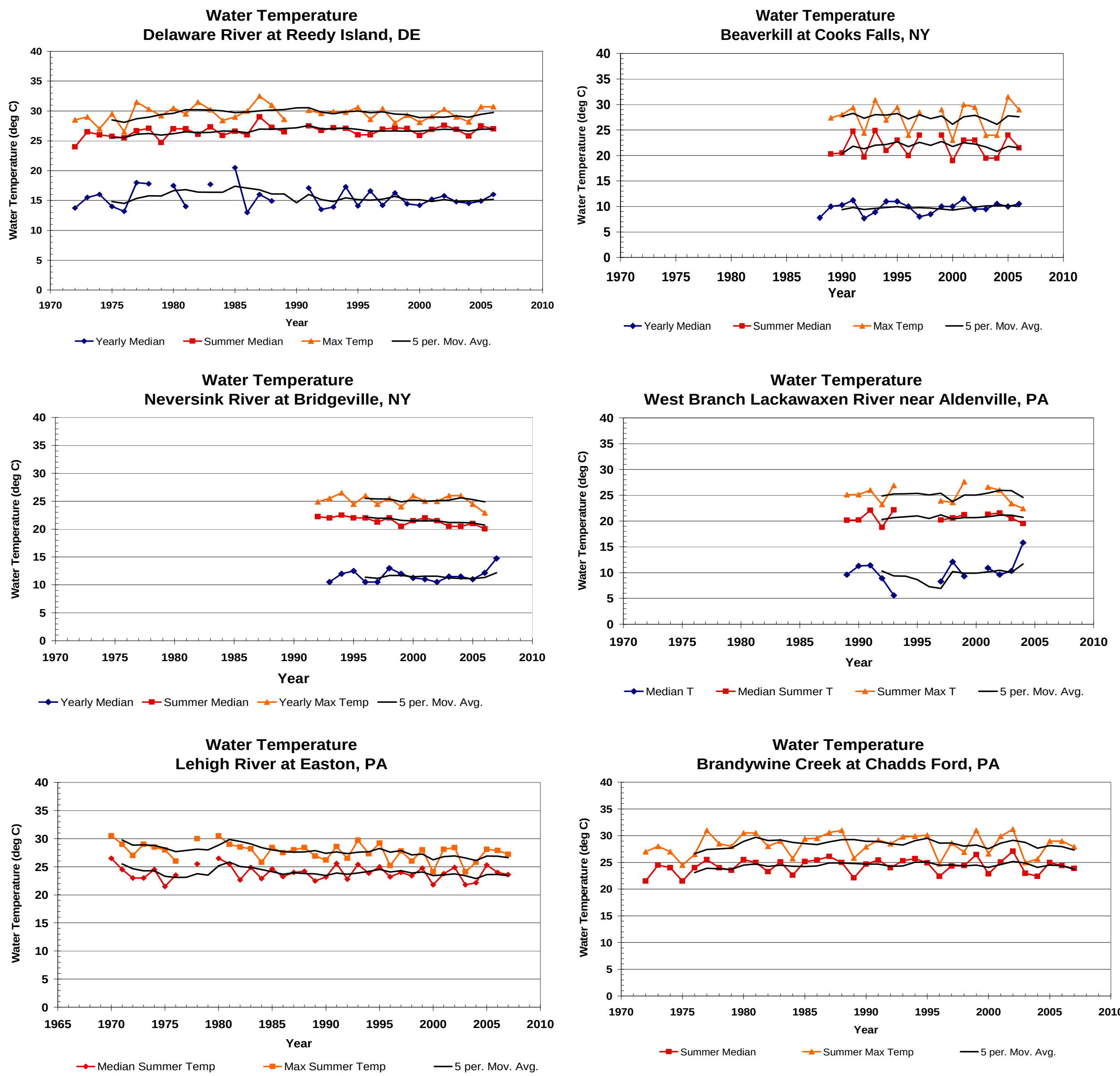


Figure 6.40 (con't). Water temperatures along the Delaware River and tributaries.

6.16. Fish Consumption Advisories

Of 23,557 Delaware Basin stream miles, 1,661 miles (7%) have full fish consumption (no consumption) and 2,274 miles (10%) have limited consumption advisories. Over 19,600 stream miles have no fish consumption advisories.

Despite the general benefits of fishing and fish consumption, there has been a growing concern regarding the presence of chemical toxins in the flesh of finfish and shellfish taken from Delaware waters and the associated health risk to anglers and their families who consume their catch. The existence of chemicals in the edible portion of some fish has resulted in public advisories. These advisories are as a result of joint action taken by the Department of Natural Resources and Environmental Control and the Department of Health and Social Service's Division of Public Health. The advisories were deemed necessary because of the nature of pollutants such as polychlorinated biphenyls (PCBs). Even when present in the water in extremely small amounts, some chemicals tend to build up over time in fish tissue because fish can absorb and concentrate contaminants from food they eat, or to a lesser extent, directly from the water. The amount of contaminants fish accumulate depends on the species, size, age, sex, and feeding area of the fish.

Table 6.13. Delaware fish consumption advisories in the Delaware Basin, 2006.

Waterbody	Species	Geographical Extent	Contaminant	Advisory
Delaware River	All Finfish	Delaware State Line to the C&D Canal	PCBs, Dioxin, Mercury, Chlorinated Pesticides	No Consumption
Lower Delaware River and Delaware Bay	Weakfish Bluefish	Chesapeake & Delaware Canal to the Mouth of the Delaware Bay	PCBs	No more than one 8-ounce meal per month
	Striped Bass White Perch Amer. Eel Catfish	Chesapeake & Delaware Canal to the Mouth of the Delaware Bay	PCBs, Mercury	No more than one 8-ounce meal per year
Shellpot Creek	All Finfish	Philadelphia Pike to the Delaware River	PCBs	No Consumption
Army Creek and Pond	All Finfish	Entire Creek and Pond	PCB, Dioxin/Furans, Dieldrin	No more than two 8-ounce meals per year
Red Lion Creek	All Finfish	Route 13 to the Delaware River	PCBs, Dioxin	No more than one 8-ounce meal per year
Chesapeake & Delaware Canal	All Finfish	Entire Canal in Delaware	PCBs, DDT, Dieldrin, Chlordane	No Consumption
Appoquinimink River	All Finfish	Tidal Portions	PCBs, Dioxin	No more than one 8-ounce meal per year
Drawyers Creek	All Finfish	Tidal Portions	PCBs, DDT	No more than one 8-ounce meal per year
Silver Lake Middletown	All Finfish	Entire Lake	PCBs, Dieldrin, DDT, Dioxin	No more than one 8-ounce meal per year
Saint Jones River	All Finfish	River Mouth to Silver Lake Dam	PCBs, Dioxin, Mercury	No more than two 8-ounce meals per year
Moores Lake	All Finfish	Entire Pond	PCBs, DDT	No more than two 8-ounce meals per year
Silver Lake Dover	All Finfish	Entire Pond	PCBs, Dioxin, Mercury	No more than two 8-ounce meals per year
Wyoming Mill Pond	All Finfish	Entire Pond	PCBs, Dioxin, DDT	No more than two 8-ounce meals per year
Tidal Brandywine	All Finfish	River Mouth to Baynard Blvd.	PCBs	No Consumption
Non-tidal Brandywine	All Finfish	Baynard Blvd. To Pennsylvania Line	PCBs, Dioxin	No more than two 8-ounce meals per year
Tidal Christina River	All Finfish	River Mouth to Smalley’s Dam	PCBs, Dieldrin	No Consumption
Non-tidal Christina River	All Finfish	Smalley’s Dam to DE/MD Line.	PCBs, Dieldrin, Chlordane	No more than six 8-ounce meals per year
Tidal White Clay Creek	All Finfish	River Mouth to Route 4	PCBs	No Consumption
Non-tidal White Clay Creek	All Finfish	Route 4 to DE/PA Line	PCBs	No more than one 8-ounce meal per month
Red Clay Creek	All Finfish	State Line to Stanton	PCBs, Dioxin, Pesticides	No more than two 8-ounce meals per year
Little Mill Creek	All Finfish	Creek Mouth to Kirkwood Highway	PCBs	No Consumption
Becks Pond	All Finfish	Entire Pond	PCBs, Mercury	No more than one 8-ounce meal per year
Stocked Trout				
Christina Creek	Stocked Trout	Rittenhouse Park to DE/MD Line	PCBs, Dieldrin	No more than six 8-ounce meals per year
Trout Streams Ponds other than Christina	Stocked Trout	Designated Trout Stocking Areas listed in Delaware 2006 Fishing Guide	PCBs	No more than one 8-ounce meal per month
Women of childbearing age and children should not consume any amount of these fish.				

Table 6.14. New Jersey fish consumption advisories in the Delaware Basin, 2006.

Waterbody	Species	General Population	High Risk Individuals
		Eat no more than:	Eat no more than:
Lower (Tidal) Delaware River, Trenton, NJ to PA/DE line, including all species to the head of tide.	Largemouth Bass	No restrictions	One meal per week
	Hybrid Str. Bass		
	American eel	One meal per year	Do not eat
	Channel Catfish		
	White Catfish	One meal per month	
	Striped Bass	Four meals per year	
	White Perch	Four meals per year	
Delaware Estuary and Bay, C & D Canal to the mouth of Delaware Bay	Bluefish < 14 in	One meal per month	
	Weakfish		
	Bluefish > 14 in)	One meal per year	Do not eat
	Striped Bass		
	White perch		
	American eel		
	Channel catfish		
	White catfish		
Alycan Lake (Gloucester Co.)	Black Crappie	No restrictions	One meal per month
Big Timber Creek (Gloucester Co.)	Channel Catfish	No restrictions	One meal per week
	Largemouth Bass		
	White Catfish		
	Brown Bullhead		No restrictions
Canistear Reservoir (Sussex Co.)	Chain Pickerel	No restrictions	One meal per month
	Yellow Perch		
	Yellow Bullhead		One meal per week
	Bluegill Sunfish		
Cedar Lake (Cumberland Co.)	Chain pickerel	One meal per week	Do not eat
	Largemouth Bass		
Clementon Lake (Camden Co.)	Chain Pickerel	One meal per week	On e meal per month
	Largemouth Bass		
Cooper River, below Evans Pond (Camden Co.)	Common Carp	One meal per month	Do not eat
	Bluegill Sunfish	One meal per week	One meal per month
Cooper R., Hopkins Pond	Brown Bullhead	One meal per month	Four meals per year
Cooper River Lake (Camden Co.)	Largemouth Bass	Four meals per year	Do not eat
	Common Carp		
	Brown Bullhead	One meal per week	One meal per month
	Bluegill Sunfish		
Cranbury Lake (Sussex Co.)	Hybrid Str. Bass	One meal per week	One meal per month
Crater Lake (Sussex Co.)	Yellow Perch	One meal per week	Do not eat
	Brown Bullhead		One meal per month
Crosswicks Creek (Mercer Co.)	Largemouth Bass	No restrictions	One meal per week
	White Catfish		
Crystal Lake (Burlington Co.)	Largemouth Bass	No restrictions	One meal per month
	Black Crappie		One meal per week
	Brown Bullhead		No restrictions
Delaware River Upstream of Watergap (Warren/Sussex Co.)	Channel Catfish	No restrictions	One meal per month
	Muskellunge		
	Smallmouth Bass	One meal per week	
	White Sucker	One meal per month	
Delaware River Watergap to Phillipsburg (Warren Co.)	White Catfish	One meal per week	Do not eat
	Channel Catfish	No restrictions	No restrictions
	Smallmouth Bass		
	Walleye		
Delaware River Phillipsburg to Trenton (Hunterdon/Mercer Co.)	Channel Catfish	Four meals per year	Do not eat
	White Sucker	One meal per month	
	Largemouth Bass	No restrictions	One meal per month
	Smallmouth Bass	One meal per week	Do not eat
	American Eel	One meal per month	
	Striped Bass	Four meals per year	

East Creek Lake (Cape May Co.)	Brown Bullhead		
	Yellow Bullhead	One meal per month	Do not eat
	Yellow Perch		
Grovers Mill Pond (Mercer Co.)	Brown Bullhead	One meal per week	One meal per month
	Chain Pickerel	No restrictions	One meal per week
L. Hopatcong (Morris/Sussex Co.)	Largemouth Bass	No restrictions	One meal per month
Lake Nummy (Cape May Co.)	Chain Pickerel		
	Yellow Perch	One meal per week	Do not eat
	Yellow Bullhead	No restrictions	One meal per month
Little Timber Creek (Camden Co.)	Brown Bullhead	No restrictions	No restrictions
Markells Mill Lake (Salem Co.)	Brown Bullhead		
	Chain Pickerel	One meal per week	One meal per month
	Largemouth Bass		
	Black Crappie	No restrictions	
Merrill Creek Reservoir (Warren Co.)	Largemouth	One meal per month	
	Smallmouth Bass		Do not eat
	Lake Trout	One meal per week	
	Yellow Perch		One meal per month
	Black Crappie		
	Bluegill Sunfish	No restrictions	One meal per week
	Brown Bullhead		
	Brown Bullhead	No restrictions	One meal per week
Mountain Lake (Warren Co.)	Largemouth Bass	One meal per week	Do not eat
New Brooklyn Lake (Camden Co.)	Chain Pickerel		Do not eat
	Largemouth Bass	One meal per week	
	Pumpkinseed Sunfish	No restrictions	One meal per month
	Black Crappie		
	Yellow Bullhead		One meal per week
Newton Creek No. (Camden Co.)	Brown Bullhead	No restrictions	No restrictions
Newton Creek, So. (Camden Co.)	Largemouth Bass	One meal per month	Do not eat
Newton Lake (Camden Co.)	Bluegill Sunfish		
	Brown Bullhead	One meal per week	One meal per month
	Largemouth Bass		Four meals per year
	Common Carp	One meal per month	Do not eat
Pennsauken Creek, Forked Landing (Camden Co.)	Common Carp	Four meal s per year	
	Largemouth Bass		Do not eat
	Pumpkinseed	One meal per month	Four meals per year
	White Catfish		One meal per year
Saw Mill Lake (Sussex Co.)	Northern Pike		One meal per month
	Brown Bullhead	No restrictions	No restrictions
Sleenykill Lake (Sussex Co.)	Largemouth Bass	No restrictions	One meal per week
Stewart Lake (Camden Co.)	Largemouth Bass	Four meals per year	Four meals per year
	Bluegill Sunfish		One meal per month
	Brown Bullhead	One meal per week	
	Common Carp	One meal per month	Do not eat
Strawbridge Lake (Burlington Co.)	Largemouth Bass		
	Bluegill Sunfish	One meal per month	One meal per year
	Common Carp	Four meals per year	Do not eat
	Brown Bullhead	One meal per week	Four meals per year
Sunset Lake (Cumberland Co.)	Largemouth Bass	One meal per week	One meal per month
Swartswood Lake (Sussex Co.)	Smallmouth Bass		One meal per month
	Chain Pickerel	No restrictions	One meal per week
Union Lake (Cumberland Co.)	White Perch	One meal per week	Do not eat
Willow Grove L. (Cumberland Co)	Brown Bullhead	No restrictions	One meal per month
Wilson Lake (Gloucester Co.)	Largemouth Bass	One meal per week	
	Yellow Perch		
	Chain Pickerel	One meal per month	Do not eat
Woodstown Memorial Lake (Salem Co.)	Black Crappie		
	Largemouth Bass	No restrictions	One meal per month

Table 6.15. New York State fish consumption advisories in the Delaware River Basin, 2006.

Water (County)	Species	Recommendations	Chemicals of Concern
Cannonsville Reservoir (Delaware)	Smallmouth bass over 15" and yellow perch	Eat no more than 1 meal per month	Mercury
Herrick Hollow Creek (Delaware)	Brook Trout	Eat no more than 1 meal per month	PCBs
Loch Sheldrake (Sullivan)	Walleye	Eat no more than 1 meal per month	Mercury
Neversink Reservoir (Sullivan)	Brown trout over 24" and smallmouth bass	Eat no more than 1 meal per month	Mercury
Pepacton Reservoir (Delaware)	Brown trout over 24" smallmouth bass over 15" and yellow perch	Eat no more than 1 meal per month	Mercury
Rio Reservoir (Orange and Sullivan	Smallmouth bass over 15"	Eat no more than 1 meal per month	Mercury
Swinging Bridge Reservoir (Sullivan)	Walleye	Eat no more than 1 meal per month	Mercury

Table 6.16. Pennsylvania fish consumption advisories in the Delaware River Basin, 2006.

Water Body	Area Under Advisory	Species	Meal Frequency	Contaminant
Brandywine Creek	From U.S. 1 at Chadds Ford to PA/DE border (3.1 mi, UE1)	American Eel	Do Not Eat	Chlordane
Beltzville Lake	Entire Lake*	Walleye	2 meals/month	Mercury
Bush Kill	Confluence of Saw Creek to mouth (3.8 mi, UC1)	American eel	2 meals/month	Mercury
Delaware River	Source to Trenton, NJ-Morrisville, PA bridge*	American eel	2 meals/month	Mercury
Delaware Estuary, tidal PA tributaries, Schuylkill River to Fairmount Dam	Trenton, NJ-Morrisville, PA bridge to PA/DE border	White perch, Channel and Flathead catfish, Striped bass	1 meal/month	PCB
		American eel, Carp	Do Not Eat	PCB
Lake Wallenpaupack	Entire Lake	Walleye	1 meal/month	Mercury
Lehigh River	Saucon Creek to mouth	Carp, American eel	1 meal/month	PCB
Levittown Lake	Entire Lake*	White perch	1 meal/month	PCB
Little Neshaminy Creek	Entire basin	Carp	1 meal/month	PCB
Promised Land Lake	Entire lake*	Largemouth bass	1 meal/month	Mercury
Prompton Reservoir	Entire lake*	Largemouth bass	1 meal/month	Mercury
		Walleye	2 meals/month	
Red Clay Creek	Entire basin (includes all tributaries)	White sucker	1 meal/month	PCB
		American eel	Do Not Eat	PCB
Schuylkill River	Confluence of Mill Cr. at Port Carbon to Auburn Dam	Brook Trout	Do Not Eat	PCB
		Brown,Rainbow trout	6 meals/year	PCB
Schuylkill River	Confluence of Mahannon Cr. At Landingville to Kernsville Dam	Bluegill, Brown bulhead	1 meal/month	PCB
Schuylkill River	Felix Dam above Reading to Fairmount Dam	Carp, Channel catfish	6 meals/year	PCB
Schuylkill River	Black Rock Dam to Fairmount Dam in Philadelphia	Carp	Do Not Eat	PCB
		Channel catfish, Flathead catfish	1 meal/month	PCB
Schuylkill River	Felix Dam above Reading to Fairmount Dam	American eel	Do Not Eat	PCB
		White sucker	1 meal/month	
Tobyhanna Creek	Pocono Lake dam to mouth	Smallmouth bass	2 meals/month	Mercury
Tulpehocken Creek	Blue Marsh Dam to mouth	Brown trout, Rainbow trout	1 meal/month	PCB
West Branch Brandywine Creek	From business Rt. 20 Coatesville to confluence of Buck Run	American eel	6 meals/year	PCB
West Branch Delaware River	Entire section in PA	Brown trout	2 meals/month	Mercury
West Branch Schuylkill River	Entire Basin	Brook trout	1 meal/month	PCB

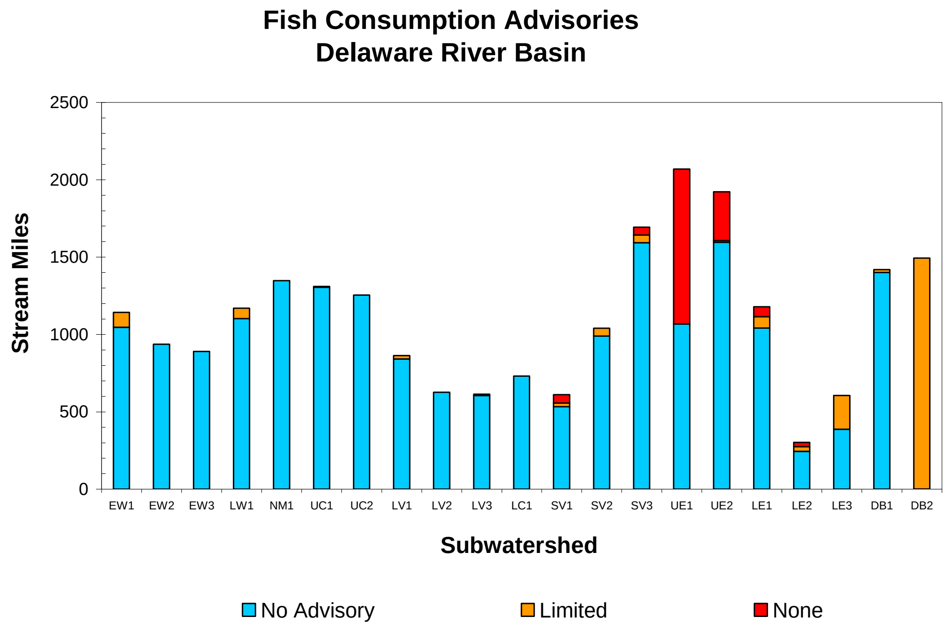


Figure 6.40. Fish consumption advisories by subwatershed in the Delaware River Basin.

Table 6.17. Fish consumption advisories in the Delaware River Basin, 2006.

Watershed	Streams (mi)	No Consume (mi)	Limited Consume (mi)	No Advisory (mi)	No Consume (%)	Limited Consume (%)	No Advisory (%)
EW1 West Branch	651		96	1047		8%	92%
EW2 East Branch	583			937			100%
EW3 Mainstem	554			891		0	100%
LW1 Lackawaxen	686		67	1103		6%	94%
NM1 Neversink/Mongaup	843			1348			100%
UC1 Penns. Tribs.	814		4	1306		3%	97%
UC2 NJ Tributaries	848			1254			100%
LV1 Above Lehighton	523		21	842		2%	98%
LV2 Above Jim Thorpe	391			627			100%
LV3 Above Easton	375	10		604	2%		98%
LC1 Above Trenton	565			732			100%
SV1 Above Reading	331	54	24	533	9%	4%	13%
SV2 Above Valley Forge	628		50	990		5%	95%
SV3 Head of tide at Phila	991	52	49	1593	1%		99%
UE1 Penna. Piedmont	2070	1003	0	1067	48%		52%
UE2 NJ coastal plain	1922	315	10	1597	16%	1%	17%
LE1 Christina River	1180	65	73	1042	5%	6%	89%
LE2 C & D Canal, DE	302	28	30	244	9%	10%	81%
LE3 Salem River, NJ	605		218	387		36%	64%
DB1 DE Coastal Plain	1420		20	1400		2%	98%
DB2 NJ Coastal Plain	1495		1493	1		100%	0%
Delaware River/Bay							
Port Jervis, NY (RM 253)	77			77			100%
Port Jervis –Reigelsville (RM 175)	78		78			100%	
Reigelsville - Trenton, NJ (RM 134)	41		41			100%	
Trenton – Philadelphia (RM 100)	34	34			100%		
Phila - C & D Canal (RM 59)	41	41			100%		
C & D Canal - Cape Henelop (RM 0)	59	59			100%		
Total Delaware Basin	**23,557**	**1,661**	**2,274**	**19,622**	**7%**	**10%**	**83%**

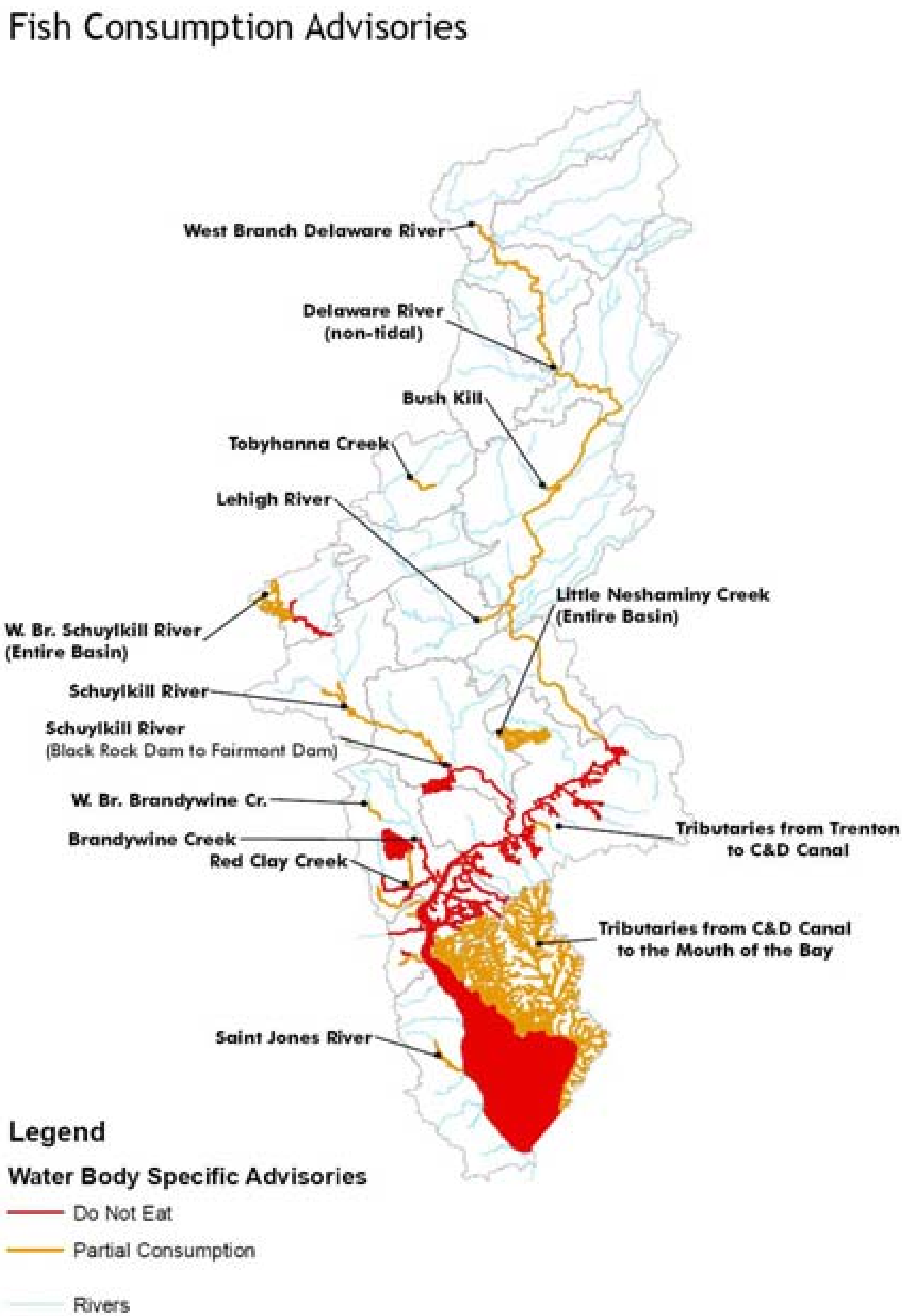


Figure 6.41. Fish consumption advisories in the Delaware River Basin, 2006.

6.17. Designated Uses/Impaired Streams

Of 23,557 miles of rivers and streams in the Delaware River Basin, 2,493 miles (11%) are impaired as assessed by the 4 states and reported to the USEPA in 2004 (Table 6.18). Over 21,000 stream miles (89%) are unimpaired.

Each state is required to assess streams and submit to the USEPA a list of streams that are impaired in accordance with Sections 305(b) and 303(d) of the Federal Clean Water Act of 1977, as amended in 1981 and 1987. The states assess the waters according to the following five categories:

Category 1: All designated uses are met.

Category 2: Some of the designated uses are met but insufficient data to determine if remaining designated uses are met.

Category 3: Insufficient data to determine whether any designated uses are met. Either no data is available or some data is available, but it is insufficient to make a determination.

Category 4: Water is impaired or threatened but a TMDL is not needed.
4A: All TMDLs for this segment have been completed and EPA approved.
4B: Control measures are expected to result in the attainment of water quality standards in a reasonable period of time.
4C: The impairment or threat is not caused by a pollutant.

Category 5: Water is impaired or threatened and a TMDL is needed for at least one pollutant or stressor.

Figure 6.43 summarizes the length of impaired and unimpaired streams in 2004 as reported by the four states in the Delaware River Basin. Figure 6.44 delineates the waters assessed by the states and found to be impaired (red on the map) as reported to the USEPA by the in the Delaware River Basin for 2004. The source of the impaired stream mapping is the USEPA EnviroMapper program which can be accessed at http://www.epa.gov/enviro/emef/.

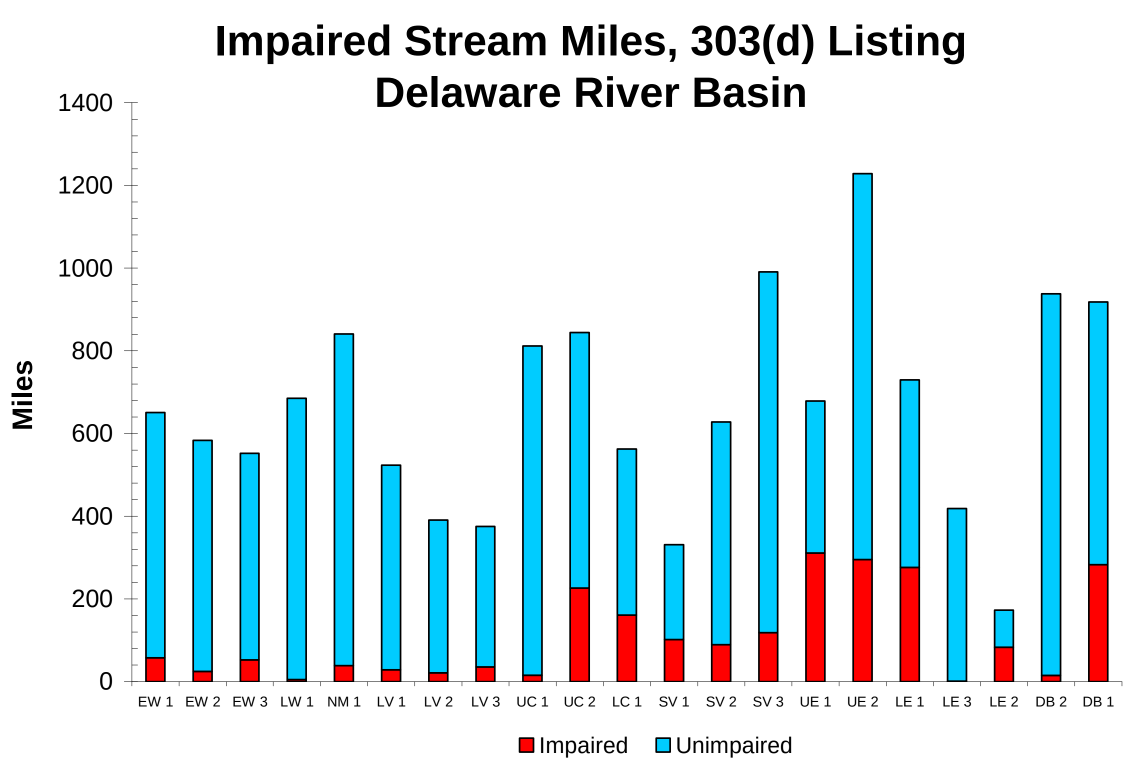


Figure 6.42. Impaired streams in the Delaware River Basin, 2004. (www.epa.gov/enviro/emef/)

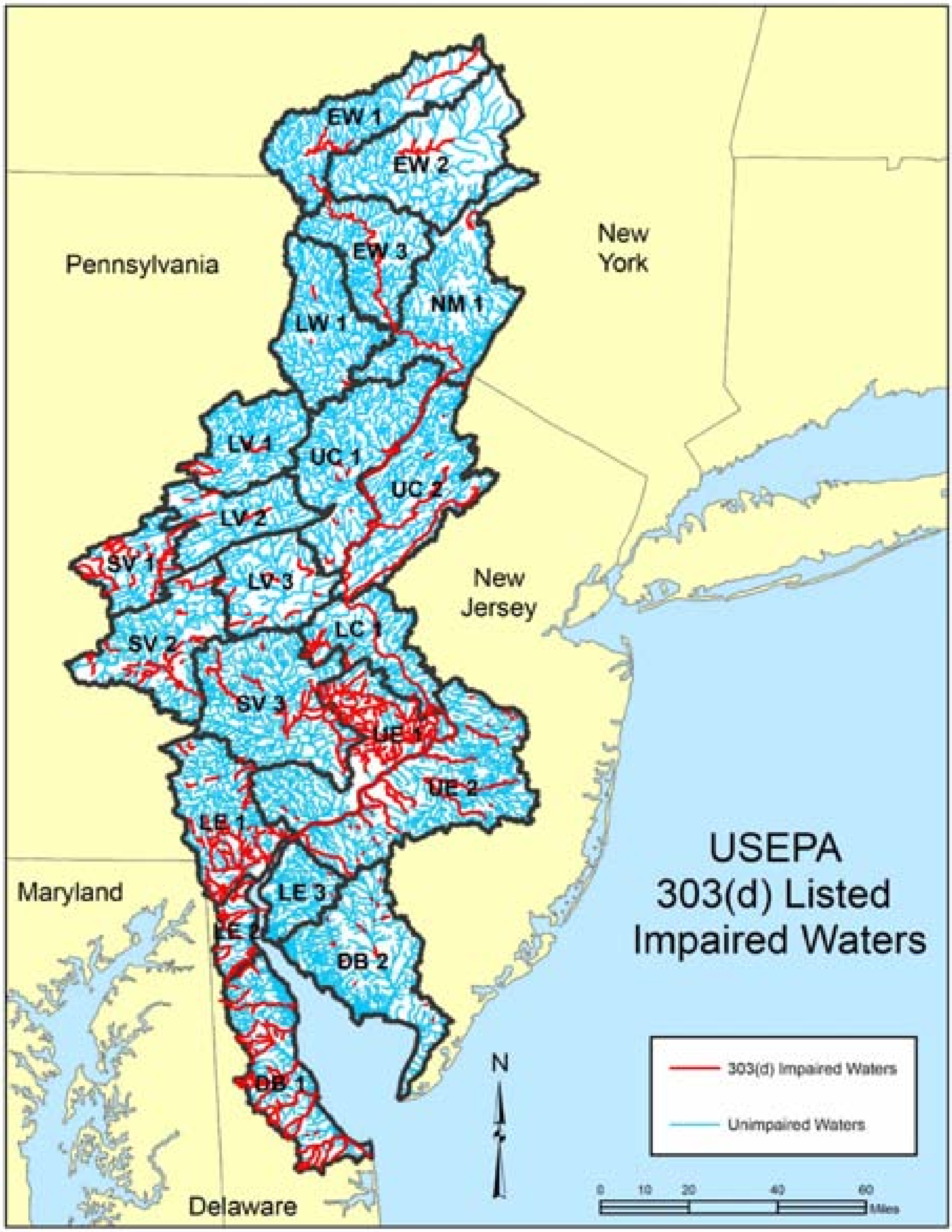


Figure 6.43. USEPA Section 303(d) impaired streams in the Delaware Basin, 2004. (www.epa.gov/enviro/emef/)

Table 6.18. Impaired stream miles in the Delaware River Basin, 2004.

	Total (mi)	**Impaired (mi)**	**Unimpaired (mi)**	**Impaired (% streams)**	**Unimpaired (% streams)**
Upper Region (NY and PA)					
EW · East/West Branch					
EW1 West Branch (Cannonsville)	651	58	593	8.9%	91%
EW2 East Branch (Pepacton))	583	25	559	4.3%	96%
EW3 Mainstem (above Narrowsburg)	552	52	500	9.5%	91%
LW · Lackawaxen	685	5	680	0.8%	99%
NM ·Neversink-Mongaup	841	38	802	4.6%	95%
Central Region (PA and NJ)					
UC ·Upper Central watersheds					
UC1 Pennsylvania tributaries	812	15	797	1.9%	98%
UC2 New Jersey tributaries	814	226	618	26.8%	73%
LV ·Lehigh Valley					
LV1 Above Lehighton	523	29	495	5.5%	95%
LV2 Above Jim Thorpe	391	21	370	5.3%	95%
LV3 Above Easton	375	36	340	9.5%	91%
LC ·Lower Central (above Trenton)	562	161	401	28.6%	71%
Lower Region (PA, NJ and DE)					
SV ·Schuylkill Valley					
SV1 Above Reading	331	102	229	30.7%	69%
SV2 Above Valley Forge	628	90	538	14.3%	86%
SV3 Head of tide at Philadelphia	991	118	873	11.9%	88%
UE ·Upper Estuary (Phila, Camden)					
UE1 Pennsylvania Piedmont	699	311	368	45.8%	54%
UE2 New Jersey Coastal Plain	1128	295	933	24.0%	76%
LE ·Lower Estuary Watersheds					
LE1 Christina River	729	276	453	37.8%	62%
LE2 C & D Canal, DE	173	83	90	48.3%	52%
LE3 Salem River, NJ	419	1	417	0.3%	99%
Bay Region					
DB ·Delaware Bay (NJ and DE)					
DB1 Delaware Coastal Plain	918	283	636	30.8%	69%
DB2 New Jersey Coastal Plain	938	15	923	1.6%	98%
Delaware River and Bay					
Port Jervis, NY (RM 253)	77				
Port Jervis –Reigelsville (RM 175)	78	78	0	100%	0%
Reigelsville - Trenton, NJ (RM 134)	41	41	0	100%	0%
Trenton – Philadelphia (RM 100)	34	34	0	100%	0%
Phila - C & D Canal (RM 59)	41	41	0	100%	0%
C & D Canal - Cape Henelop (RM 0)	59	59	0	100%	0%
Total Delaware Basin	23,557	2,493	21,064	11%	89%

6.18. Salt Line (Chlorides)

The DRBC provides the following description of the salt line.

Contrary to popular belief, the salt line is not actually a line. It is an estimation of where along the Delaware River the seven-day average chloride concentration equals 250 ppm. Most of the chlorides in the Delaware Estuary originate from the salty ocean water traveling up the Delaware River Basin. The sea water from the ocean has a chloride concentration of about 19,000 mg/l. The distance from the sea affects concentration of chlorides in the estuary. Thus, locations along the Delaware River that are closer to the sea, such as Wilmington, Delaware, will have naturally higher chloride concentrations than locations further away from the sea, such as Philadelphia, Pennsylvania.

The salt line seasonally advances and retreats along the river, advancing upstream during the summer and early fall when flows in the river are lower and concentrations of chlorides higher, and retreating during late fall, winter, and spring as flows increase and flush chlorides out to sea. Chlorides also naturally advance and retreat with each tide cycle. To determine the current salt line, the U.S. Geological Survey takes daily measurements from stations at Reedy Island Jetty near Port Penn, Delaware, and from the Kimberly Clark Corporation in Chester, Pennsylvania. Chloride concentrations in excess of 250 mg/l are usually considered undesirable for domestic use and may corrode machinery if used for industrial purposes. In order to better understand how much flow is needed in the river to keep the salt line from traveling up the Delaware River, the DRBC requires monitoring the salt line in order to set drought flow targets for the Delaware River at Trenton, New Jersey (DRBC, 2006).

The White Paper on the Status and Needs of Science in the Delaware Estuary describes the influence of salinity on the Delaware Estuary (Kreeger *et al*. 2006).

The Delaware Estuary is unique among large American estuaries in having a substantial freshwater tidal region, considered one of the largest of its kind in the world. The main mixing zone between seawater and freshwater occurs in the middle of the Estuary. Rising sea level, changes to freshwater inflows, and other factors might be leading to movement of the salinity gradient towards the upper Estuary. This in turn could be having ecological effects, and more study will be needed to deduce such impacts. In addition to its ecological effects within the tidal Estuary, changes in the balance between saltwater and freshwater are already impacting human activities in southern New Jersey. For example, in Cape May County saltwater from Delaware Bay is infiltrating the groundwater leading to salt contamination of wells for drinking water. While it appears that most of these changes in the salt balance of groundwater are being driven by groundwater withdrawals, rising sea level is expected to contribute to this problem.

Salinity in the Estuary is sensitive to a variety of natural hydrodynamic and climatic factors, including variation in freshwater inflow and tidal currents associated with year to-year changes in climate (temperature, rainfall, snow melt). In addition, discharges of freshwater to the estuary have been altered and largely dampened by regulation of the Delaware River above Trenton since the 1970's. Unidirectional shifts in the balance between salt and fresh water are also likely because of sea level rise. Increasing salinity in the middle and upper estuary is likely to have a variety of direct and indirect effects on the ecology of those areas, particularly for biota that are insensitive to saltwater. For example, documented losses of freshwater tidal marshes and the upstream migration of brackish marsh communities demonstrate the potential impacts of flow regulation that need further investigation. Freshwater tidal wetlands are a signature trait of the Delaware Estuary having high primary productivity, biodiversity and functionality

The location of the furthest annual upstream salt line (250 mg/l chloride) along the Delaware River was plotted from 1990 through 2005 (Figure 6.45). During this 15 year period, the salt line reached its most upstream point at river mile 90 (2 miles downstream of the Schuylkill mouth) during 2005. During the drought of record, the salt line reached river mile 102 which is 2 miles upstream from the Ben Franklin Bridge but 5 miles downstream from the City of Philadelphia Torresdale water intake at river mile 107 (Figure 6.46). Table 6.19 summarizes the top 5 years in terms of most upstream salt line migration as compared to lowest stream flow that year. Since the salt line never reached the mouth of the Schuylkill during these more recent droughts, it indicates the DRBC flow management program to leave sufficient freshwater flow in the Delaware and the Schuylkill (more than 3,000 cfs) is working to keep salt water from contaminating the Philadelphia water intakes. During wet years such as 2003 and 2004 the furthest upstream salt line was measured at river mile 72 which is a few miles upstream from the mouth of the Christina River at Wilmington and the Delaware Memorial Bridge. The furthest upstream salt line seems to oscillate every other year or so from wet year to dry year within twice the amplitude of 15 to 20 miles ranging from just upstream from the Delaware Memorial Bridge to just downstream from the Schuylkill mouth.

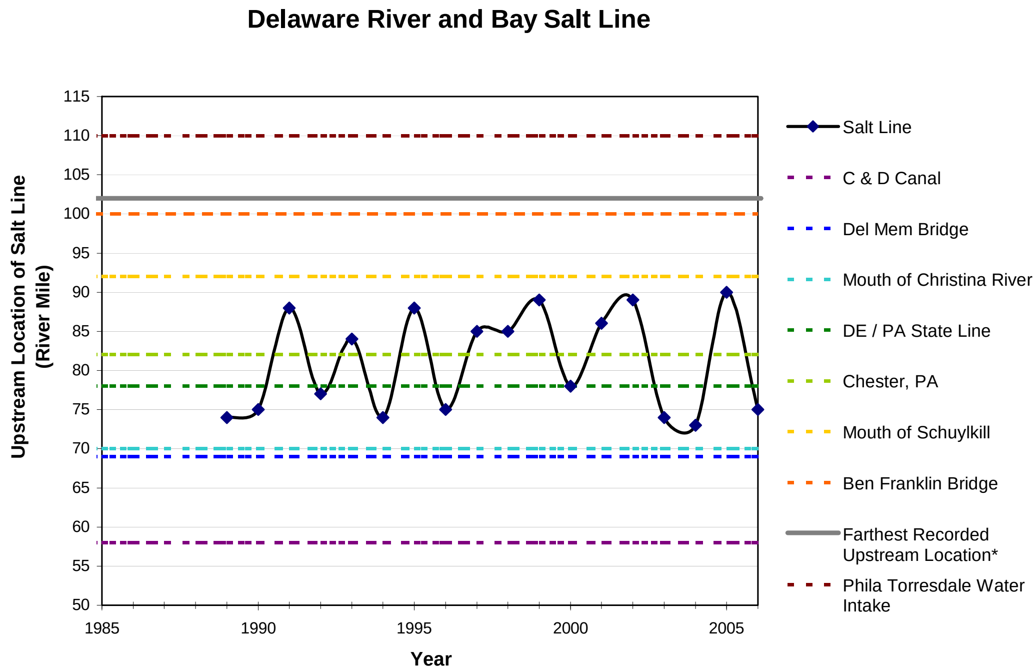


Figure 6.44. Annual location of advanced salt line in the Delaware River.

Figure 6.45. Salt line location along Delaware River during the 1960s drought of record**.**

Table 6.19. Locations of furthest upstream salt line in the Delaware River.

Year	Salt Line Location River Mile	Miles downstream from Schuylkill (RM 92)	Low Flow at Trenton, NJ (cfs)	Date
2005	90	- 2	2,520	9/20/05
2002	89	- 3	2,840	9/13/02
1999	89	- 3	2,260	7/13/99
1995	88	- 5	2,480	8/13/95
1991	88	- 5	2,390	11/8/91

Chapter 7 - Water Quantity/Hydrology

7.1. Water Supply/Demand

The DRBC has published estimates of water supply and demand for each of the 4 regions and 10 watersheds in the Delaware River Basin. Almost 70% of surface water withdrawals in the basin are by the power sector, 10% are for public surface water supplies, and 10% are by industry (Figure 7.1). In 1996, surface water withdrawals in the Delaware River Basin ranged from 7,310 mgd annually to 8,264 mgd peak (Figure 7.2). By 2020, annual and peak surface water withdrawals are forecast to be 9,800 mgd and 11,274 mgd, respectively.

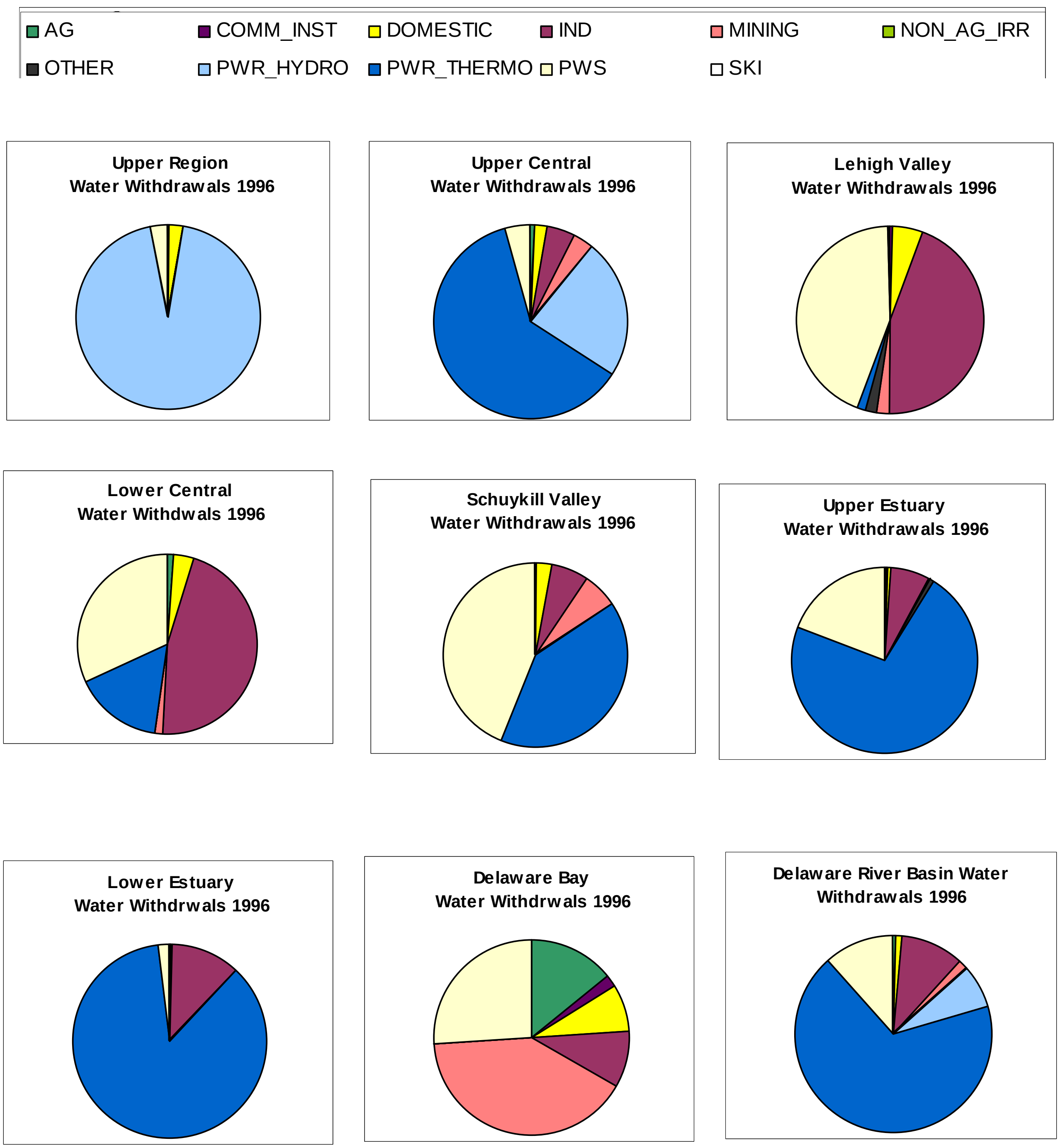


Figure 7.1. Water supply withdrawals in the Delaware River Basin.

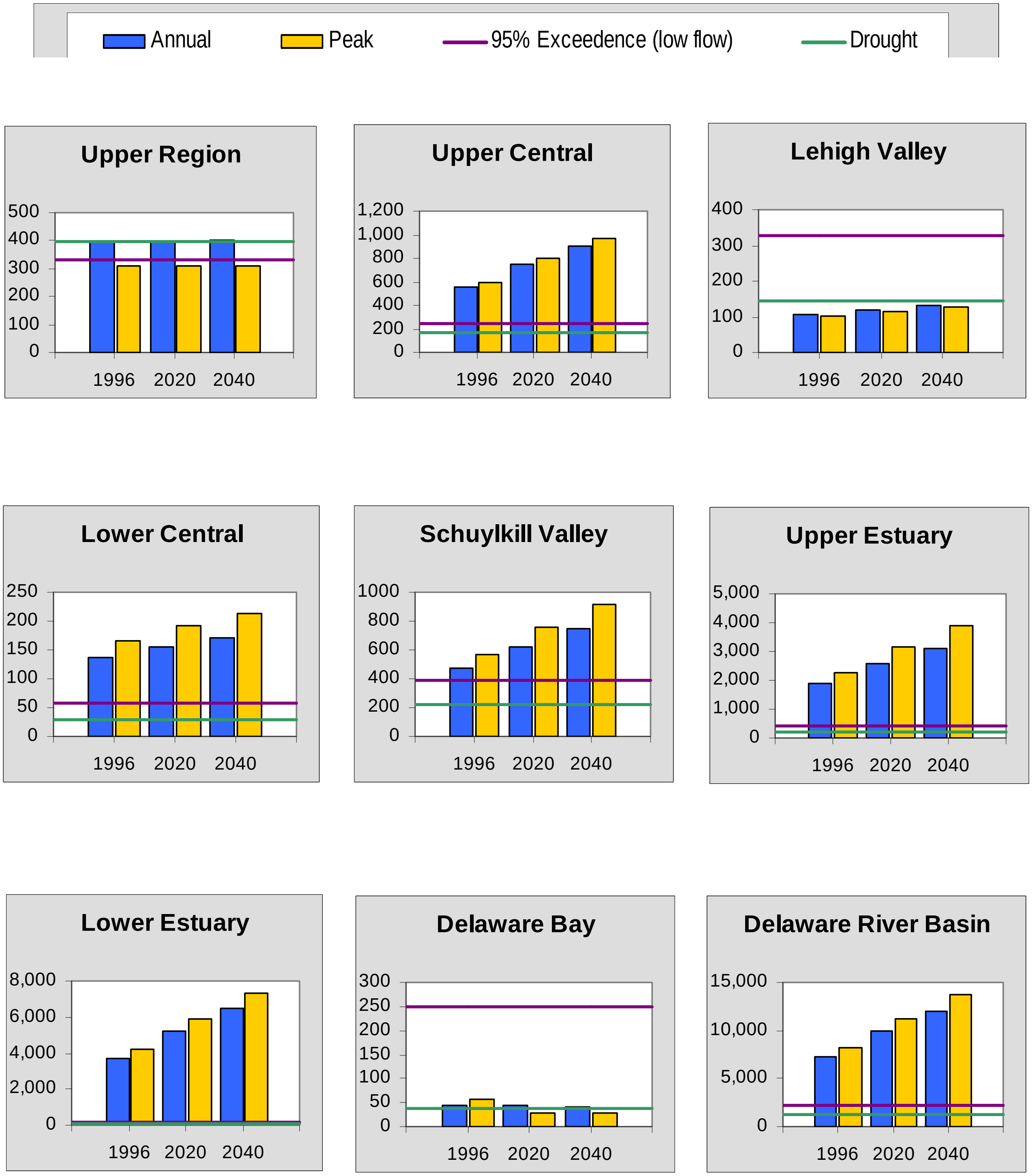


Figure 7.2. Annual/peak surface water withdrawals in the Delaware River Basin in July (mgd).

7.2. Streamflow/Precipitation

Precipitation and stream flow are components of the hydrologic cycle. Sufficient stream flow is needed for drinking water, fishery, ecology, and recreation purposes. Hydrology is the study of water quantity dispersed between the earth and the atmosphere usually expressed in terms of a water budget. The hydrologic cycle starts with a form of precipitation - rain, fog, sleet, or snow - falling from the sky. Precipitation falls on to the ground and either runs off to a waterway (runoff), permeates into the ground (infiltration), disperses back into the atmosphere (evaporation) or is absorbed by plants and trees (transpiration). Figure 7.3 illustrates the key components of the hydrologic cycle.

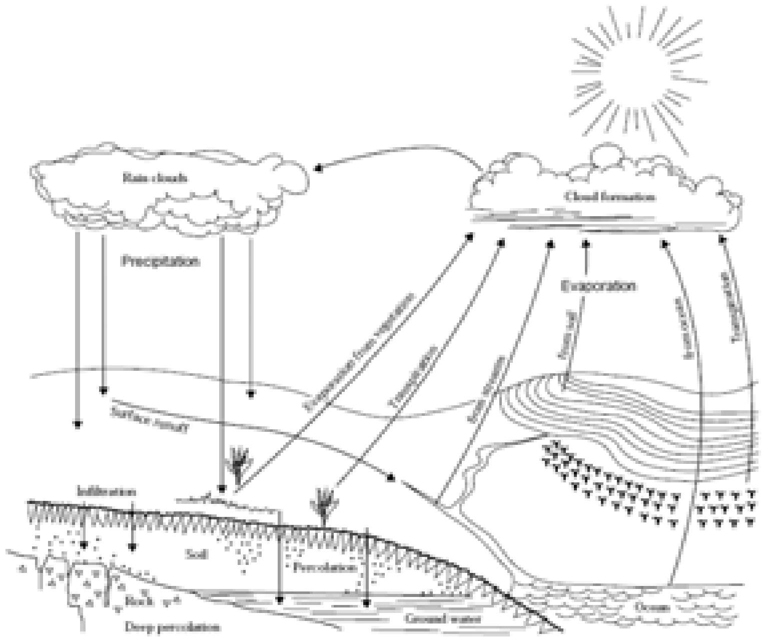


Figure 7.3. The hydrologic cycle (USDA-NRCS)

The science of hydrology is defined by the water budget equation of the hydrologic cycle.

$P = R + I + ET - \Delta S$

Where:
P = precipitation

R = runoff that flows overland to a waterway

I = infiltration into the groundwater table

ET = sum of evaporation (E) to atmosphere plus transpiration (T) by plants

ΔS = change in moisture storage in surface water, groundwater, and/or soil

With watershed urbanization and climate change, the frequency and intensity of flood peak flows may increase and the low flows during drought may decrease leading to more flooding and more water shortages during drought. Annual precipitation, mean annual flow, maximum peak flow, and low flow at USGS stream gages along the Delaware River and tributaries are plotted to determine if changes in land use, water intakes/discharges, and/or climate change are affecting stream flows during the period of record.

The DRBC runs a river operations plan to maintain the 250 ppm isochlor (salt line) below the Philadelphia drinking water intakes and Camden wellfields and sets minimum flow objectives at three locations along the Delaware River.

USGS Stream Gage at Montague, N. J*:* The Delaware River Master appointed by the U.S. Supreme Court decree of 1954 supervises the operation of New York City reservoir releases in the Catskills to sustain a minimum flow of 1,750 cfs at Montague. New York City operates three reservoirs in the headwaters of the Delaware Basin: the Cannonsville Reservoir on the West Branch of the Delaware River, Pepacton Reservoir on the East Branch of the Delaware River, and Neversink Reservoir on the Neversink River.

USGS Stream Gage at Trenton, N. J: The minimum flow objective is set at 3,000 cfs which is to protect drinking water supplies along the upper tidal Delaware River and aquifers adjacent to the river.

Delaware River below Schuylkill River, PA: The DRBC has established a minimum flow objective of 3,600 cfs for the Delaware River below the Schuylkill including all the upstream tributaries.

The White Paper on the Delaware Estuary discusses the interaction between freshwater stream flow and estuary salinity and further links to oyster abundance and tidal marsh impacts (Kreeger *et al.* 2006)

Study and management of the water budget is complicated by the difficulty in differentiating between natural cycles that are associated with climate variation (e.g., El Nino, North Atlantic Oscillation, wet/dry years) and the effects of human management (e.g., flow regulation, channel deepening, diversions out of the watershed, groundwater withdrawals). Some forcing functions are unidirectional, such as sea-level rise. Changes in the balance between saltwater and freshwater can have important direct effects on human activities. Infiltration of saltwater into the groundwater in southern New Jersey is leading to salt contamination of wells for drinking water. While most of these changes in the salt balance of groundwater are being driven by groundwater withdrawals, a better understanding the water budget of the Estuary, and its likely response to rising sea level, will help water resources managers better predict and plan for such problems in the future.

The water budget is also critically important for the biological communities of the Estuary. One of the distinguishing characteristics of the Delaware Estuary compared to other large American estuaries is the size of the freshwater tidal region, considered one of the largest of its kind in the world. The main mixing zone between seawater and freshwater occurs in the middle of the estuary. Any further reduction in freshwater inflow, combined with rising sea level, is certain to shift the salinity gradient towards the upper estuary. Increased salinity in the middle and upper Estuary will impact all of the species and habitats that reside in those areas because most animals and plants in freshwater tidal marshes have very narrow physiological tolerance limits for salt exposure.

Oyster reefs and freshwater tidal marshes are both regarded as signature habitat types of the Delaware Estuary. Oysters (Crassostrea virginica) could be impaired by increasing salinity because disease agents tend to be more virulent in dry years when bay salinities are higher than normal. Increasing salinity due to sea-level rise and freshwater withdrawal will exacerbate this tendency. This issue is of increased importance because the bay narrows appreciably just above the area of the oyster beds leaving little area for up-estuary movement of the resource. Freshwater tidal marshes contain high plant diversity and species of special interest such as wild rice (Zizania aquatica). These plants cannot tolerate saltwater. Being situated in the urban corridor of the Estuary where they are impacted by development and pollution, freshwater tidal marshes are vestigial compared to their historic acreage. Key links between ecology and physical processes need resolution of the importance of: the magnitude and seasonal timing of freshwater flow location of the salt line; and, flow management and the interrelationship between flow regulation, natural flow variation, and other impacts.

The USGS maintains a long term stream gaging program. Stream gage records can be used to assess trends in stream flow. Changes in stream flow can be due to climatic effects (i.e. it may be raining more) and/or changes in development and urbanization (i.e. there could be less infiltration and more runoff due to more impervious cover and water withdrawals or there could be more flood flows due to urbanization). The U.S. National Weather Service maintains a long term precipitation monitoring program. Changes in precipitation (less or more rain and snow) could be due to natural climatic cycles, global warming, or natural phenomena such as El Nino and La Nina which are related to temperature changes in the Pacific Ocean and the North Atlantic Oscillation (NAO). Figures 7.4 and 7.5 illustrate the stream gaging stations and mean annual precipitation in the Delaware Basin, respectively.

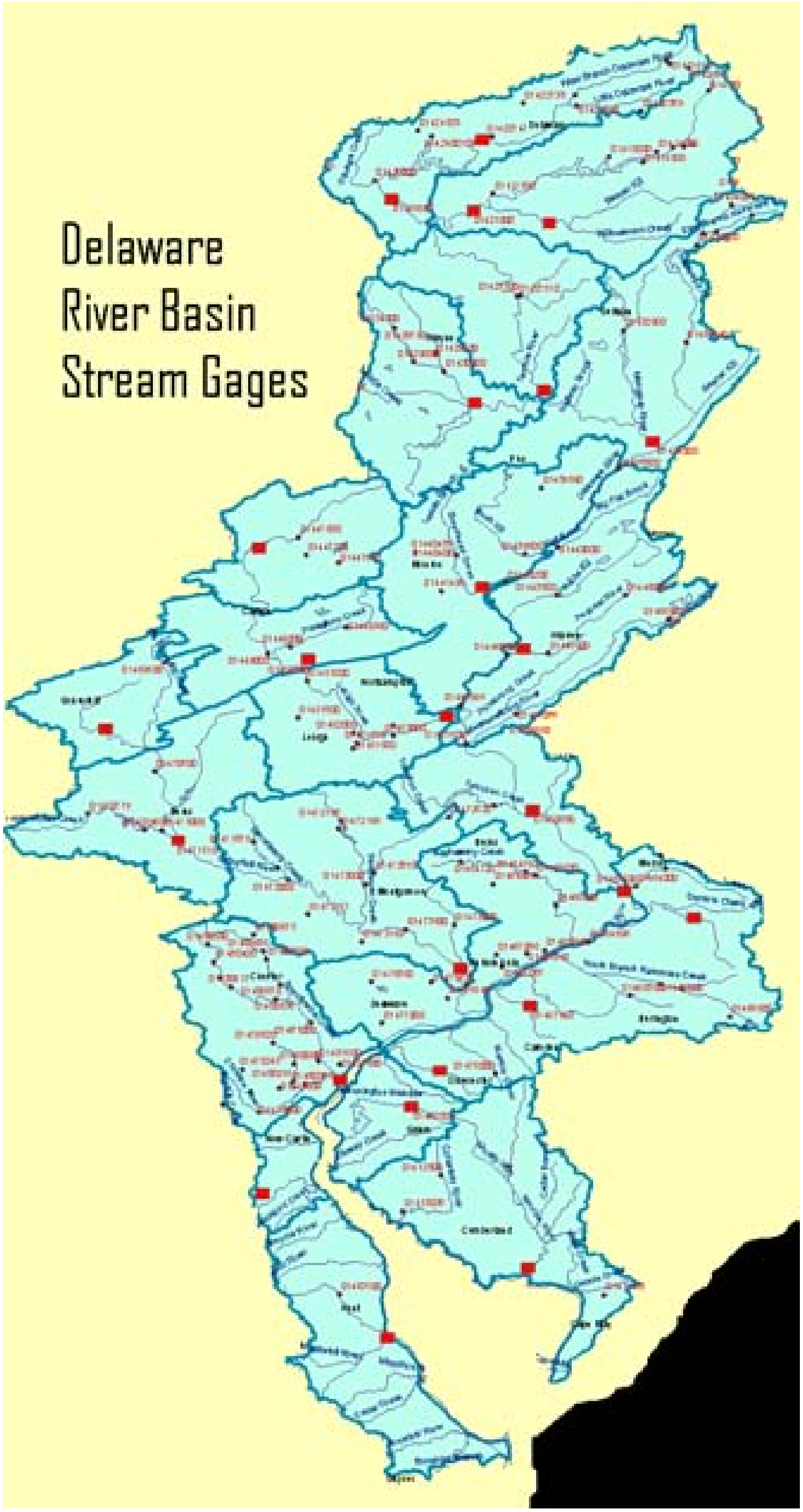


Figure 7.4. Stream gages in the Delaware River Basin..

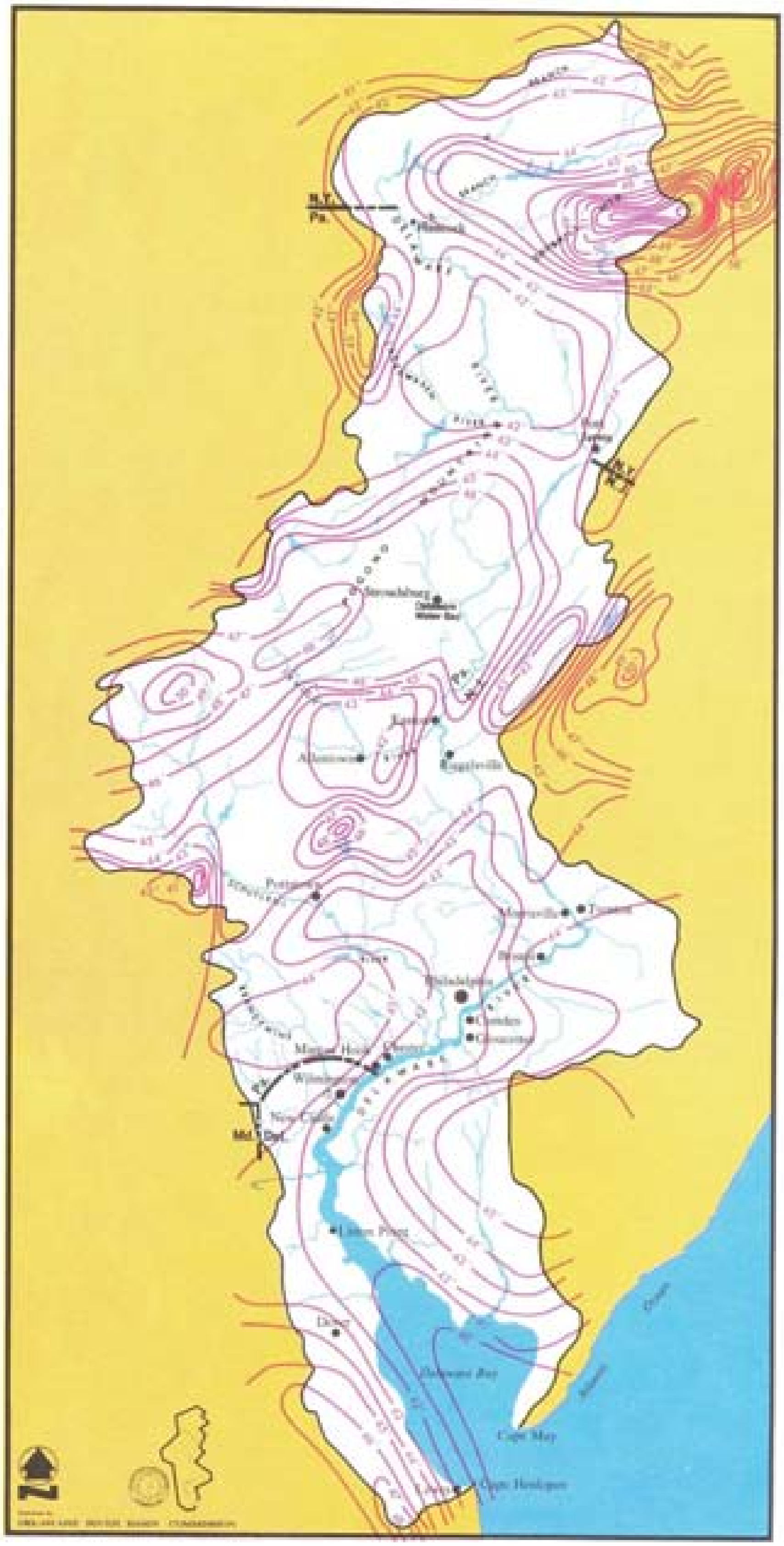
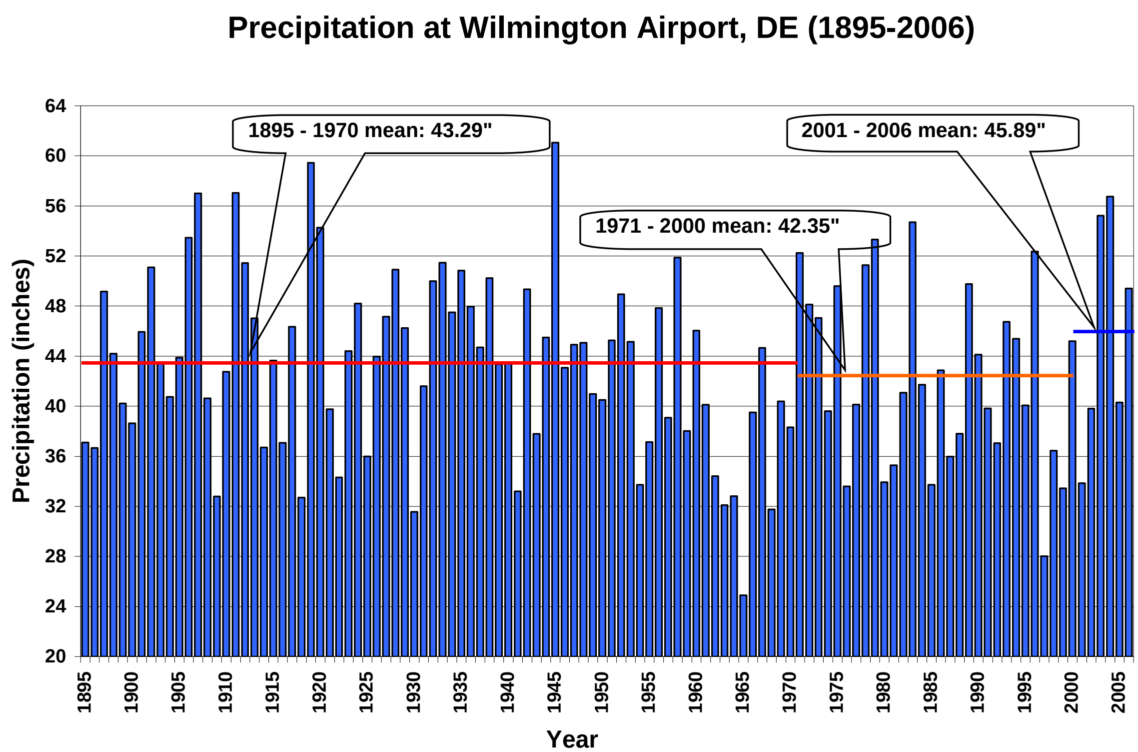


Figure 7.5. Mean annual precipitation in the Delaware River Basin.



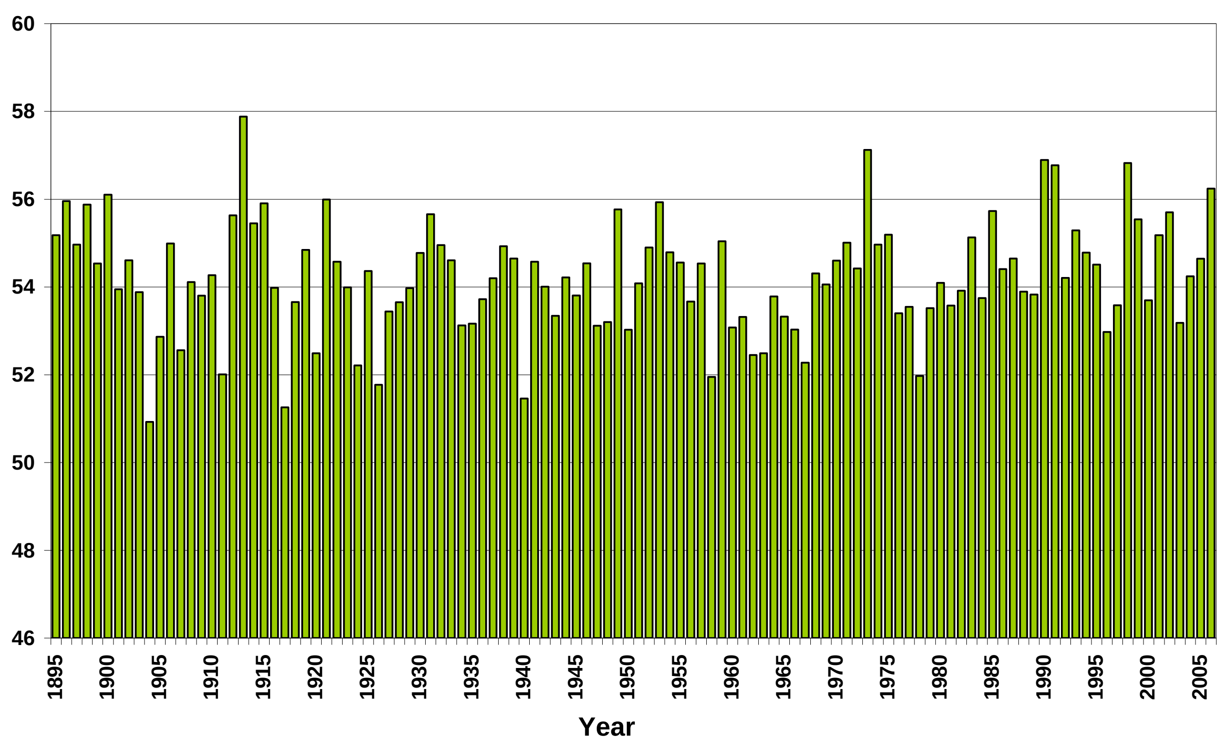


Figure 7.6. Precipitation and temperature at Wilmington Airport, Delaware. (USNWS)

Delaware River

Annual precipitation and stream flow (annual mean flow, maximum peak flow, and minimum daily low flow) were plotted at the following USGS stream gages along of the Delaware River:

River Mile 304 - Delaware River at Callicoon, New York, USGS Gage 1427510

River Mile 253 - Delaware River at Port Jervis, New York, USGS Gage 1434000

River Mile 246 - Delaware River at Montague, New Jersey, USGS Gage 1438500

River Mile 175 - Delaware River at Riegelsville, New Jersey, USGS Gage 1457500

River Mile 134 - Delaware River at Trenton, New Jersey, USGS Gage 1463500

Median annual precipitation between 2001 and 2005 ranged from 40 to 52 inches at the five stream gages along the Delaware River above Trenton. Since 1990, precipitation remained constant at 3 gages, increased along the Delaware River at Riegelsville and decreased along the Delaware River at Montague (Table 7.1).

Median annual flow or runoff between 2001 and 2005 ranged from 27 to 31 in at four gages with mean annual flow increasing as one proceeds downstream. Since 1990, mean annual flow increased at 3 gages and remained constant at one gage the Delaware River at Trenton.

Maximum peak flow between 2001 and 2005 ranged from 12 to 25 cfs/sq mi at the 5 gages and the peak flow decreases as one proceeds downstream. Since 1990, peak flow trends have remained constant at 4 gages and increased at the Delaware River at Riegelsville.

Minimum daily flows between 2001 ranged from 0.34 to 0.46 cfs per sq mi at 4 gages and generally increases as one proceeds downstream. Since 1990, minimum flows have remained constant at 4 gages with sufficient data.

Table 7.1. Precipitation and stream flow trends along the Delaware River since 1990.

USGS Stream Gage	Annual Precipitation (in/yr)	Mean Annual Flow (in/yr)	Maximum Peak Flow ($ft^3/s/mi^2$)	Minimum Daily Flow ($ft^3/s/mi^2$)
RM 304 – Delaware River at Callicoon, NY Gage 1427510	45 →	27 ↑	25 →	0.34 →
RM 253 – Delaware River at Port Jervis,NY Gage 01434000	45 →	29 ↑	19 →	0.37 →
RM 246 – Delaware River at Montague, NJ Gage 1438500	40 ↓	29 ↑	17 →	0.35 →
RM 175 – Delaware River at Riegelsville, NJ Gage 1457500	52 ↑	Limited Data	13 ↑	Limited Data
RM 134 – Delaware River at Trenton, NJ Gage 1463500	48 →	31 →	12 →	0.46 →

15 = 5-yr median 2001 – 2005

Precipitation and stream flow trends since 1990:

↑ = increasing → = constant ↓ = decreasing

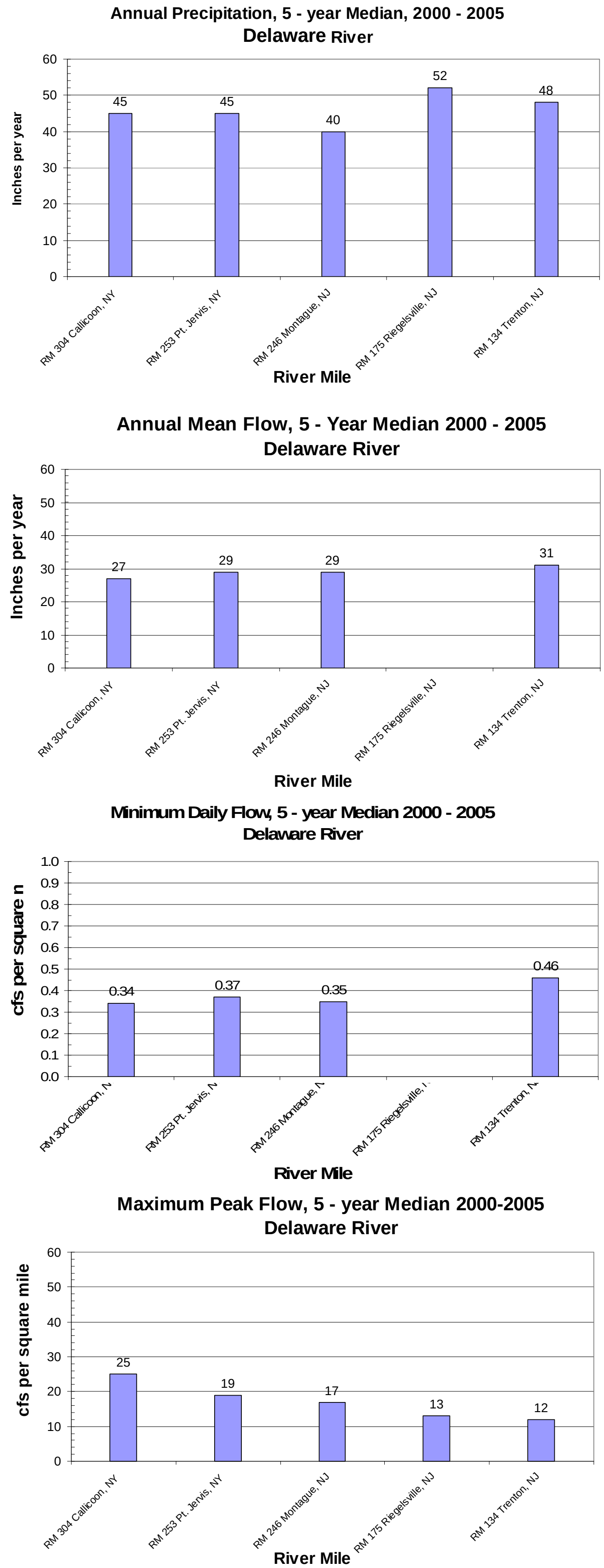
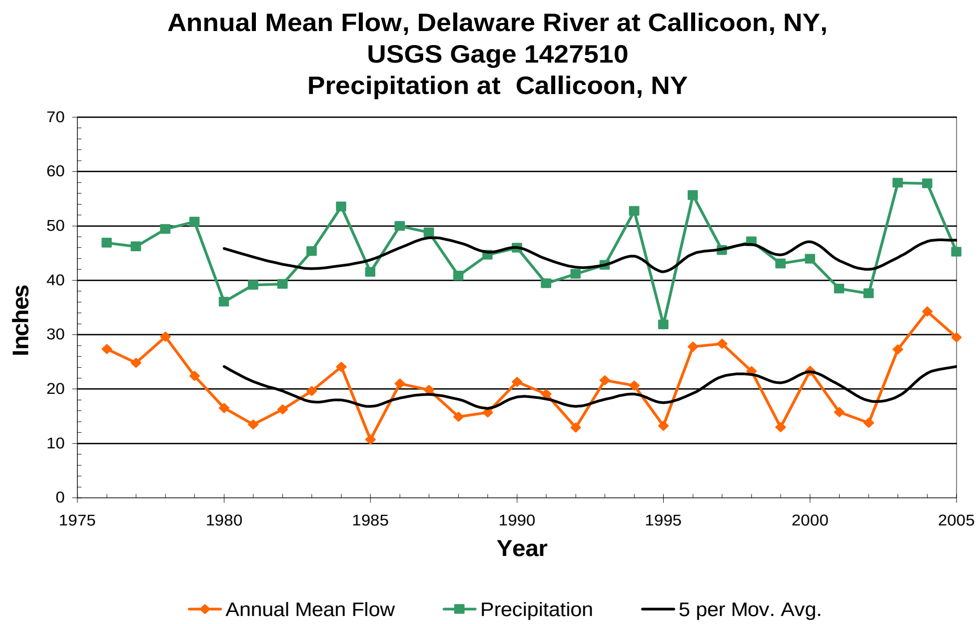


Figure 7.7. Precipitation and stream flow along the Delaware River.

River Mile 304 - Delaware River at Callicoon, New York, USGS Gage 1427510
Drainage area = 1,820 sq mi. Period of record = 1975 - 2004

Maximum peak flows along the Delaware River at Calicoon, New York as recorded by a 5 year moving average have remained constant since 1990 ranging from 20 to 25 cfs per sq mi. Watershed land use above Callicoon remains mostly forested and little land use change has occurred over that period.

Minimum annual low flows as measured by a 5 year moving average has remained constant since 1990 at 0.30 cfs per sq mi The watershed above Callicoon is almost entirely forested. Low flows along the Delaware River at Callicoon are regulated by upstream New York City reservoirs at Cannonsville and Pepacton.



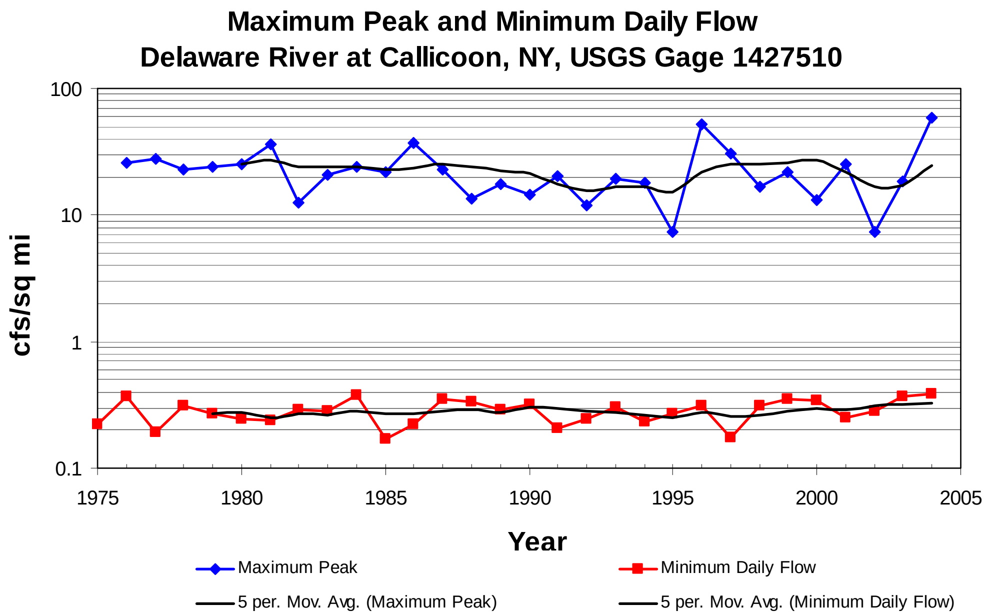
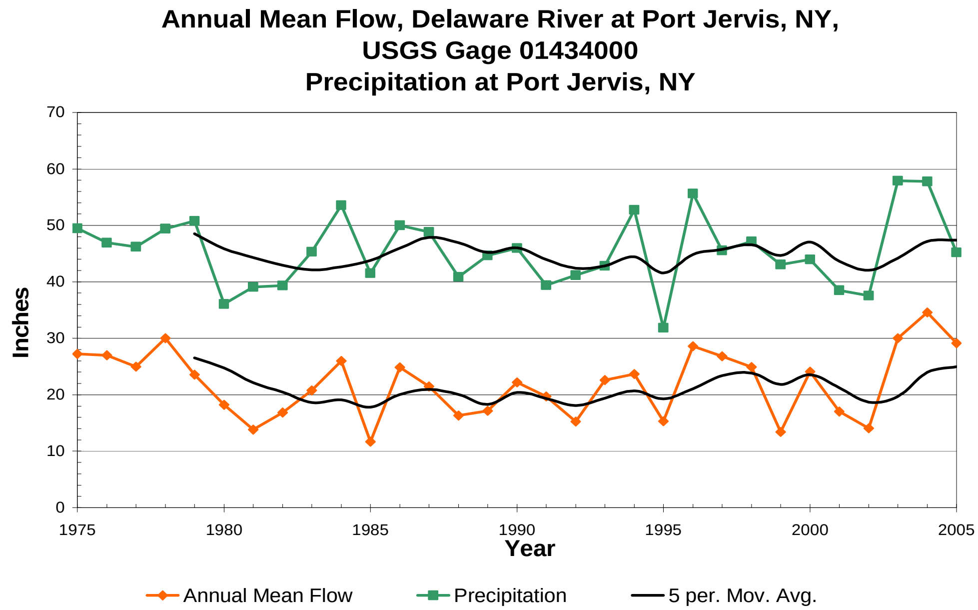


Figure 7.8. Precipitation and stream flow along the Delaware River at Callicoon, N. Y.

River Mile 253 - Delaware River at Port Jervis, New York, USGS Gage 1434000
Drainage area = 3,070 sq mi.. Period of record = 1970 - 2004

Maximum peak flows along the Delaware River at Port Jervis, New York as recorded by a 5 year moving average have remained constant since 1990 between 15 to 20 cfs per sq mi. Watershed land use above Port Jervis has not received much development over that period and much of the watershed remains forested.

Minimum daily low flows as measured by a 5 year moving average has remained constant since 1990 at 0.30 to 0.35 cfs per sq mi. Development has not increased in the watershed and much of the drainage upstream remains forested. Low flows in the Delaware River here are regulated by upstream New York City reservoirs at Cannonsville and Pepacton and Neversink.



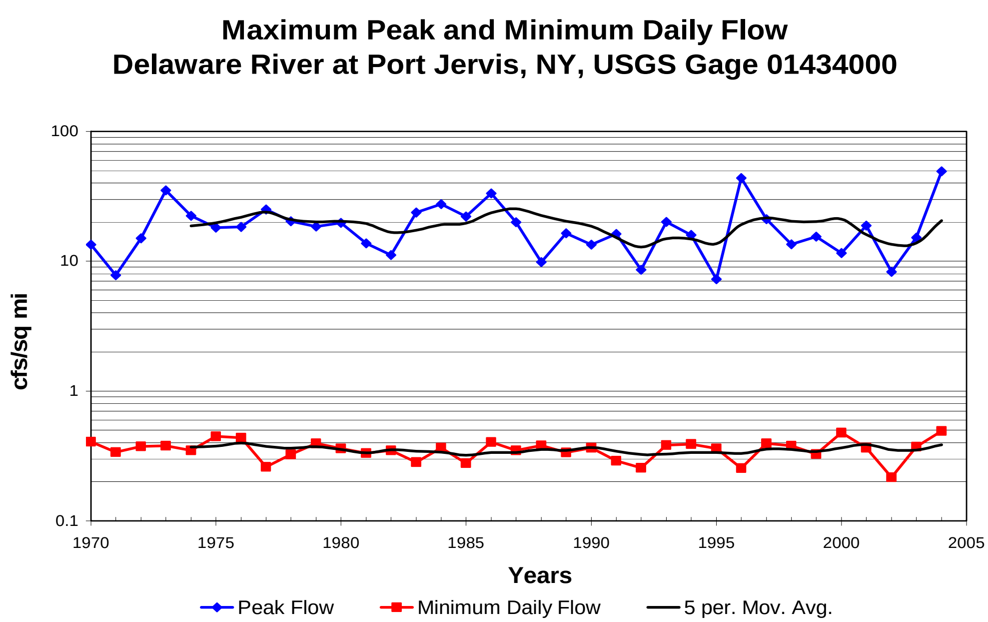
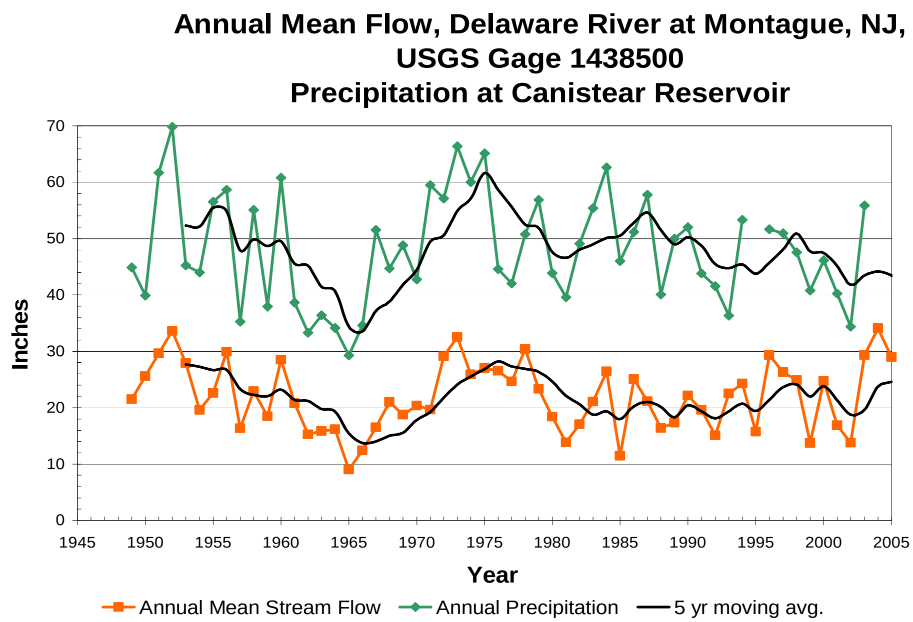


Figure 7.9. Precipitation and stream flow along the Delaware River at Port Jervis, N. Y.

River Mile 246 - Delaware River at Montague, New Jersey, USGS Gage 1438500
Drainage area = 3,480 sq mi. Period of record = 1936 - 2006

Maximum peak flows along the Delaware River at Montague, New Jersey as recorded by a 5 year moving average have remained constant since 1990 between 15 to 20 cfs per sq mi. The watershed has not received much development over that period and much of the watershed above remains forested.

Minimum daily low flows as measured by 5 year moving average have remained constant since 1990 at 0.3 cfs per sq mi. Development has not increased in the watershed during this period. Low flows in the Delaware River here are regulated by New York City reservoirs at Cannonsville, Pepacton, and Neversink.



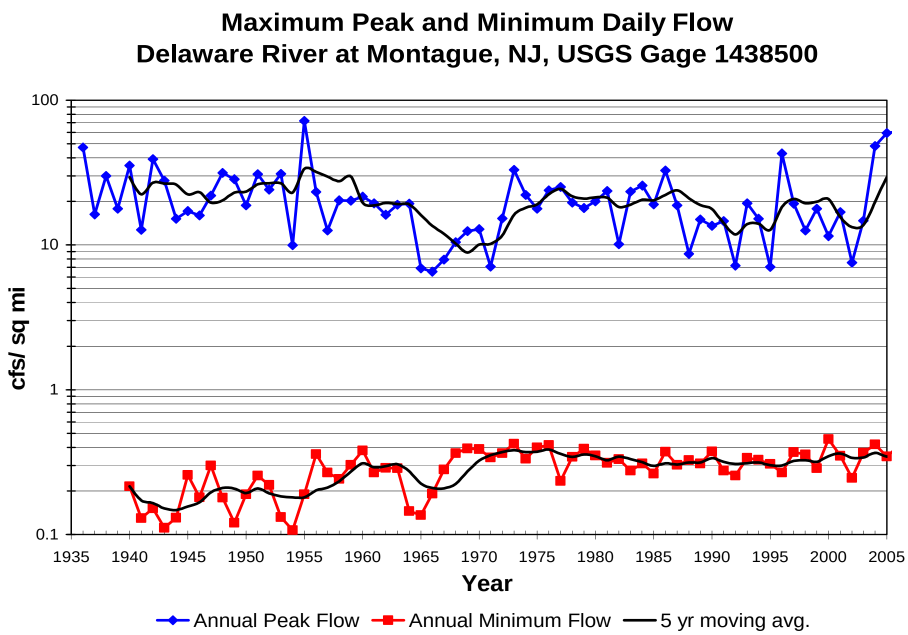
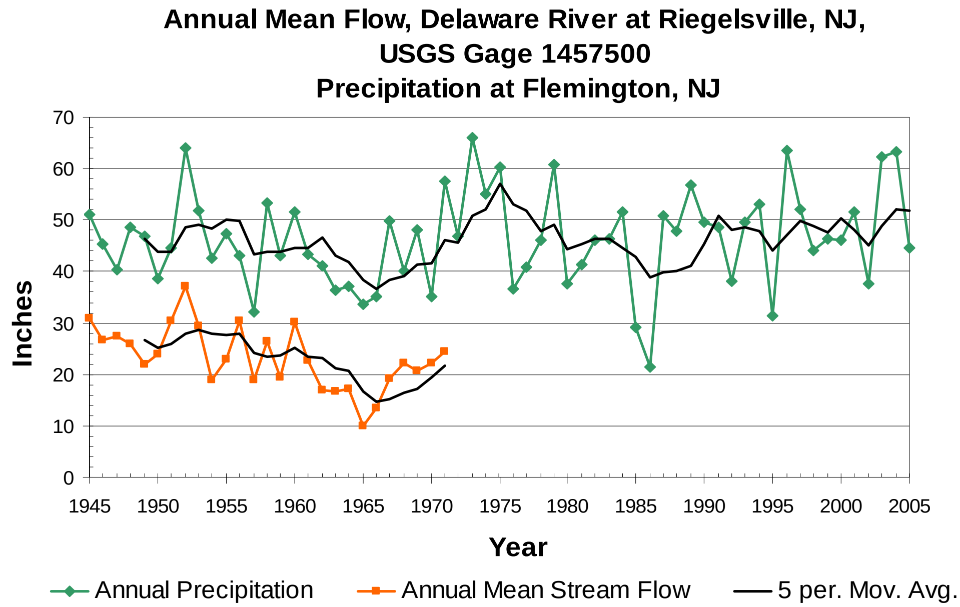


Figure 7.10. Precipitation and stream flow along the Delaware River at Montague, N. J.

River Mile 175 - Delaware River at Riegelsville, New Jersey, USGS Gage 1457500
Drainage area = 6,328 sq mi. Period of record = 1904 to 2005

Maximum peak flows along the Delaware River at Riegelsville, New Jersey as recorded by a 5 year moving average have increased rising from 10 cfs per sq mi in 1990 to 20 cfs per sq mi by 2005.



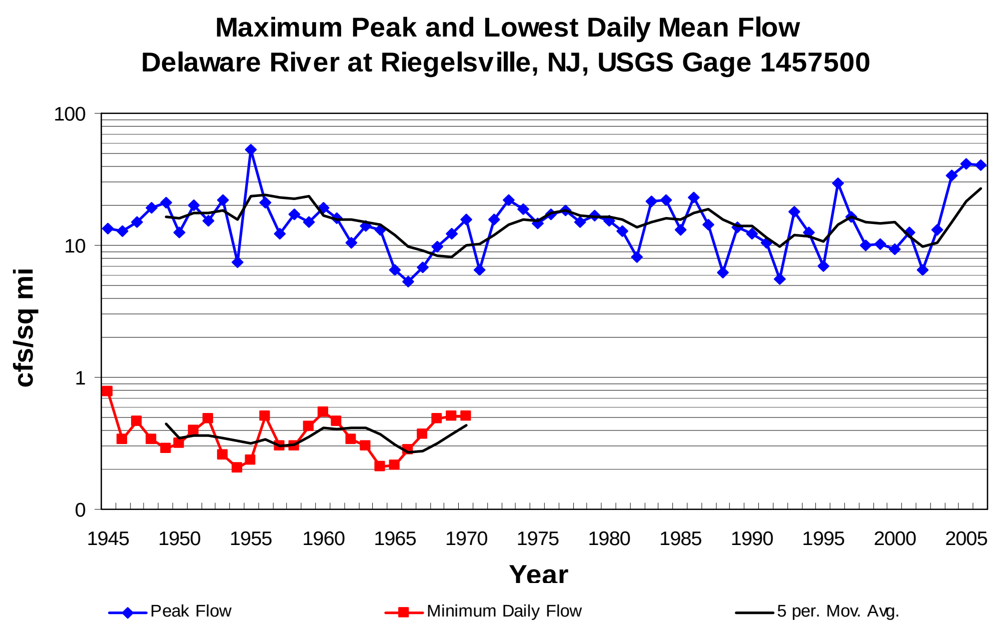
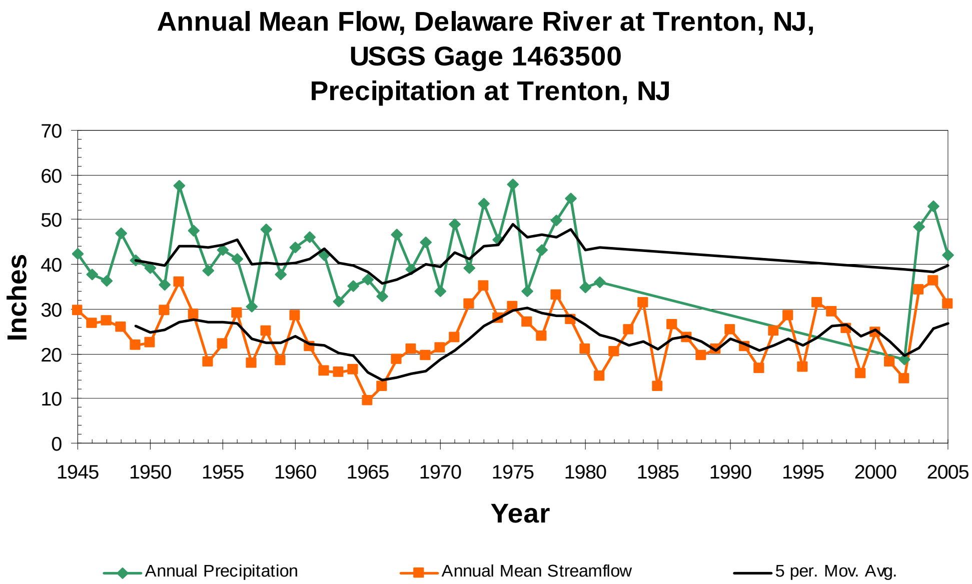


Figure 7.11. Precipitation and stream flow along the Delaware River at Riegelsville, N. J.

River Mile 134 - Delaware River at Trenton, New Jersey, USGS Gage 1463500
Drainage area = 6,780 mi. Period of record = 1900 to 2005

Maximum peak flows along the Delaware River at Trenton, New Jersey as recorded by a 5 year moving average have remained constant since 1990 ranging between 10 to 15 cfs per sq mi. Minimum daily low flows as measured by 5 year moving average have remained constant since 1990 at 0.4 cfs per sq mi/yr.



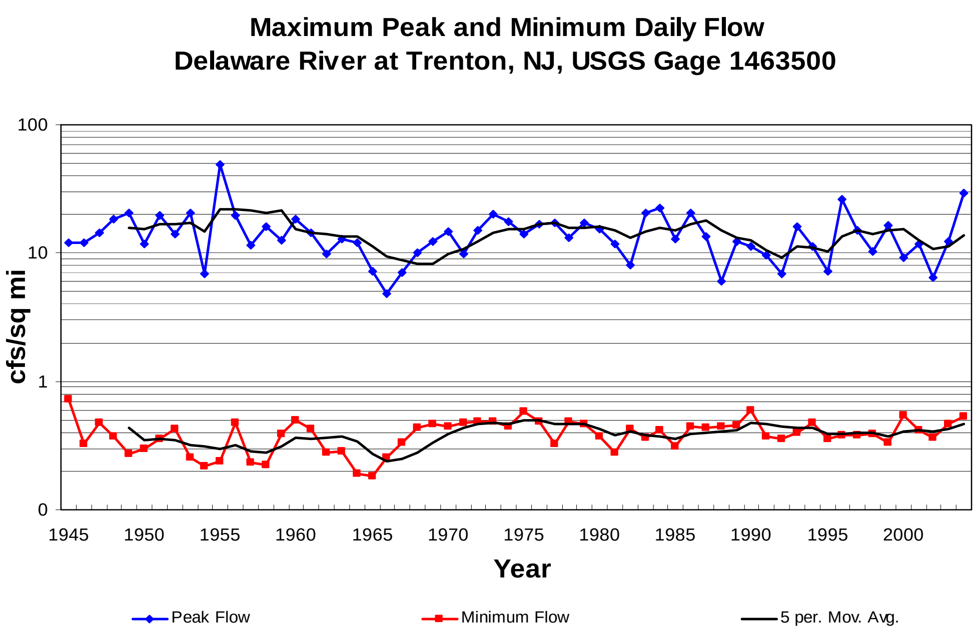


Figure 7.12. Precipitation and stream flow along the Delaware River at Trenton, N. J.

Delaware River at Trenton

Figure 7.13 depicts theDelaware River at Trenton, New Jersey stream flow hydrograph from 1920 through 2005 to examine if flow volumes are changing over time particularly during the spring snow melt freshet or the late summer low flow period. Figure 7.14 plots cumulative runoff along the Delaware River at Trenton beginning in 1920. Figures 7.15, and 7.16 include the total volume of runoff (cubic feet) for two week periods totaled every 20 years, and 40 years.

Based on the stream flow record from 1912 through 2005, major Delaware River floods occurred on:

Date	Name	Peak Flow
Mar 19, 1936	St. Patrick's Day Flood	214,000 cfs
Aug 20, 1955	Hurricane Diane	279,000 cfs
Sep 19, 2004	Tropical Storm Ivan	181,000 cfs
Apr 4, 2005	The Spring Flood	230,000 cfs
Jun 28, 2006		

Extended low flow periods or droughts occurred during the 1930s, 1960s, early 1980s, 1995, 1999, and 2002.

The straight line nature of the cumulative runoff graph indicates that the flow trend remained mostly unchanged since 1920 except for an increase in runoff volume during the 1950's (slope of curve increases), a decrease in runoff volume during the drought of the 1960's (slope of line decreases), and an increase in runoff volume during the 1970s. Since the 1970's the cumulative runoff volume curve is essentially a straight line indicating little change in runoff volume since that time.

The 20-year period hydrograph of stream flow volume indicates during 1921 - 1940 and 1941 – 1960, runoff volume increases during late February peaking in early April. There are little changes in runoff during the spring during the years 1961 - 1980 and 1981 – 2000. Spring peak runoff over the last 40 years is lower than the pre 1960s decades during late March and early April indicating less snowmelt. Perhaps there was less snow pack during the late winter?

The 40-year period hydrograph of stream flow volume indicates compared to the 40 year period from 1921 – 1960, there is more runoff volume during 1961 – 2000 in January and February, less runoff during the March and April spring freshet, and less runoff during August and September when the lowest flows of the year usually occur. The last 40 years includes the drought of the early 1960s so this extreme 6 year dry period may lower the stream flow volume compared to 1921 – 1960. During the last 40 years as compared to 1921 - 1960, there appears to be less runoff flowing down the Delaware River at Trenton during the critical spring March - April and late summer August – September periods. However, the total volume of runoff flowing down has been consistent lately during the 1980s and 1990s at around 40,000,000 cf every decade.

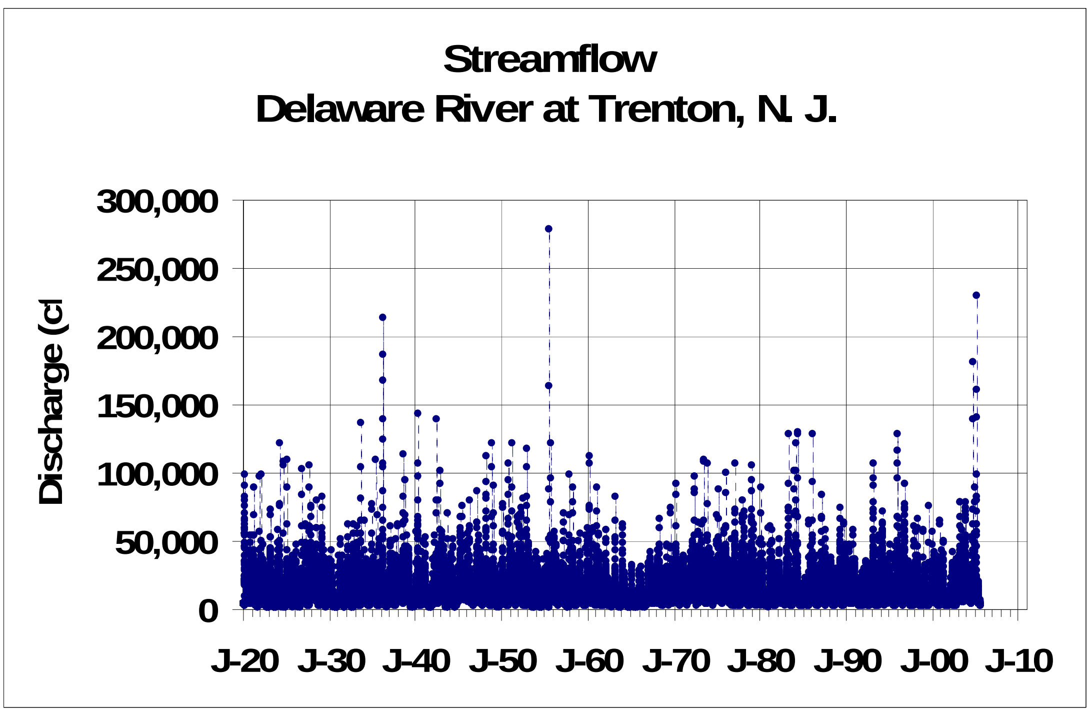


Figure 7.13. Streamflow hydrograph at USGS Gage Delaware River at Trenton, N. J.

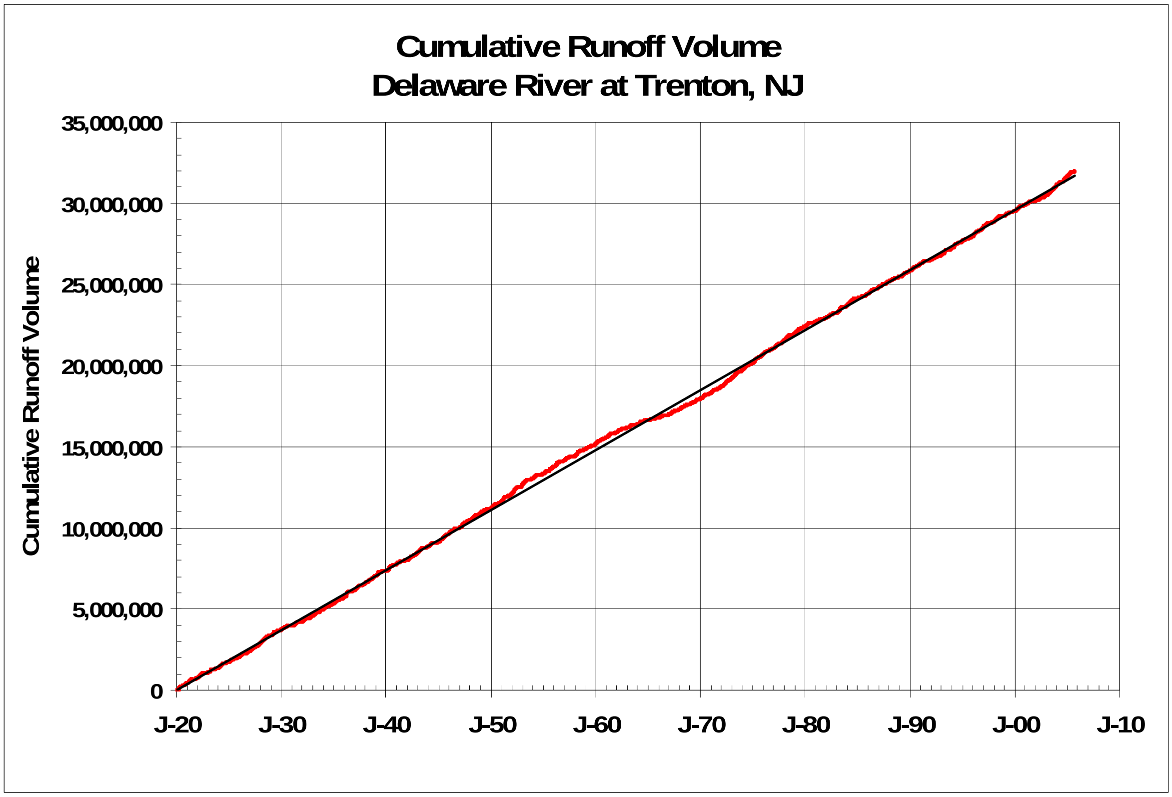


Figure 7.14. Cumulative runoff volume along the USGS Gage Delaware River at Trenton, N. J.

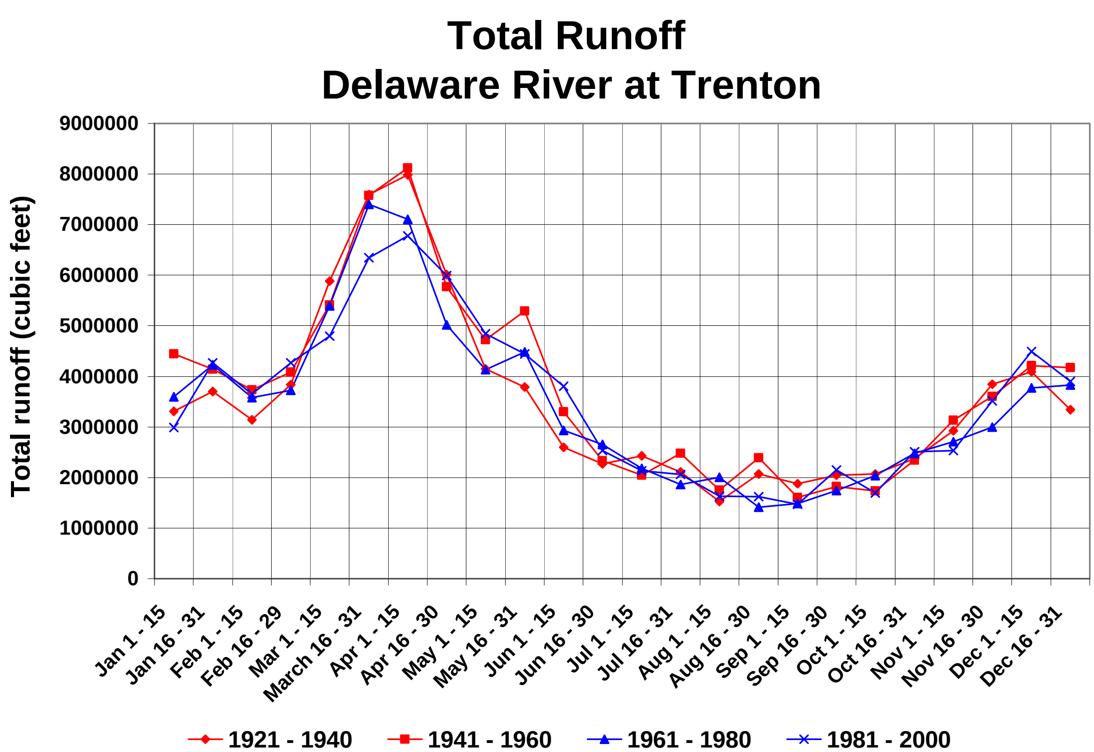


Figure 7.15. Total runoff along the Delaware River at Trenton every 20 years.

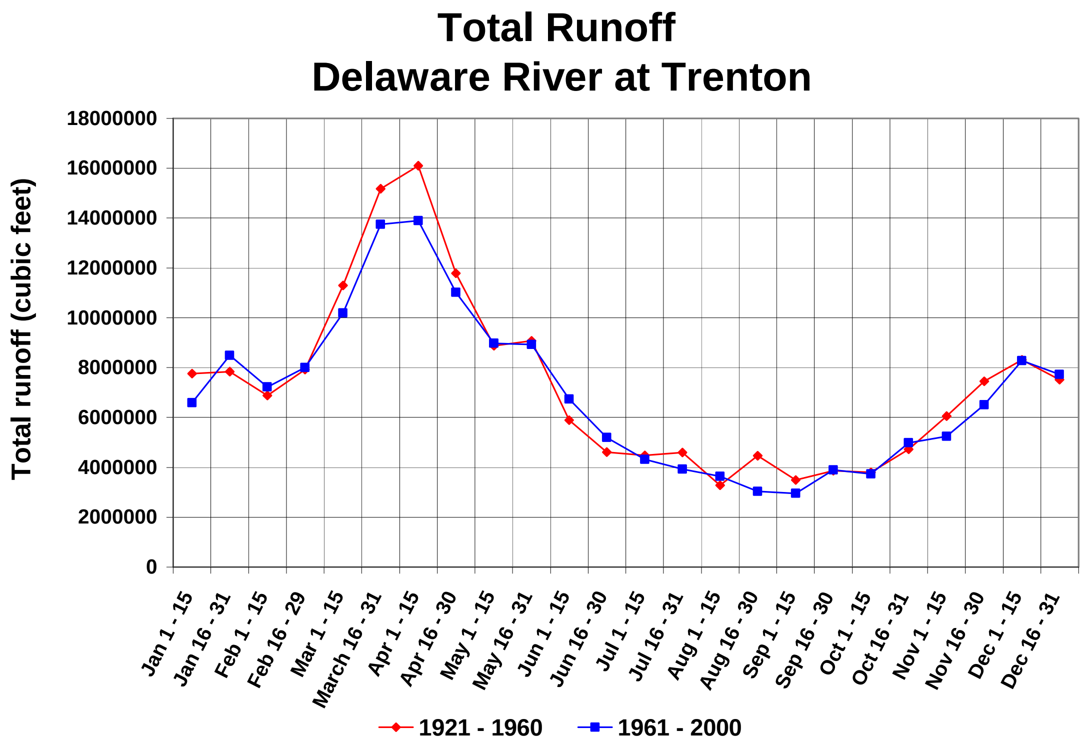


Figure 7.16. Total runoff along the Delaware River at Trenton every 40 years.

Delaware River Tributaries

Annual precipitation and stream flow (annual mean flow, maximum peak flow, and minimum daily low flow) and were plotted at 21 USGS stream gages in the subwatersheds of the Delaware River Basin (Table 7.2).

Median annual precipitation between 2001 and 2005 ranged from 36 to 57 in at the gages in the subwatersheds of the Delaware Basin. Since 1990, precipitation remained constant at 15 gages and at 4 gages.

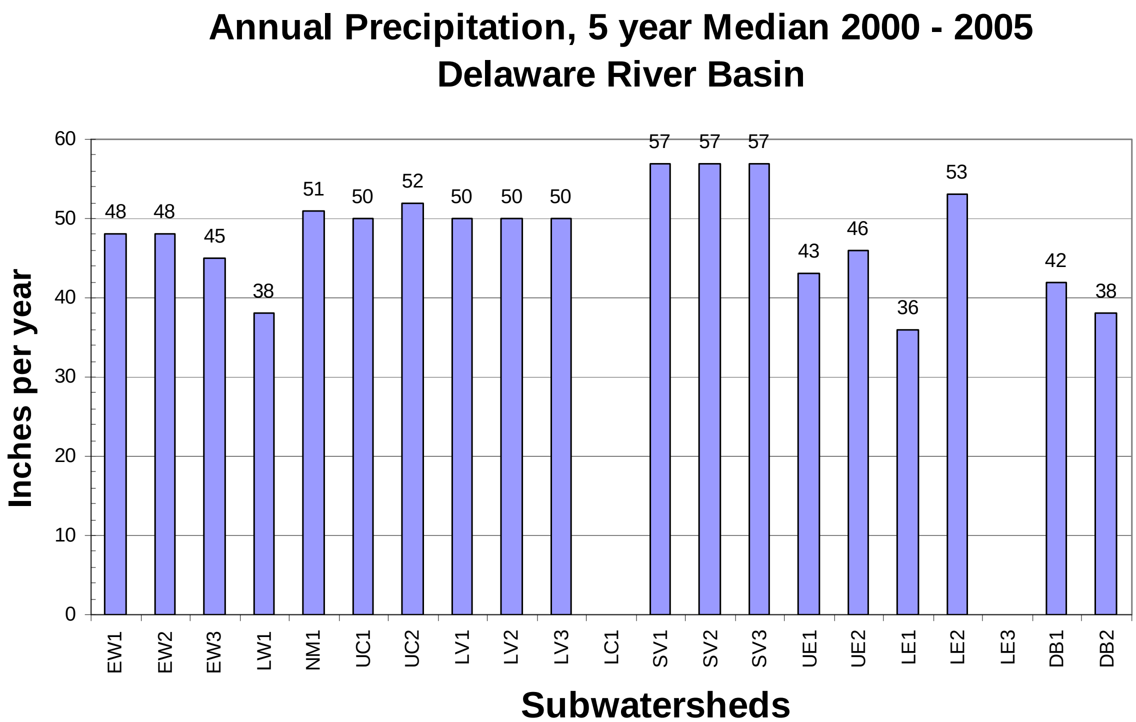
Median annual flow or runoff between 2001 and 2005 ranged from 17 to 35 inches at the subwatersheds of the Delaware Basin. Since 1990, mean annual flow has remained constant at 14 gages and increased at 4 gages.

Maximum peak flow between 2001 and 2005 ranged from 5 to 58 $ft^3/s/mi^2$ at the gages in the subwatersheds of the Delaware Basin. Since 1990, peak flow trends have remained constant at 10 gages, increased at 8 gages, and decreased at 2 gages

Minimum daily flows between 2001 ranged from 0.06 to 0.49 $ft^3/s/mi^2$ at the gages in the subwatersheds of the Delaware Basin. Since 1990, minimum flows have remained constant at 13 gages, increased at 4 gages, and decreased at 3 gages.

Table 7.2. Precipitation and streamflow trends in Delaware Basin subwatersheds since 1990.

Subwatershed	Annual Precipitation (in/yr)	Mean Annual Flow (in/yr)	Maximum Peak Flow ($ft^3/s/mi^2$)	Minimum Daily Flow ($ft^3/s/mi^2$)
NY				
EW1 West Branch Delaware River at Hale Eddy, NY USGS Gage 01426500	48 ↑	23 ↑	17 ↑	0.30 ↑
EW2 East Branch Delaware River at Fishs Eddy, NY USGS Gage 01421000	48 ↑	25 ↑	19 ↑	0.28 ↑
EW3 Delaware River at Port Jervis,NY USGS Gage 01434000	45 →	29↑	19 →	0.37 →
NM1 Neversink R. at Godeffroy, NY USGS Gage 01437500	51 ↑	23 →	15 ↑	0.48 →
PA				
LW1 Lackawaxen R. at Hawley, PA USGS Stream Gage 01431500	38 →	32 →	26 →	0.09 →
UC1 Brodhead Cr. Minisink Hills, PA USGS Gage 01442500	50 →	34 →	46 →	0.27 →
LV1 Lehigh R. near White Haven, PA USGS Gage 01447800	50 →	35 →	26 →	0.25 →
LV2 Aquashicola Cr at Palmerton, PA USGS Gage 01450500	50 →	32 →	58 ↓	0.26 ↓
LV3 Lehigh River near Glendon, PA USGS Gage 01454700	50 →	34 →	21 →	0.47 →
SV1 Schuylkill River at Berne, PA USGS Gage 01470500	57 →	32 →	36 →	0.33 →
SV2 Schuylkill River at Reading, PA USGS Gage 01471510	57 →	29 →	22 →	0.35 →
SV3 Schuylkill River at Pottstown, PA USGS Gage 01472000	52 →	29 →	20 →	0.32 →
LC1	No data	No data	No data	No data
UE1 Schuylkill R at Philadelphia, PA USGS Gage 01474500	43 →	27 →	28 ↑	0.22 →
NJ				
UC2 Paulins Kill at Blairstown, NJ USGS Gage 01443500	52 →	27 →	20 ↑	0.14 →
LC1	Limited Data	Limited Data	Limited Data	Limited Data
UE2 Crosswicks Cr at Extonville, NJ USGS Gage 01464500	46 →	20	19 →	0.23 ↓
LE3 Salem River at Woodstown, NJ USGS Gage 01482500	Limited Data	Limited Data	32 →	0.09 →
DB2 Maurice River at Norma, NJ USGS Gage 01482500	38 →	19 →	5 ↓	0.38 ↓
DE				
LE1 Brandywine R.at Wilmington, DE USGS Gage 01481500	36 →	28 →	29 ↑	0.30 →
LE2 Silver Lake Trib Middletown, DE, USGS Gage 01483155	53 →	23 →	28 ↑	0.49 ↑
DB1 St. Jones River at Dover, DE USGS Gage 01483700	42 ↑	17 ↑	17 ↑	0.06 ↑



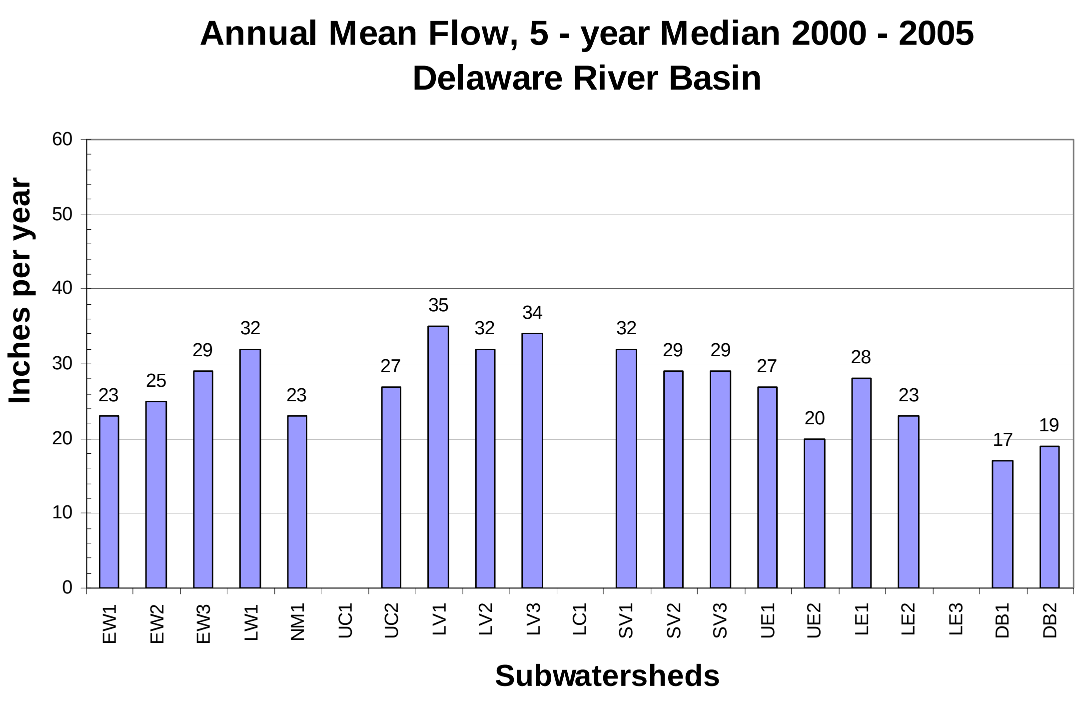
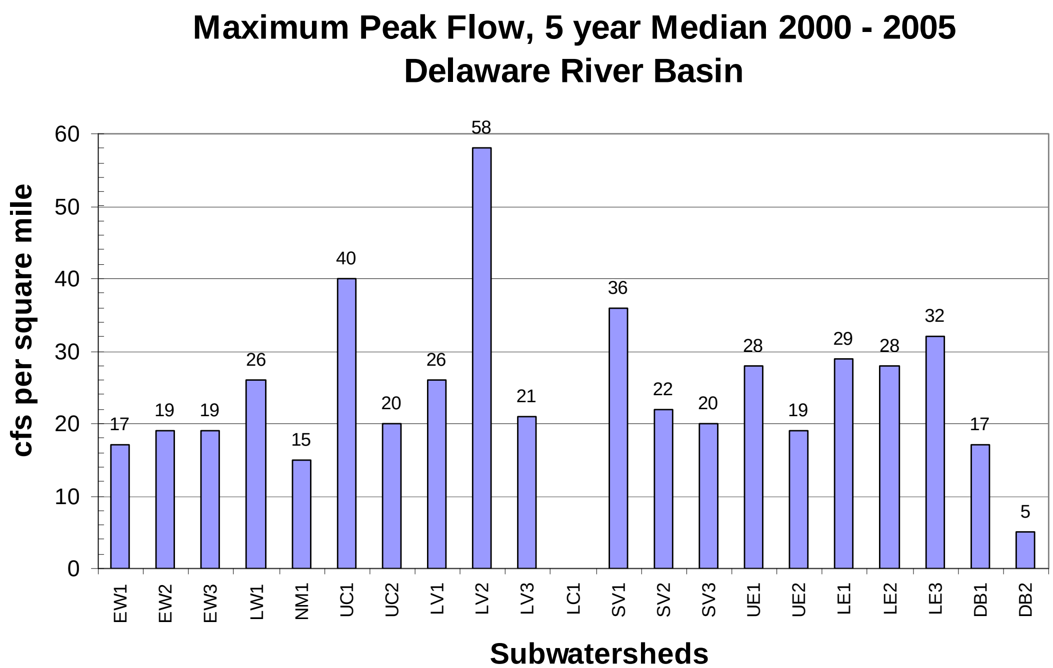


Figure 7.17. Annual precipitation and mean annual flow for Delaware River Basin subwatersheds.



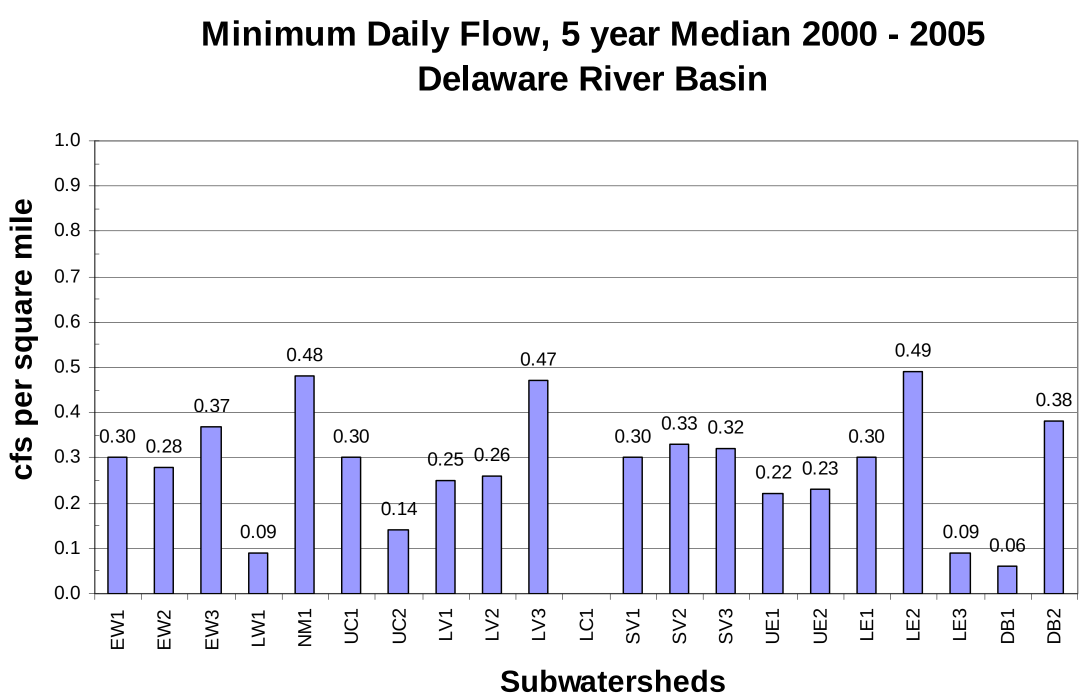
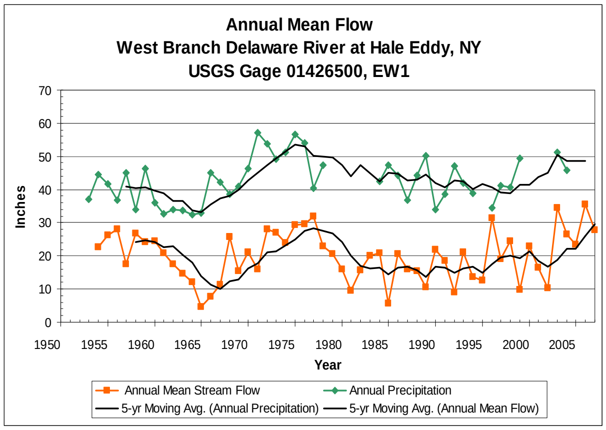
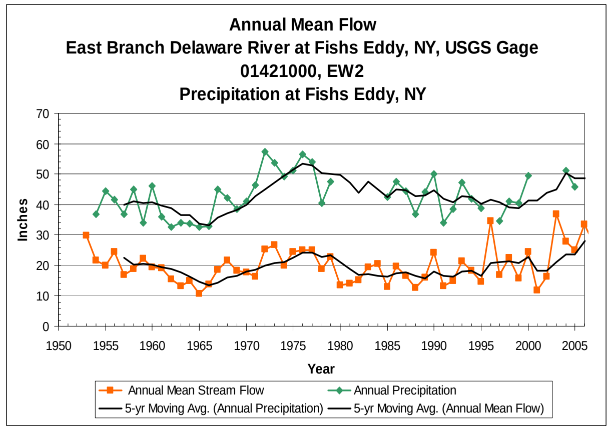
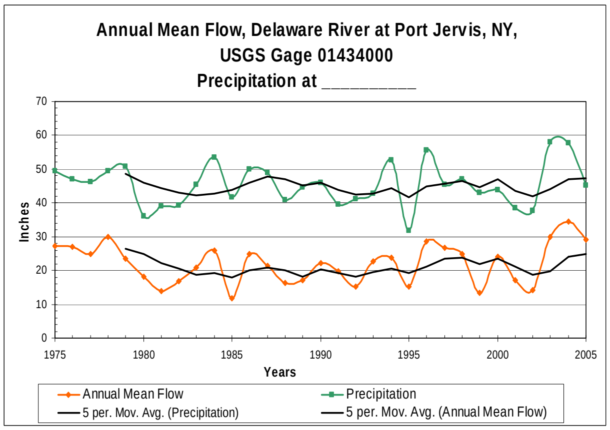
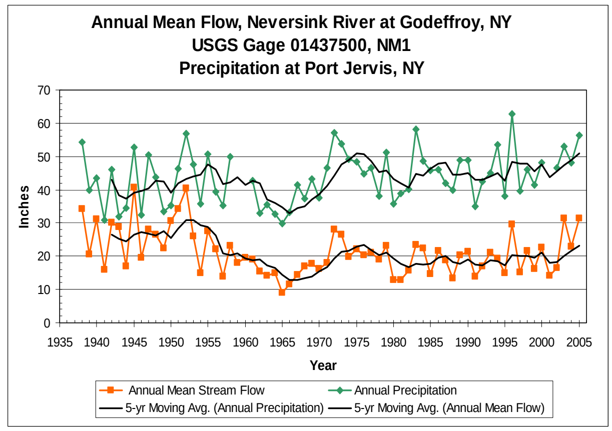


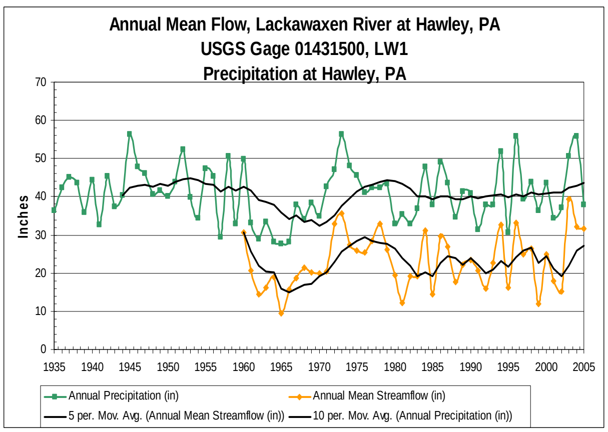
Figure 7.18. Annual peak and minimum daily low flow along Delaware River Basin subwatersheds.

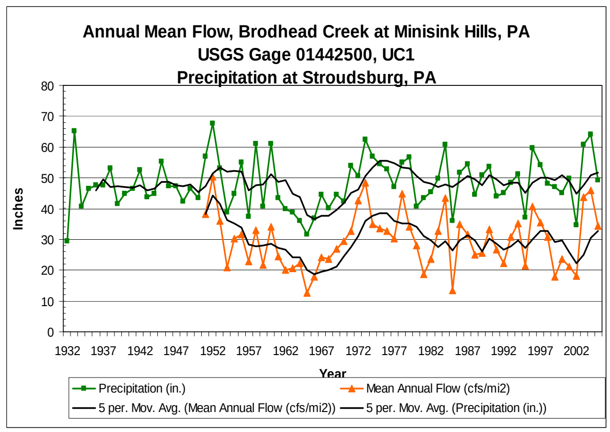

Annual Mean Flow
West Branch Delaware River at Hale Eddy, NY
USGS Gage 01426500, EW1
Inches
Year
Annual Mean Stream Flow
Annual Precipitation
5-yr Moving Avg. (Annual Precipitation)
5-yr Moving Avg. (Annual Mean Flow)

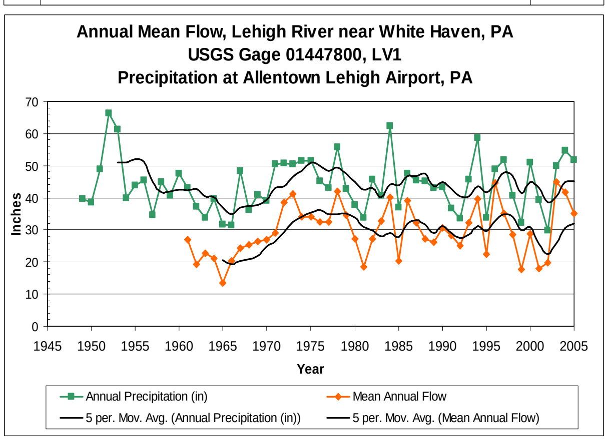

Annual Mean Flow
East Branch Delaware River at Fishs Eddy, NY, USGS Gage 01421000, EW2
Precipitation at Fishs Eddy, NY
Inches
Year
Annual Mean Stream Flow
Annual Precipitation
5-yr Moving Avg. (Annual Precipitation)
5-yr Moving Avg. (Annual Mean Flow)

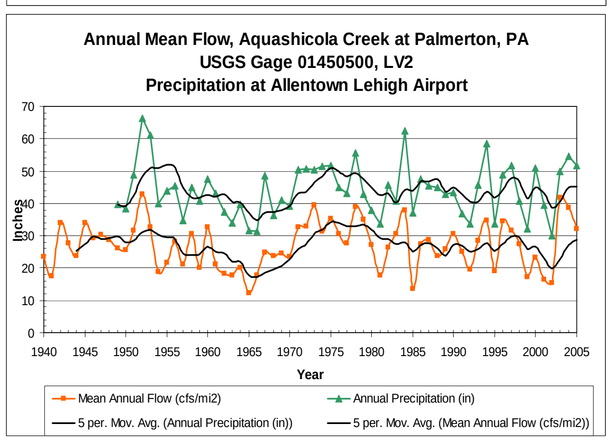

Annual Mean Flow, Delaware River at Port Jervis, NY,
USGS Gage 01434000
Precipitation at __________
Inches
Years
Annual Mean Flow
Precipitation
5 per. Mov. Avg. (Precipitation)
5 per. Mov. Avg. (Annual Mean Flow)

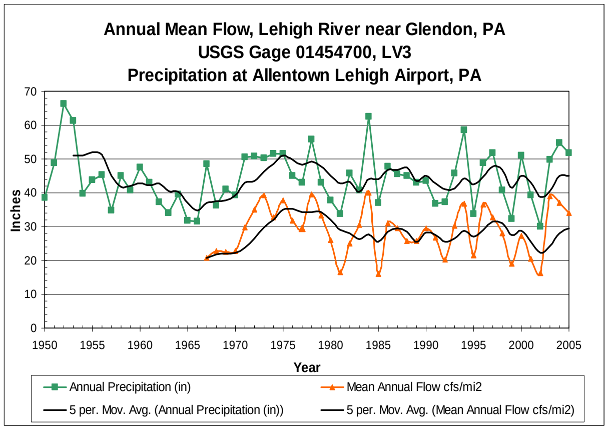

Annual Mean Flow, Neversink River at Godeffroy, NY
USGS Gage 01437500, NM1
Precipitation at Port Jervis, NY
Inches
Year
Annual Mean Stream Flow
Annual Precipitation
5-yr Moving Avg. (Annual Precipitation)
5-yr Moving Avg. (Annual Mean Flow)

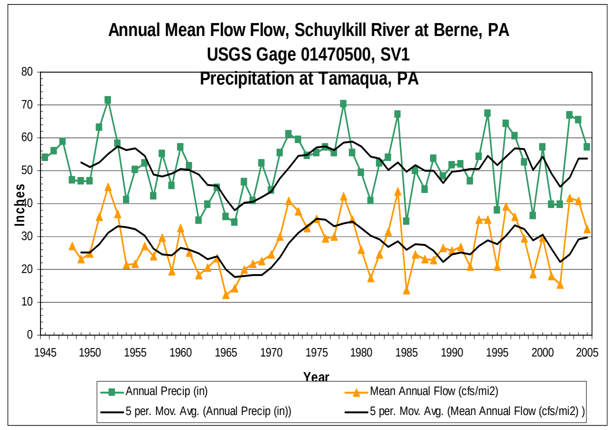

Annual Mean Flow, Lackawaxen River at Hawley, PA
USGS Gage 01431500, LW1
Precipitation at Hawley, PA
Inches
Annual Precipitation (in)
Annual Mean Streamflow (in)
5 per. Mov. Avg. (Annual Mean Streamflow (in))
10 per. Mov. Avg. (Annual Precipitation (in))

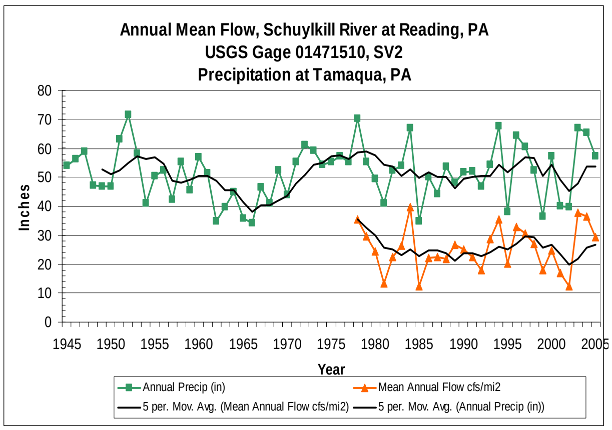

Annual Mean Flow, Brodhead Creek at Minisink Hills, PA
USGS Gage 01442500, UC1
Precipitation at Stroudsburg, PA
Inches
Year
Precipitation (in.)
Mean Annual Flow (cfs/mi2)
5 per. Mov. Avg. (Mean Annual Flow (cfs/mi2))
5 per. Mov. Avg. (Precipitation (in.))

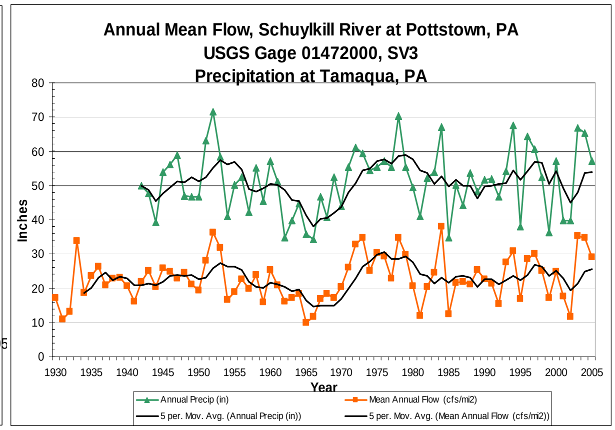

Annual Mean Flow, Lehigh River near White Haven, PA
USGS Gage 01447800, LV1
Precipitation at Allentown Lehigh Airport, PA
Inches
Year
Annual Precipitation (in)
Mean Annual Flow
5 per. Mov. Avg. (Annual Precipitation (in))
5 per. Mov. Avg. (Mean Annual Flow)

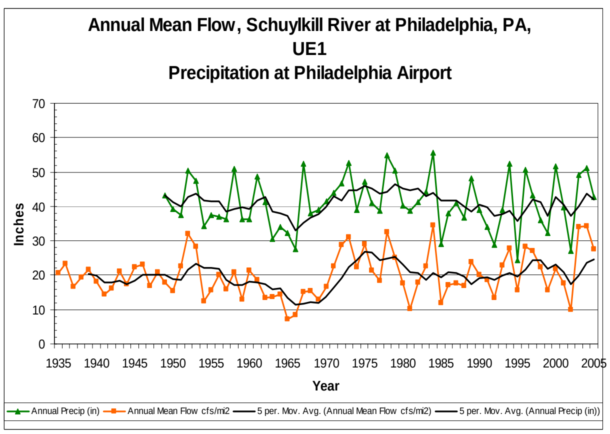

Annual Mean Flow, Aquashicola Creek at Palmerton, PA
USGS Gage 01450500, LV2
Precipitation at Allentown Lehigh Airport
Inches
Year
Mean Annual Flow (cfs/mi2)
Annual Precipitation (in)
5 per. Mov. Avg. (Annual Precipitation (in))
5 per. Mov. Avg. (Mean Annual Flow (cfs/mi2))

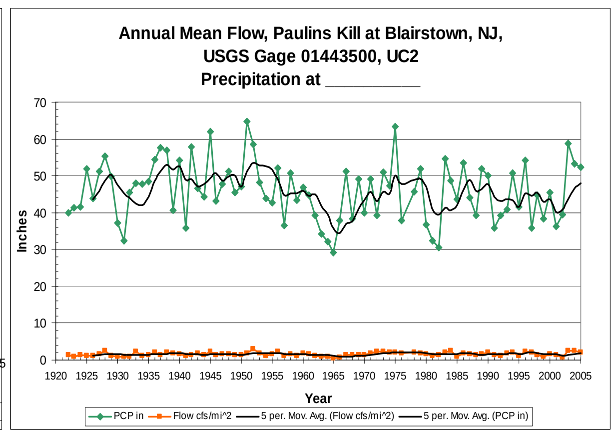

Annual Mean Flow, Lehigh River near Glendon, PA
USGS Gage 01454700, LV3
Precipitation at Allentown Lehigh Airport, PA
Inches
Year
Annual Precipitation (in)
Mean Annual Flow cfs/mi2
5 per. Mov. Avg. (Annual Precipitation (in))
5 per. Mov. Avg. (Mean Annual Flow cfs/mi2)

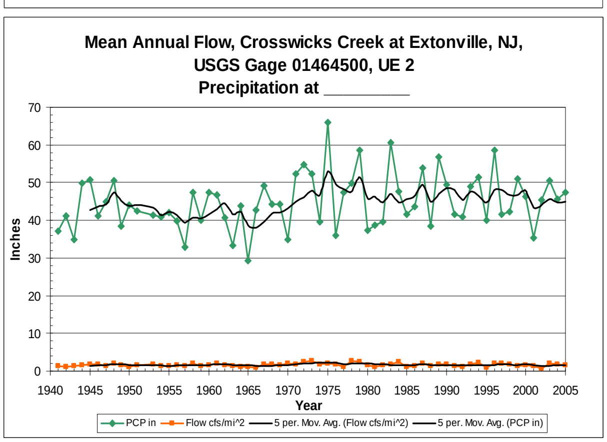

Annual Mean Flow Flow, Schuylkill River at Berne, PA
USGS Gage 01470500, SV1
Precipitation at Tamaqua, PA
Inches
Year
Annual Precip (in)
Mean Annual Flow (cfs/mi2)
5 per. Mov. Avg. (Annual Precip (in))
5 per. Mov. Avg. (Mean Annual Flow (cfs/mi2))

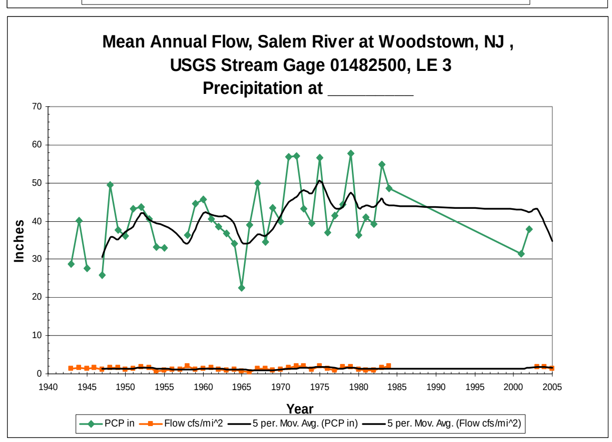

Annual Mean Flow, Schuylkill River at Reading, PA
USGS Gage 01471510, SV2
Precipitation at Tamaqua, PA
Inches
Year
Annual Precip (in)
Mean Annual Flow cfs/mi2
5 per. Mov. Avg. (Mean Annual Flow cfs/mi2)
5 per. Mov. Avg. (Annual Precip (in))


Annual Mean Flow, Schuylkill River at Pottstown, PA
USGS Gage 01472000, SV3
Precipitation at Tamaqua, PA
Inches
Year
Annual Precip (in)
Mean Annual Flow (cfs/mi2)
5 per. Mov. Avg. (Annual Precip (in))
5 per. Mov. Avg. (Mean Annual Flow (cfs/mi2))


Annual Mean Flow, Schuylkill River at Philadelphia, PA, UE1
Precipitation at Philadelphia Airport
Inches
Year
Annual Precip (in)
Annual Mean Flow cfs/mi2
5 per. Mov. Avg. (Annual Mean Flow cfs/mi2)
5 per. Mov. Avg. (Annual Precip (in))


Annual Mean Flow, Paulins Kill at Blairstown, NJ,
USGS Gage 01443500, UC2
Precipitation at __________
Inches
Year
PCP in
Flow cfs/mi^2
5 per. Mov. Avg. (Flow cfs/mi^2)
5 per. Mov. Avg. (PCP in)


Mean Annual Flow, Crosswicks Creek at Extonville, NJ,
USGS Gage 01464500, UE 2
Precipitation at _________
Inches
Year
PCP in
Flow cfs/mi^2
5 per. Mov. Avg. (Flow cfs/mi^2)
5 per. Mov. Avg. (PCP in)


Mean Annual Flow, Salem River at Woodstown, NJ ,
USGS Stream Gage 01482500, LE 3
Precipitation at _________
Inches
Year
PCP in
Flow cfs/mi^2
5 per. Mov. Avg. (PCP in)
5 per. Mov. Avg. (Flow cfs/mi^2)

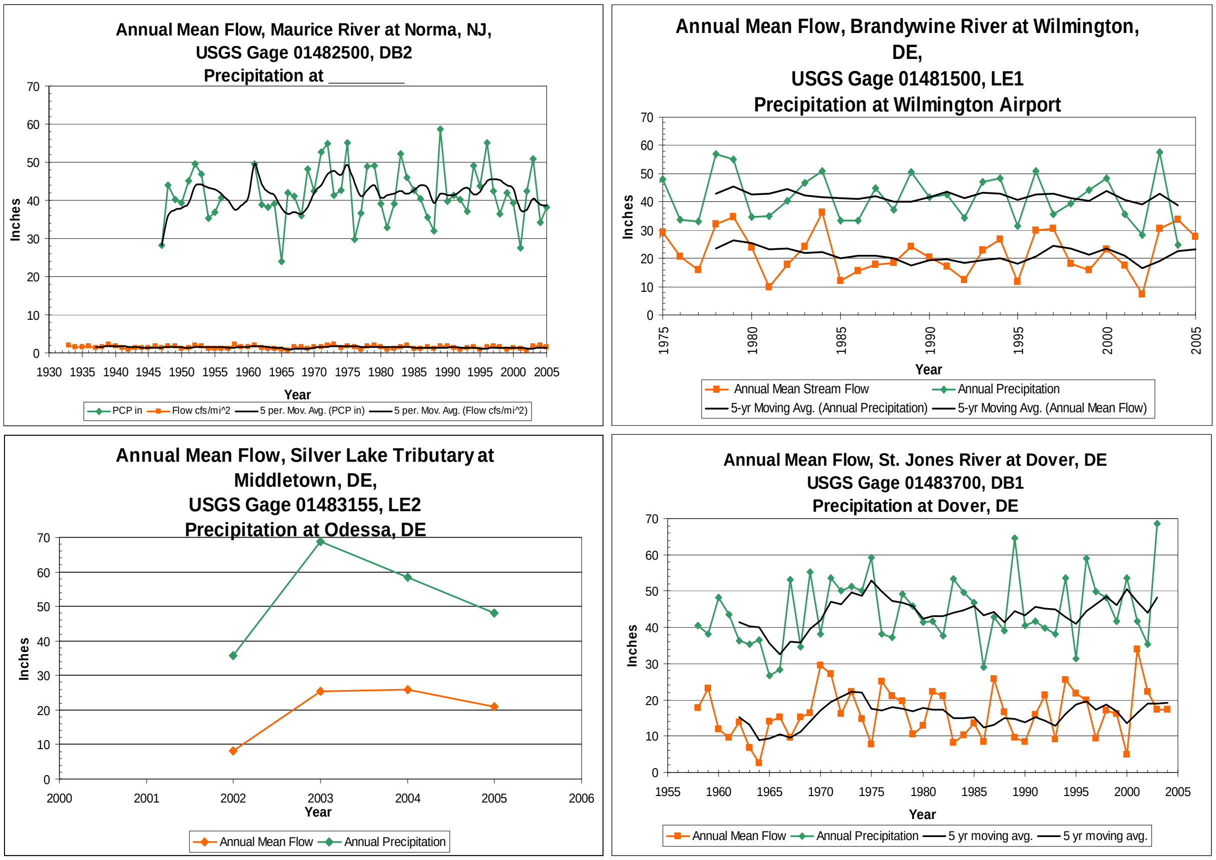
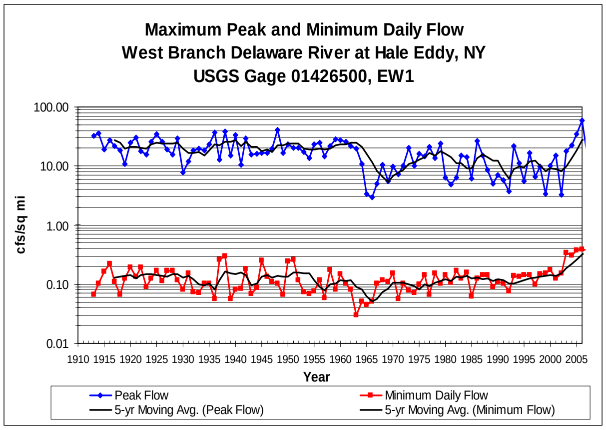
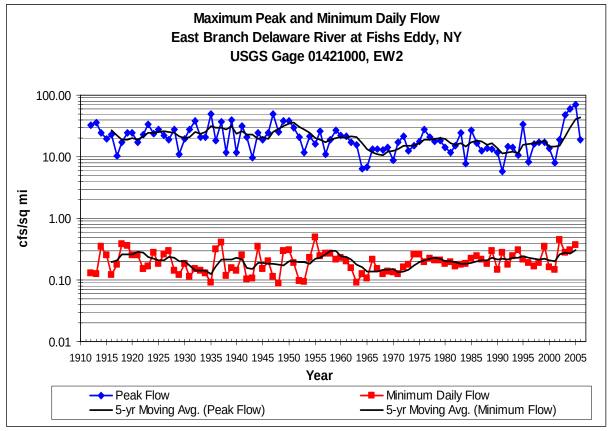
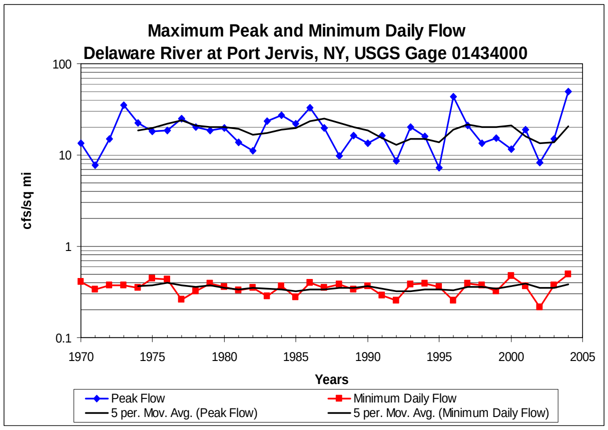
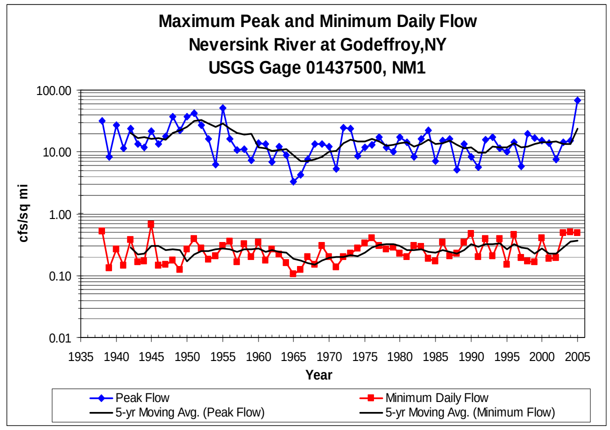


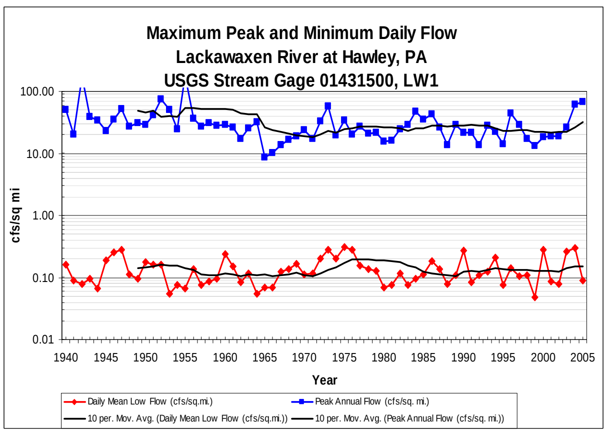
Figure 7.19. Precipitation and annual mean flow in Delaware River Basin subwatersheds.

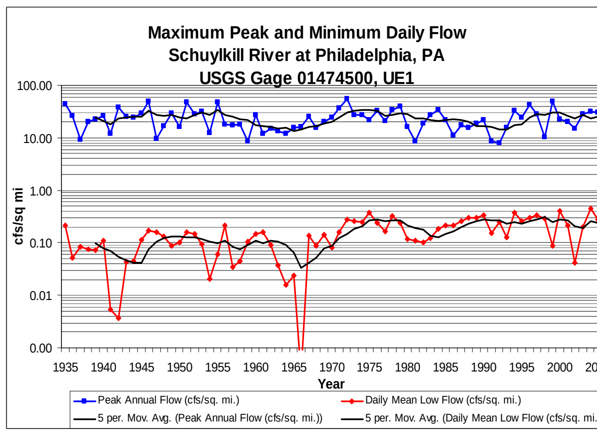

Maximum Peak and Minimum Daily Flow
West Branch Delaware River at Hale Eddy, NY
USGS Gage 01426500, EW1
cfs/sq mi
Year
Peak Flow
Minimum Daily Flow
5-yr Moving Avg. (Peak Flow)
5-yr Moving Avg. (Minimum Flow)

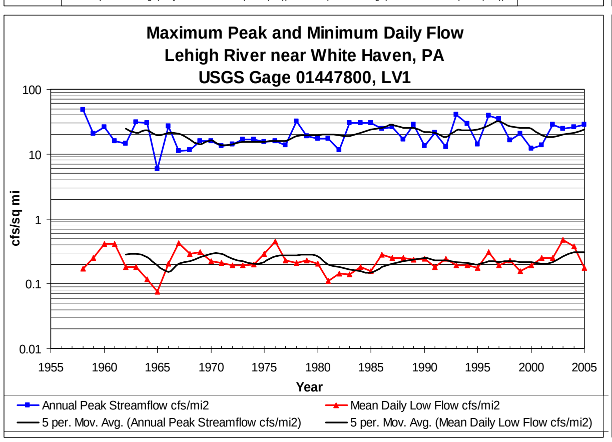

Maximum Peak and Minimum Daily Flow
East Branch Delaware River at Fishs Eddy, NY
USGS Gage 01421000, EW2
cfs/sq mi
Year
Peak Flow
Minimum Daily Flow
5-yr Moving Avg. (Peak Flow)
5-yr Moving Avg. (Minimum Flow)

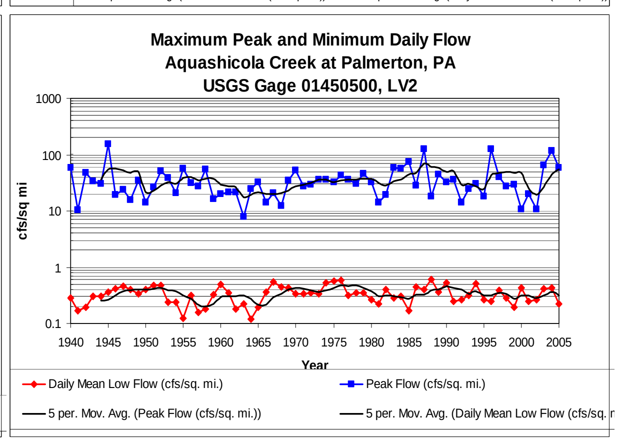

Maximum Peak and Minimum Daily Flow
Delaware River at Port Jervis, NY, USGS Gage 01434000
cfs/sq mi
Years
Peak Flow
Minimum Daily Flow
5 per. Mov. Avg. (Peak Flow)
5 per. Mov. Avg. (Minimum Daily Flow)

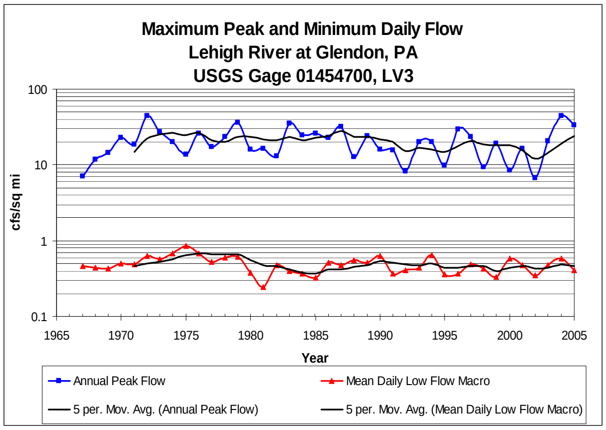

Maximum Peak and Minimum Daily Flow
Neversink River at Godeffroy,NY
USGS Gage 01437500, NM1
cfs/sq mi
Year
Peak Flow
Minimum Daily Flow
5-yr Moving Avg. (Peak Flow)
5-yr Moving Avg. (Minimum Flow)

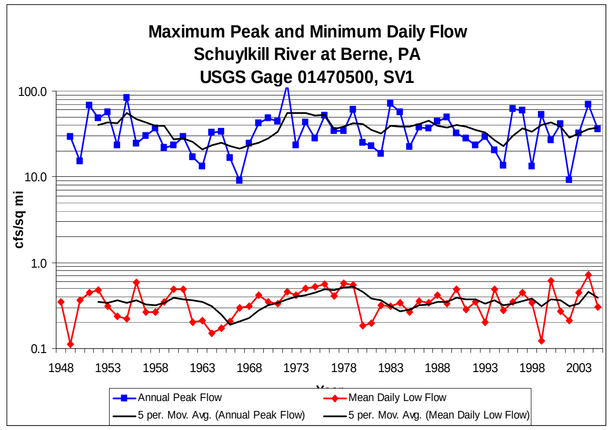

Maximum Peak and Minimum Daily Flow
Lackawaxen River at Hawley, PA
USGS Stream Gage 01431500, LW1
cfs/sq mi
Year
Daily Mean Low Flow (cfs/sq.mi.)
Peak Annual Flow (cfs/sq. mi.)
10 per. Mov. Avg. (Daily Mean Low Flow (cfs/sq.mi.))
10 per. Mov. Avg. (Peak Annual Flow (cfs/sq. mi.))

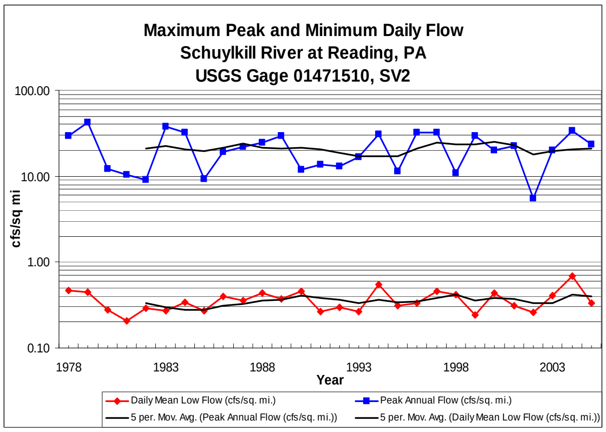

Maximum Peak and Minimum Daily Flow
Schuylkill River at Philadelphia, PA
USGS Gage 01474500, UE1
cfs/sq mi
Year
Peak Annual Flow (cfs/sq. mi.)
Daily Mean Low Flow (cfs/sq. mi.)
5 per. Mov. Avg. (Peak Annual Flow (cfs/sq. mi.))
5 per. Mov. Avg. (Daily Mean Low Flow (cfs/sq. mi.))

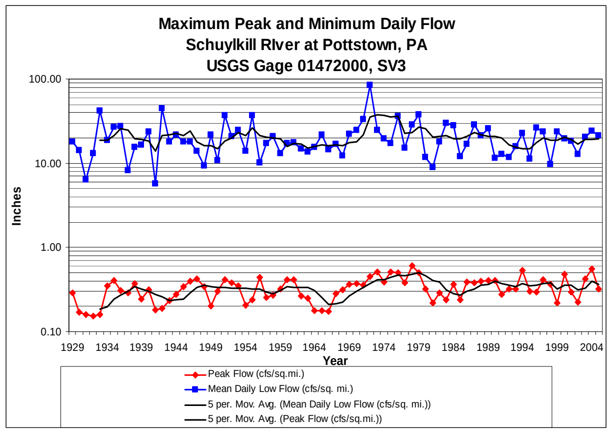

Maximum Peak and Minimum Daily Flow
Lehigh River near White Haven, PA
USGS Gage 01447800, LV1
cfs/sq mi
Year
Annual Peak Streamflow cfs/mi2
Mean Daily Low Flow cfs/mi2
5 per. Mov. Avg. (Annual Peak Streamflow cfs/mi2)
5 per. Mov. Avg. (Mean Daily Low Flow cfs/mi2)

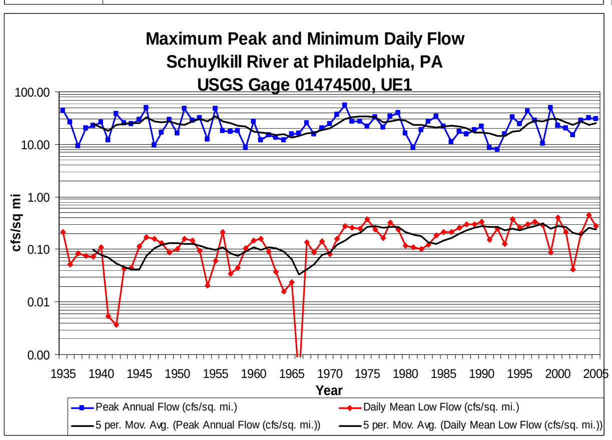

Maximum Peak and Minimum Daily Flow
Aquashicola Creek at Palmerton, PA
USGS Gage 01450500, LV2
cfs/sq mi
Year
Daily Mean Low Flow (cfs/sq. mi.)
Peak Flow (cfs/sq. mi.)
5 per. Mov. Avg. (Peak Flow (cfs/sq. mi.))

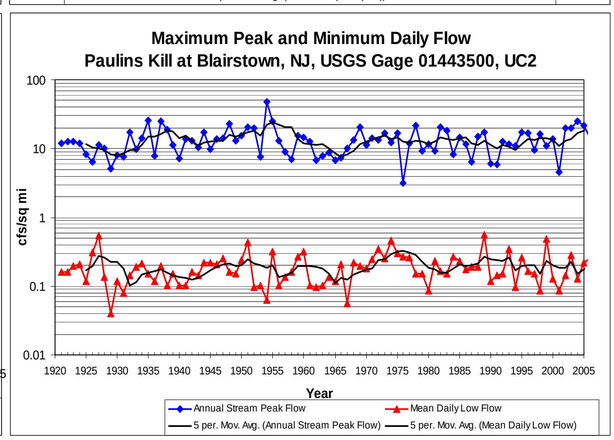

Maximum Peak and Minimum Daily Flow
Lehigh River at Glendon, PA
USGS Gage 01454700, LV3
cfs/sq mi
Year
Annual Peak Flow
Mean Daily Low Flow Macro
5 per. Mov. Avg. (Annual Peak Flow)
5 per. Mov. Avg. (Mean Daily Low Flow Macro)

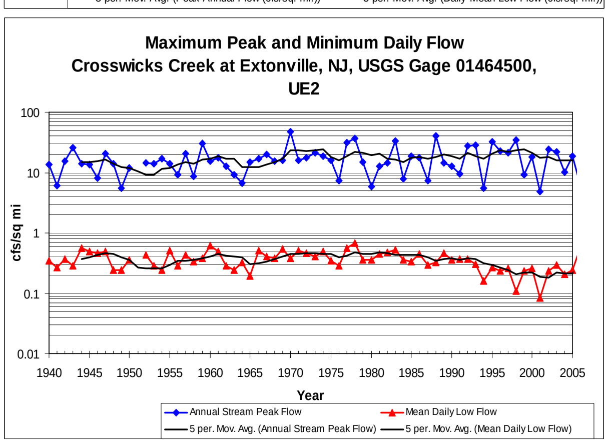

Maximum Peak and Minimum Daily Flow
Schuylkill River at Berne, PA
USGS Gage 01470500, SV1
cfs/sq mi
Annual Peak Flow
Mean Daily Low Flow
5 per. Mov. Avg. (Annual Peak Flow)
5 per. Mov. Avg. (Mean Daily Low Flow)

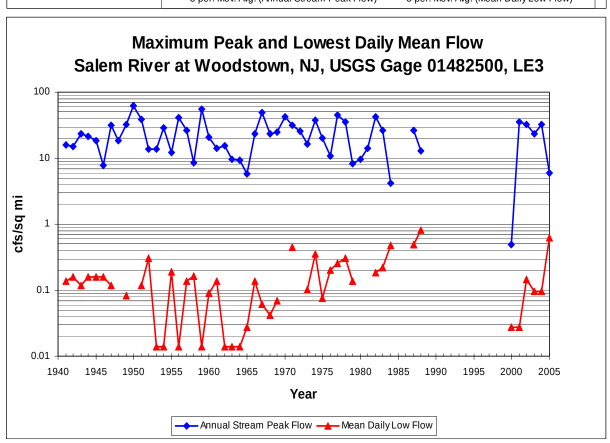

Maximum Peak and Minimum Daily Flow
Schuylkill River at Reading, PA
USGS Gage 01471510, SV2
cfs/sq mi
Year
Daily Mean Low Flow (cfs/sq. mi.)
Peak Annual Flow (cfs/sq. mi.)
5 per. Mov. Avg. (Peak Annual Flow (cfs/sq. mi.))
5 per. Mov. Avg. (Daily Mean Low Flow (cfs/sq. mi.))


Maximum Peak and Minimum Daily Flow
Schuylkill RIver at Pottstown, PA
USGS Gage 01472000, SV3
Inches
Year
Peak Flow (cfs/sq.mi.)
Mean Daily Low Flow (cfs/sq. mi.)
5 per. Mov. Avg. (Mean Daily Low Flow (cfs/sq. mi.))
5 per. Mov. Avg. (Peak Flow (cfs/sq.mi.))


Maximum Peak and Minimum Daily Flow
Schuylkill River at Philadelphia, PA
USGS Gage 01474500, UE1
cfs/sq mi
Year
Peak Annual Flow (cfs/sq. mi.)
Daily Mean Low Flow (cfs/sq. mi.)
5 per. Mov. Avg. (Peak Annual Flow (cfs/sq. mi.))
5 per. Mov. Avg. (Daily Mean Low Flow (cfs/sq. mi.))


Maximum Peak and Minimum Daily Flow
Paulins Kill at Blairstown, NJ, USGS Gage 01443500, UC2
cfs/sq mi
Year
Annual Stream Peak Flow
Mean Daily Low Flow
5 per. Mov. Avg. (Annual Stream Peak Flow)
5 per. Mov. Avg. (Mean Daily Low Flow)


Maximum Peak and Minimum Daily Flow
Crosswicks Creek at Extonville, NJ, USGS Gage 01464500,
UE2
cfs/sq mi
Year
Annual Stream Peak Flow
Mean Daily Low Flow
5 per. Mov. Avg. (Annual Stream Peak Flow)
5 per. Mov. Avg. (Mean Daily Low Flow)


Maximum Peak and Lowest Daily Mean Flow
Salem River at Woodstown, NJ, USGS Gage 01482500, LE3
cfs/sq mi
Year
Annual Stream Peak Flow
Mean Daily Low Flow

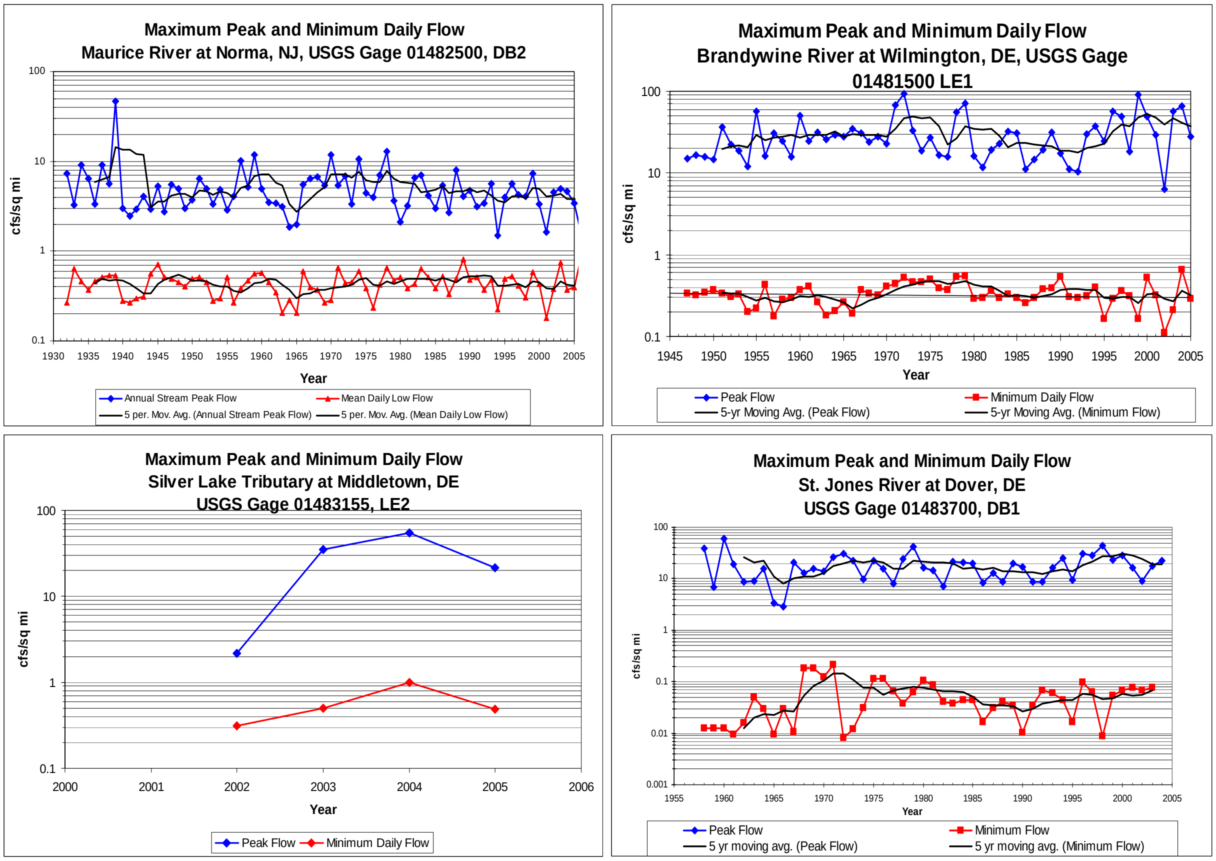


Figure 7.20. Maximum peak and minimum daily flow in Delaware River Basin subwatersheds.

7.3. Groundwater Quantity

The United States Geological Survey quantified groundwater availability and withdrawals for watersheds in the Delaware Basin as described in the following report abstract and in Table 7.3 (Sloto and Buxton 2006).

Ground-water availability using a watershed-based approach was estimated for the watersheds that make up the Delaware River Basin. Different procedures were used to estimate ground-water availability for the region underlain by fractured rocks in the upper part of the basin and for surficial aquifers in the region underlain by unconsolidated sediments in the lower part of the basin. For all watersheds, ground-water availability was equated to average annual base flow. Estimated 2-, 5-, 10-, 25-, and 50-year annual base-flow-recurrence interval values for each watershed in the Delaware River Basin are considered to be the quantity of ground water available for each watershed over a range of climatic conditions. The recurrence intervals are considered to be relative indicators of climatic difference; the 2-year-recurrence value represents wetter years, and the 50-year-recurrence value represents drier years. The remaining available ground water in each watershed was determined by subtracting current (1997-2000) ground-water withdrawals and consumptive domestic use and adding water recharged by agricultural irrigation and land application of treated-sewage effluent.

Ground-water use ranged from 0 to 127 percent of available ground water for the 50-year-recurrence interval; it exceeded 25 percent in 11 watersheds, 50 percent in 6 watersheds, and 125 percent in 1 watershed.

Table 7.3. Groundwater availability in the Delaware River Basin. (Sloto and Buxton 2006)

Sub-watershed	Area (mi^2)	Groundwater Availability (mgd/mi^2)	Groundwater Availability (mgd)	Groundwater Withdrawal (mgd/mi^2)	Groundwater Withdrawal (mgd)	Remaining Groundwater (mgd/mi^2)	Remaining Groundwater (mgd)	Available Groundwater Used (%)
EW1	666	0.389	259.6	0.004	2.4	0.386	257.3	0.9%
EW2	841	0.401	337.6	0.002	1.5	0.400	336.1	0.4%
EW3	521	0.402	209.5	0.001	0.6	0.401	208.9	0.3%
LW1	598	0.479	286.5	0.002	1.4	0.477	285.0	0.5%
NM1	853	0.412	351.7	0.005	4.1	0.407	347.6	1.2%
UC1	754	0.427	321.8	0.046	34.8	0.380	287.0	10.8%
UC2	722	0.322	232.9	0.032	23.1	0.290	209.8	9.9%
LV1	363	0.494	179.1	0.010	3.8	0.483	175.3	2.1%
LV2	455	0.485	220.7	0.006	2.5	0.479	218.2	1.2%
LV3	544	0.307	167.0	0.067	36.3	0.241	130.8	21.7%
LC1	466	0.185	86.0	0.019	8.7	0.166	77.4	10.1%
SV1	342	0.480	164.3	0.066	22.5	0.415	141.8	13.7%
SV2	712	0.245	174.5	0.029	20.7	0.216	153.8	11.9%
SV3	856	0.227	194.2	0.044	38.1	0.182	156.1	19.6%
UE1	658	0.258	169.9	0.026	16.8	0.233	153.0	9.9%
UE2	1043	0.432	450.5	0.100	104.6	0.332	345.8	23.2%
LE1	609	0.274	167.0	0.023	13.8	0.251	153.1	8.3%
LE2	155	0.265	41.1	0.081	12.5	0.184	28.6	30.4%
LE3	262	0.430	112.8	0.039	10.1	0.391	102.7	9.0%
DB1	635	0.204	129.3	0.024	15.1	0.180	114.2	11.6%
DB2	790	0.494	390.2	0.064	50.6	0.430	339.6	13.0%
Total	12846	0.362	4645.9	0.033	423.9	0.329	4222.0	9.1%

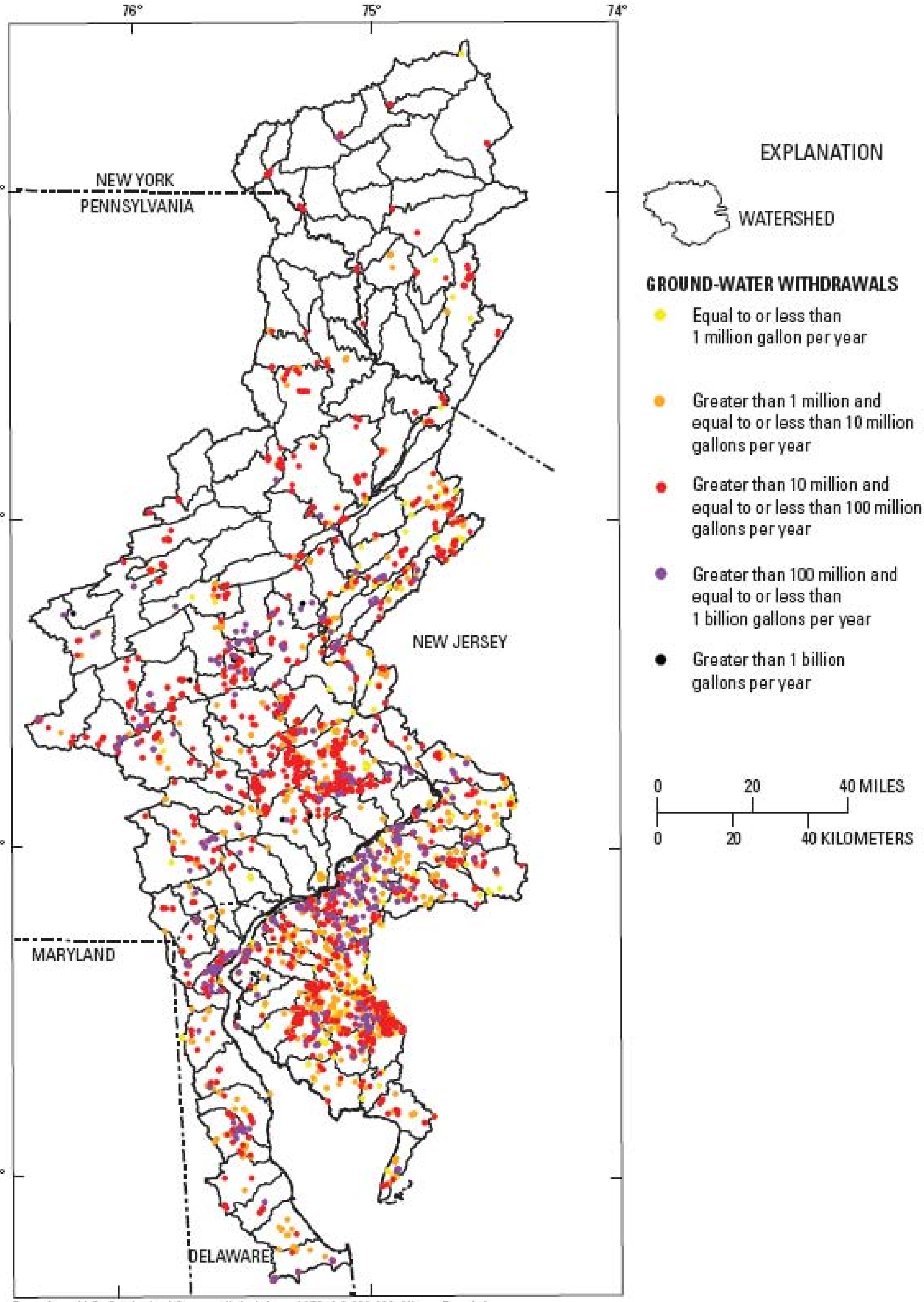


Figure 7.21. Groundwater withdrawals in the Delaware River Basin, 1997-2000. (Sloto and Buxton 2006)

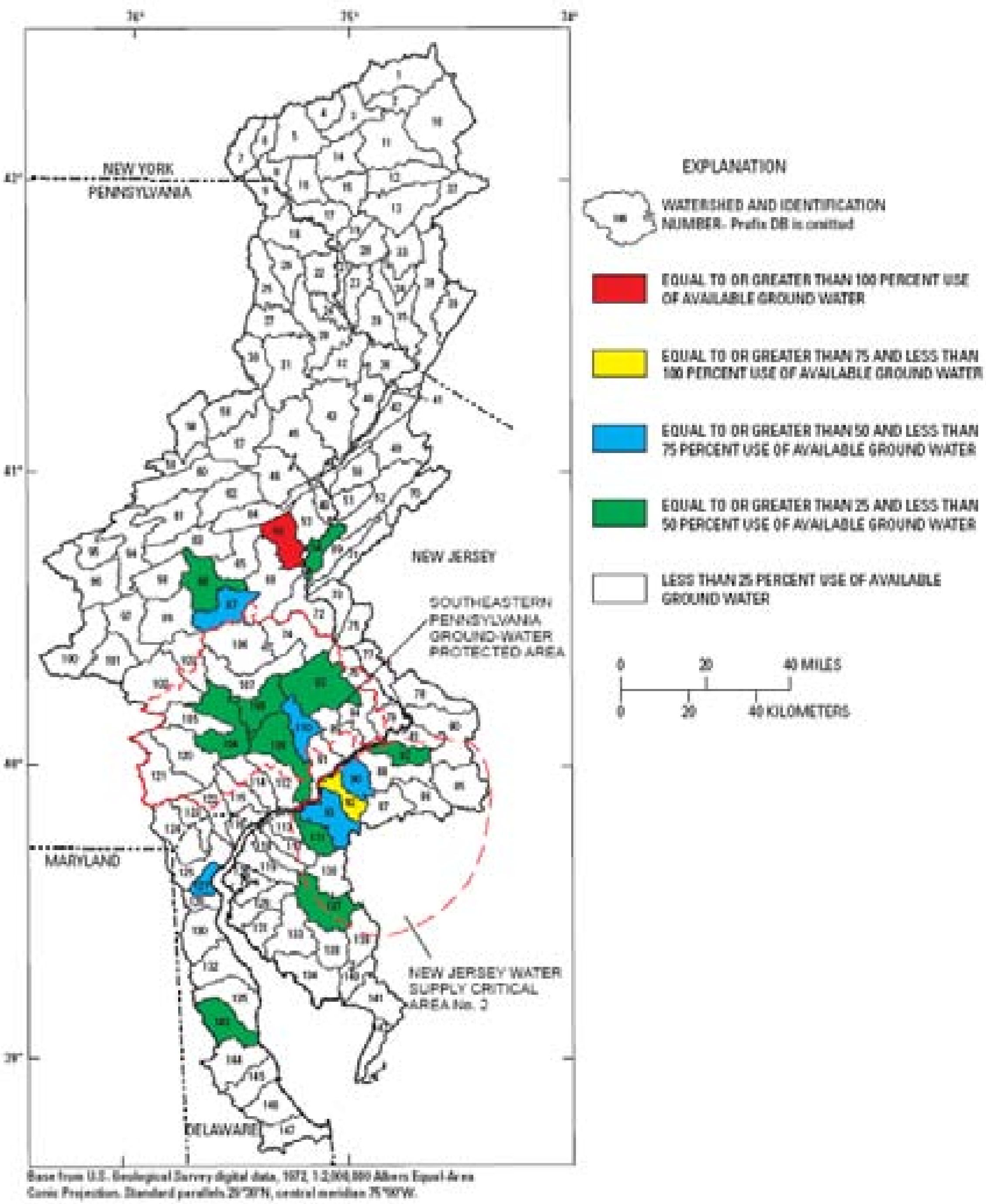
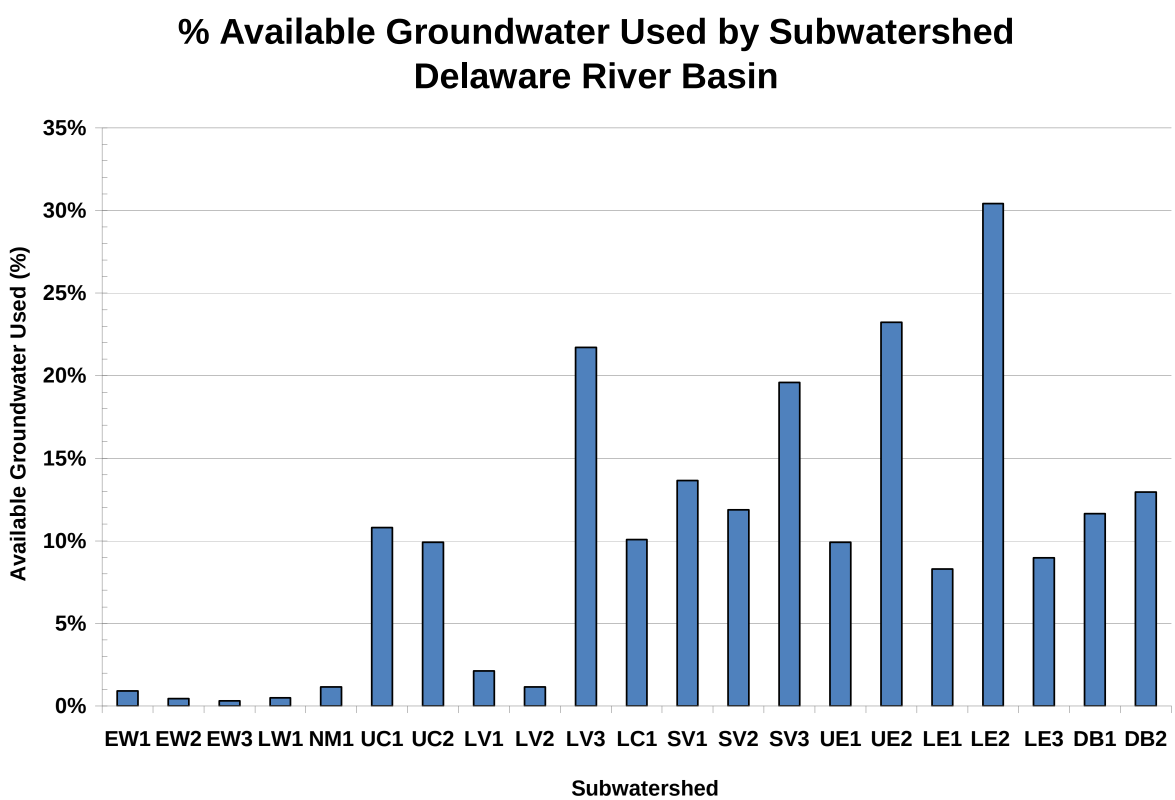


Figure 7.22. Groundwater use for 50 – year annual base flow in the Delaware Basin. (Soto and Buxton 2006)



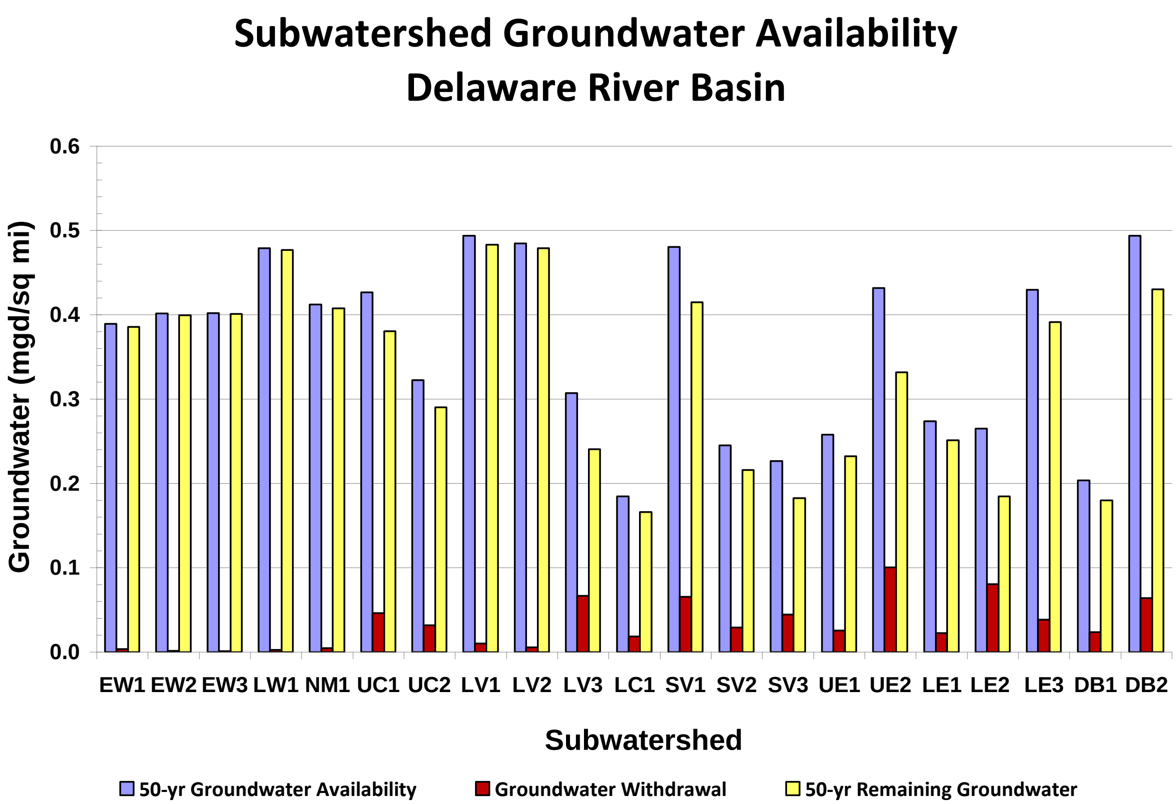


Figure 7.23. Groundwater availability in the Delaware Basin. (Sloto and Buxton 2006)

7.4. Flooding Claims

The DRBC maintains a database of flooding claims per watershed based on data compiled by the Federal Emergency Management Agency (FEMA). Figure 7.24. depicts the flood insurance claims for the April 2005 flood event.

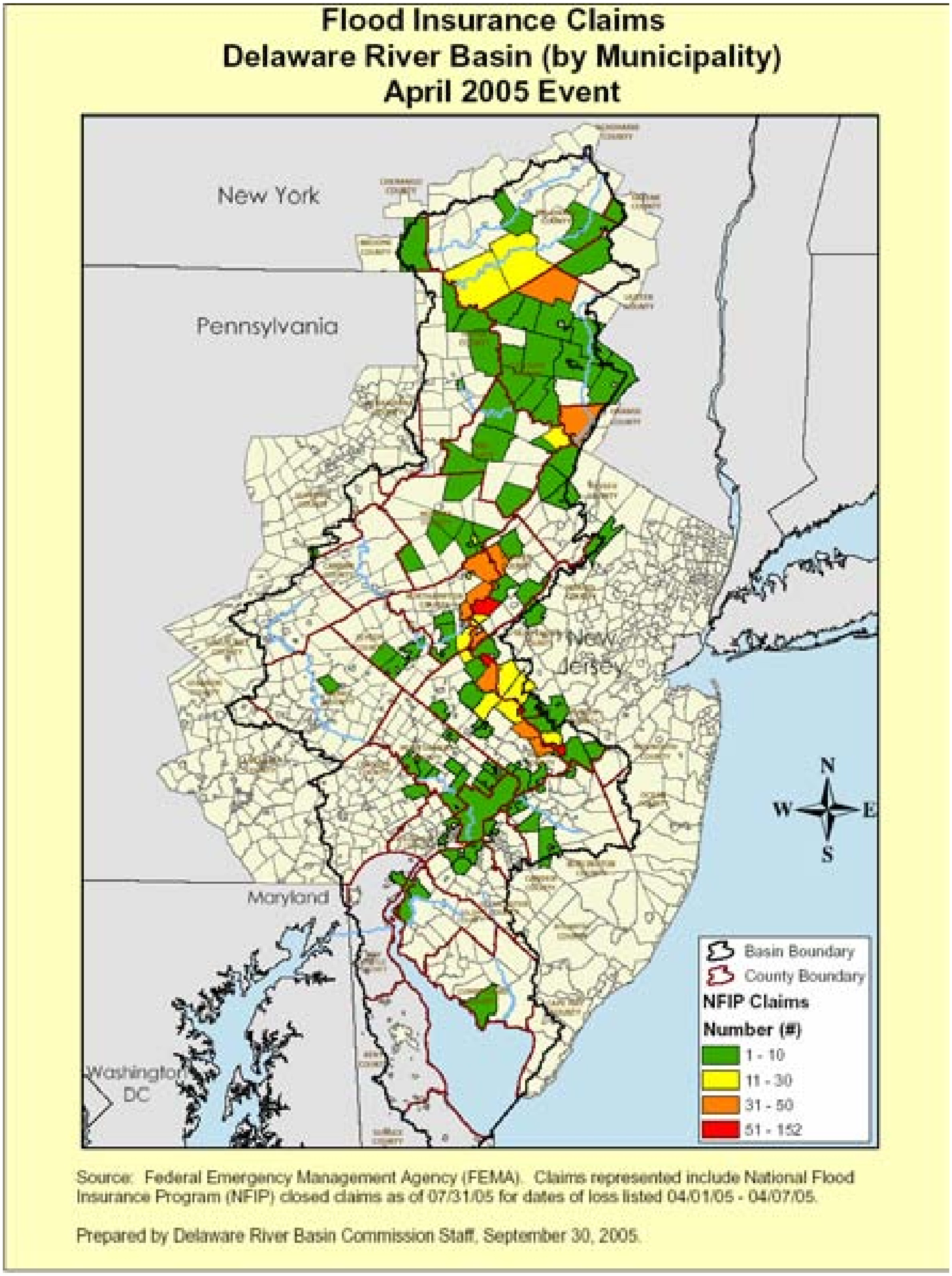


Figure 7.24. Flood insurance claims in the Delaware River Basin. (FEMA and DRBC)

7.5. Dams (Hydrologic Impairment)

Dams can be hydrologic impairments to fish migration. The Partnership for the Delaware Estuary retained the Battelle Corporation to assemble a data base of dams (fish blockages) that exist along the streams in the Delaware River Basin. The following tables and figures are excerpts from the draft Battelle report to the PDE (Battelle draft 2006).

The spatial distribution of fish blockages were provided by the national U.S Fish and Wildlife Service (USFWS) database and from both the New Jersey Department of Environmental Protection (NJDEP) and the Pennsylvania Department of Environmental Protection (PADEP) where more detail (e.g., year constructed, year inspected) has been added to dam-specific attributes based on the National Inventory of Dams (NID). 1,446 dams have been identified within the Delaware Bay Estuary watershed based on these data sources. Out of these, 467 (32%) have dates associated with the year of construction (year built).

Table 7.4. Cumulative distribution of dams in the Delaware Basin. (Battelle draft 2006)

Subwatershed	1850	1875	1900	1925	1950	1975	2000	Total
DB1	2	2	4	5	8	15	15	51
DB2	2	3	5	7	16	18	18	69
EW1	0	0	1	2	2	2	2	9
EW2	0	0	0	0	0	0	0	0
EW3	1	2	3	8	10	14	14	52
LC1	0	0	2	3	5	8	12	30
LE1	1	1	4	9	11	19	27	72
LE2	0	0	0	0	1	5	5	11
LE3	0	0	0	4	8	11	11	34
LV1	0	0	3	8	10	15	16	52
LV2	0	0	3	8	10	15	16	52
LV3	1	1	2	4	7	7	14	36
LW1	4	9	12	19	28	45	46	163
NM1	0	1	1	3	4	11	11	31
SV1	3	6	10	15	19	26	26	105
SV2	0	1	3	6	10	18	23	61
SV3	2	2	5	6	13	17	25	70
UC1	0	0	3	20	34	48	54	159
UC2	2	2	5	16	30	43	45	143
UE1	1	1	2	8	14	20	28	74
UE2	1	2	6	15	33	46	50	153
Total	20	33	73	166	275	412	467	1446

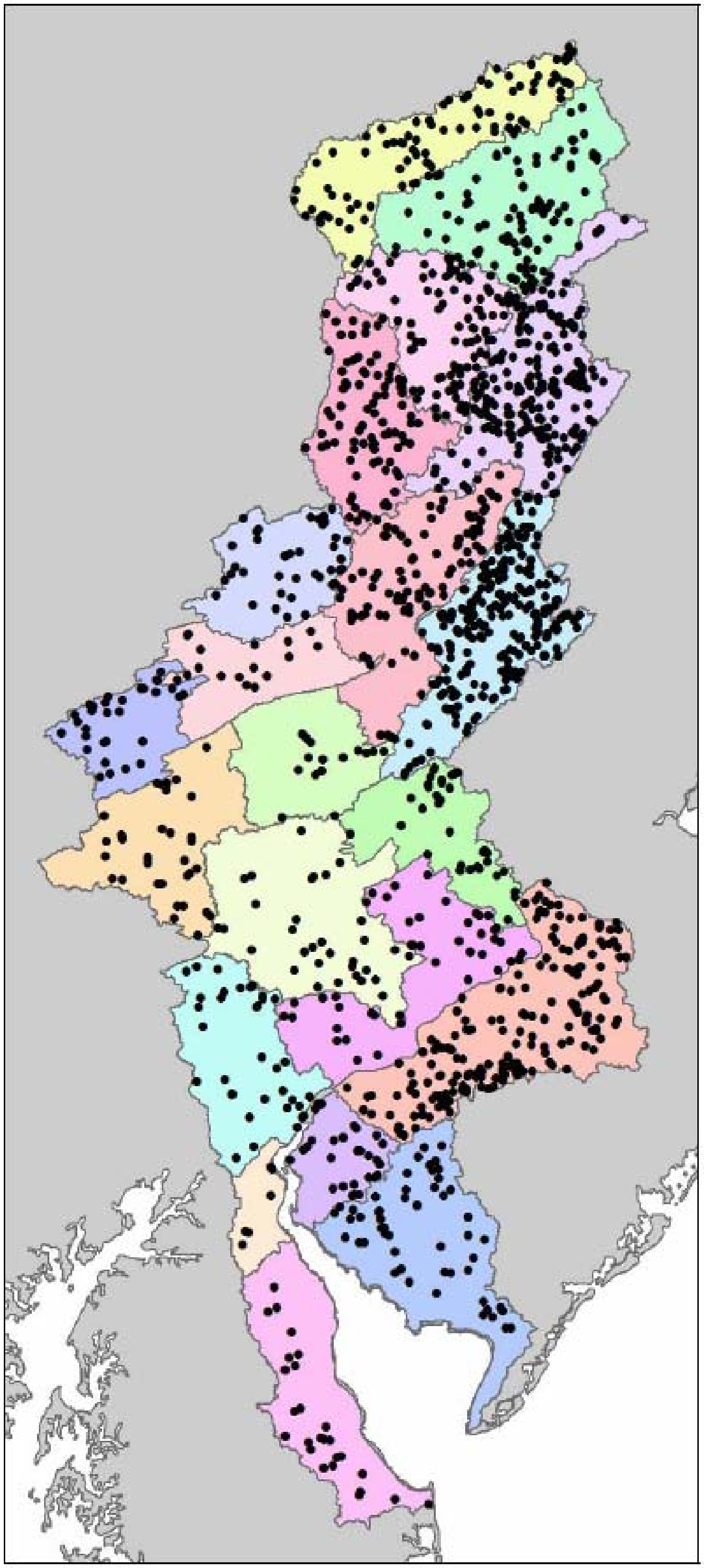


Figure 7.25. Dams in the Delaware Basin. (National Inventory of Dams and USFWS)

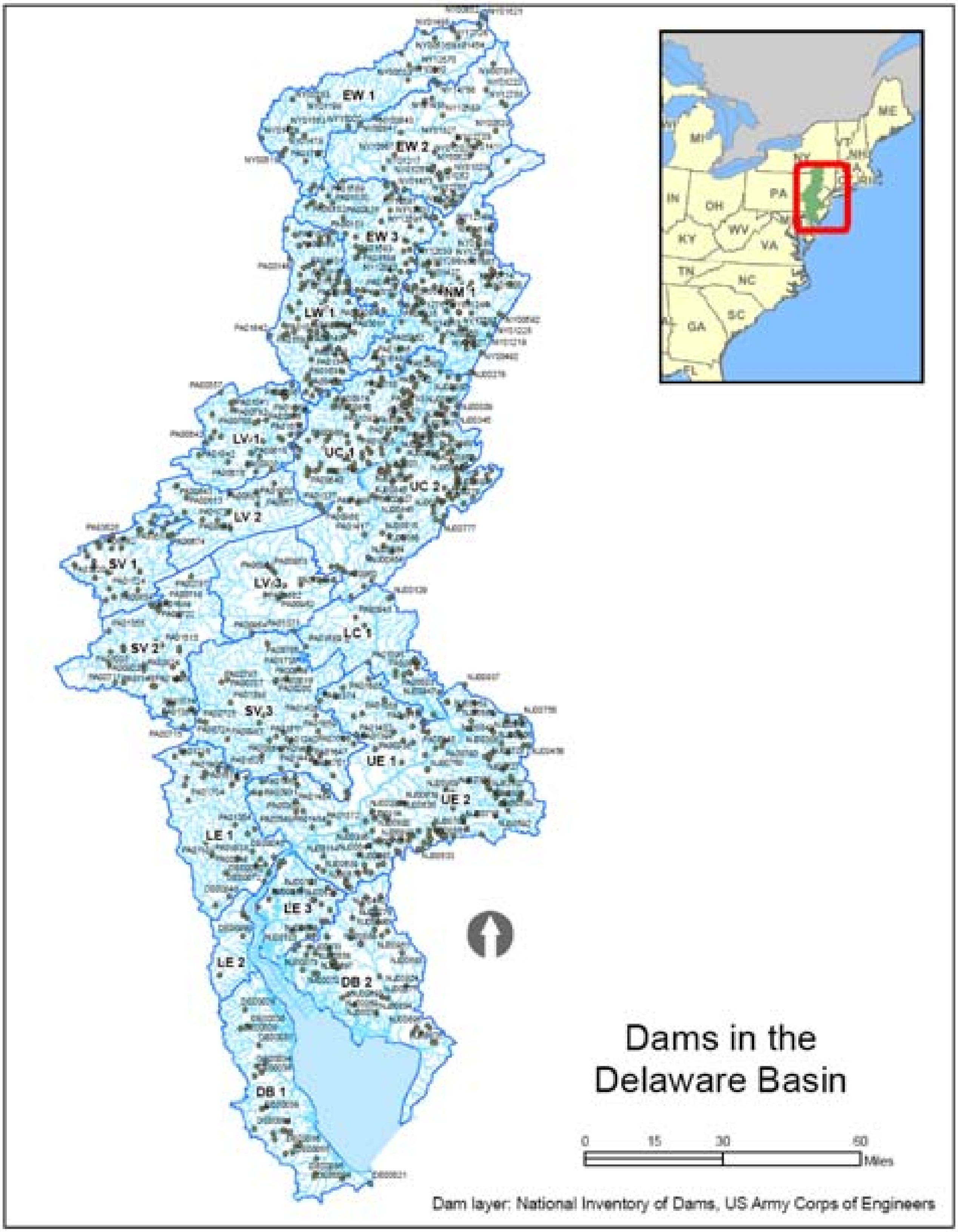


Figure 7.26. Dams in the Delaware River Basin. (NID and U. S. Army Corps of Engineers)

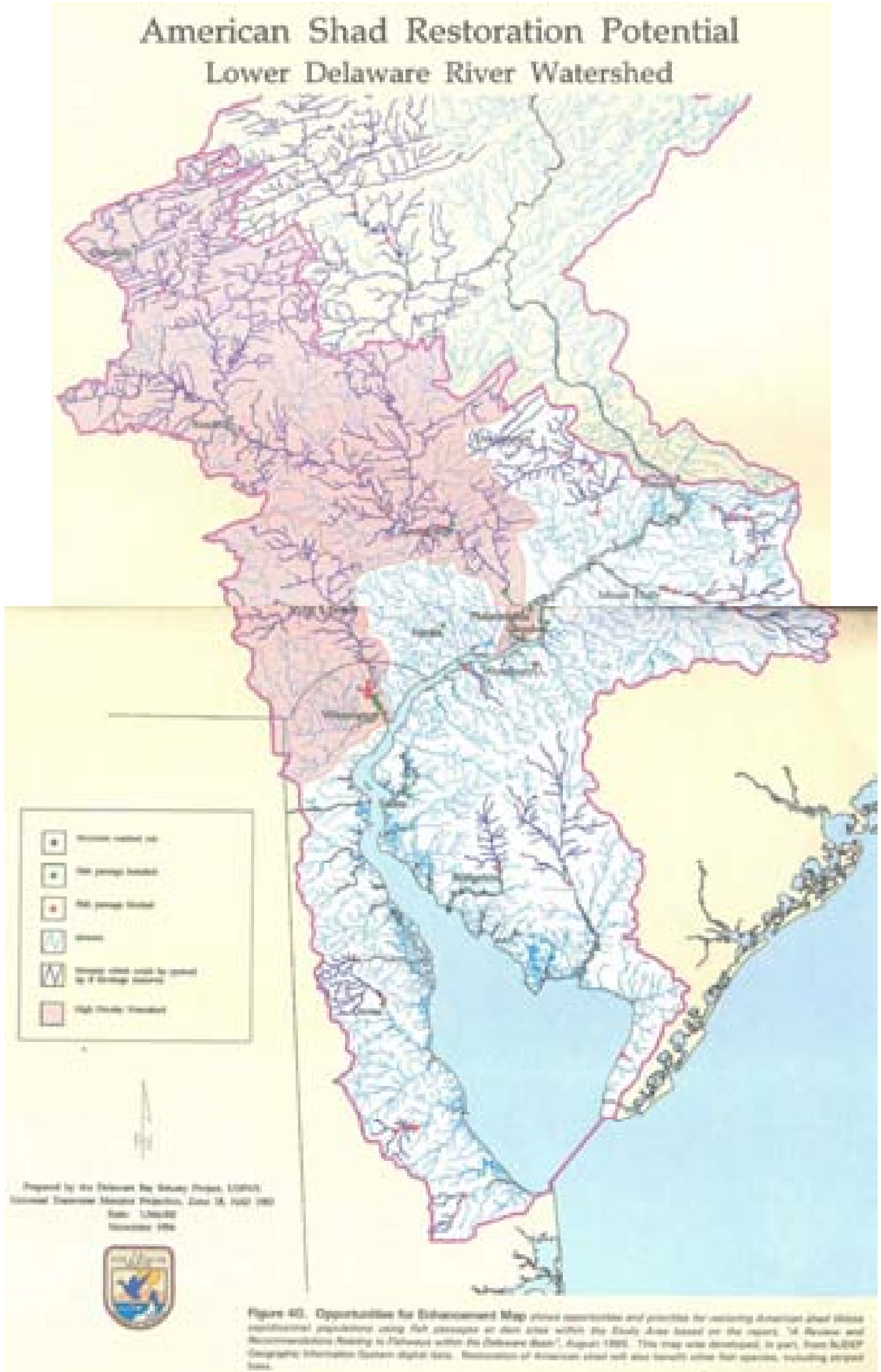


Figure 7.27. American shad restoration potential based on dam removal in the Delaware Basin (Partnership for the Delaware Estuary and USFWS 1996)

Chapter 8 - Living Resources

The White Paper on Science in the Delaware Estuary discusses ecologically significant species (Kreeger *et al.* 2006):

More than 200 migrant and resident finfish species use the Delaware Estuary for feeding, spawning, or nursery grounds, including sharks, skates, striped bass, shad, sturgeon, American eel, blueback herring, Atlantic menhaden, alewife, bluefish, weakfish, and flounder. Oysters and blue crabs represent important shellfish resources in this system. The Estuary is home to the largest population of horseshoe crabs in the world, and is an important link in the migratory path of a wide variety of shorebirds and waterfowl (Dove and Nyman 1995). The tidal marshes, intertidal mudflats, oyster reefs, sandy beaches, inland wetlands, riparian corridors, and upland meadows and forests make up the important habitats in the Estuary.

Ecologically significant species are species of animals or plants that are recognized as functional dominants in the ecology of the system, or are recognized as being signature traits that characterize the unique identity of the system. Another term used to describe these biota is keystone species. "Critical habitats" represent prominent habitat types that are either important centers of ecosystem function, biological hot spots containing high biodiversity, or essential habitat for species of special concern.

8.1. Macroinvertebrates

Aquatic macroinvertebrates are found in lakes, streams, and ponds and maintain the health of the ecosystem by eating bacteria, and decaying plants and animals. Macroinvertebrates are separated into four categories of pollution tolerance: sensitive, semi-sensitive, semi-tolerant, and tolerant to pollution. Macroinvertebrates such as stoneflies, mayflies and water pennies require high dissolved oxygen levels and their abundance is an indication of good water quality. The prevalence of low-oxygen tolerant macroinvertebrates increases with pollution. Pollution tolerant macroinvertebrates dominate, while pollution sensitive or semi-sensitive organisms will be unable to survive. Pollution tolerant species of macroinvertebrates such as aquatic worms and leeches usually indicate water systems with low dissolved oxygen levels. The life cycle of a macroinvertebrate varies from 2 weeks to two years or longer. Many species are aquatic for the egg and larval stages, but not in the adult stage.

Table 8.1 and Figure 8.1 summarizes macroinvertebrate health along Delaware Basin streams as good, fair, or poor.

The New York DEC assesses macroinvertebrate health using biomass data in the following categories:

- Moderately Impacted
- Slightly Impacted
- Non Impacted

The Pennsylvania DEP utilizes Beck Biotic Index values corresponding to the following water quality assessments.

- 0 – 10 (Grossly polluted)
- 11- 20 (Moderately polluted)
- 21 – 30 (Clean but limited habitat quality)

The New Jersey DEP assesses macroinvertebrate health according to biological impairments as:

- Severe (Poor)
- Moderate (Fair)
- None (Good)

The Delaware DNREC assesses macroinvertebrate health using biological classification index as a percentage (BCI):

- 0% - 33% BCI (Poor)
- 34% - 67% BCI (Fair)
- 68% - 100% BCI (Good)

Table 8.1. Macroinvertebrate health in the Delaware River Basin. (NYSDEC, PADEP, NJDEP, DNREC)

Macroinvertebrate Health		No. of Stream Miles	% of Stream Miles	Map Color
Poor	NY: Moderately Impacted PA: Grossly Polluted (0 – 10) NJ: Severe, Poor DE: Poor (0% - 33% BCI)			Orange/Red
Fair	NY: Slightly Impacted PA: Moderately Polluted (11 – 20) NJ: Moderate, Fair DE: (34% - 67% BCI)			Yellow
Good	NY: Non-impacted PA: Clean (21 – 49) NJ: None, Good DE: Good (68% - 100% BCI)			Green

Table 8.2. Macroinvertebrate health of Delaware River Basin watersheds (2002).

Macroinvertebrates	Assessed Streams (mi)	Good (mi)	Fair (mi)	Poor (mi)	Good (%)	Fair (%)	Poor (%)
Upper Region (NY and PA)							
EW · East/West Branch							
EW1 East Branch (Cannonsville)	573	150	423	0	26%	74%	0%
EW2 West Branch (Pepacton))							
EW3 Mainstem (above Narrowsburg)	552	72	403	77	13%	73%	14%
LW1 · Lackawaxen	585	0	110	575	0%	19%	81%
NM1 ·Neversink-Mongaup	841	177	437	227	21%	52%	27%
Central Region (PA and NJ)							
UC ·Upper Central watersheds							
UC1 Pennsylvania tributaries	812	227	374	211	28%	46%	26%
UC2 New Jersey tributaries	844	168	279	397	20%	33%	47%
LV ·Lehigh Valley							
LV1 Above Lehighton	523	52	209	262	10%	40%	50%
LV2 Above Jim Thorpe	373	2	242	129	0%	65%	35%
LV3 Above Easton	375	0	135	240	0%	36%	64%
LC1 ·Lower Central (above Trenton)							
Lower Region (PA, NJ and DE)							
SV ·Schuylkill Valley							
SV1 Above Reading	331	46	119	166	14%	36%	50%
SV2 Above Valley Forge	627	6	125	496	1%	20%	79%
SV3 Head of tide at Philadelphia	990	9	109	872	1%	11%	88%
UE ·Upper Estuary (Phila, Camden)							
UE1 Pennsylvania piedmont	698	14	104	580	2%	15%	83%
UE2 New Jersey coastal plan							
LE ·Lower Estuary Watersheds							
LE1 Christina River	107	27	60	20	25%	56%	19%
LE2 C and D Canal, DE	39	1	11	27	3%	28%	69%
LE3 Salem River, NJ							
Bay Region							
DB ·Delaware Bay (NJ and DE)							
DB1 Delaware coastal plain	59	14	32	13	24%	54%	22%
DB2 New Jersey coastal plain							

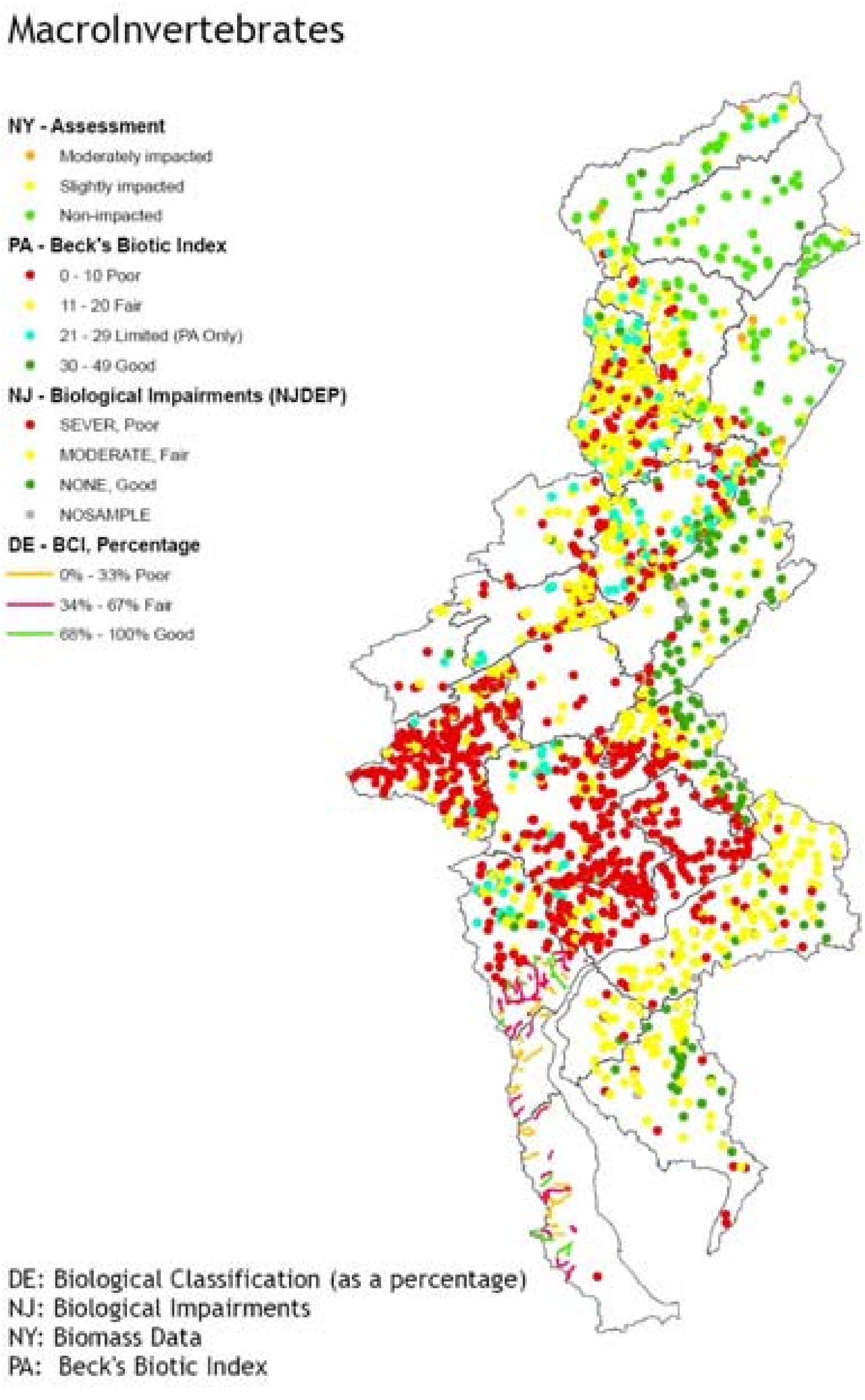
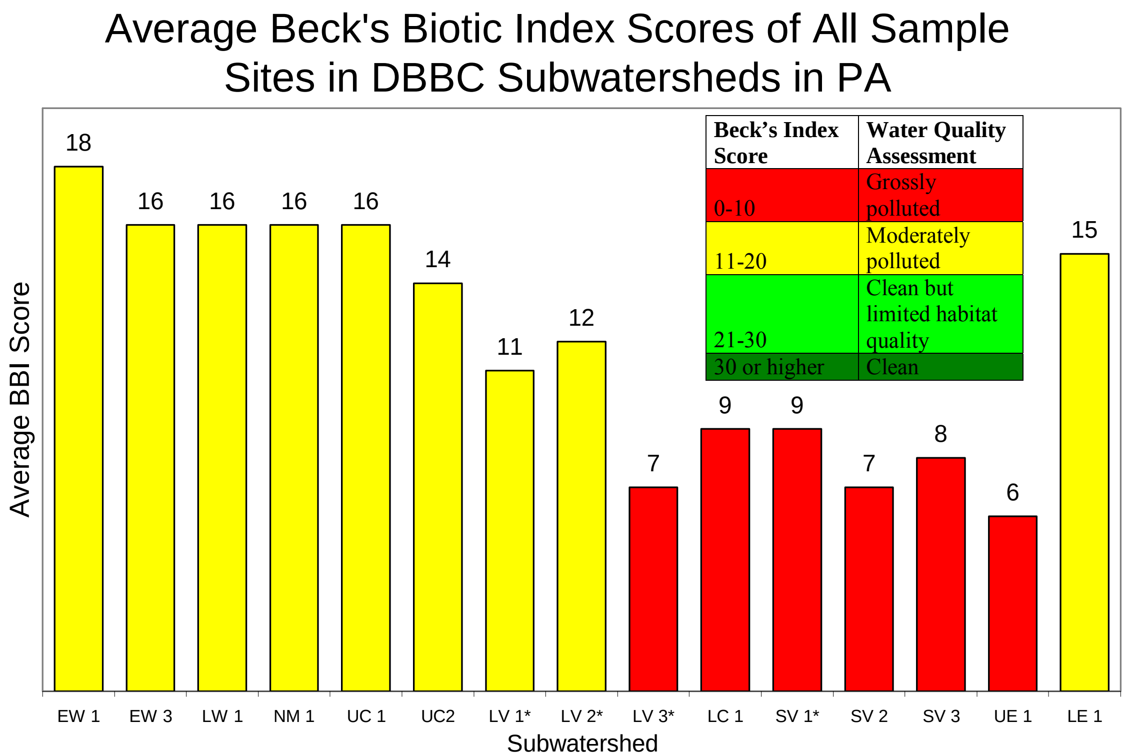
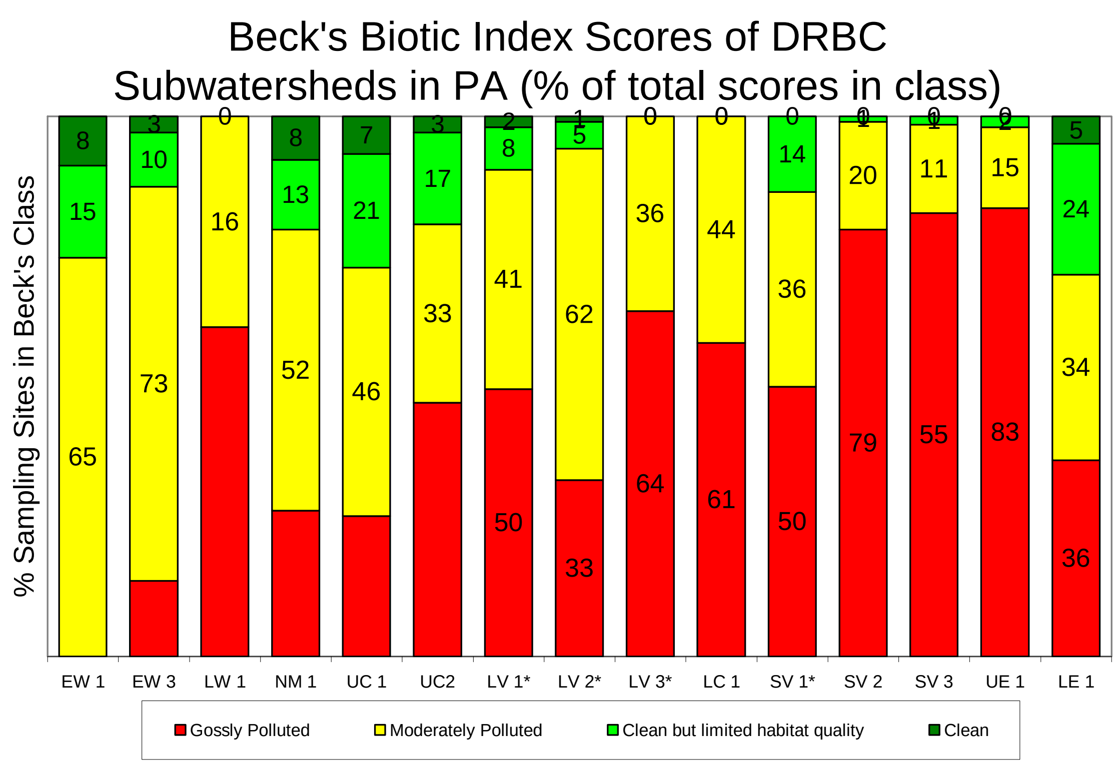


Figure 8.1. Macroinvertebrate assessment along streams in the Delaware River Basin.





* Limited sample sites in subwatershed. Data may not be representative.

Figure 8.2. Beck's biotic index of Pennsylvania streams in the Delaware River Basin. (PADEP)

8.2. Oyster Beds

In the Delaware Estuary (Figure 8.3), oysters grow from the bay entrance up to Bombay Hook on the Delaware side and up to Artificial Island on the New Jersey side, a salinity range of 30 to 5 parts per thousand (Dove and Nyman, 1995). New Jersey has established a high recruitment zone near Cape Map to stimulate the growth of Cape Nay salt oysters (Figure 8.4). Delaware and New Jersey license 14 mi^2 of Delaware Bay oyster beds at the following sites.

Round Island (upstream)	Bennies
Upper Arnolds	Nantuxent Point
Arnolds	Hog Shoal
Upper Middle	Hawk's Nest
Middle	Strawberry
Ship John	New Beds
Cohansey	Beadons
Sea Breeze	Vexton
Shell Rock	Ledge
Bennies Sand	Egg Island (downstream)

Natural beds or reefs cover much of the upper bay and produce seed oysters (Figure 8.5). In both states, the oyster growing grounds are separated into upper bay seed beds and lower bay leased grounds. Young oysters (spat) set and grow naturally in an area where predators and the MSX disease are inhibited by low salinities. Each spring, the planters transplant seed oysters from the natural beds to their leased grounds, and after a period of several months to a year, they market the oysters. In the lower bay, the oysters grow faster and attain a better meat quality then on the seed beds, but the higher salinity also favors predators and disease. Three - dimensional mapping of the Delaware Bay indicates that in some locations the oyster shell substrate is sloughing from the shelf into the main shipping channel (Madsen, Wilson, and Carter, 2007)

Figure 8.3. Oyster seed beds in the Delaware Estuary. (Rutgers Haskins Laboratory)

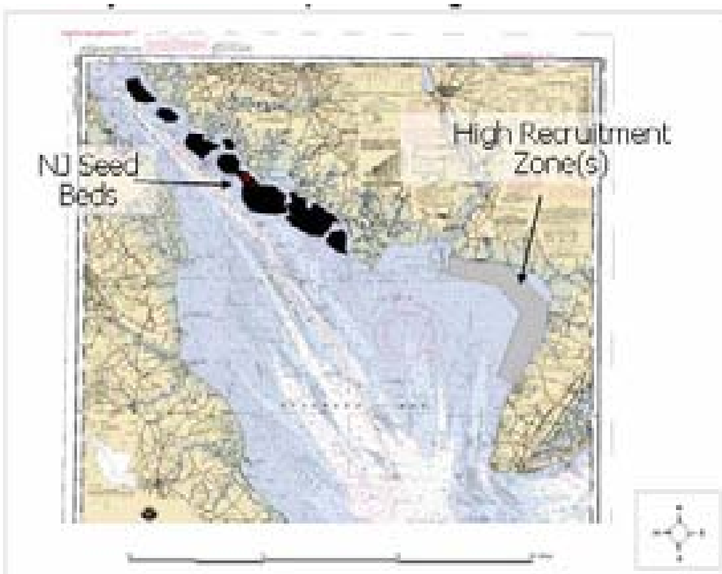


Figure 8.4. New Jersey oyster seed beds in the Delaware Estuary. (Rutgers Haskins Laboratory)

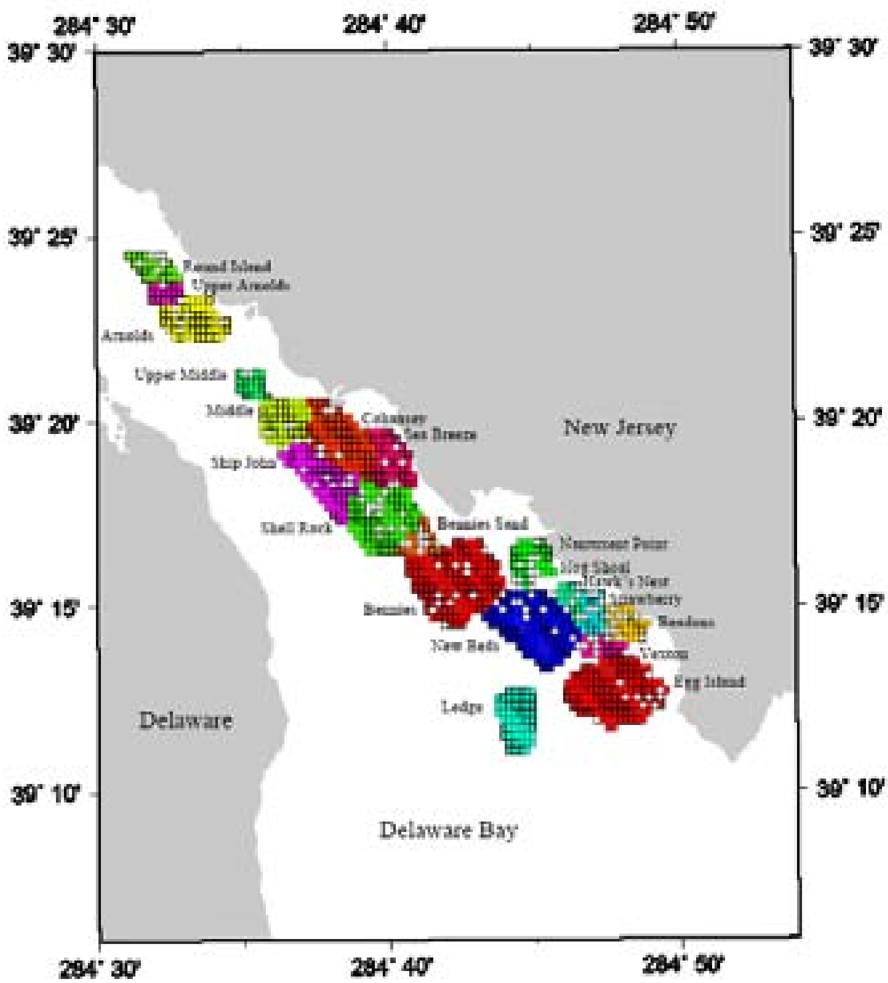


Figure 8.5. Delaware Bay oyster beds. (Rutgers Haskins Laboratory, 2005)

Currently, Delaware and New Jersey are cooperating on the Delaware Bay Oyster Restoration project as a cooperative initiative to revitalize Eastern oysters, a signature species, in the Delaware Estuary (PDE, 2006). The goal of the project is revitalization of the Delaware Bay oysters. Existing beds are planted with clean sea clam and oyster shell that is strategically placed in the Delaware Bay. These shell planting sites provide surfaces to which oyster larvae can grow. The project also includes transplanting of oysters from the lower Bay where salinity is high, to further north where they have a better chance of surviving in lower salinity. In the first two years of the project, oyster recruitment has doubled. If the same progress is maintained, the bay shore communities and shellfish industry may realize an economic boost. A resurgent oyster population will also improve water quality, since each oyster can filter 50 gallons per day. Tables 8.3 and 8.4 summarize the progress of the Delaware Bay Oyster Restoration Project to date.

Table 8.3. Progress of the Delaware Bay Oyster Restoration Project.

	2004 (bushels)	**2005 (bushels)**	**2006 (bushels)**	**2010 (bushels)**
Amount of shell planted		280,000	505,000	
Industry harvest allocation	100,000			
Annual harvest goal	400,000			

Table 8.4. Delaware oyster shell planting activity (2005 and 2006).

Location	**Year**	**Area (acres)**	**Planted Shell Volume** (bushels)
Lower Middle	2005	22.3	64,160
Ridge	2005	19.7	54,650
Pleasonton's Rock	2006	40.9	53,986
Drum Bed	2006	32.9	47,582
Silver Bed	2006	29.9	81,156
Total		145.7	301,534

The Delaware Bay Oyster Restoration Project partners include:
Delaware

- Senator Joe Biden
- Senator Tom Carper
- Congressman Mike Castle
- Governor Ruth Ann Minner

New Jersey

- Senator Frank Lautenberg
- Senator Robert Menendez
- Congressman Frank LoBiondo
- Governor Jon Corzine

Cumberland County Empowerment Zone
Delaware and New Jersey Shellfish Industry
DE DNREC
Delaware River and Bay Authority
Delaware River Basin Commission
NJDEP
Partnership for the Delaware Estuary
Rutgers University Haskin Shellfish Research Lab
US Army Corps of Engineers, Philadelphia District

8.3. Eastern Oysters

The University of Delaware Sea Grant Program (2006) and *Living Resources of the Delaware Estuary* (Dove and Nyman 1995) described the oyster in the Delaware Bay.

The Eastern oyster (crassostrea virginica) is a bottom dwelling, indigenous invertebrate native to the Delaware Bay which may grow to 10 inches long. Oysters are recognized by their rough, irregular-shaped shells, which tend to be dissimilar in size. The upper shell is flattish, and the lower is concave, providing space for the soft body of the oyster. While young, the oyster attaches to a hard surface by means of a limy secretion and remains sedentary for the rest of its life. The opening and closing of the oyster's shells is regulated by one abductor muscle, which is capable of closing the shells completely. Each female may produce up to 100 million eggs per year. To obtain food, oysters filter microscopic plankton from the water. Oyster reefs contribute habitat for other species in the estuary.

Oysters are valued for three important reasons: for their ecological services, as a sentinel bio-indicator of water quality and habitat conditions, and as a commercial shellfishery. An individual adult oyster filters more than a liter of water per hour and populations of oysters living on reefs are responsible for moving vast quantities of particulate matter from the water column and enriching the sediments with bio-deposits. Oyster reefs are important structurally and as essential fish habitat. Their importance as bio-indicators follows because their sessile lifestyle is conducive to site-specific analyses.

The UD Sea Grant Program writes:

Oyster meat has been sought for human consumption since the 18th century. Americans eat more oysters than any other people in the world. An average of 100,000 bushels of oysters per year is harvested from the Delaware Bay. At a current value of $45 per bushel, the oyster haul is worth about $4.5 million annually to the economy of the Delaware Bay shoreline communities. The eastern or Atlantic oyster ranges from the Gulf of St. Lawrence to the Gulf of Mexico. Crassostrea virginica accounts for the majority of oyster production in the U.S. The color of the meat varies with the color of the algae the oyster feeds upon. Unlike most other seafood, the taste of oysters varies greatly depending on the type of algae fed upon and the salinity in the area they are harvested. The typical color of freshly shucked oyster meats is cream, tan or gray. Oysters are harvested year-round, but catches are heaviest in October, November, and December. Contrary to belief, all oysters are edible during their spawning season or the months without an "R".

Recent estimates of oyster abundance in Delaware Bay suggest that average population density of adults is declining and especially worrisome is a precipitous drop in average spat (juvenile oysters) recruitment that could result in a point-of-no-return abundance for the overall population. Despite declines, oysters remain one of the most important commercial shellfish in Delaware Estuary. However, the population has been victimized by the parasite Dermo since 1990, especially on the New Jersey side of the bay. Researchers are working to develop a disease-resistant oyster and to better manage the Eastern oyster market. The commercial oyster fishery has also been hampered at times by shellfish bed closures. The number of acres of prohibited areas remained fairly constant throughout the 1990s (slightly less than 370,000 acres), and the number of approved harvest areas actually decreased in the late 1990s. The oyster restoration program for this estuary has set a specific goal for a five-fold increase in the oyster population by 2015, which is contingent on the funding provided. A shell-planting program was initiated in 2005 to help in this revitalization effort.

Oysters provide ecological benefits with the potential to refilter and recirculate up to 11.2 billion liters per hour in the Delaware Estuary (Bushek and Kreeger 2007).

The Rutgers Haskins Oyster Lab (Babb, Hearon, Bushek and Powell 2007) reports:

Natural oyster production on Delaware Bay seed beds is close to collapse following six consecutive years of low recruitment. Few young oysters are available to replace those lost to harvesting or natural mortality. The reasons for the decline remain unclear.

Eastern oyster landings in the Delaware Estuary presently average just below 100,000 bushels per year, down from peaks of 550,000 bushels in 1984 and 800,000 bushels in 1974 (Figure 8.6). From the late 1930s to 1956, the combined oyster landings from Delaware and New Jersey averaged 750,000 bushels annually.

In the late 1950's, MSX disease devastated the oyster stocks and oyster landings dipped below 100,000 bushels per year. Research indicates that MSX disease increases with estuary salinity which is thought to be caused by decreased freshwater river flow. The oyster stocks rebounded during the 1960s and 1970s with a high of 800,000 bushels per year in 1974. The oyster stocks were again devastated by the MSX disease during the mid 1980s followed by the onset of Dermo disease in 1989. Unlike MSX, salinity has relatively little effect on Dermo disease.

By the 1990s and early 2000 the oyster stocks have hovered at just under 100,000 bushels per year. At an estimated market rate of $45 per bushel, the economic benefit of oyster landings in the Delaware Estuary is around $4,500,000 annually.

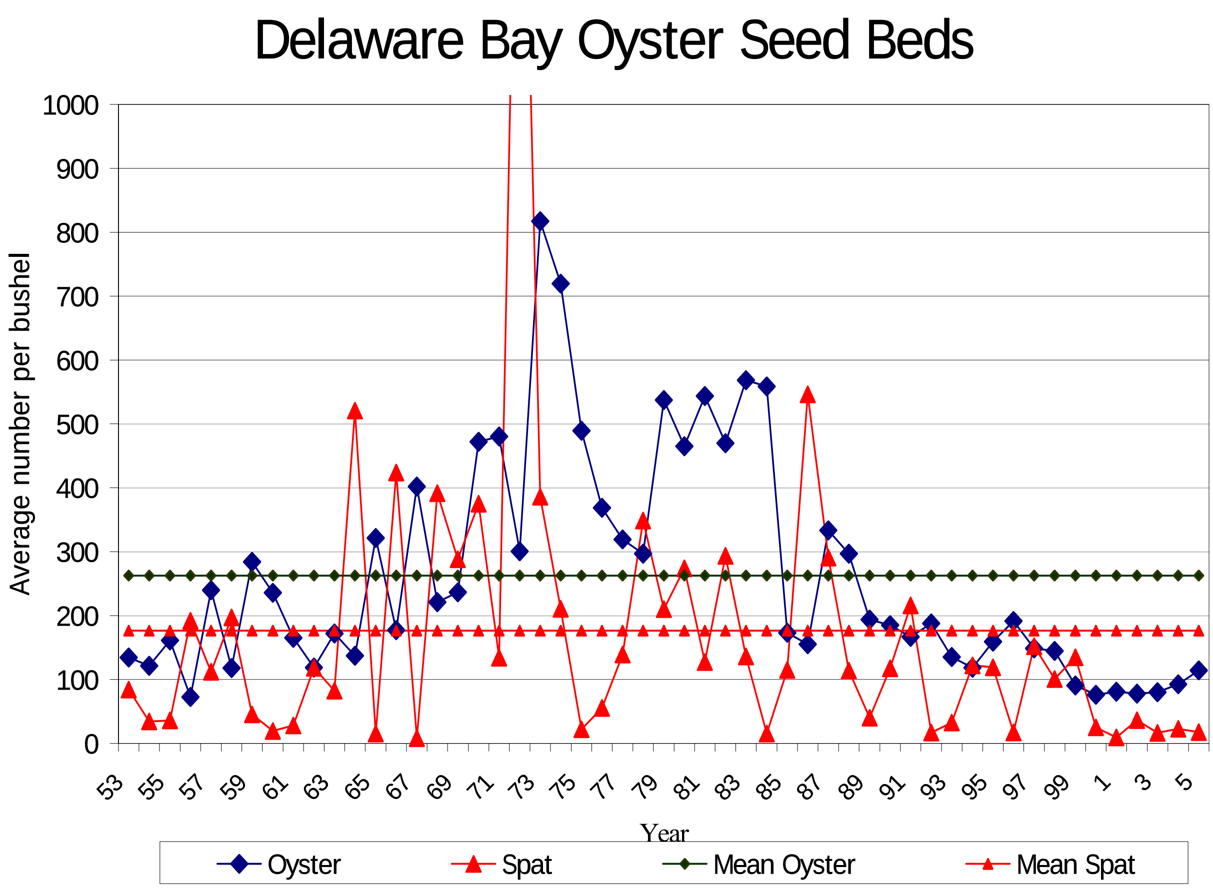


Figure 8.6. Oyster harvest in the Delaware Bay. (Rutgers Haskins Laboratory)

Oyster Chronology (Bushek, Kraueter, Powell, and Ashton-Alcox, Rutgers Haskins Lab, 2006)

Early 1800's	Large scale harvesting by oyster dredge begins.
1840's	Dimensional aspect of oysters reefs beginning to be destroyed.
1850s	Natural oyster beds in lower bay largely extinct.
1880	1,400 sailing vessels taking oysters from the Delaware Estuary.
1887	21.9 million pounds of oysters harvested from the Delaware Bay.
1880 to 1930	Combined oyster landings from Delaware and New Jersey between 1 and 3 million bushels per year. Port Norris, N.J. one of the wealthiest towns in America with main street known as millionaire's row.
1910	Value of New Jersey oyster harvest in Delaware Bay exceeds the state's wheat harvest by $ 1 million.

1914	Area of leased oyster grounds at 30,000 acres, up from 12,000 acres in 1900.
1930s to 1950	Combined oyster landings from Delaware and New Jersey above 750,000 bushels annually.
Late 1950s	MSX disease devastates oyster stocks in the Delaware Bay
Early 1960s	Oyster harvest declines to 160,000 bushels in 1965. Delaware Basin experiences drought of century.
1972	In June, hurricane causes heavy freshwater runoff, lowering salinity, and suppressing the MSX parasite. This results in the best setting of seed oysters that oystermen could remember.
1973 to 1984	Oysters rebound with harvest at 450,000 bushels in 1980.
1985	Drought causes high salinities. MSX again devastates oyster stocks in the Delaware Bay.
1987	New Jersey and Delaware Shellfish Councils close Delaware Bay oyster seed beds to dredging.
1989	Dermo disease prevalent
1990	Oyster beds on New Jersey side of bay opened to dredging. 280,000 bushels of oysters taken in 1991
2006	Oyster landings below 100,000 bushels per year. The PDE, DRBC, Rutgers, and both states lead replenishment of oyster substrate and disease resistant oyster stocks. Fledgling oyster aquaculture operations produce large quantities of oysters known as Cape May Salts.

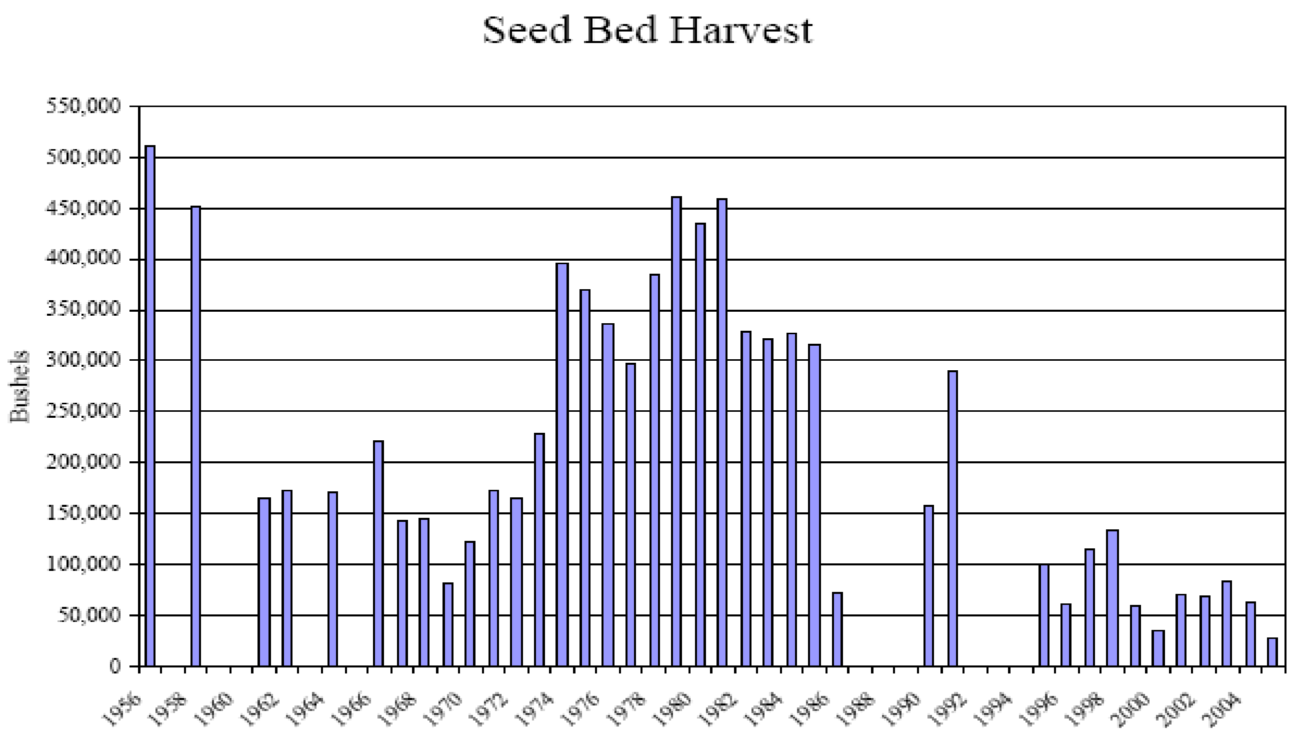


Figure 8.7. Oyster seed bed harvest in the Delaware Bay. (Rutgers Haskins Laboratory)

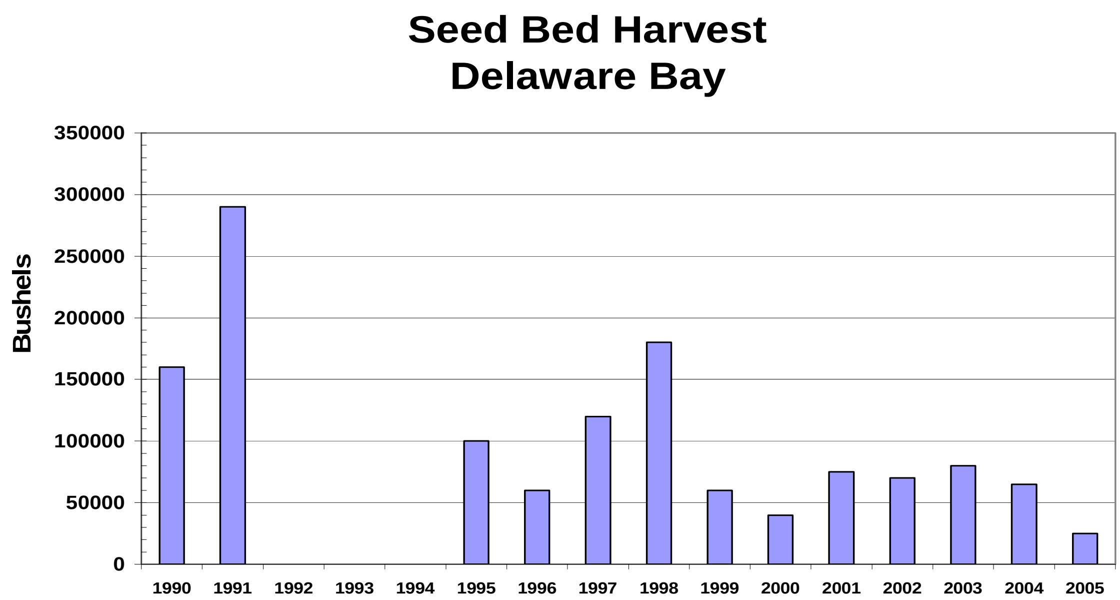


Figure 8.8. Oyster seed bed harvest in the Delaware Bay. (Rutgers Haskins Laboratory)

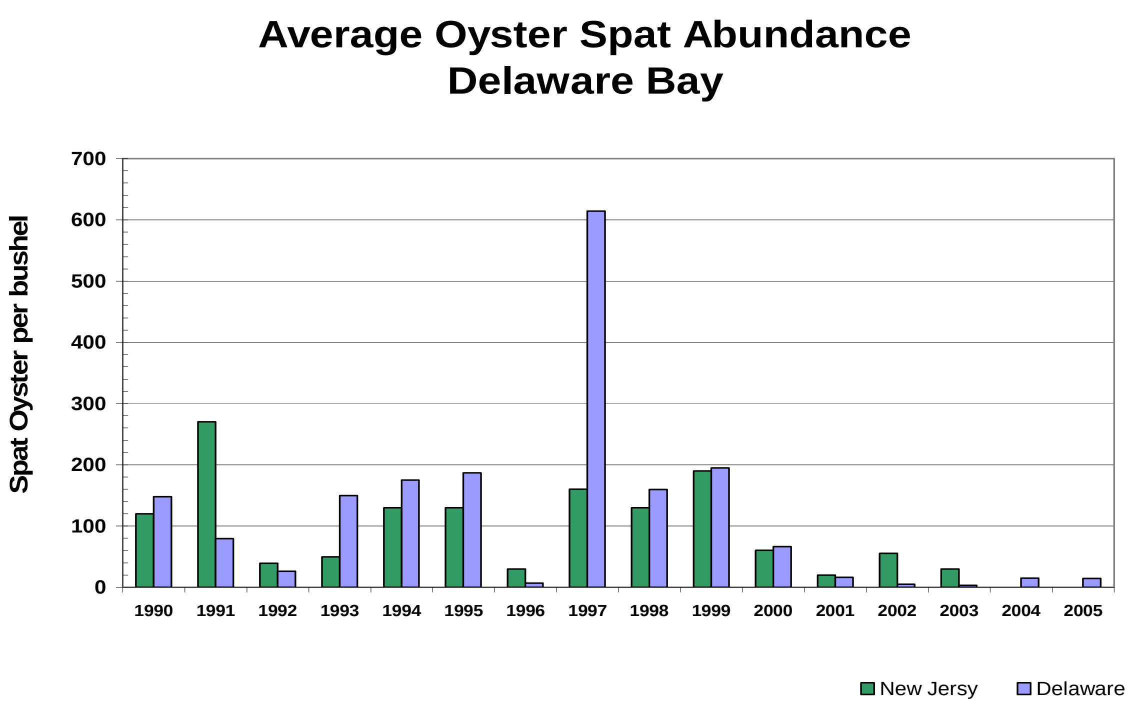


Figure 8.9. Average oyster spat abundance in the Delaware Bay. (Rutgers Haskins Laboratory)

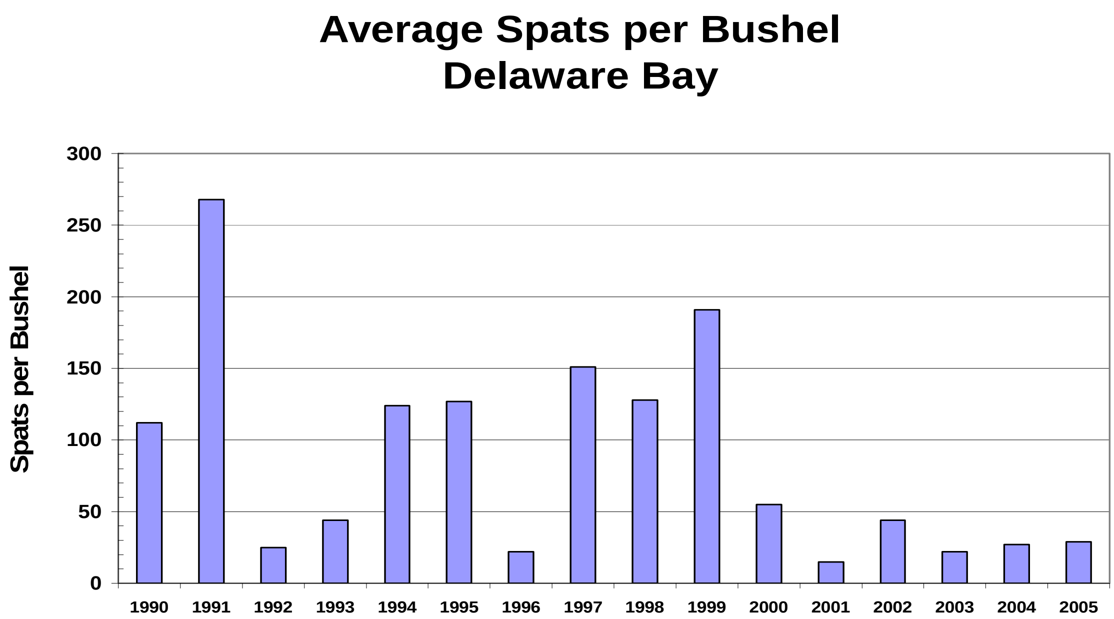


Figure 8.10. Delaware Bay-wide average oyster spat count. (Rutgers Haskins Laboratory)

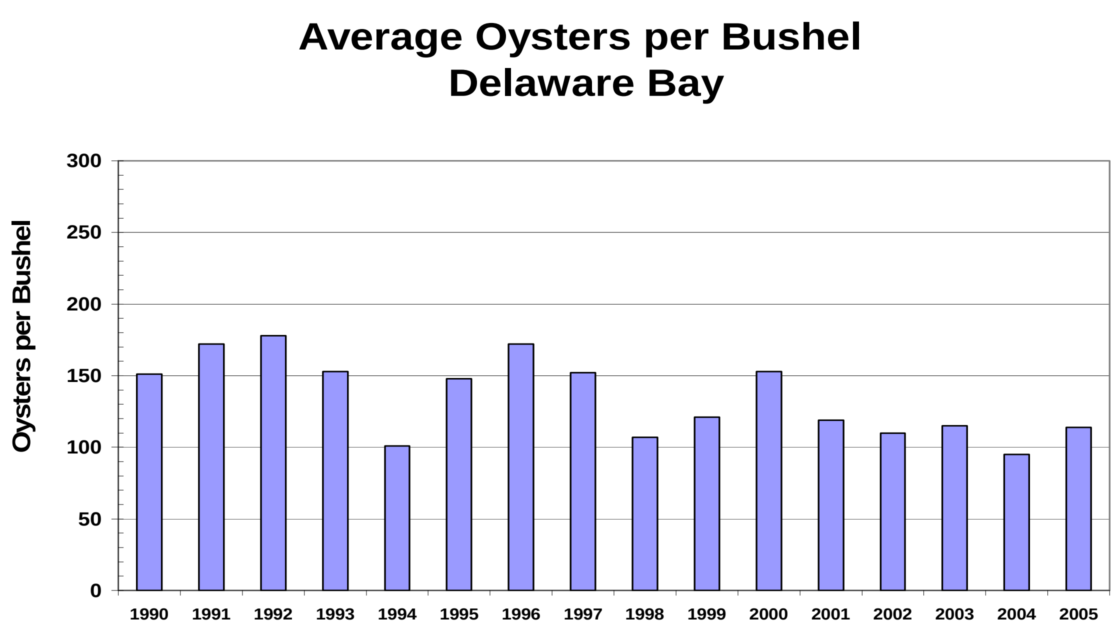


Figure 8.11. Average Delaware Bay oyster abundance per 37 quart bushel. (Rutgers Haskins Laboratory)

8.4. Horseshoe Crab

The Delaware Bay is home to the world's largest population of horseshoe crabs (*Limulus polyphemus*). The horseshoe crab is Delaware's state marine animal. Once called horse foot crabs, the horseshoe crab isn't really a crab. Horseshoe crabs belong to the phylum of Arthropods, making them more closely related to spiders than crabs. Their exclusive class is called Merostomata, meaning "legs attached to mouth" (Sutton, O'Herron, and Zappalorti 1996).

Horseshoe crabs have been on earth for 350 million years, since the days of the dinosaur. They have survived because their hard, curved shells made it difficult for predators to overturn them and expose their soft underbellies. The horseshoe crab has also survived because it can go a year without eating and endure extreme temperatures and salinity.

Horseshoe crabs have few natural enemies except humans. Decades ago, the horseshoe crabs were loaded on trucks and shipped to be ground up as fertilizer. Delaware Bay watermen ship horseshoe crabs to Virginia as bait for the eel and conch fishery. This commercial harvesting has taken a toll on the population. The value of the horseshoe crab to Delaware and New Jersey watermen as bait is estimated at $100,000 annually.

The horseshoe crab is the largest food source for migrating shorebirds at Delaware Bay beaches (Figure 8.12). The Delaware Estuary is the largest stop for shorebirds in the Atlantic Flyway and is the second largest staging site in North America. About 425,000 to 1,000,000 migratory shorebirds converge on the Delaware Bay to feed and build energy reserves prior in northward migration. Red knot, dunlin, ruddy turnstine, sanderling, semi-palmated sandpiper and other migratory shorebirds feed on horseshoe crab eggs almost exclusively during the Delaware Bay stopover (PDE, 2002).

The Delaware Estuary's population of horseshoe crabs is regarded as one of the most important indicators of health of living resources in the region. Horseshoe crabs are important ecologically, commercially, and as a signature species of the Delaware Estuary. This remarkable species plays a vital role in the life of anyone who has received an injectable medication. With their blood, the biomedical industry is able to produce limulus amebeyte lysate or LAL which is used for testing drugs and biomedical devices for endotoxins. Once blood is drawn, the horseshoe crabs are returned to there natural environment unharmed. Chitin in the crab's shell also is used in sutures and burn dressings to speed healing.

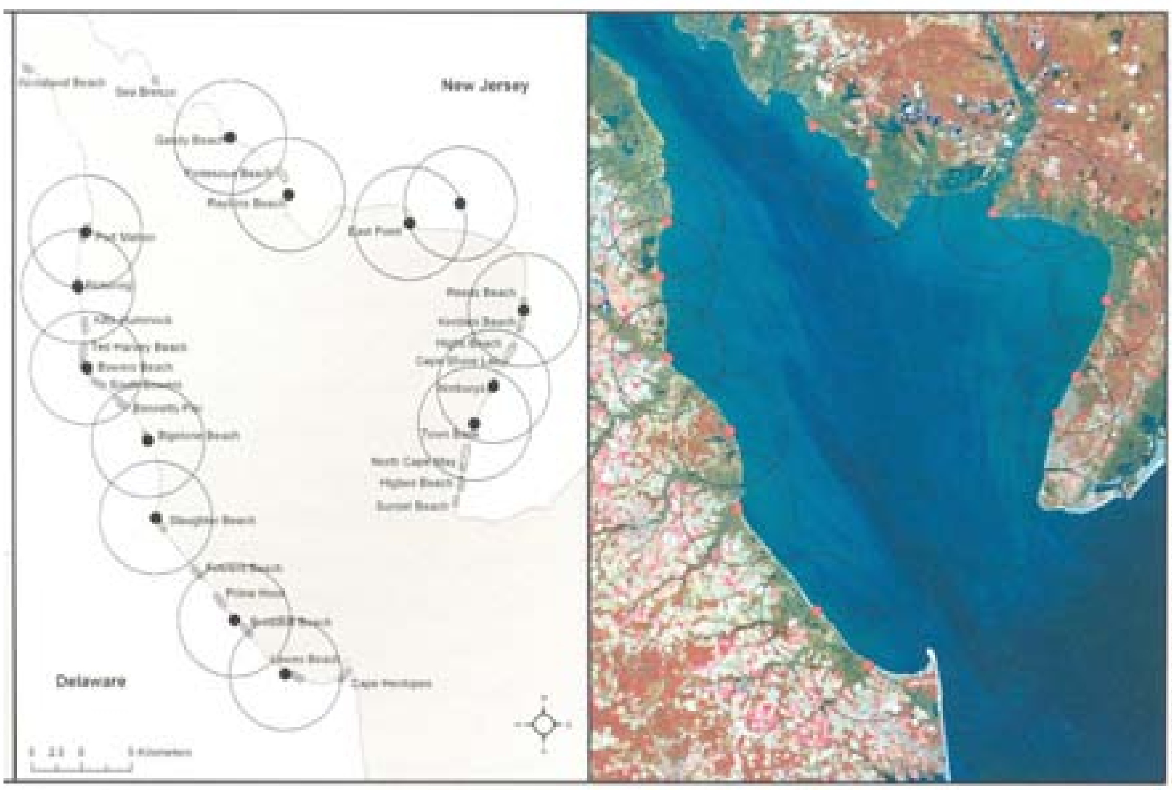


Figure 8.12. Horseshoe crab beach locations. (PDE 1996)

Kreeger *et al*. reported in 2006:

Recent estimates of horseshoe crab abundance in the Delaware Bay suggest that the size of the spawning population may be in a state of decline. However, recent reports have highlighted the complexities of relating abundance to harvest pressure and natural fluctuation (Botton and Loveland 2005) and abundance surveys must better consider spatial and temporal distribution patterns (Smith et al. 2005). The record shows that horseshoe crab populations in the Delaware Estuary declined significantly in the 1990s in the Delaware Bay – the epicenter for horseshoe crabs – and therefore "Delaware and New Jersey together need to act to preserve and foster the environment for horseshoe crabs."

Horseshoe crabs are monitored during their spawning period during May and June at 30 beaches along the Delaware and New Jersey coasts of the Delaware Bay. Horseshoe crab eggs provide food for about 425,000 to 1,000,000 migratory shorebirds such as the red knot which converge on the Delaware Bay to feed and build energy reserves prior to completing their northward migration. Each bird can eat thousands of eggs per day. Numbers are dwindling due to harvests by watermen that use the horseshoe crabs for conch bait.

A draft 2006 Battelle report indicates the USGS index of spawning activity (ISA) for the horseshoe crab along the Delaware and New Jersey coasts of the Delaware Estuary is relatively stable at a ratio of 0.8 (Figure 8.13). Along the Delaware coast the spawning index has decreased from 1.0 in 1999 to 0.6 by 2005 which means spawning horseshoe crabs are dwindling. Along the New Jersey side of the bay, the ISA has increased from 0.6 to 1.0. Both states have recently imposed a moratorium on the harvest of horseshoe crabs to save the species and preserve the food source for the migrating shore birds.

Table 8.5. Horseshoe crab spawning ISA along the Delaware Bay. (Battelle, draft 2006)

Delaware Bay 1 (DB1)															
Year	**EastPoint**	**Fortescue**	**Gandys**	**Higbees**	**HighsBeach**	**Kimbles**	**Norburys**	**NorthCapeMay**	**PiercesPoint**	**Raybins**	**Reeds**	**SeaBreeze**	**CapeShoreLab**	**Sunset**	**Townbank**
1999		0.2473	0.4014		0.7892	0.7063		0.225			0.3808	0.0947	1.2452		
2000	0.3458		0.3922		0.9594	0.8521		0.05	0.6138	0.0259	0.6468	0.1094	1.3311		0.7362
2001			0.4521	0.0361	0.795	0.4773	0.46	0.0904			0.4049	0.2991	1.2775		0.3958
2002			1.4122		0.4685	0.4976	0.6242	0.0845	0.673		0.8768	1.6283	0.685	0.1139	0.4589
2003		0.4184	0.5498		0.5275	0.497	0.5362	0.1233	0.73		0.8225	0.3892	0.6283		
2004		0.5408	0.8166		0.6963	0.4054	0.6707	0.02	0.9602		0.4162	0.4275	0.9042		0.2037

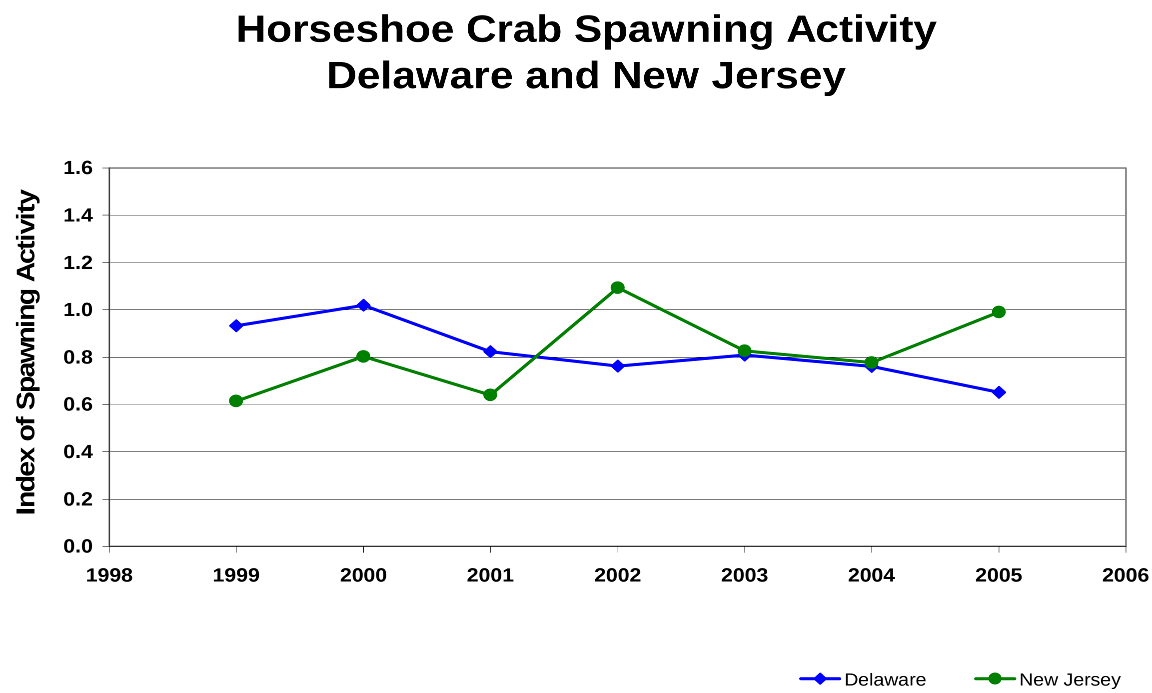


Figure 8.13. Horseshoe crab spawning activity in Delaware and New Jersey. (Battelle draft 2006)

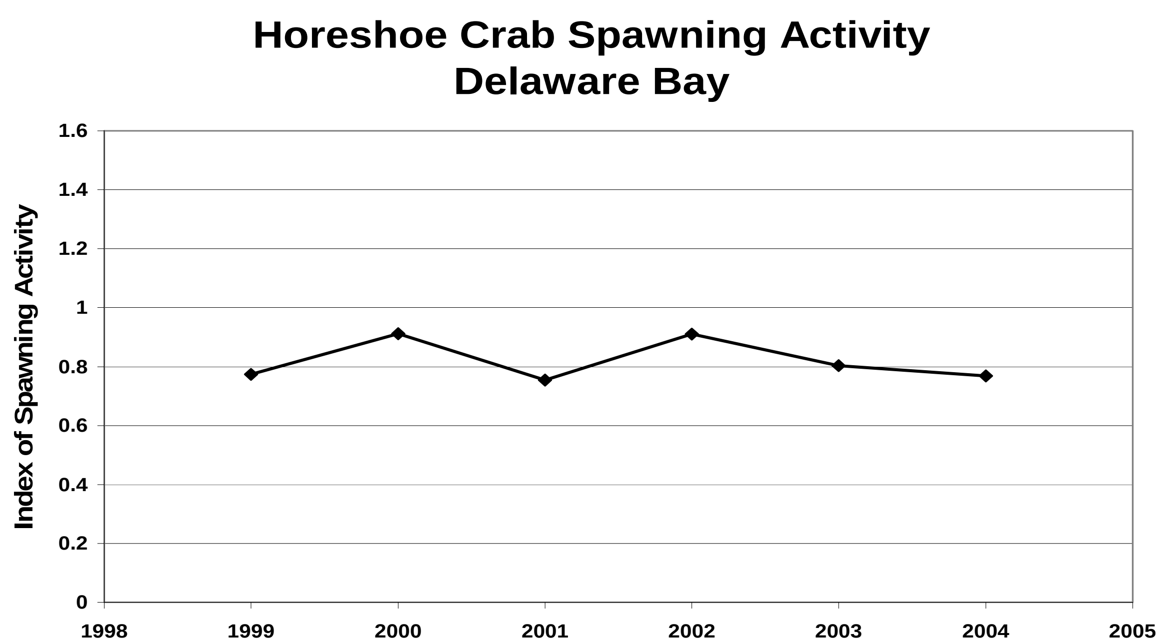


Figure 8.14. Baywide spawning activity for horseshoe crabs in Delaware and New Jersey**.** (Battelle, draft 2006)

Figure 8.15 indicates commercial horseshoe crab landings in the Delaware Bay have declined since 1998 (Hooker, Mangold, Michels, Spear, ASMFC, 2008). In 2007, New Jersey instituted a moratorium on horseshoe crab harvests and Delaware implemented a maximum harvest of 100,000 male horseshoe crabs per year.

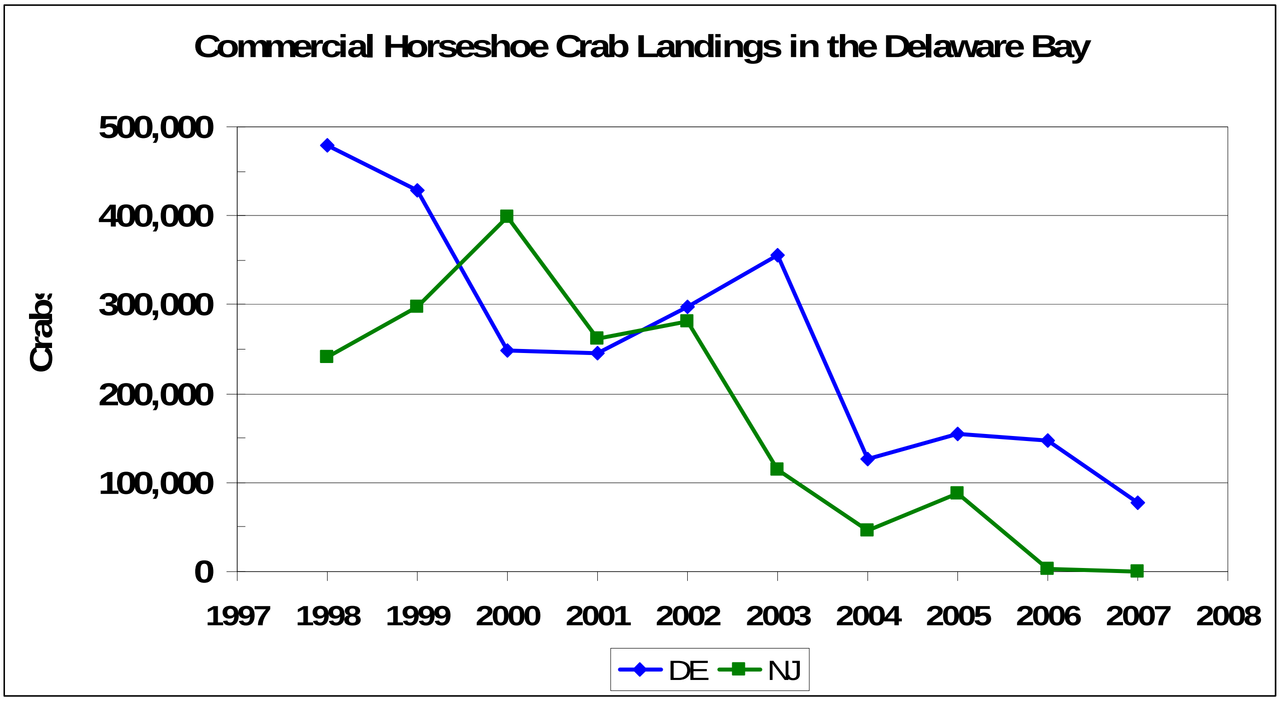


Figure 8.15. Commercial horseshoe crab landings in the Delaware Bay (Hooker, Mangold, Michels, Spear, ASMFC, 2008)

Effective June 11, 2007, Delaware DNREC adopted emergency regulations limiting the annual Delaware harvest of horseshoe crabs to 100,000 male-only crabs. The emergency regulations are a result of a ruling handed down by the Delaware Superior Court on June 8, 2007, which overturned Delaware's horseshoe crab harvest moratorium. The Secretary's Order cites that the emergency regulations are necessary, because the harvesting of excessive numbers of horseshoe crabs and female horseshoe crabs constitutes an actual and imminent threat to the resource and the fishery. The emergency regulations are consistent with the recommendations of the Atlantic States Marine Fisheries Commission (ASMFC). Without the new regulations, Delaware will be non-compliant with the ASMFC and subject to federal sanctions.

Horseshoe crabs play a vital role in the ecology and fisheries of the Delaware Bay. Their eggs serve a primary food source for migratory shorebirds, at least seven species of commercially and/or recreationally- important finfish and a variety of crabs. Horseshoe crabs are harvested for the manufacture of limulus amoebocyte lysate (LAL), the standard for testing virtually all pharmaceuticals for the presence of gram negative bacteria. Horseshoe crabs are important in the diets of federally-protected loggerhead sea turtles and are extensively harvested for use as primary bait in the American eel and conch (whelk) pot fisheries.

Records show that in the 1990s horseshoe crab populations declined significantly in the Delaware Bay due to over-harvesting of horseshoe crabs. Scientists and wildlife managers believe that declining horseshoe crab populations have adversely affected shorebird populations, including the red knot, because horseshoe crab eggs are the primary food resource of migratory shorebirds that visit the bay each spring. The red knot stops in the Delaware Bay in search of horseshoe crab eggs on its journey from its wintering home in South America to its breeding grounds in the Arctic. The red knot feeds on horseshoe crab eggs to double its weight in order to survive the migration.

Horseshoe Crab Facts (UD Sea Grant**)**

- Despite their size and intimidating appearance, horseshoe crabs are not dangerous.
- A horseshoe crab's tail, while menacing, is not a weapon. Instead, the tail is used to plow the crab through the sand and muck, to act as a rudder, and to right the crab when it accidentally tips over.
- The horseshoe crab's central mouth is surrounded by its legs and while harmless, it is advisable to handle a horseshoe crab with care since you could pinch your fingers between the two parts of its shell while holding it.
- Horseshoe crabs have 2 compound eyes on the top of their shells with a range of about 3 feet. The eyes are used for locating mates.
- Horseshoe crabs can swim upside down in the open ocean using their dozen legs (most with claws) and a flap hiding nearly 200 flattened gills to propel themselves.
- Horseshoe crabs feed mostly at night and burrow for worms and mollusks.
- Horseshoe crabs grow by molting and emerge 25 percent larger with each molt. After 16 molts (usually between 9 and 12 years) they will be fully grown adults.
- Horseshoe crab eggs are important food for migratory shore birds that pass over the Delaware Bay during the spring mating season. Fish also eat the juveniles or recent molts.
- In the 1900s, horseshoe crabs were dried for use as fertilizer and poultry food supplements before the advent of artificial fertilizers.
- The medical profession uses an extract from the horseshoe crab's blue, copper-based blood called lysate to test the purity of medicines. Certain properties of the shell have also been used to speed blood clotting and to make absorbable sutures.

Figure 8.16. Horseshoe crabs (Wall Street Journal)

8.5. Blue Crab

The UD Sea Grant program (2006) reports:
Blue crabs are invertebrates belonging to the largest group, or phylum, of animals called Arthropoda, or joint-legged animals. More specifically, they are decapod crustaceans, meaning they are arthropods with 10 legs and a hard shell. Scientists know the blue crab as Callinectes sapidus, which is quite descriptive since Callinectes means beautiful swimmer and sapidus means savory

Juvenile and adult blue crabs inhabit the entire Delaware Estuary, including tidal freshwaters, from Cape Henlopen to Philadelphia. Adult males desire low salinity areas upstream in the estuary and adult females congregate near the high salinity areas near the mouth of the bay for spawning. During the warmer months most crabs are found in less than 4 feet of water. During winter the adult crabs migrate to deep channels where they borrow into the mud until spring. Juvenile blue crabs are prey for eels, striped bass, and weakfish.

Blue crabs are hardy animals and are tolerant of low dissolved oxygen levels, low salinity, and high water temperatures. Blue crabs are rarely affected by low dissolved oxygen levels in the Delaware Estuary because the incoming tidal flow greatly exceeds riverine flow thus resulting in a well mixed estuary. The seasonal low dissolved oxygen levels that once were prevalent in the upper estuary between Wilmington and Philadelphia have greatly increased to due water treatment improvements thus allowing for the northward movement of blue crabs into upstream tidal freshwaters.

Blue crabs are the most lucrative commercial fishery in the Delaware Estuary. In 2005, at $100 per bushel and a catch of 70,000 bushels annually, the blue crab industry adds at least $7 million to the annual economy. Along with the commercial fishery, there is a well developed recreational fishery along the Delaware and New Jersey shores extending from Cape Henlopen and Cape May upstream to tidal freshwater near Philadelphia. On the New Jersey bay side, over 2 million blue crabs are caught annually by recreational crabbers, representing 21% of the commercial harvest (Muffley and Luring 2007). Bay shore towns contain many old fashioned crab houses where people crack and eat crabs.

The Atlantic blue crab is one of the most popular and widely studied of the marine creatures and represents an important regional shell fishery. Blue crabs are the most lucrative commercial fishery in the Delaware Estuary. From the mid 1980s to the present, blue crab catches in the Delaware Estuary ranged from 0.9 to 2.3 million lb annually, up from the 1970's when blue crab catches were under 220,000 lb per year. In 2005, about 860,000 lb of blue crabs were caught on the New Jersey side and 590,000 lb were caught on the Delaware side of the bay.

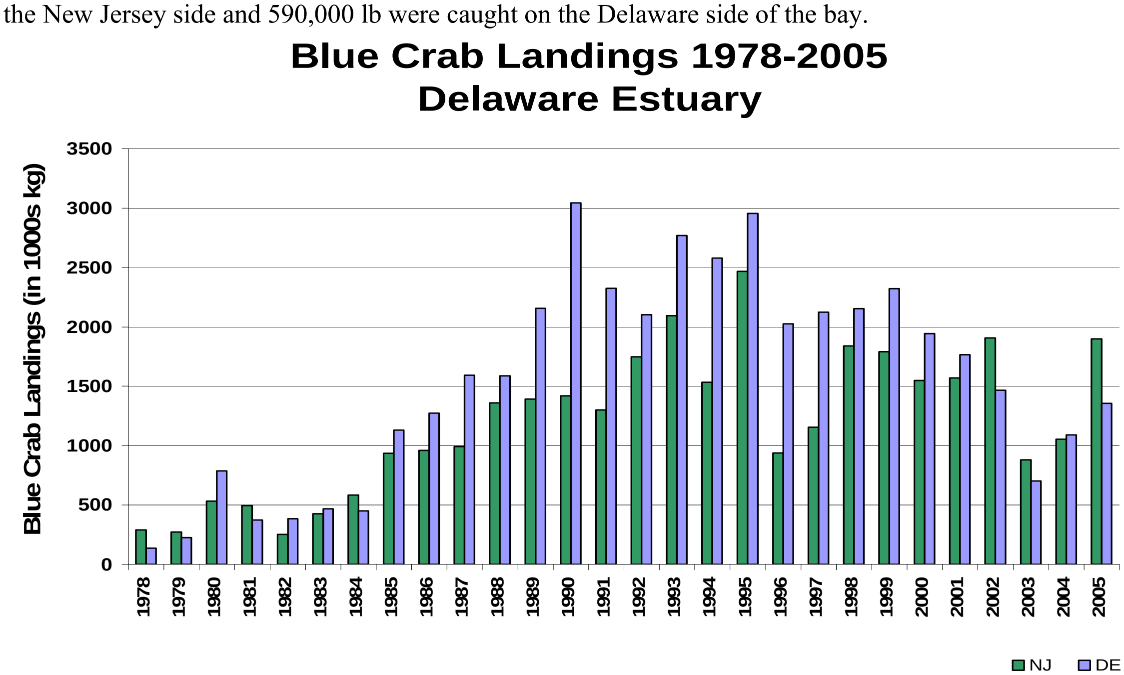


Figure 8.17. Blue crab landings in the Delaware Estuary.

8.6. Freshwater Mussels

The United States has the greatest diversity of freshwater mussels on earth with 300 species residing in the nation's streams (Williams and Neves 2007). Native Americans utilized the mussels for tools and jewelry. Until the 1940s, the shells were used to make buttons. Today, freshwater mussel shells are exported to the Orient for the production of spherical beads that are inserted into oysters, to produce pearls, an industry worth $6 per pound in 1993. Since the 1800s, freshwater mussels have been declining due to habitat loss from dams and pollution. The decline of freshwater mussels largely went unnoticed until 30 years ago.

Gattenby, Patterson, and Kreeger (2007) discussed the decline of freshwater mussels at the 2007 Delaware Estuary Science Conference:

In the United States, 70% of native freshwater mussel species are in serious decline because of habitat degradation, toxic spills, and invasion of the invasive zebra mussel. Approximately 23% of native freshwater mussels are federally endangered and another 7% are already extinct. Freshwater mussels are suspension feeders equipped with very large gills; thus, they can filter 1000s of gallons per day, providing clean water and suitable habitat for other species.

Figure 8.18 maps the location of freshwater mussels in the Delaware River Basin in eastern Pennsylvania as documented in *Uniod Bivalves of Southeastern Pennsylvania.*

Alasmidonta heterdon
Found: Delaware River, Shawnee, Monroe Co.
Princess Creek, Monroe Co.
Schuylkill Canal, Manayunk, Philadelphia Co.
Big Neshaminiy Creek, Edderton, Bucks Co.

Alasmidonta undulate
Found: Delaware River, Yardley, Bucks Co.
White Clay Creek, Avondale, Chester Co.
Schulkyll Canal, Manyunk, Philadelphia Co.
Kimberton Dam, Phoenixville, Chester Co.
Big Elk Creek, Westgrove, Chester Co.
Manatawny Creek, Earlville, Berks Co.
Schuylkill River, Phoenixville, Chester Co.
Sacony Creek, Kutztown, Berks Co.
Valley Creek, Coatesville, Chester Co

Alasmidonta varicose
Found: Delaware River, Shawnee, Monroe Co.
White Clay Creek, Avondale, Chester Co.
Ridley Creek, Delaware Co.
Neshaminy Creek, Edderton, Bucks Co.
Sacony Creek, Kutztown, Berks Co,
Pennypack Cr., Holmesburg, Philadelphia Co.
Swamp Creek, Zieglerville, Montgomery Co.
Manatawny Creek, Earlville, Berks Co.
Maiden Creek, Berks Co.

Anodonta cataracta
Found: Delaware River, Penns Manor, Bucks Co.
White Clay Creek, Avondale, Chester Co.
Crum Creek, Delaware Co.
Schuylkill Canal, Manayunk, Philadelphia Co.
Schuylkill River, Philadelphia
Wissahickon Creek, Roxboro, Philadelphia Co.
Neshaminy Creek, Edderton, Bucks Co.
Eastwicks Park, Grays Ferry, Philadelphia
Wister Dam, Germantown, Philadelphia Co.
Oxford, Guinea Creek, Woodbourne, Bucks Co.

Anondonta implicata
Found: Delaware River, Yardley, Bucks Co.
;Torresdale. Philadelphia Co
Thorps Mill Pond, Branchton, Philadelphia Co.

Elliptio complanata
Found: Delaware River, Penns Manor and Yardley, Bucks Co.
White Clay Creek, Avondale, Chester Co.
Schuylkill Canal, Manayunk, Philadelphia Co.
Wissahickon Creek, Flourtown, Montgomery Co.
Little Neshaminy Creek, Grenoble, Bucks Co.
Common Creek, Tullytown, Bucks County
Big Neshaminy Creek, Edderton, Bucks Co.
Guinea Creek, Woodbourne, Bucks Co.

Lampsilis cariosa
Found: Delaware River, Taylorsville and Yardley, Bucks Co.

Lampsilis ochracea
Found: Delaware Meadows, League Island, Philadelphia

Lampsilis radiate
Found: Delaware River, Yardley, Bucks Co.
Schuylkill Canal, Manayunk, Philadelphia Co.

Lasmigona subviridis
Found: Delaware River, Yardley, Bucks Co.
Schuylkill Canal, Manayunk, Philadelphia Co.
Valley Creek, Coatesville, Chester Co.
Sucker Run, Trib to West Branch Brandywine Creek, Coatesville, Chester Co.

Strophitus undulates
Found: Delaware River, Penns Manor and Yardley, Bucks Co.
Schuylkill River, Manayunk, Philadelphia Co.
Schuylkill Canal, Manayunk, Philadelphia Co.
Wissahickon Creek, Roxboro, Philadelphia Co.
Little Neshaminy Creek, Grenoble, Bucks Co.
Big Elk Creek, West Grove, Chester Co.
Chester Creek, Delaware Co.
Big Neshaminy Creek, Edderton, Bucks Co.

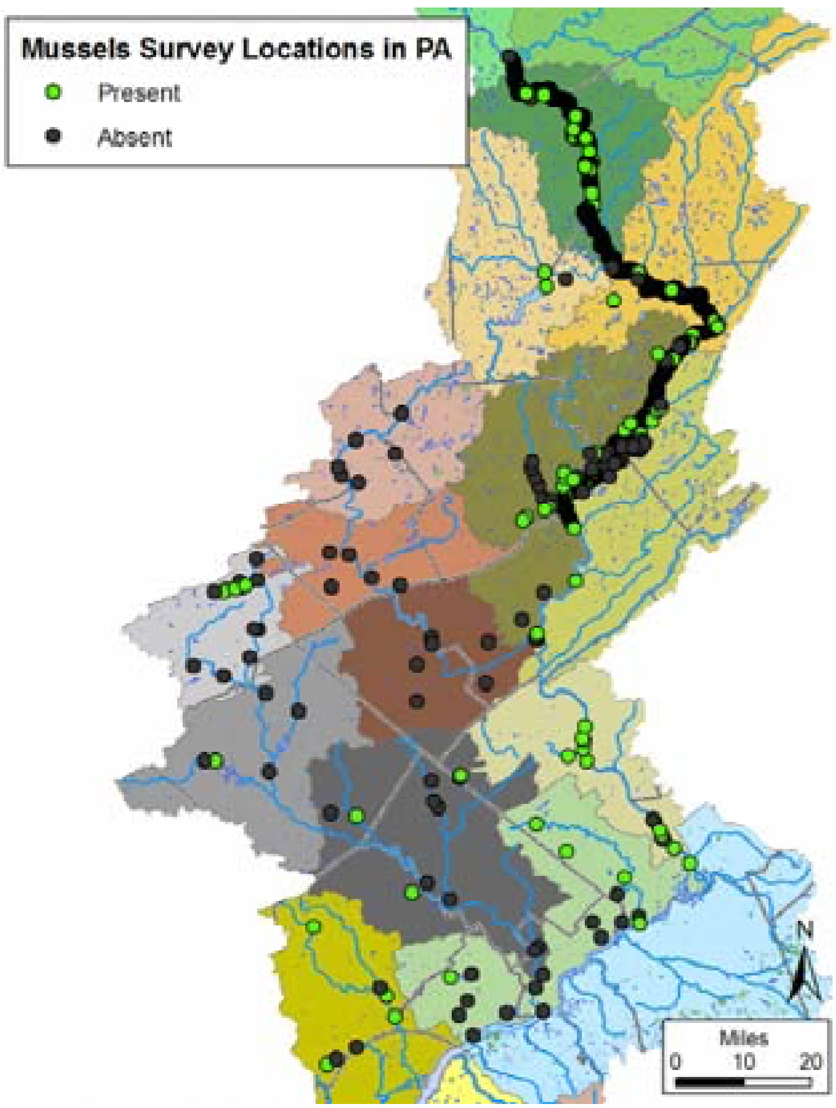


Figure 8.18. Mussel survey locations in Pennsylvania portion of the Delaware Basin

8.7. Zebra Mussels

The United States Geological Survey (2006) writes:

Zebra mussels (Dreissena polymorpha) are an invasive shellfish species that have been introduced to U. S. waters from their native waters in the Black and Caspian Seas. Zebra mussels are small (less than 2 inches) shellfish named for the striped pattern of their shells.

Zebra mussels were first discovered in North America in 1988 in the Great Lakes. The following year, zebra mussels escaped the Great Lakes basin and found their way into the Illinois and Hudson rivers. The release of larval mussels during the ballast exchange of a single commercial cargo ship, traveling from the north shore of the Black Sea to the Great Lakes, is the likely vector of introduction to North America. Rapid dispersal throughout the Great Lakes and major river systems occurred through passive drifting of the larval stage, and its ability to attach to boats navigating these lakes and rivers. Rapid range expansion was driven by barge. Overland dispersal is also a possibility. Trailering boats from infested waters to small inland lakes near unconnected by waterways, further spread zebra mussels. Under cool, humid conditions, zebra mussels can stay alive for several days out of water.

Zebra mussels are notorious for their biofouling capabilities by colonizing water supply pipes of hydroelectric and nuclear power plants, public water supply plants, and industrial facilities. Although there is little information on zebra mussels affecting irrigation, farms and golf courses could be likely candidates for infestations. Zebra muscles increase drag of navigational and recreational boating vessels. Fishing gear can be fouled if left in the water for long periods. Deterioration of dock pilings has increased when they are encrusted with zebra mussels. Continued attachment of zebra mussel can cause corrosion of steel and concrete affecting its structural integrity.

Zebra mussels can have profound effects on the ecosystems they invade. They primarily consume phytoplankton, but other suspended material is filtered from the water column including bacteria, protozoans, zebra mussel veligers, other micro-zooplankton and silt. At a 90% efficiency rate, zebra mussels are much more efficient at filtration of such small particles than are unionids and Asiatic clams. Filtering rate is highly variable, depending on temperature, concentration of suspended matter, phytoplankton abundance, and mussel size. Reductions in zooplankton biomass may cause increased competition, decreased survival and decreased biomass of planktivorous fish. Alternatively, because micro-zooplankton are more heavily impacted by zebra mussels, the larval fish population may be more greatly affected than later life stages. This may be especially important to inland lakes with populations of pelagic larval fish such as bluegills. Benthic feeding fish may benefit as opposed to planktivorous fish, or behavioral shifts from pelagic to benthic-feeding may occur. In addition, proliferation of macrophytes may alter fish habitat.

Zebra mussels represent one of the most important biological invasions into North America, having profoundly affected the science of Invasion Biology, public perception, and policy. In the 1980's Invasion Biology began to emerge as a true sub-discipline of ecology as evidenced by an exponential increase in scientific output on the subject (Raikow, unpubl. data). After the discovery of zebra mussels in 1988 the exponential rate of scientific output on invasions itself increased (Raikow, unpubl. data), the Non-indigenous Aquatic Nuisance Prevention and Control Act was written and passed, and invasions became a topic discussed in the media. Today biological invasions are described as the second leading cause of extinction behind habitat destruction. Aquatic invasions are a topic of much research. For these reasons the zebra mussel is often described as the "poster child" of biological invasions.

Figure 8.19 maps the distribution of the zebra mussel in the United States by 2006. The only reported sighting of the zebra mussel in the Delaware Basin was in a quarry in the Lehigh River subwatershed between Easton and Allentown, Pennsylvania. There have been several sightings of the zebra mussel in nearby watersheds of the Hudson River and the Susquehanna River/Chesapeake Bay basins. Zebra mussels may be detected in the future in the Delaware Basin due to marine ship ballast discharges to the Delaware Estuary or from mussels clinging to boats trailered to the Delaware Basin from docks in the nearby Hudson River or Chesapeake Bay basins.

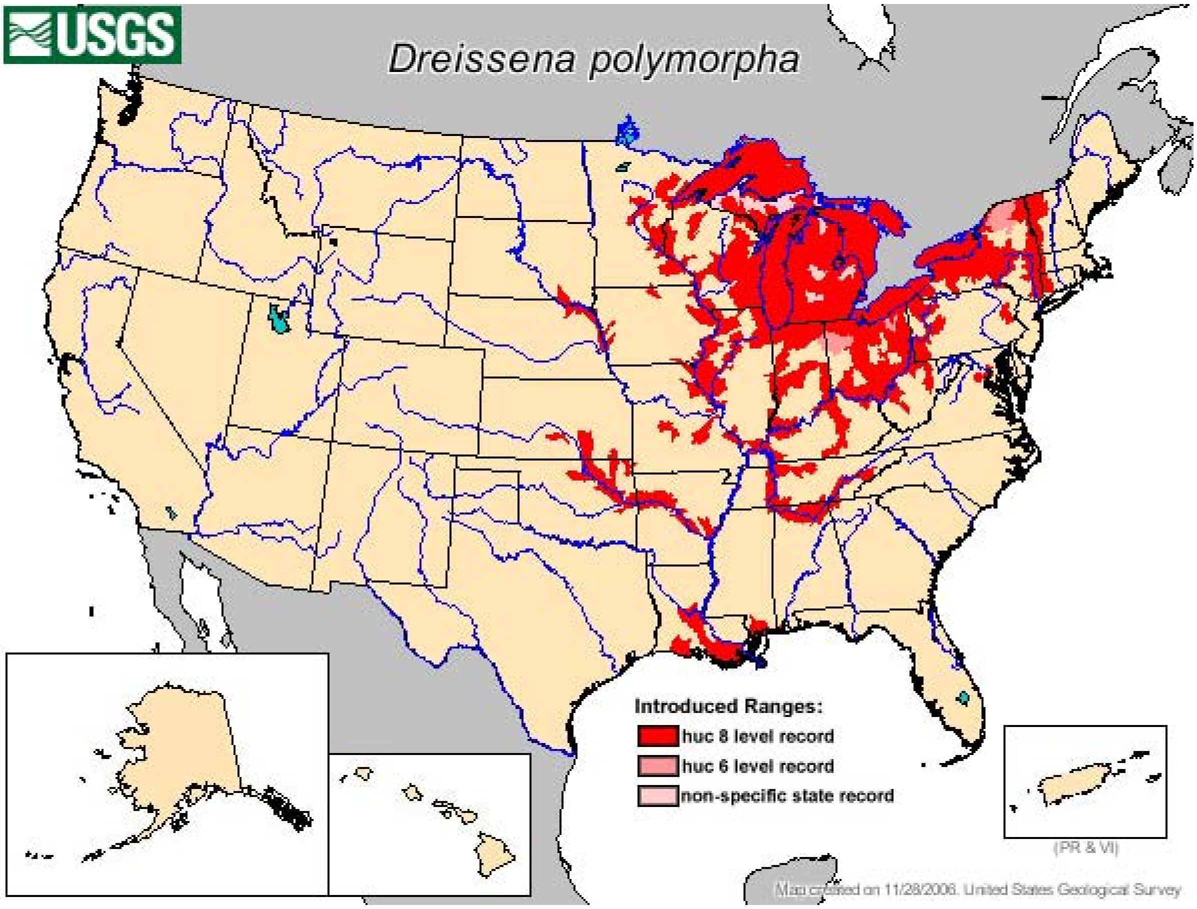


Figure 8.19. Zebra mussel distribution map. (USGS 2006)

8.8. American Shad

Princeton author John McPhee considered shad as "*America's founding fish*" because it reportedly served as a major food source for George Washington's starving troops at Valley Forge in the spring of 1778. The American shad (*Alosa sapidissima*) is the largest member of the herring family. It may grow to a length of 24 inches and weigh from 10 to 12 pounds, although the average shad weighs about 5 pounds. It is found along the Atlantic Coast of the United States from the Gulf of Saint Lawrence to Florida, but it is most abundant in the Delmarva area (UD Sea Grant, 2006). The American shad is a native species of the Atlantic Ocean and, like the striped bass, is an anadromous fish that migrates annually during the spring from the Atlantic to the Delaware River to spawn. Shad live their adult lives in the Atlantic Ocean. After they reach three to five years of age, the shad enter the bay and return to their natural freshwater streams to spawn. Some shad begin arriving in the Delaware streams as early as February, but the main spawning run occurs from late April until early June.

American shad begin their lives in freshwater, like the Delaware River. After hatching in the spring, the young shad (called "fry") grow rapidly, feeding on plankton and insects. Decreasing water temperatures and cool fall rains trigger a downriver migration to the ocean. Once in the ocean, where they live most of their lives, shad will migrate up and down the coast, from their winter range off the mid-Atlantic to their summer range in the Bay of Fundy, off Nova Scotia. After 3 to 5 years at sea, American shad will return in the spring to the river of birth to reproduce, or spawn. Fish that follow this migration pattern are called "anadromous" (DRBC, 2006).

Shad are recognized as one of the most popular fisheries on the Delaware River and is among the strongest and hardest fighting of all fish found in freshwater. Delaware River Basin communities such as Lambertville, New Jersey and Easton, Pennsylvania now hold annual shad festivals in the spring to celebrate the shads return to local waters.

The Delaware River once supported immense populations of shad. Between 1880 and 1890, fishermen caught between 10 to 20 million pounds of shad annually in the Delaware River. Around 1910, their numbers began to decline rapidly and by 1920 shad populations were so low that productive shad fisheries were no long a viable economic industry. Overfishing, degradation of water quality, and perilously low dissolved oxygen levels were principal factors in the decline of the shad. Many tributaries of the Delaware River have been dammed obstructing their spawning habitats.

The commercial shad fishery was and is valuable. At one time the Delaware River shad fishery was the largest on the Atlantic Coast. In 1896 over 14 million pounds of shad were caught with a value of $400,000 ($10,000,000 converted to 2006 dollars). The shad sport fishery has become increasingly popular. In 1996, the economic value of the recreational shad fishery in the Delaware River was $3.2 million based on a $50 per day replacement value assessment by the anglers (Dove and Nyman 1995). Converting to 2006 dollars, the recreational shad fishery is worth an estimated $6 million assuming an annual inflation rate of 3%.

Cooperative water quality management among state and federal agencies have been responsible for the return of shad to the Delaware Estuary. Although numbers have diminished since the 1990s, the Delaware River supports a viable commercial and sport shad fishery. The resurgent shad population is attributed to increased levels of dissolved oxygen in the Delaware Estuary due to upgrading sewage treatment facilities. The Delaware River's shad population should increase with improved water quality and by removing dams or installing fish ladders as impediments to fish spawning.

Shad Time Line (DELEP, DNREC, NJDEP, PADEP)

1896 Extensive spawning in tidal in tidal as well as non-tidal tidal portions of the Delaware River.

1960s/1970s Spawning only in the upper freshwater portion of their range above Trenton due to low oxygen levels and pollution in river between Wilmington and Trenton.

1974 Chittenden asserts that due to water quality concerns and the threat of a main channel impoundment *"extirpation of the remnant (shad) runs is a distinct possibility"*.

1980s/1990s Evidence of spawning again in the tidal river downstream of Trenton as DO levels increase.

2002 29,029 shad caught in Delaware River by Delaware DNREC, Division of Fish and Wildlife.

2005 Almost 200,000 migrating shad detected along Delaware River at Lambertville, New Jersey.

At Lambertville, New Jersey the estimated shad population has ranged from 100,000 to 400,000 fish per year between 2000 and 2005, down from highs of 600,000 to 800,000 fish per year during the 1980's, but above the 100,000 fish recorded annually during the 1970s (Figure 8.20).

From 2003 – 2005, the number of juvenile shad collected at Trenton, Byrum-Lumberville, Phillipsburg, Delaware Water Gap and Milford along the Delaware River has ranged from 10,000 to 15,000 per year (Figure 8.21) and the catch per unit effort has ranged from 250 to 350 fish.

Commercial shad landings in the Delaware Basin have decreased from a high of over 600,000 pounds in Delaware and 250,000 pounds in New Jersey in 1990 to 100,000 pounds in Delaware and about 80,000 pounds in New Jersey in 2006, but up from under 50,000lbs in New Jersey in 1954 (Figure 8.22).

Table 8.6 summarizes Delaware DNREC, Division of Fish and Wildlife trawl survey reports on American shad catches in the Delaware River.

Table 8.6. American shad recreational catches in the Delaware River
(Delaware DNREC, Division of Fish and Wildlife)

Year	Caught	Harvested	Caught/hr
1986	56,320	27,471	0.19
1994	3,141	16,387	0.25
2002	29,029	6,068	0.20

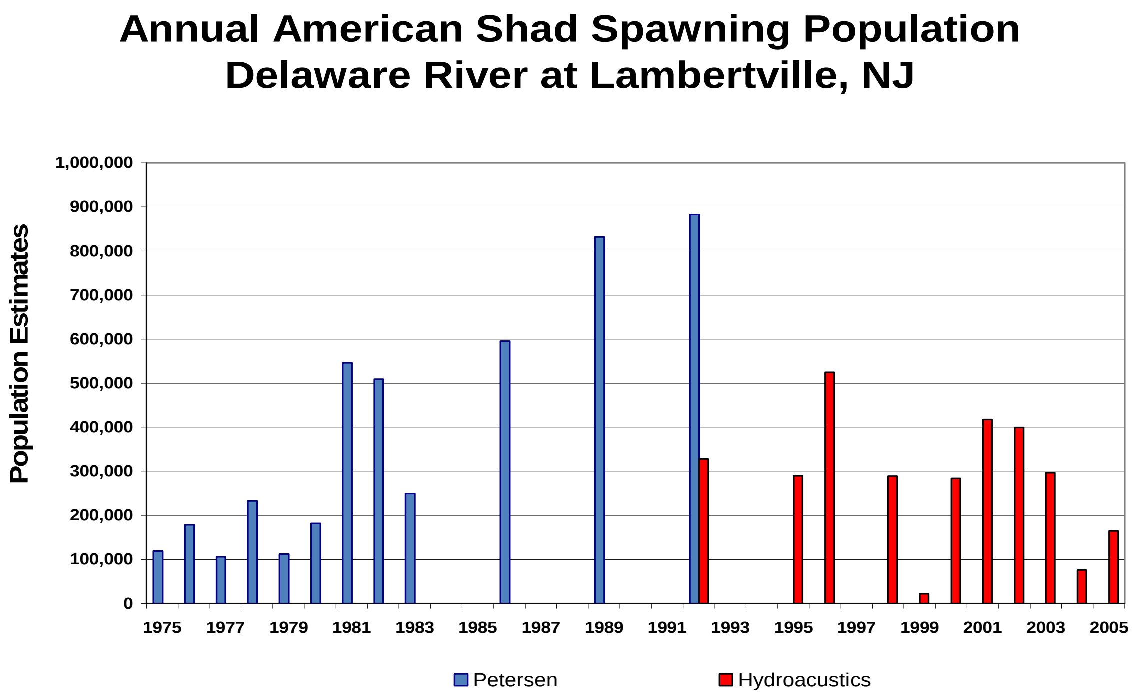


Figure 8.20. American shad population in the Delaware River at Lambertville, New Jersey.

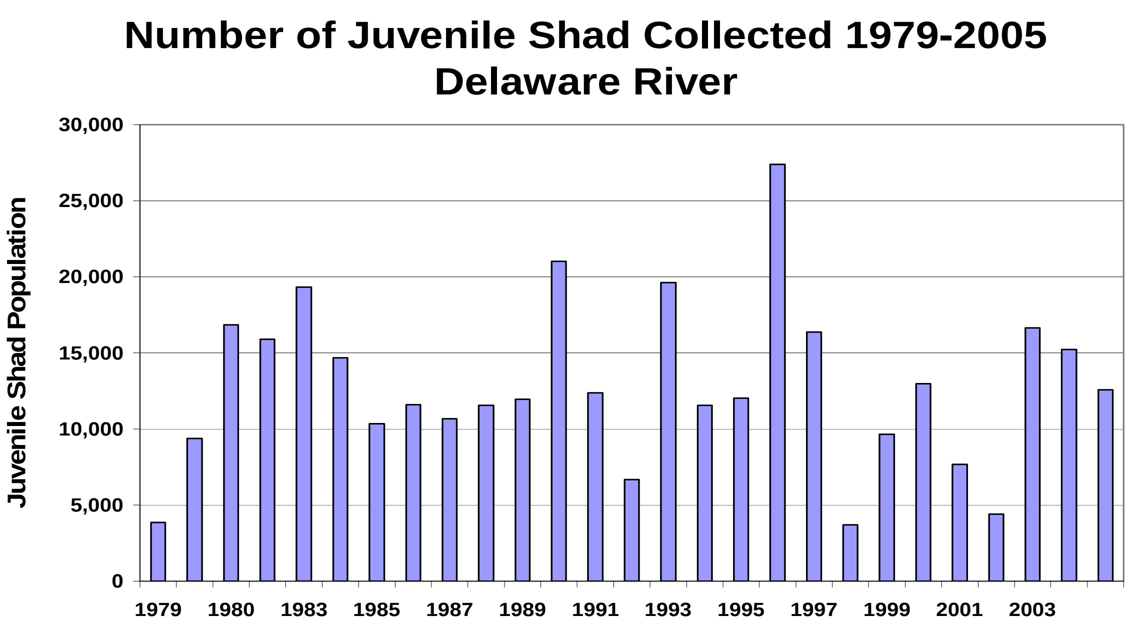


Figure 8.21. Catch of juvenile shad along the Delaware River.

Figure 8. **Commercial landings (lbs) of American shad, by state, in the Delaware River Basin, 1954-2006 (Source: ASMFC 2007a, NJ Division of Fish and Wildlife, DE Division of Fish and Wildlife). Landings from the State of Delaware are not available before 1985.**

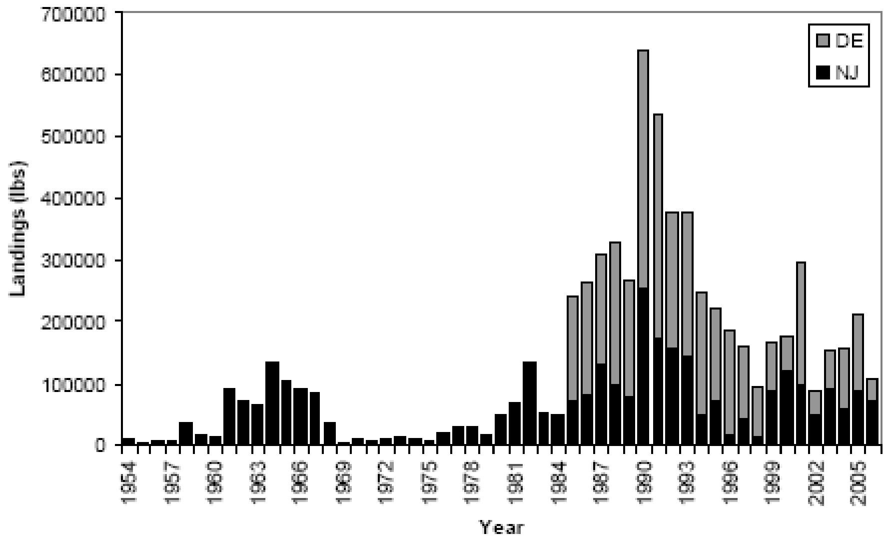


Figure 8.22. Commercial landings of American shad in the Delaware River Basin. (ASMFC,NJDEP. DNREC, 2007)

In 2004 along the Schuylkill River, 91 American shad were counted, the highest recorded. The only previous 24 hour counts were in 1979 when 2 shad were counted between April 30, 1979 and May 31, 1979. During 2005, 41 American shad were counted, lower than 2004, but higher than annual counts during the 1970's and 1980's.

Along the Lehigh River, close to 1000 shad were counted at Easton and Glendon, up from 750 shad in 2004 but down from 6,800 shad in 2001 (Table 8.7 and Figure 8.23)

Table 8.7. Fish monitoring along the Lehigh River.

Lehigh River - Easton Dam Fishway												
	Pre-Fishway Modifcation							**Post-Fishway Modification**				
Fish	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
American shad	87	873	1141	1428	3293	2346	2094	4740	3314	422	754	675
Striped bass		19	5	1	0	0	0	0	1	0	1	3
American eel		1	4	*	2*	4*	1*	*	12*	*	1*	35
Trout		109	43	79	193	111	231	267	309	75	199	313
Lehigh River - Chain Dam Fishway												
	Pre-Fishway Modification							**Post-Fishway Modification**				
Fish			**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
American shad			496	126	694	479	645	2057	1479	40	.	324
Striped bass			2	0	0	0	0	0	0	0	.	0
American eel			34	*	32*	*	13*	*	80*	5*	.	401
Trout			96	119	238	220	318	205	321	106	3	352

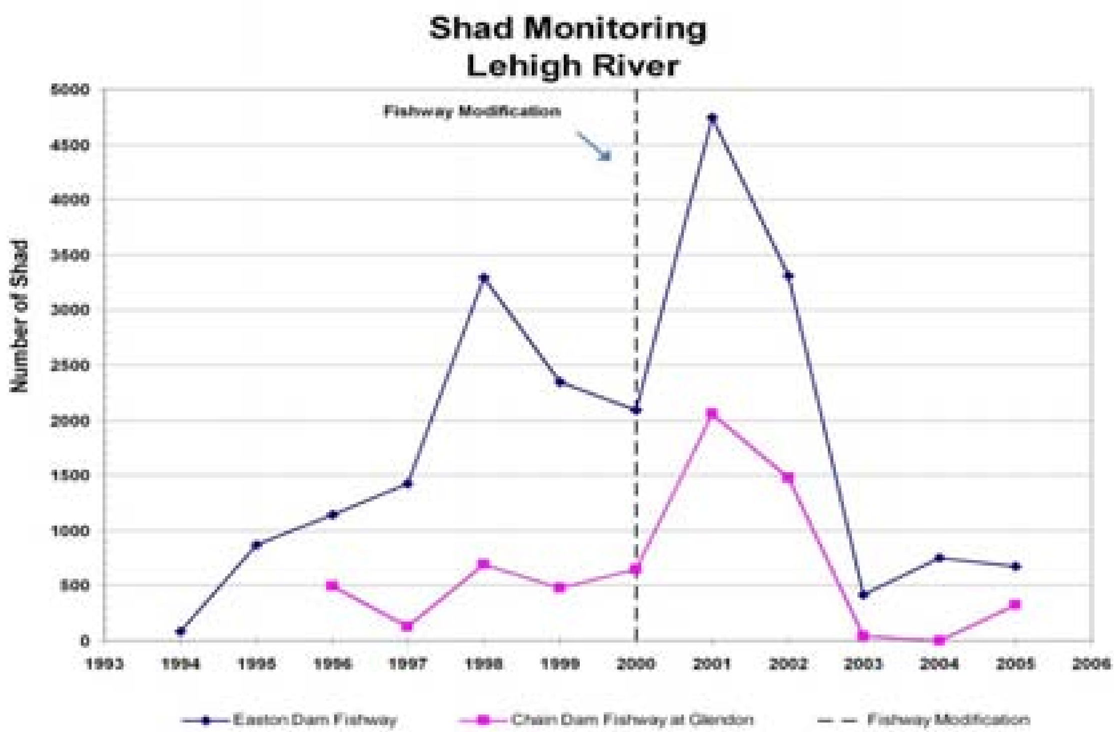


Figure 8.23. Shad monitoring along the Lehigh River.

While the Delaware River is the longest free-flowing river east of the Mississippi, 100s of small dams were built in tributaries to the Delaware from its northernmost reaches in upstate New York to the lower Delaware Bay. Historically, dams were built to impound water for mills, agricultural and municipal water supplies, and to create lakes and ponds. These dams prevent anadromous fish, such as striped bass or shad, from completing upstream spawning migrations.

Today, a national effort is underway to remove obsolete dams or install fish ladders for migratory fish to regain access to lost habitat. Several dams have been removed from the Schuylkill River watershed upstream from Philadelphia. Fish ladders have been constructed at dams along coastal plain tributaries in Delaware and New Jersey (Table 8.8). Since 1991, fish ladder construction has opened up approximately 165 miles to fish migration in the Delaware Estuary. The Brandywine Conservancy is leading an effort with the Delaware DNREC to install fish ladders and rock ramps or remove dams along the Brandywine Creek though Wilmington (Lonsdorf 2007). Since 2005, three dams have been removed along Pennypack Creek in Philadelphia with a fourth slated for removal and a fifth dam planned for a rock ramp fishway

Along the Schuylkill, Fairmount Dam (mile 9) has a vertical slot fishway in place and was planned to be rebuilt by 2005. The upgrade has been delayed until at least 2006 due to a shortage of funds within the U.S. Army Corps of Engineers for the project. Flat Rock Dam (mile 15) groundbreaking ceremonies were held for construction of a fishway in March 2004. The Norristown Dam (mile 21) and Black Rock Dam (mile 37) are scheduled to have fish ladders in place by 2008. Three dams will be breached or removed at Plymouth Dam (mile 18), Vincent Dam (mile 42) , and Felix Dam (mile 79).

Table 8.8. Alaska steepass fish ladders in the Delaware Basin.

Delaware	New Jersey
McGinnis Pond	Sunset Lake
Coursey Pond	Cooper River Lake
McColley Pond	Stewart Lake
Garrison Lake	Newton Lake
Moores Lake	

8.9. Brook Trout

The native brook trout is the state fish of New Jersey, New York and Pennsylvania. Delaware River Basin cold water streams support reproducing wild trout in New Jersey, New York, and Pennsylvania. Delaware has no wild trout streams as the waters become too warm during the summer to support reproducing populations of native trout. Brook trout are the only cold water fish native to the streams in the Delaware River Basin. Many streams are cold enough and pure enough to support other stocked trout species such as brown trout and rainbow trout, these non - native species were introduced from Europe and California, respectively.

The brook trout thrives in cold water streams with heavily forested watersheds and low densities of human population. According to the Eastern Brook Trout Joint Venture (2005), the brook trout population is declining due to:

- Climate Change – temperature increases across the eastern United States are likely to warm the streams and decrease the distribution and abundance of the brook trout, particularly in watersheds at more southerly latitudes.

- Acid Deposition – Airborne emissions of sulfur dioxide, nitrogen oxide, and ammonia; and mine drainage have increased acidity of the streams to the point where more than 2,000 miles of trout streams in Pennsylvania have been adversely affected. Promisingly, with the passage of Clean Air Act Amendments in 1990, acid producing emissions have reduced and water chemistry has improved, notably in northern Pennsylvania and New York.

- Watershed Changes – Increased human development and deforestation have increased water temperatures due to lack of canopy cover and increased sediment loads which disturb the stream substrate and spawning areas.

Figure 8.24 maps remaining eastern brook trout habitat in the Delaware Basin according to data from the Eastern Brook Trout Joint Venture. Approximately 15% of native brook trout habitat is extirpated in the Delaware Basin including portions of the following subwatersheds: Christina River (LE1), middle and lower Schuylkill (SV2, SV3), and lower Lehigh River (LV3). About 50% of the basin remains as brook trout habitat, although somewhat to greatly reduced.

The NJDEP (2004) designates the following wild trout streams in the New Jersey portion of the Delaware River Basin.

Bear Creek (Southtown)	Ledgewood Brook (Ledgewood)
Dark Moon Brook	Merrill Creek (Stewartsville)
Bear Brook (Johnsonburg)	Mill Brook (Montague)
Dunnfield Creek (Delaware Water Gap)	Parker Brook (Stokes State Forest)
Jackson Brook (Mine Hill Twp.)	Stephensburg Creek (Stephensburg)
York Brook (Little York)	Stony Brook (Stokes State Forest)
Van Campens Brook (Delaware Water Gap NRA)	

Trout production waters in New Jersey (Figure 8.25) have the following attributes:

- High gradient streams in the ridge and valley, highlands, and piedmont physiographic provinces.
- Limestone, shale and granite
- Cooler water temperatures
- Heavily forest covered watersheds with little impervious cover

All streams in the New York portion of the Delaware Basin are rated to support wild trout.

The Pennsylvania Fish and Boat Commission classifies streams according to self-sustaining wild trout populations. The classification focuses on native brook trout streams and highlights populations that have not been stocked sustain themselves as needing special recognition. The Commission has classified trout waters as follows: stream sections classified as A (excellent standing stock of wild trout), B (good standing stock of wild trout), C (fair standing stock of wild trout), and D (few to no wild trout. Figure 8.26 tallies the mileage of Pennsylvania wild trout streams in the Delaware River Basin.

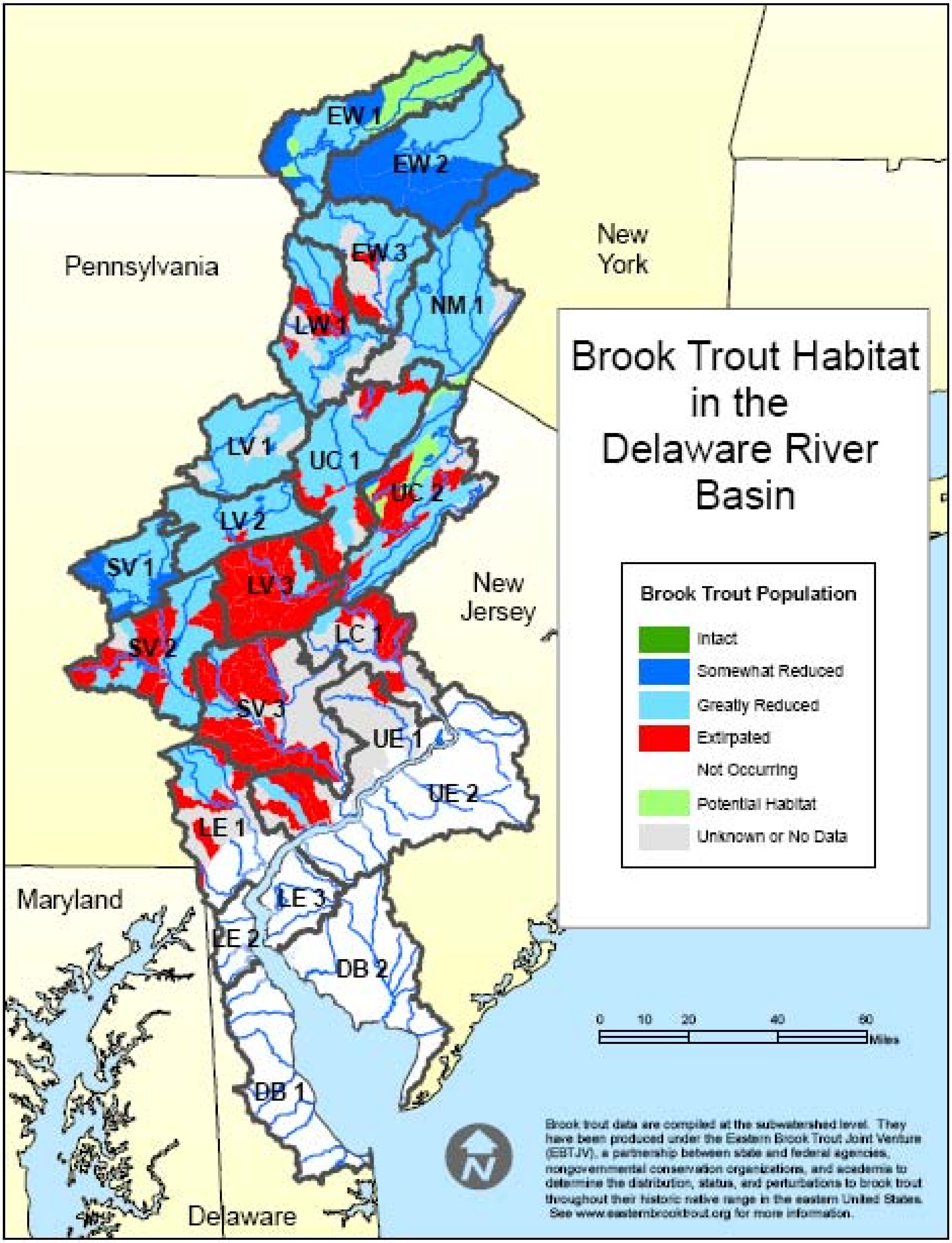


Figure 8.24. Brook trout habitat in the Delaware River Basin.
(Eastern Brook Trout Joint Venture, Conservation Strategy Work Group, 2005).

Table 8.9. Brook trout habitat in the Delaware River Basin.

Subwatershed	Brook Trout Habitat (% of subwatershed)		
	Intact or Reduced	**Extirpated**	**Not occuring**
Upper Region (NY and PA)			
EW · East/West Branch			
EW1 West Branch (Cannonsville)	100	0	0
EW2 East Branch (Pepacton))	100	0	0
EW3 Mainstem (above Narrowsburg)	70	10	20
LW1 · Lackawaxen	60	20	20
NM 1·Neversink-Mongaup	75	0	25
Central Region (PA and NJ)			
UC ·Upper Central watersheds			
UC1 Pennsylvania tributaries	70	25	5
UC2 New Jersey tributaries	65	30	5
LV ·Lehigh Valley			
LV1 Above Lehighton	75	0	25
LV2 Above Jim Thorpe	95	5	0
LV3 Above Easton	10	90	0
LC1 ·Lower Central (above Trenton)	4	40	55
Lower Region (PA, NJ and DE)			
SV ·Schuylkill Valley			
SV1 Above Reading	100	0	0
SV2 Above Valley Forge	50	45	5
SV3 Head of tide at Philadelphia	10	55	40
UE ·Upper Estuary (Phila, Camden)			
UE1 Pennsylvania piedmont	0	5	95
UE2 New Jersey coastal plan	0	0	100
LE ·Lower Estuary Watersheds			
LE1 Christina River	25	25	50
LE2 C and D Canal, DE	0	0	100
LE3 Salem River, NJ	0	0	100
Bay Region			
DB ·Delaware Bay (NJ and DE)			
DB1 Delaware coastal plain	0	0	100
DB2 New Jersey coastal plain	0	0	100

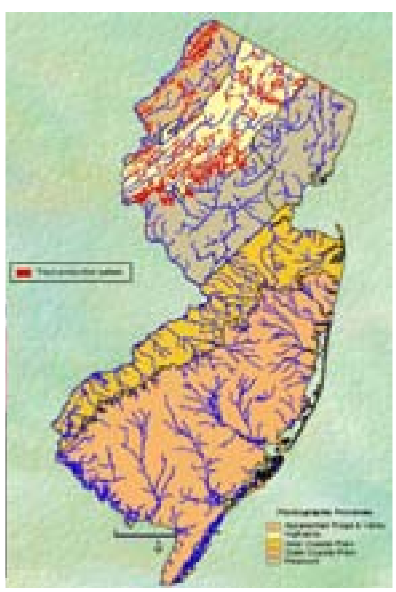


Figure 8.25. Trout production waters in New Jersey. (NJDEP)

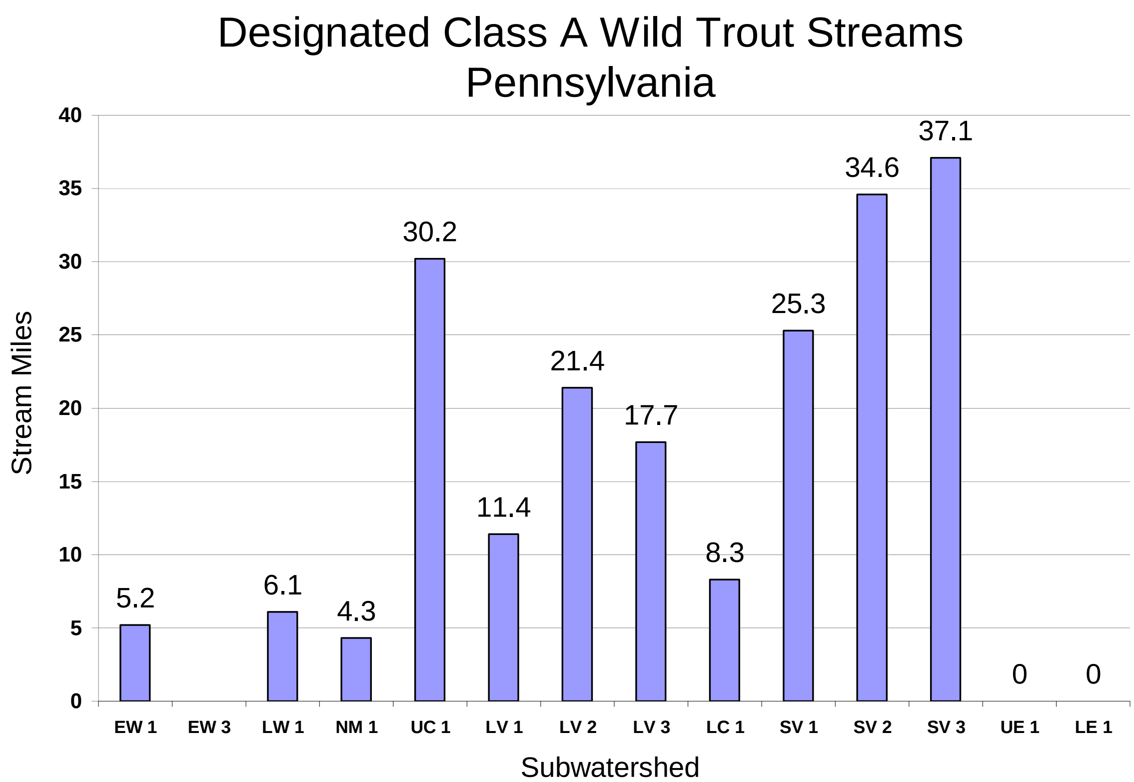


Figure 8.26. Class A wild trout streams in Pennsylvania portion of Delaware Basin. (PA Fish and Boat Commission)

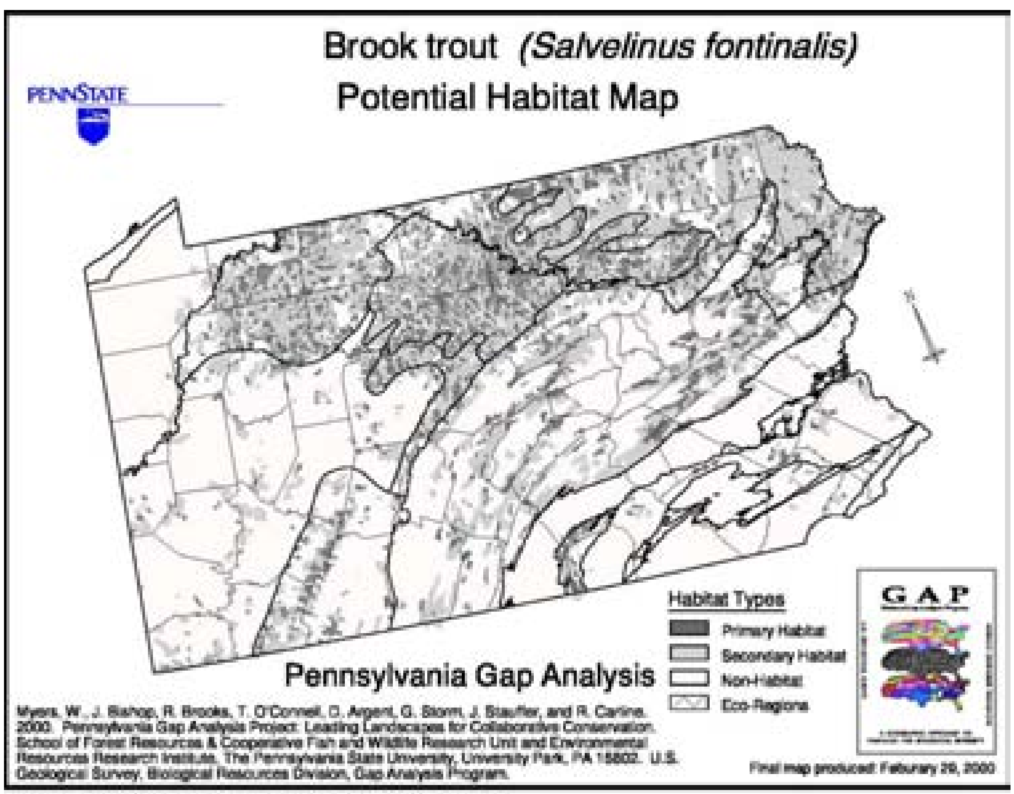


Figure 8.27. Brook trout potential habitat map in Pennsylvania. (Penn State University)

8.10. Striped Bass

The return of the striped bass to the Delaware River is a watershed success story. Fishery management and water quality improvements have returned bass to high levels not seen in over 50 years. A striped bass fishing moratorium was imposed in 1985 by Delaware, New Jersey, Pennsylvania and mid Atlantic states. Improved dissolved oxygen in the Delaware Estuary between Wilmington, Philadelphia, and Trenton have led to resurging striped bass fishery stocks. The striped bass (*Morone saxatilis*) is anadromous as it lives mostly in the ocean but returns to fresh water to spawn. Striped bass have long been commercially and recreationally important in the Delaware Bay (Dove and Nyman, 1995).

Spawning populations of the striped bass were nearly eliminated by pollution from wastewater discharges between Wilmington and Philadelphia. Dissolved oxygen levels were so low that the adult striped bass could not migrate past the oxygen block to spawn. Along tributaries, dams prevented striped bass from reaching their spawning grounds. Virtual disappearance of bass in the late 1970s led resource managers to close the fishery and helped stimulate increased research on hatchery production of striped bass. In the last 25 years, the striped bass has made a successful comeback to the estuary. The Delaware Estuary is one of the major striped bass producing areas on the East Coast.

The Delaware DNREC conducts annual sampling of Delaware Estuary striped bass populations (Kahn, Zimmerman, and Murphy 2006). The DNREC counted 40,000 striped bass caught in the Delaware Estuary in 2000 and 20,000 fish in 2005, up from 1990 to 1994 when less than 5,000 striped bass were caught (Figure 8.28). The Delaware juvenile striped bass index improved from less than 1 during 1980 – 1987, to 2 or more for all years since 1992 except for 2002 (Figure 8.29). Between 2000 and 2005, the Delaware recreational striped bass harvest in the Delaware Estuary ranged from 200,000 to 300,000 pounds per year, up from 20,000 pounds harvested between 1990 and 1994.

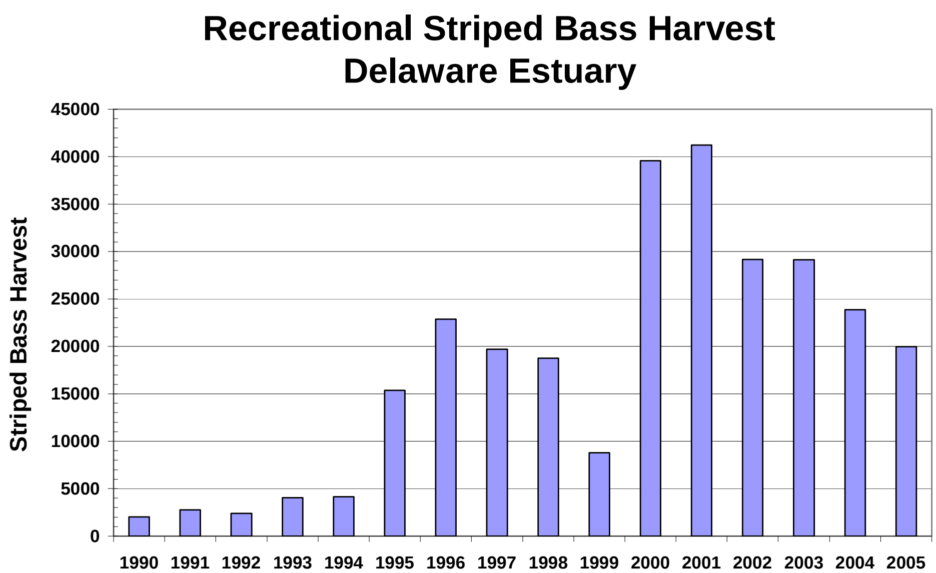


Figure 8.28. Recreational striped bass harvest in the Delaware Estuary. (DNREC 2006)

Striped Bass Milestones

Middle 1800s	Anecdotal records indicate striped bass are abundant before Industrial Revolution.
1896	Fisheries report to Pennsylvania governor cites 76 lb striper above Gloucester, N. J.
1952	Ichthyologist Edward Raney cites Delaware River as *"outstanding example of destruction of bass habitat by industrial and domestic pollution"*.
1960s	DO in Delaware River from Wilmington to Philadelphia reach near zero from May into autumn.
1972	Congress passes Federal Clean Water Act.
1970s/1980s	Cities upgrade 5 sewage treatment plants resulting in DO improvements in the lower Delaware River.

Early 1980s	Spawning stocks start to decline due to over fishing. DO levels increase as water quality improves.
1985	Delaware, New Jersey, Pennsylvania, and ASFMC close striped bass fishery.
1990	States reopen striped bass fisheries. < 5,000 stripers caught by Delaware recreational fishermen.
1995	Atlantic States Marine Fisheries Commission declares East Coast striped bass stocks restored.
1998	ASMFC declares Delaware River striped bass stocks restored.
2005	Delaware recreation striped bass landings measured at 250,000 pounds or 20,000 striped bass.

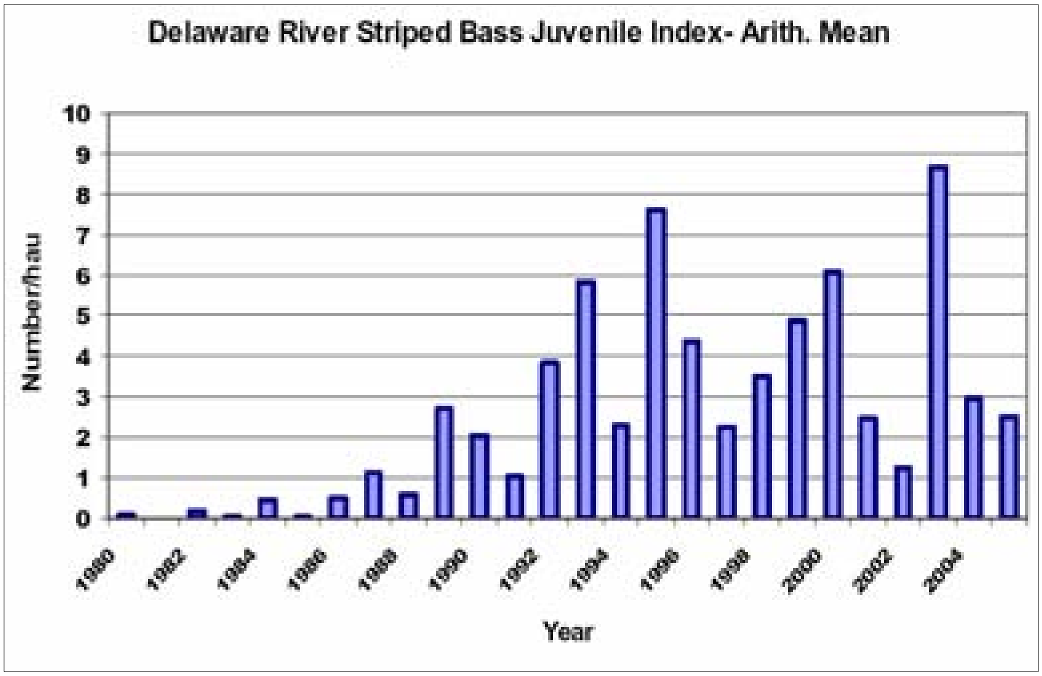


Figure 8.29. Juvenile striped bass index in the Delaware River. (DNREC 2006)

8.11. Atlantic Sturgeon

The Delaware River and Bay once supported the largest Atlantic sturgeon population in the world. The Atlantic sturgeon was such a lucrative fish that one-time boom town and now submerged Caviar (Bayside) near Greenwich, New Jersey was founded to process the roe for world export. Record harvests combined with poor water quality and low reproductive rates caused the collapse of the population during the late 1800's. Large habitat alterations such as ship channel dredging coupled with boat strikes and by catch in fish trawls and nets are factors in the delayed recovery of the Atlantic sturgeon. Telemetry indicates this fish utilizes the main channel with habitats of coarse sediments. Due to changes in salinity and bottom habitat it's likely that sturgeon spawn far upstream (between Wilmington and Trenton) from their historic spawning reaches which were downstream from Wilmington (Fox *et al.,* 2007)

The Atlantic Sturgeon (*Acipenser oxyrhynus*) is an ancient fish and top line predator that lives in the Delaware River and estuary and other large east coast rivers in North America from Labrador to Florida. The Delaware Estuary was at one time considered the hub of the Atlantic sturgeon fishery, but at the present time only the Hudson Estuary in New York has enough stock to support a viable fishery along the Atlantic coast. The Atlantic sturgeon enters the river in late winter and spawns upstream from Wilmington during April and May when water temperatures are 55 to 65 deg F. After spawning the adults swim to the sea over the summer and fall. Sturgeons are deep water fish and will spend most of their time near the deep river channel so dredging could be particularly injurious to their habitat.

Sturgeons are prized for their caviar (roe) and smoked fish. Prior to the harvest moratorium, the large size of the Atlantic sturgeon and high market value of caviar made it the second most economically valuable fish in the Delaware

Estuary. In 1986, the Atlantic sturgeon was valued at $3,000 per fish (PDE, 1995), which computes to $5,000 per fish when converted to 2006 dollars assuming an annual inflation rate of 3%.

According to annual catch rates by the DNREC Division of Fish and Wildlife, the Atlantic sturgeon is in serious decline (Figure 8.30). In 1991, 32 Atlantic sturgeon were caught per net-hour. By 1998 the number of fish dwindled to 2 per net-hour. By 2004, 2 fish were caught and no fish were caught in 2005.

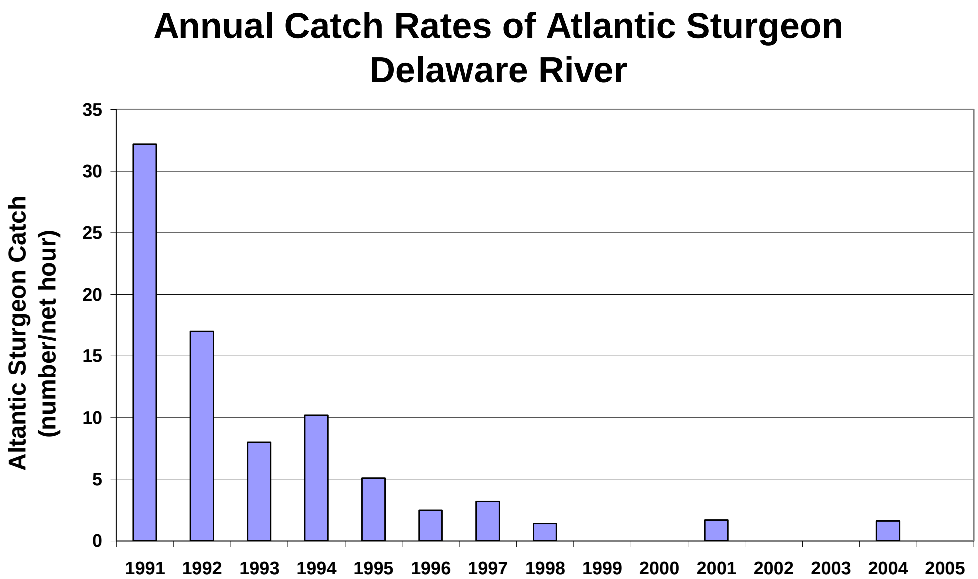


Figure 8.30. Annual catch rates of Atlantic sturgeon collected in the Delaware River. (DNREC 2006)

The National Marine Fisheries Service and the states of New Jersey and Delaware have enacted fishery management measures to restore the Atlantic sturgeon stocks. In 1991, a 7 feet size minimum was adopted for anyone catching a fish. By 1998, a complete harvest moratorium was imposed. The benefits of a fishery closure may take 15 to 25 years to accrue without more active intervention. The U.S. Fish and Wildlife Service was petitioned to add the Atlantic sturgeon to the Federal endangered species list. The Atlantic sturgeon is on the Delaware endangered species list but not on the New Jersey or Pennsylvania state list.

Fox and Simpson (2006) tracked the movements of the Atlantic sturgeon in the Delaware Estuary (Figures 8.31 and 8.32). Fishing locations were in the Delaware River between Wilmington, Delaware and the PA/DE state line and in the estuary off the mouth of the Smyrna River and Liepsic Rivers. Sediment substrate and manual tracking locations were plotted in the Delaware River off Marcus Hook and Chester below the Commodore Barry bridge.

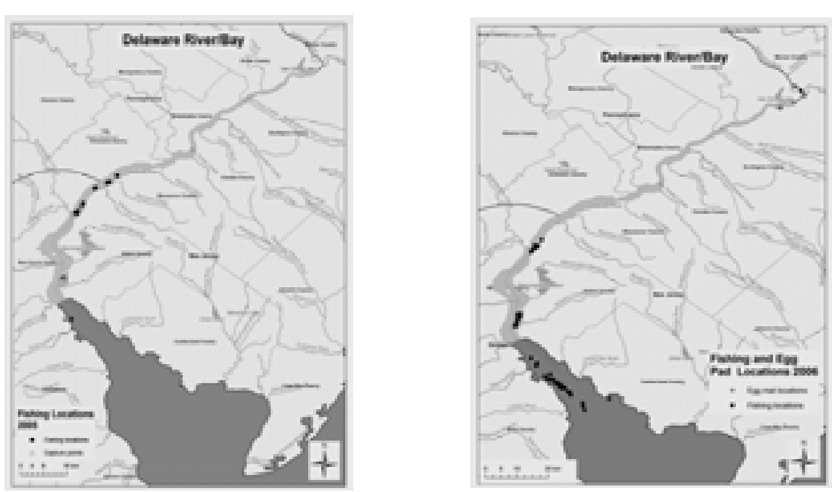


Figure 8.31. Atlantic sturgeon fishing locations along the Delaware Estuary in 2005. (Fox and Simpson, 2006)

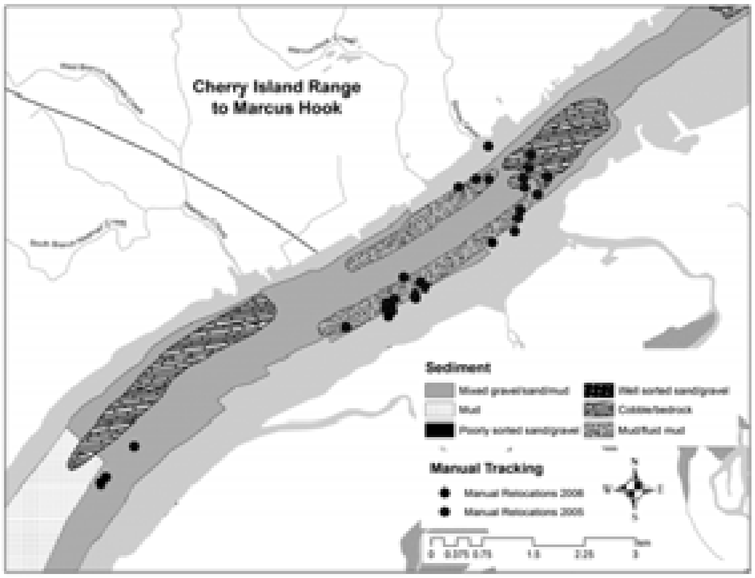


Figure 8.32. Atlantic sturgeon tracking locations in the Delaware Estuary. (Fox and Simpson, 2006)

8.12. Weakfish

The weakfish or sea trout, Delaware's state fish, returned to the Delaware Estuary in great numbers during the 1990s and 2000 – 2002 but are down recently (Figure 8.33). Delaware DNREC trawl surveys indicate weakfish abundance has annually exceeded 50 fish per nautical mile since 1991 with a peak of over 200 fish in 2000 and 175 fish in 2002. These numbers are in contrast to the abundance surveys during the 1980s when less than 50 fish per mile were sampled in the Delaware Estuary. By 2005 weakfish numbers were again down to less than 50 fish per mile.

The weakfish (*Cynoscion regalis*) gets its name because it has weak mouth tissues that are easily torn by hooks. Weakies use the Delaware Bay during summer as a breeding and feeding ground. The weakfish may grow to 3 feet long and over 17 pounds (Delaware Sea Grant 2006). The weakfish range is along the Atlantic coast from Florida to Massachusetts and is centered in the Delaware Estuary. The sea trout is an important recreational and commercial fishery important to the Delaware and New Jersey coastal economy. Weakfish move south into the Atlantic Ocean off the Carolinas during autumn and winter and migrates close to the Delaware Bay for peak spawning occurring from May to June when the water temperature reaches 66 deg F. Weakfish consume smaller species such as herring, crabs, clams, anchovies and croaker. Weakfish inhabit the open waters of the estuary from the capes to Philadelphia and virtually every tidal tributary. The primary concern about the viability of weakfish is water quality and over fishing (PDE 1995).

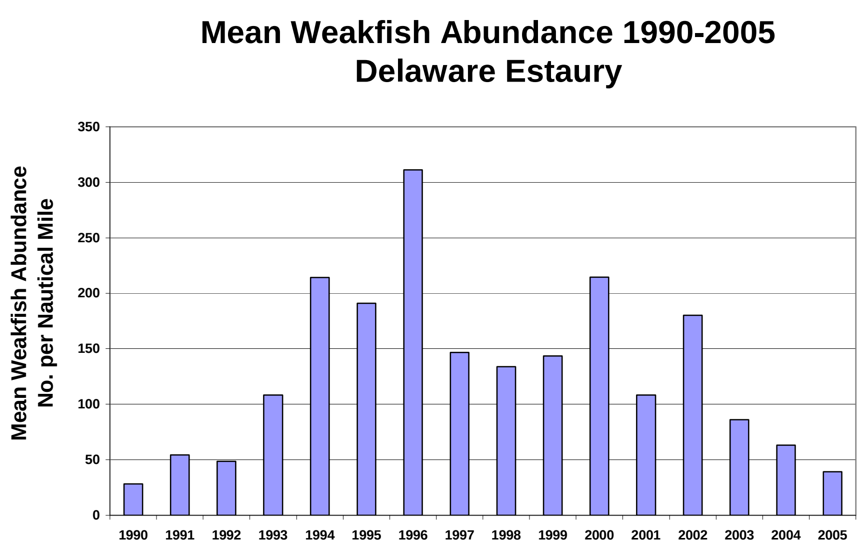


Figure 8.33. Mean weakfish abundance in the Delaware Estuary. (DNREC 2006)

8.13. Summer Flounder

The summer flounder (*Parallichthys dentatus*) is recovering in the Delaware Estuary. The fluke is one of the larger flounders. It feeds on fish, squid, shrimp, and crabs, and may grow to 37 inches and 26 pounds. Since the implementation of management plans for commercial and recreational summer flounder fisheries in the early 1990s by the National Marine Fisheries Service, the species has been improving over their entire range. The summer flounder fishery ranks among the three most important recreational fisheries in the Delaware Bay (PDE 1995).

According to Figure 8.34, by 2005, the estimated biomass of summer flounder in the Delaware Bay was around 50,000 metric tons, up from 30,000 metric tons in 2000 and up even more from the early 1990's when the biomass was around 20,000 metric tons (NMFS 2006).

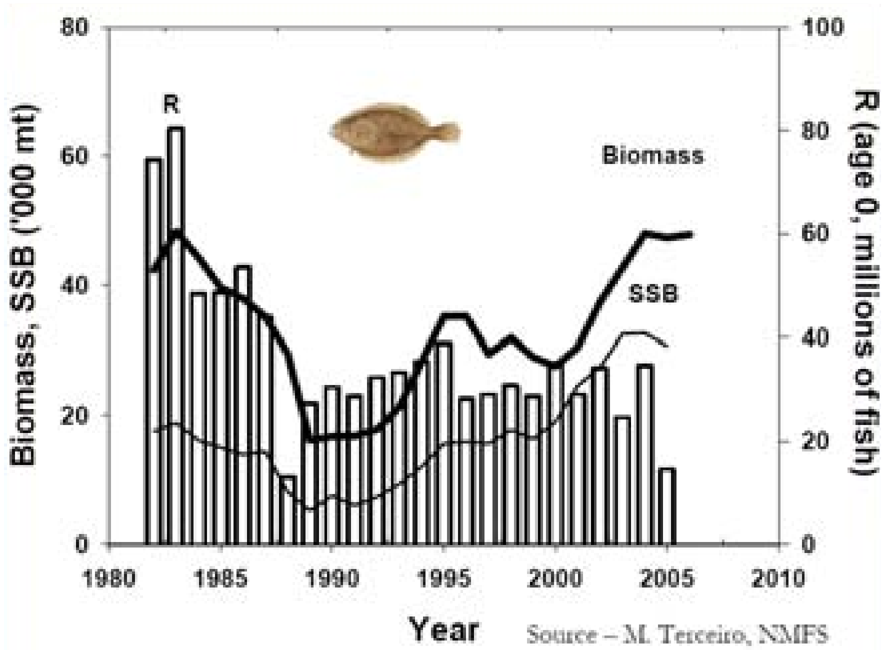


Figure 8.34. Biomass of summer flounder in the Delaware Bay. (NMFS 2006)

8.14. Louisiana Waterthrush

Lyle Sherwin of the Penn State Center for Watershed Stewardship describes the humble Louisiana waterthrush (*Seiurus motacilla*) as an excellent biological indicator of healthy land and water environments through the entire Delaware River Basin. It is the only obligate headwater riparian songbird in the Delaware River Basin and the entire eastern United States (Mulvihill 1998). The Louisiana waterthrush returns from its South America and Central America winter range to nesting grounds in April to share cold spring waters with trout. The ecology of the species is tied to specialized riparian habitats in breeding grounds, migration, and neotropical wintering areas (Carline et. al. 1993).

Highest breeding densities are reached in forested upland brooks and low order streams of medium-high gradient (Eaton 1958). Nesting has been confirmed at all elevations even in urban Philadelphia (Brauning 1992). Nesting records in the city extend back more than a century. The Louisiana waterthrush is an excellent biological indicator because breeding populations are recorded in all of the physiographic regions encompassed by the watershed (Brauning 1992).

The breeding abundance of the Louisiana waterthrush correlates positively with riparian tree density and continuity (Anderson et. al. 1981). However, breeding success, in terms of nest density, is a robust metric because it is so closely tied to the bird's reliance on aquatic macroinvertebrates. In a paired watershed study of pristine and polluted watersheds impacted by acid atmospheric deposition and abandoned mine drainage on the Laurel Hill of southwestern Pennsylvania, Mulvihill (1998) found more than double the number of nests per kilometer of stream in unpolluted streams versus acidified streams with much lower species diversity and abundance of macroinvertebrates.

The Louisiana waterthrush's value as a biological indicator of watershed health is also being utilized by the National Park Service in the Environmental Condition assessment protocol of the Delaware Water Gap National Recreation Area which is expected to serve as a national model for other NPS sites. From the standpoint of the availability of credible scientific data to monitor temporal trends in indicator metrics, the USGS Fish and Wildlife Service Migratory Bird Station at Laurel, Maryland is the repository for long-term population data on the Louisiana waterthrush throughout its' range in the Delaware River Basin. Finally, some recent data suggest an upward trend in populations and distribution of the species-a positive environmental health indicator we can hope will be reflected in other biological and physical attributes of the Delaware River Basin.

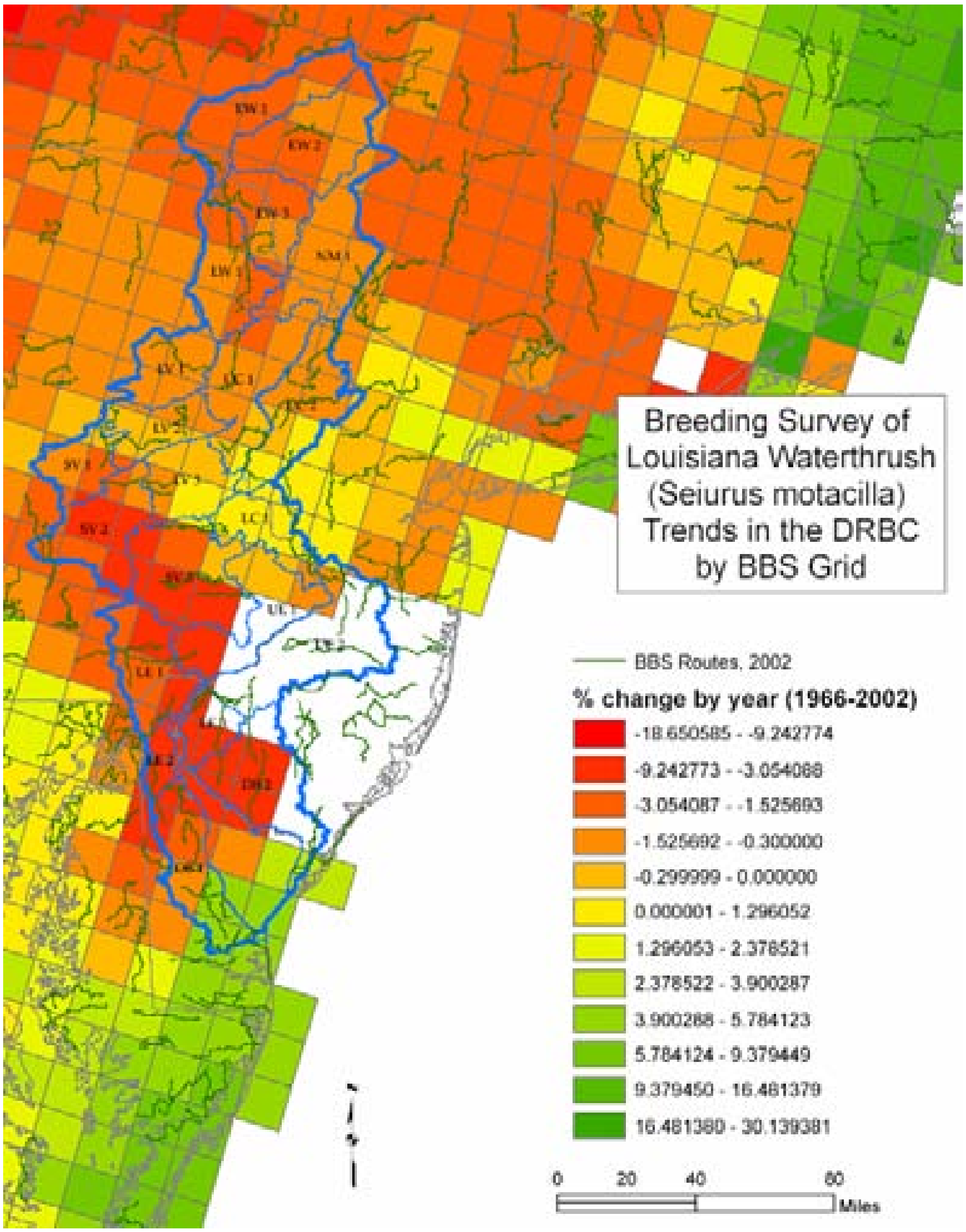


Figure 8.35. Louisiana waterthrush breeding survey trends in the Delaware River Basin.

8.15. Red Knot

The Delaware Estuary is the largest stop over for shorebirds in the Atlantic flyway and is the second largest staging site in North America. About 425,000 to 1,000,000 migratory shorebirds converge on the Delaware Bay to feed and build energy reserves prior to completing their northward or southward migrations. Red knot, dunlin, ruddy turnstine, sanderling, semi-palmated sandpiper and other migratory shorebirds feed on horseshoe crabs almost exclusively during their stopover on the Delaware Bay. Each bird can eat thousands of eggs per day (PDE 2002).

Both Delaware and New Jersey have recently imposed moratoriums on the harvest of horseshoe crabs to protect the food source of the shorebirds and red knots. Horseshoe crab eggs were dwindling due to harvesting of the crabs by watermen for conch bait.

The Delaware Bay red knot stopover population has been declining since 1997 (Figures 8.36 and 8.37). Peak numbers of red knots over 100,000 in the 1980s have fallen to 13,455 in 2006 and the red knots have not recovered. The number of red knots spotted on the Delaware shore of the bay during the migratory stopover declined from 50,000 in 1998 to about 12,000 birds by 2006. The number of red knots on the New Jersey shore of the bay declined from 25,000 per year in 1998 to about 6,000 birds by 2006. At the current rate of decline, biologists fear that the red knot could become extinct by the end of this decade unless the horseshoe crab, the food source of these shorebirds, is protected.

Red knots (Figure 8.38) pass through the Delaware Bay during their annual migrations from the tip of South America to the Arctic (Figure 8.39). One of the more notable Delaware Bay shorebirds is the red knot because their populations are dwindling precipitously. Shorebirds depend on horseshoe crab eggs to sustain themselves as they fly north or south.

The Audubon Society describes the red knot *(Calidris canutus)* as:

…..one of the champion long-distance migrants of the bird world, with some individuals migrating from their high Arctic breeding grounds in North America to wintering grounds in extreme southern South America. When seen during migration along the Delaware Bay coast, this species is often found in huge, densely-packed flocks.
Red Knot is a plump, medium-sized shorebird with a fairly short bill. In breeding plumage, its face and under parts are a rich chestnut red, much like the color of an American Robin's breast. In winter plumage, red knot is predominantly gray, with a gray head, breast, and upperparts, and a white belly.

Red Knot has widespread distribution. In North America, red knot can be found breeding in Greenland and northeastern Canada, and also in northwestern Alaska and the high Arctic islands of Nunavut. The bulk of the population completes a long-distance migration to winter in southern South America. There are numerous sites include the Delaware Coastal Zone IBA, where red knots and other shorebirds gather in the tens of thousands to feed on horseshoe crab eggs during the spring time.

A number of different methods suggest that populations of red knot breeding in North America have experienced a drastic decline in numbers in the past thirty years. These methods include aerial surveys conducted at Delaware Bay and counts made at key Canadian migration stopover sites. Recent aerial surveys in the southern South American wintering areas have shown a 50% decrease in numbers of red knot wintering there.
On migration and on its wintering grounds, red knot is often found on coastal mudflats and tidal zones, as well as occasionally on sandy beaches. During spring migration along the Atlantic Coast of the U.S., the species relies heavily on the eggs of horseshoe crabs, which are deposited in the billions along sandy beaches. Recently, there has been great concern about the continued ability of Red Knot to use Delaware Bay as a major migratory staging area, due to the increased harvest of horseshoe crabs whose eggs provide a primary food source for the birds along the mid-Atlantic Coast.

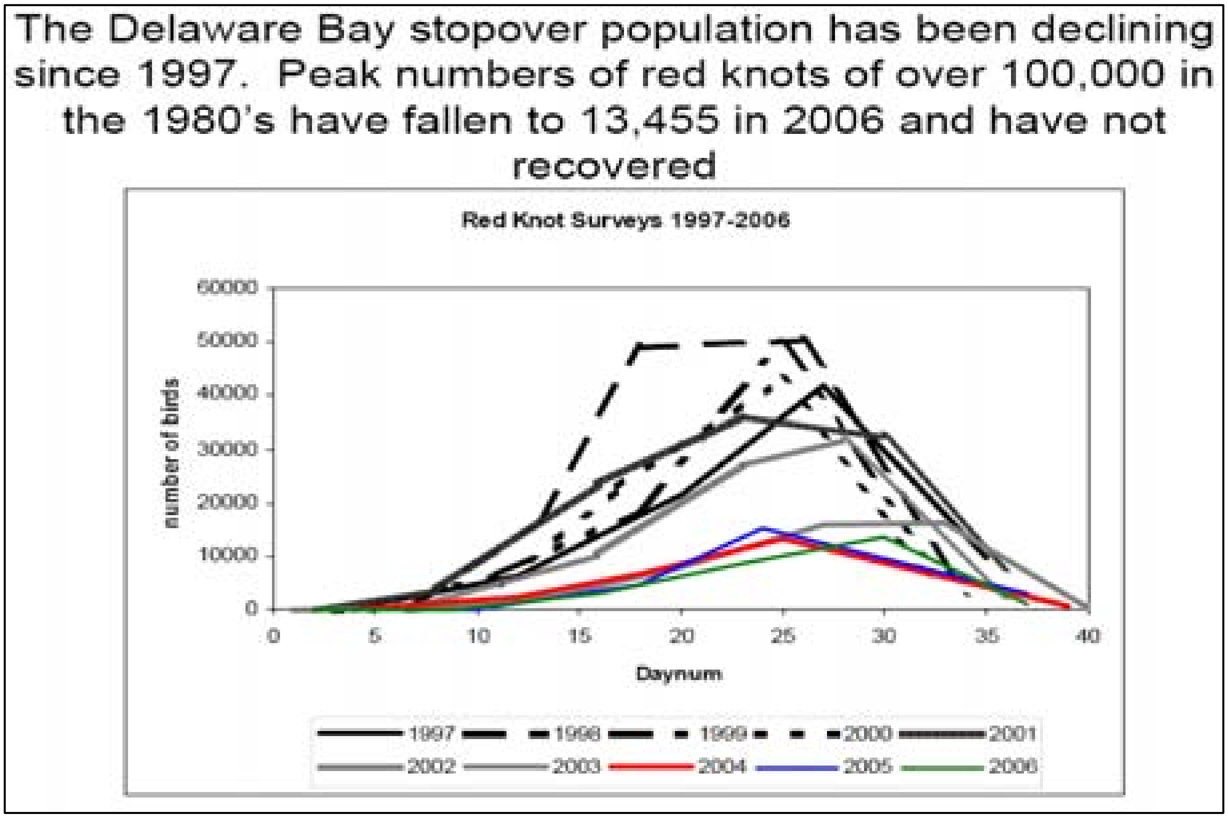


Figure 8.36. Survey of red knots in the Delaware Bay. (NJDEP)

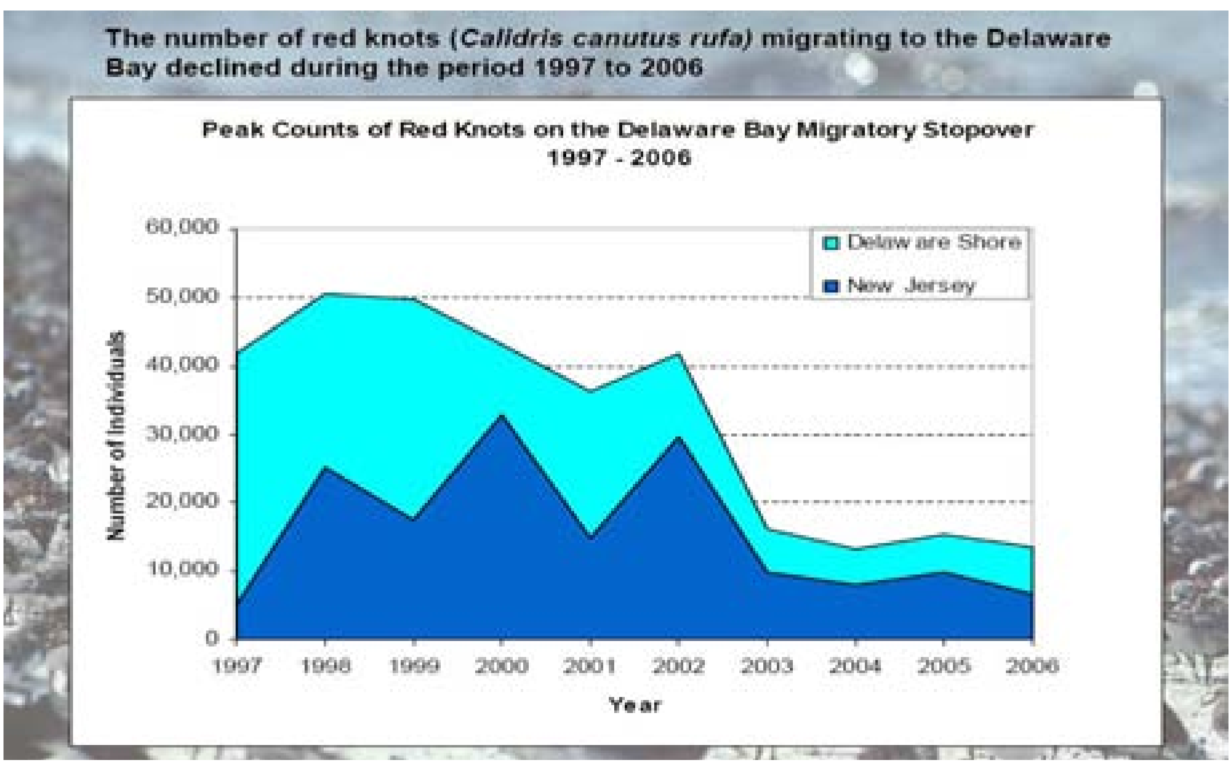


Figure 8.37. Peak counts of red knots on the Delaware Bay migratory stopover. (NJDEP)

Figure 8.38. Red knot along the Delaware Bay in 2007 (Wall Street Journal)

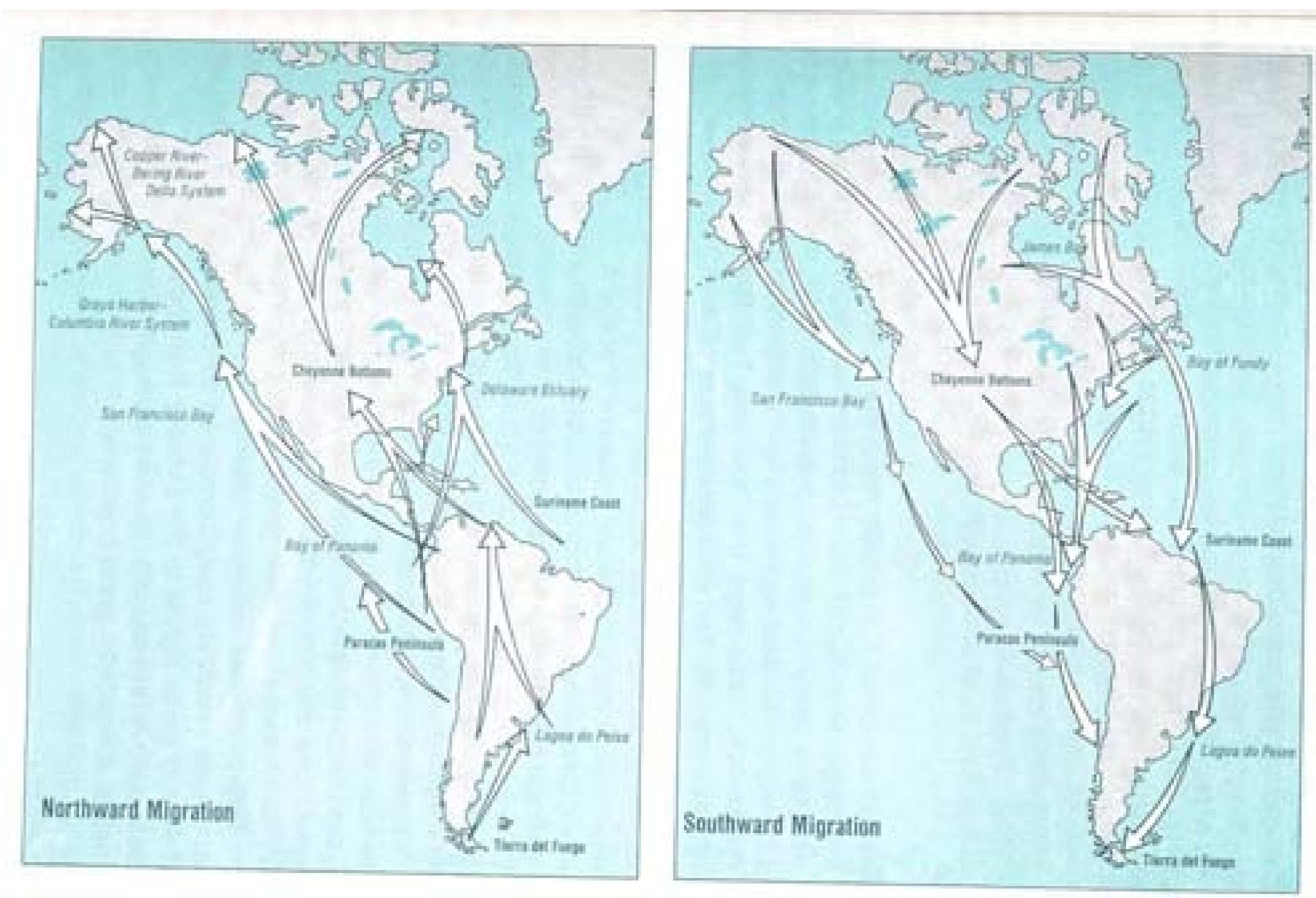


Figure 8.39. Shore bird migration path. (Sutton, O'Herron, and Zappalorti 1996)

8.16. Bald Eagle

Recently delisted as a federal endangered species, the return of the bald eagle to the Delaware River Basin is remarkeable. Bald eagle nests have increased significantly in all four states in the Delaware River Basin (Table 8.10 and Figure 8.40). In 2004, 96 bald eagle nests were spotted in the basin, over double the 44 nests spotted in 2001.

In 1962, Rachel Carson's book *Silent Spring* pointed out the dangers of DDT as a pesticide and impact on the thinning of bald eagle shells. Bald eagles would ingest DDT resulting in egg shells so thin that mother eagles would crush the eggs before the eaglets could be hatched. The book led to public pressure for the USEPA to ban pesticides such as DDT in 1972. With the DDT ban and protection by the Endangered Species Act, nesting populations of bald eagles returned.

In 2007, a nesting pair of bald eagles were sighted at the confluence of the Schuylkill and Delaware Rivers at the Philadelphia Navy Yard in South Philadelphia. Since fish are part of the main diet of eagles, the birds may be returning to nests near the Delaware River in greater numbers due to cleaner water.

The bald eagle (*Haliaeetus leucocephalus*) is the only eagle unique to North America. The bald eagle's scientific name signifies a sea (halo) eagle (aeetos) with a white (leukos) head. At one time, the word "bald" meant "white," not hairless. Dead or dying fish are an important food source for all bald eagles.

Although Benjamin Franklin was opposed and preferred the wild turkey, the bald eagle was chosen June 20, 1782 as the emblem of the United States of America. The bald eagle is thought of now as a national symbol appearing on U.S. currency and other emblems of America. The eagle is also the mascot of the popular football team in the most populous city in the Delaware Basin – the Philadelphia Eagles.

The Bald Eagle Protection Act of 1940 prohibited shooting or otherwise harming the birds in the U.S. but didn't cover the pesticides that within a decade began to destroy eagles' eggs. By the 1960s only about 400 breeding pairs of bald eagles remained in the lower 48. The banning of DDT in 1972 and other measures launched a comeback by the eagles.

Bald eagles were officially declared an endangered species in 1967 in all areas of the United States south of the 40th parallel, under a law that preceded the Endangered Species Act of 1973. Until 1995, the bald eagle had been listed in 43 of the 48 lower states, and listed as threatened in Wisconsin, Minnesota, Michigan, Washington and Oregon. In July of 1995, the U. S. Fish and Wildlife Service upgraded the status of bald eagle from endangered to threatened. Today, with more than 6,000 breeding pairs, the USFWS removed the bald eagle from the Federal endangered species list in 2007.

Table 8.10. Bald eagle nests in the Delaware River Basin. (DNREC, PA Game, NYSDEC, NJDEP)

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Delaware	6	7	6	7	10	11	15	14	13	14	16	17	26	32	36		
New Jersey												11	13	16	22	22	
New York				1	1	1	1	1	2	4	4	5	5	6	5	5	
Pennsylvania							2	2	0	3	7	11	26	20	33	39	17
Delaware Basin Total	6	7	6	8	11	12	18	17	15	21	27	44	70	74	96	66	17

Along the Upper Delaware River from Port Jervis to Hancock, the New York State DEC recorded 114 bald eagles during the 2005 winter count, up from 28 sighted in 2004 and 28 in 1998. In 2005, 5 pairs of bald eagles nested along the New York side of the Delaware River, the same as 2004. An average of 1 nesting pair were observed during the 1990s. The NYSDEC notes that development and logging along the Delaware River corridor are a concern leading to a loss of habitat. The NYSDEC and the National Park Service have developed a joint study to determine essential bald eagle habitats along the upper Delaware River and documentation of human disturbances.

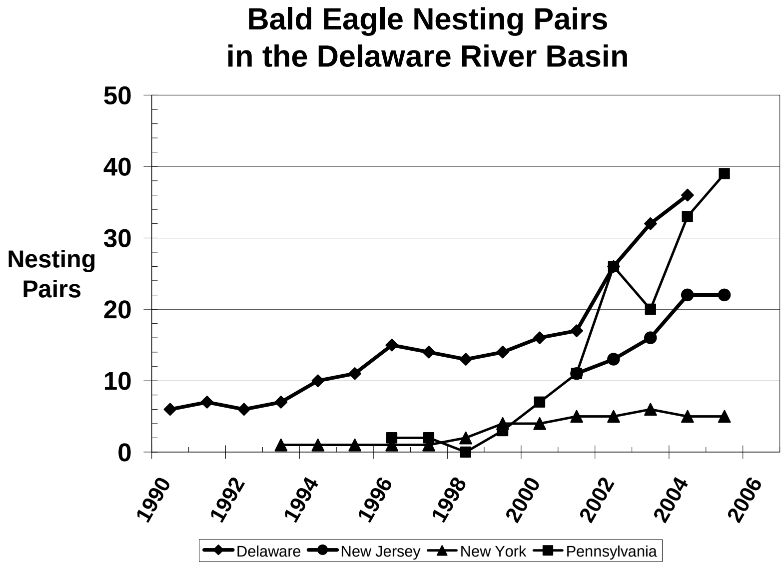


Figure 8.40. Bald eagle nesting pairs in the Delaware River Basin. (DNREC, PA Game, NYSDEC, NJDEP)

By 2004, 34 nesting pairs were sighted in Delaware where 60% of the state lies in the Delaware River Basin. During the early 1990s, there were 5 nesting pairs of bald eagles in the Delaware portion of the Delaware River Basin. A sharp increase in bald eagle nesting pairs is also found in Pennsylvania, New Jersey and New York in the Delaware Basin.

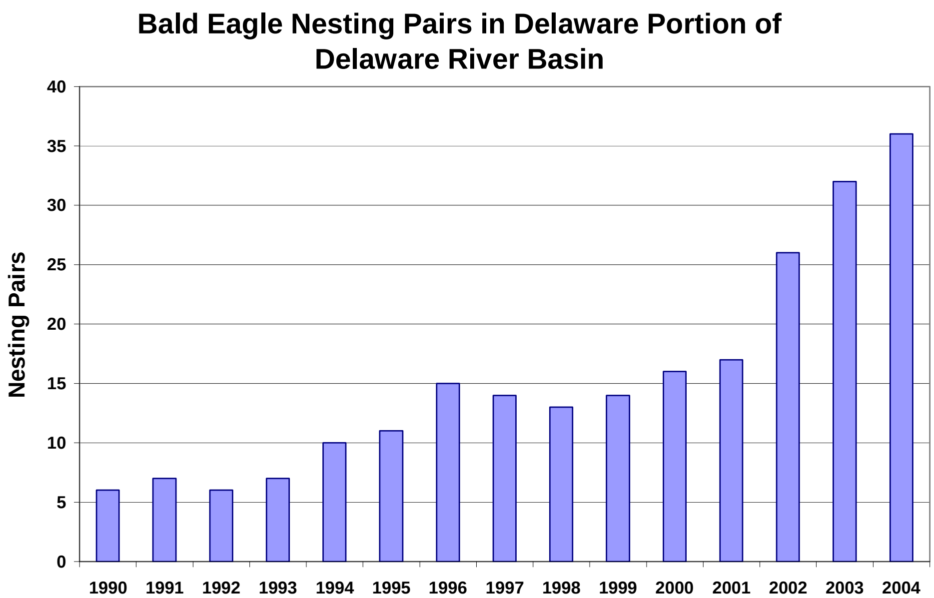


Figure 8.41. Bald eagle nesting pairs in the Delaware portion of the Delaware Basin. (DNREC)

In 2006, 17 bald eagle nests were detected in the Pennsylvania portion of the Delaware Basin (Figure 8.42). Five nests were observed in the UC1 subwatershed in the forested highlands above the Delaware Water Gap. The reintroduction program started in the early 1980s with eaglets from Canada to hacking towers at Shohola.

The Pennsylvania Game Commission writes:
Pennsylvania's nesting bald eagle population has been on the rise in recent years. As recently as 1980, the state's known nesting population numbered three pairs. From 1997 to 1999, the nesting population doubled from 20 to 43 pairs. This recovery continued into the next century. By 2005, there were at least 96 nesting pairs found in the state and additional territorial pairs that also may be nesting. We are poised to pass the Century mark in eagle nests soon.

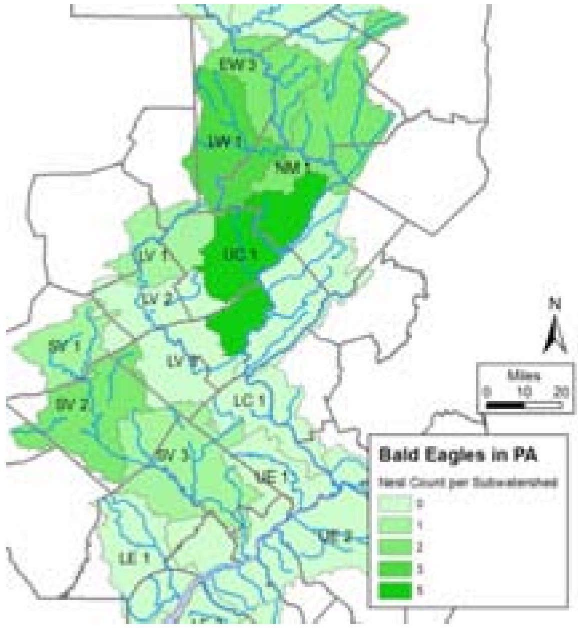


Figure 8.42. Bald eagle nests in Pennsylvania portion of the Delaware River Basin. (PA Game Commission)

According to the NJDEP Division of Fish, Game, and Wildlife, 22 nesting bald eagles pairs were sighted in 2005 in the New Jersey portion of the Delaware River Basin, up from 11 pair observed in 2001. Primary bald eagle habitat distribution lies along the Delaware Bay coast and the highlands above the Delaware Water Gap.

Figure 8.43. Bald eagle habitat in the New Jersey portion of the Delaware River Basin. (NJDEP)

8.17. Black Bear

With the reemergence of contiguous forests, black bears are returning to the top of the food chain in the mountainous reaches of the upper Delaware Basin where the states of New Jersey, New York and Pennsylvania join together.

The American black bear (*Ursus americanus*) is the only bear species living in the eastern United States. Black bears primarily live in a continuous band extending along the Appalachian Mountains from Maine to Georgia (Figure 8.44). Bears in Pennsylvania are contiguous with populations in New York, New Jersey, West Virginia, and Maryland. Prime bear habitat in the Delaware River Basin is in the forested highlands north of Easton, Pennsylvania to the Catskills.

Black bears primarily live in temperate deciduous forests. The optimal habitat includes forest stands dominated by mature, hard-mast-producing trees interspersed with a diversity of soft-mast trees, under story shrubs, and vines, punctuated with herbaceous and grass-covered openings.

Samuel Rhoads, author of *The Mammals of Pennsylvania and New Jersey*, described the abundance of bears in 1903 as:

"Once uniformly and abundantly represented in every county of the two states. Now almost exterminated in N.J. …and in the most densely populated counties of PA it is unknown, and in about half of those remaining it is found only as a straggler."

At the time of European settlement large numbers of black bears likely existed throughout Pennsylvania. Mature forests covered 95% of the state and mortality from people was minimal.

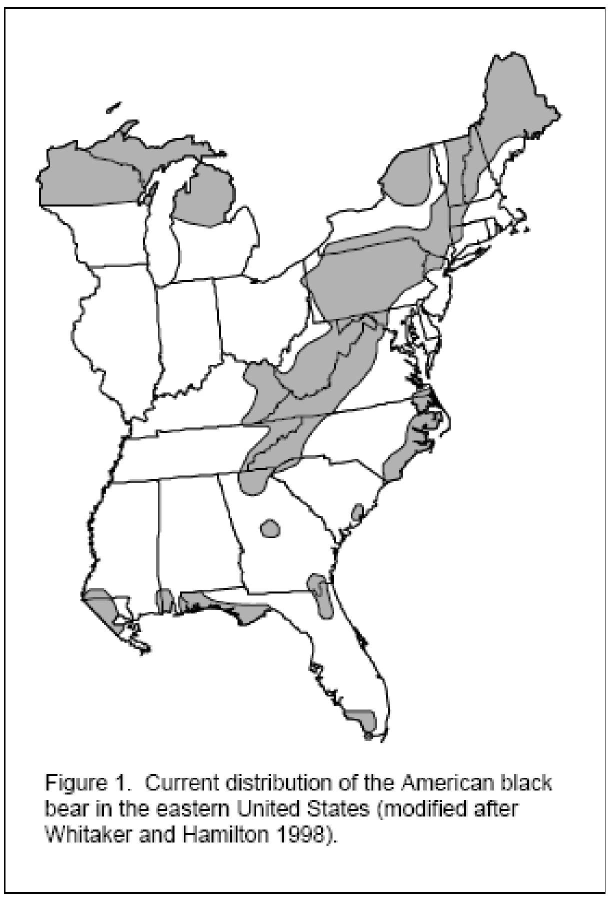


Figure 8.44. Distribution of black bear in the eastern United States.

In the early 1900s, decreased forest coverage and the decline of the American chestnut reduced habitat conditions for all forest-dwelling wildlife. Today, bears are more abundant than at any other time since European settlement and about four times more abundant than 25 years ago when the trend began. The area occupied by bears likewise has increased to record levels.

The black bear population (as recorded by hunt harvest records) in the Delaware Basin and surrounding watersheds in New Jersey, New York and Pennsylvania is expanding Table 8.11 and Figure 8.45). The annual black bear harvest reached 4,200 in 2005 in Pennsylvania, up from 500 or so between 1915 and 1975. In the Catskill region of New York, the annual bear harvest in the five county area exceeded 200 from the years 2000 through 2004, up from 87 in 1995 (NYSDEC, undated). Almost 5,800 black bears were harvested in the Delaware Basin, up from 4,280 bears in 2002

Table 8.11. Black bears in the Delaware River Basin states.

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Delaware																				
New Jersey																	1317	1490	1439	1606
New York										87	223	149	272	112	287	208	278	399	257	
Pennsylvania	1362	1560	1614	2220	1200	1687	1589	1760	1365	2190	1796	2110	2598	1741	3075	3063	2686	3000	2972	4164
DRB Total	1362	1560	1614	2220	1200	1687	1589	1760	1365	2277	2019	2259	2870	1853	3362	3271	4281	4889	4668	5770

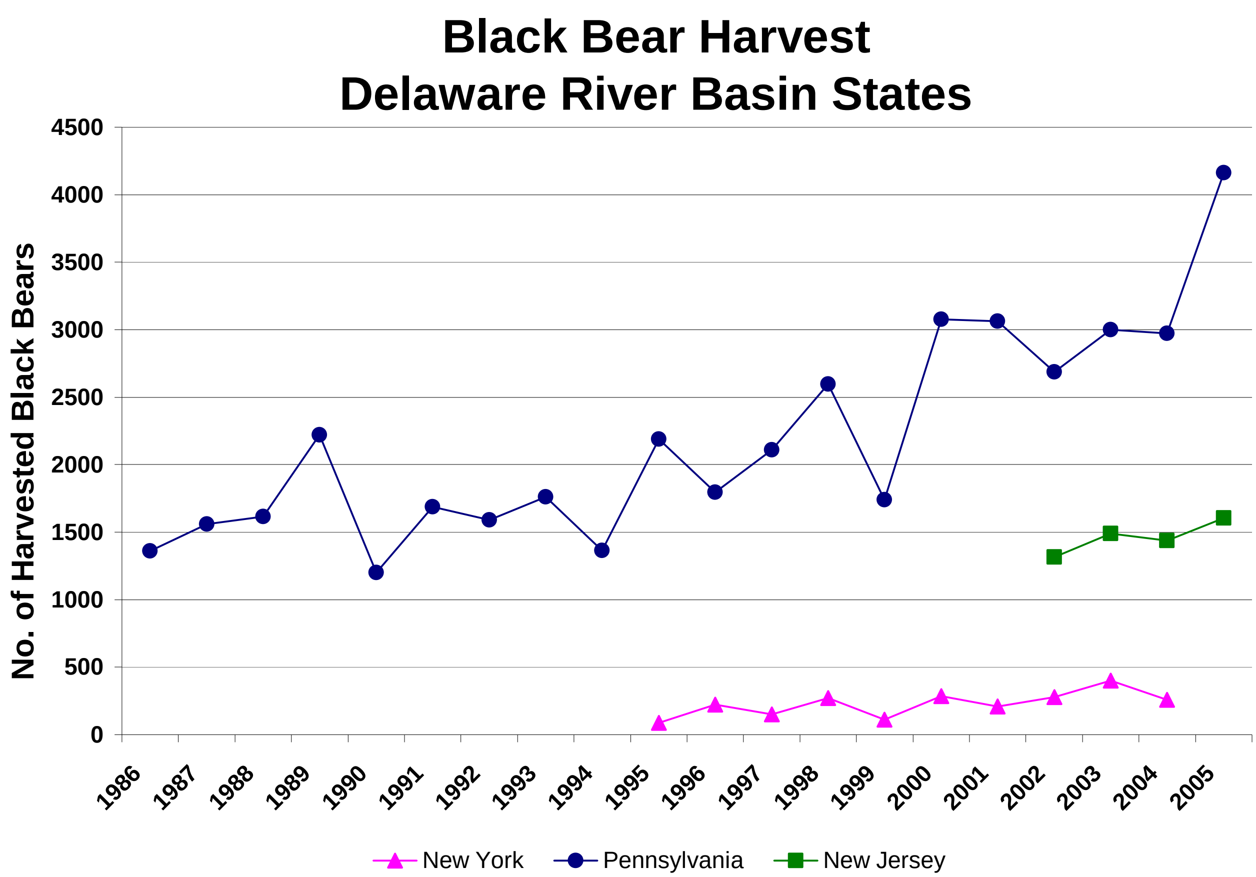


Figure 8.45. Black bear harvest in the Delaware River Basin states.

8.18. Bog Turtle

Information regarding the bog turtle was adapted from:

Herp Atlas Project, 2007. New York State Dept. of Environmental Conservation, Bureau of Wildlife.
Delaware Natural Heritage and Endangered Species Program
New Jersey Division of Fish and Wildlife, *New* Jersey Bog Turtle Project
Pennsylvania Department of Conservation and Natural Resources, Wildlife Resource Conservation Program.

The Bog Turtle *(Clemmys muhlenbergii*) is a Federal threatened species and is listed as endangered on the state lists of New Jersey, New York, and Pennsylvania. Approximately half of the area of the Delaware River Basin is known habitat for the bog turtle in its range in the eastern United States (Figure 8.46). The smallest turtle in the Delaware River Basin, it reaches a maximum length of 4.5 inches. A bright yellow/orange blotch on each side of its head and neck are a distinctive feature of this species.

The bog turtle emerges from hibernation often spent in an abandoned muskrat lodge or other burrow, by mid-April. . Mating occurs primarily in the spring but may also occur in the fall and may be focused in or near the hibernaculum (winter shelter). In early to mid-June, a clutch of two to four eggs is laid in a nest which is generally located inside the upper part of an unshaded tussock. The eggs hatch around mid-September. The adults enter hibernation in late October. A bog turtle may live for more than 30 years. Although generally very secretive, the bog turtle can be seen basking in the open, especially in the early spring just after emerging from hibernation. It is an opportunistic feeder, eating what it can get, although it prefers invertebrates such as slugs, worms, and insects. Seeds, plant leaves, and carrion are also included in its diet. In New York, the bog turtle is generally found in open, early successional types of habitats such as wet meadows or open calcareous boggy areas generally dominated by sedges (*Carex spp.*) or sphagnum moss.

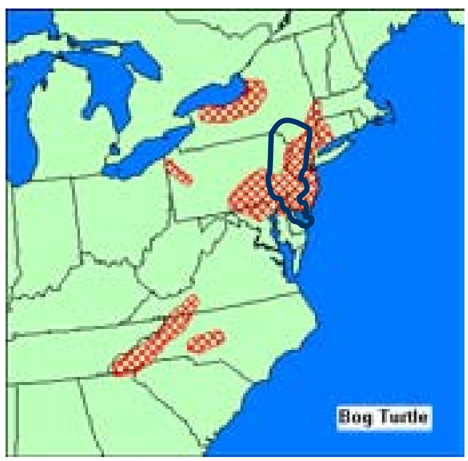


Figure 8.46. Bog turtle habitat in the eastern United States. (NYSDEC)

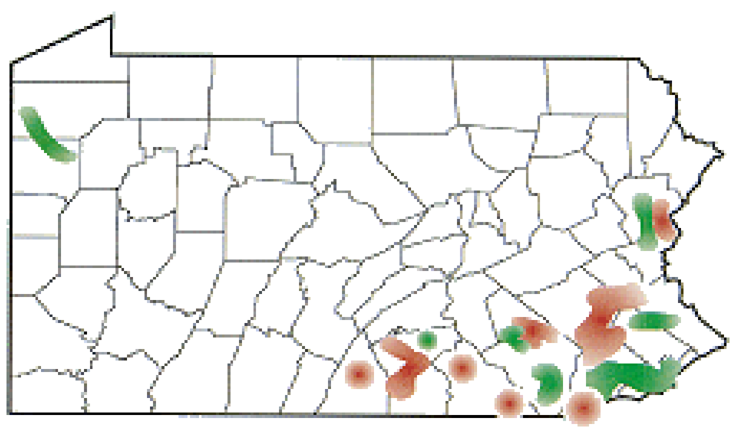


Figure 8.47. Verified (red) and historical occurrences (green) of bog turtles in Pennsylvania. (PADCNR)

8.19. Threatened and Endangered Species

Among the Delaware River Basin indicators; the bald eagle, bog turtle, Atlantic sturgeon, and red knot are listed as endangered species by at least one of the basin states: Delaware, New Jersey, New York, Pennsylvania (Table 8.12). There seems to be inconsistency between the adjacent states in listing the endangered and threatened species that share the common ecosystem of the Delaware River Basin. While the bog turtle is listed by New Jersey, New York, and Pennsylvania, it is not listed by Delaware. The Atlantic sturgeon is only listed by Delaware. The red knot, with populations dwindling along the Delaware Bay, is listed by New Jersey, but not by Delaware on the other side of the bay. Only the bald eagle is listed as endangered by all 4 states in the Delaware River Basin. It is recommended that the endangered species programs of all 4 states conduct an interstate review to ensure that their listings are consistent between neighboring states in the Delaware River Basin.

Table 8.12. Threatened and endangered species in the Delaware River Basin
E = Endangered, T = Threatened

Category	Species	Scientific Names	DE[1]	NJ[2]	NY[3]	PA[4]
Amphibians and Reptiles	Eastern Tiger Salamander	*Ambystoma tigrinum tigrinum*	**E**	**E**		
	Barking Treefrog	*Hyla gratiosa*	**E**			
	Bog Turtle	*Glyptemys muhlenbergii.*		**T**	**E**	**E**
	New Jersey Chorus Frog	*Pseudacris triseriata kalmi.*				**E**
	Coastal Plain Leopard Frog	*Rana sphenocephala.*				**E**
	Massasauga Rattlesnake	*Sistrurus catenatus.*				**E**
	Kirtland's Snake	*Clonophis kirtlandii.*				**E**
	Eastern Mud Salamander	*Pseudotrion m. montanus.*		**T**		**E**
	Eastern Spadefoot Toad	*Scaphiopus holbrookii.*				**E**
	Rough Green Snake	*Opheodrys aestivus.*				**E**
	Rattlesnake, timber	*Crotalus h. horridus*		**E**		
	Snake, corn	*Elaphe g. guttata*		**E**		
	Snake, queen	*Regina septemvittata*		**E**		
	Atlantic hawksbill	*Eretmochelys imbricata***		**E**	**E**	
	Atlantic leatherback	*Dermochelys coriacea***		**E**	**E**	
	Atlantic loggerhead	*Caretta caretta***		**E**	**T**	
	Atlantic Ridley	*Lepidochelys kempi***		**E**	**E**	
	Snake, northern pine	*Pituophis m. melanoleucus*		**T**		
	Turtle, Atlantic green	*Chelonia mydas***		**T**	**T**	
	Turtle, wood	*Clemmys insculpta*		**T**		
	Salamander, blue-spotted	*Ambystoma laterale*		**E**		
	Salamander, long-tailed	*Eurycea longicauda*		**T**		
	Treefrog, southern gray	*Hyla chrysocelis*		**E**		
	Treefrog, pine barrens	*Hyla andersonii*		**T**		
Birds	Brown Creeper	*Certhia americana*	**E**			
	Bald Eagle	*Haliaeetus leucocephalus*	**E**	**E**	**T**	**T**
	Pied-billed Grebe	*Podilymbus podiceps*	**E**	**E**		
	Northern Harrier	*Circus cyaneus*	**E**	**E**		
	Cooper's Hawk	*Accipiter cooperii*	**E**	**T**		
	Black-Crowned Night-Heron	*Nycticorax nycticorax*	**E**	**T**		**E**
	Yellow-Crowned Night-Heron	*Nyctanassa violacea*	**E**	**T**		**E**
	Northern Parula	*Parula americana*	**E**			
	Piping Plover	*Charadrius melodus*	**E**	**E**	**E**	
	Short-eared Owl	*Asio flammeus*	**E**	**E**		**E**
	American Oystercatcher	*Haematopus palliatus*	**E**			
	Black Rail	*Laterallus jamaicensis*	**E**	**T**		
	Upland Sandpiper	*Bartramia longicauda*	**E**	**E**		**T**
	Loggerhead Shrike	*Lanius ludovicianus*	**E**	**E**		**E**
	Black Skimmer	*Rynchops niger*	**E**	**E**		
	Sparrow, Henslow's	*Ammodramus henslowii*	**E**	**E**		

	Common Tern	*Sterna hirundo*	**E**			**E**
	Forster’s Tern	*Sterna forsteri*	**E**			
	Least Tern	*Sterna antillarum*	**E**	**E**		
	Cerulean Warbler	*Dendroica cerulea*	**E**			
	Hooded Warbler	*Wilsonia citrina*	**E**			
	Swainson’s Warbler	*Limnothlypis swainsonii*	**E**			
	Red-headed Woodpecker	*Melanerpes erythrocephalus*	**E**	**T**		
	Sedge Wren	*Cistothorus platensis*	**E**	**E**		**E**
	American Bittern	*Botaurus lentiginosus*		**E**		**E**
	Least Bittern	*Ixobrychus exilis*				**E**
	Great Egret	*Ardea alba*				**E**
	Peregrine Falcon	*Falco peregrinus*		**E**		**E**
	King Rail	*Rallus elegans*				**E**
	Black Tern	*Childonias niger*				**E**
	Yellow-bellied Flycatcher	*Empidonaxflaviventris*				**E**
	Dickcissel	*Spizza americana*				**E**
	Blackpoll Warbler	*Dendroica striata*				**E**
	Osprey	*Pandion Haliaetus*		**T**		**T**
	Goshawk, northern	*Accipiter gentilis*		**E**		
	Hawk, red-shouldered	*Buteo lineatus*		**T**		
	Sparrow, vesper	*Pooecetes gramineus*		**E**		
	Tern, roseate	*Sterna dougallii*		**E**	**E**	
	Bobolink	*Dolichonyx oryzivorus BR*		**T**		
	Knot, red	*Calidris canutus BR*		**T**		
	Owl, barred	*Strix varia*		**T**		
	Owl, long-eared	*Asio otus*		**T**		
	Sparrow, grasshopper	*Ammodramus savannarum*		**T**		
	Sparrow, Savannah	*Passerculus sandwichensis*		**T**		
	Woodpecker, red-headed	*Melanerpes erythrocephalus*				
Fish	Atlantic Sturgeon	*Acipenser oxyrhynchus*	**E**			
	Northern Brook Lamprey	*Ichthyomyzon fossor*				**E**
	Shortnose sturgeon	*Acipenser brevirostrum*		**E**	**E**	**E**
	Lake sturgeon	*Acipenser fulvescens*				**E**
	Spotted gar	*Lepisosteus oculatus*				**E**
	Cisco	*Coegonus artedi*				**E**
	Silver chub	*Macrhybopsis storeriana*				**E**
	Gravel chub	*Erimystax x-punctatus*				**E**
	Bridle shiner	*Notropsis bifrenatus*				**E**
	River shiner	*Notropsis blennius*				**E**
	Ghost shiner	*Notropis buchanani*				**E**
	Ironcolor shiner	*Notropis chalybaeus*				**E**
	Blackchin shiner	*Notropis heterodon*				**E**
	Redfin shiner	*Lythrurus umbratilis*				**E**
	Longnose sucker	*Catostomus catostomus*				**E**
	Bigmouth buffalo	*Ictiobus cyprinellus*				**E**
	Black bullhead	*Amerius melas*				**E**
	Mountain madtom	*Noturus eleutherus.*				**E**
	Tadpole madtom	*Noturus gyrinus.*				**E**
	Northern madtom	*Noturus stigmosus.*				**E**
	Burbot	*Lota lota*				**E**
	Threespine stickleback	*Gasterosteus aculeatus.*				**E**
	Banded sunfish	*Enneacanthus obesus.*				**E**
	Warmouth	*Lepomis gulosus.*				**E**
	Longear sunfish	*Lepomis megalotis.*				**E**
	Iowa darter	*Etheostoma exile.*				**E**

	Eastern sand darter	*Etheostoma pellucida.*				**E**
	Northern riffleshell mussel	*Epioblasma torulosa rangiana.*				**E**
	Clubshell mussel	*Pleurobema clava.*				**E**
	Dwarf wedgemussel	*Alasmidonta heterodon.*		**E**	**E**	**E**
	Eastern pearlshell mussel	*Margaritifera margaritifera.*				**E**
	Copper, bronze	*Lycaena hyllus*		**E**		
	Floater, brook (mussel)	*Alasmidonta varicosa*		**E**		
	Floater, green (mussel)	*Lasmigona subviridis*		**E**		
	Floater, triangle (mussel)	*Alasmidonta undulata*		**T**		
	Lampmussel, eastern (mussel)	*Lampsilis radiata*		**T**		
	Lampmussel, yellow (mussel)	*Lampsilis cariosa*		**T**		
	Mucket, tidewater (mussel)	*Leptodea ochracea*		**T**		
	Pondmussel, eastern (mussel)	*Ligumia nasuta*		**T**		
Insects	Little White Tiger Beetle	*Cicindela lepida*	**E**			
	White Tiger Beetle	*Cicindela dorsalis*	**E**			
	Seth Forest Scavenger Beetle	*Hydrochus spp.*	**E**			
	Frosted Elfin	*Incisalia irus*	**E**			
	Bethany Firefly	*Photuris bethaniensis*	**E**			
	Hessel’s Hairstreak	*Mitoura hesseli*	**E**			
	King’s Hairstreak	*Satyrium kingi*	**E**			
	Rare Skipper	*Problema bulenta*	**E**			
	Mulberry Wing	*Poanes massasoit chermocki*	**E**			
	Beetle, American burying	*Nicrophorus mericanus*		**E**		
	Beetle, northeastern beach tiger	*Cincindela d. dorsalis*		**E**		
	Satyr, Mitchell's (butterfly)	*Neonympha m. mitchellii*		**E**		
	Skipper, arogos (butterfly)	*Atrytone arogos arogos*		**E**		
	Skipper, Appalachian grizzled (butterfly)	*Pyrgus wyandot*		**E**		
	Elfin, frosted (butterfly)	*Callophrys irus*		**T**		
	Fritillary, silver-bordered (butterfly)	*Bolaria selene myrina*		**T**		
	White, checkered (butterfly)	*Pontia protodice*		**T**		
	Karner Blue Butterfly	*Lyaaeides Melissa samuelis*			**E**	
	Chittenango snail	*Succinea chittenangoensis*			**E**	
Mammals	Delmarva Fox Squirrel	*Sciurus niger cinereus*	**E**			**E**
	Indiana Bat	*Myotis sodalis*		**E**	**E**	**E**
	West Virginia Water Shrew	*Sorex palustris punctulatus*				**T**
	Allegheny Woodrat	*Neotoma magister*		**E**		**T**
	Small-footed Myotis Bat	*Myotis leibii*				**T**
	Bobcat	*Lynx rufus*		**E**		
	Whale, black right	*Balaena glacialis*		**E**	**E**	
	Whale, blue	*Balaenoptera musculus*		**E**	**E**	
	Whale, fin	*Balaenoptera physalus*		**E**	**E**	
	Whale, humpback	*Megaptera novaeangliae*		**E**	**E**	
	Whale, sei	*Balaenoptera borealis*		**E**	**E**	
	Whale,sperm	*Physeter macrocephalus*		**E**	**E**	
	Canada lynx	*Lynx canadenisis*			**T**	
	Eastern Puma	*Puma concolor couguar*			**E**	
	Least Shrew	*Cryptotis parva*				**E**

1 – Listed by Delaware Natural Heritage and Endangered Species Program.
2 – Listed by New Jersey Department of Environmental Protection Endangered and Nongame Species Program.
3 – Listed by New York Endangered Species Program.
4 – Listed by Pennsylvania Fish and Boat Commission and Pennsylvania Game Commission.

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