STATE OF THE BASIN 2019

Delaware River Basin Commission

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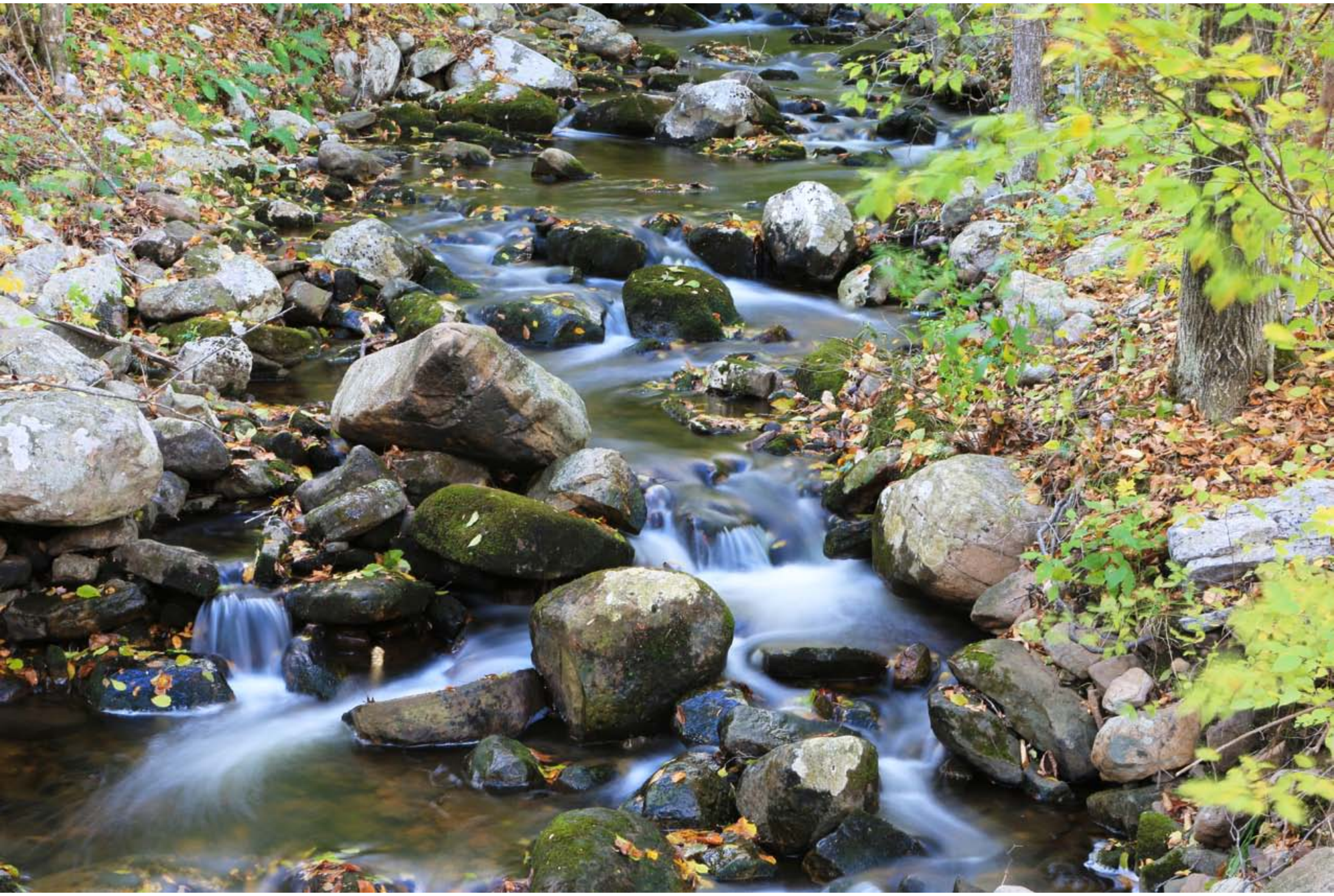

Water's journey through the park.
Photo credit: Kevin Haines.

Message from the Executive Director

I am pleased to report that the state of the water resources of the Delaware River Basin is generally good and improving. The Commission's State of the Basin Report 2019 – our third such publication since 2004 – benchmarks conditions and tracks progress toward achieving key DRBC water resource management goals for maintaining an adequate supply of suitable quality water to meet the diverse needs of our region for public water supply, recreation, industry, commerce, agriculture, and aquatic life.

This year's report provides a detailed evaluation – essentially, a focused snapshot – of 31 indicators for watersheds and landscapes, water quantity, water quality, and living resources, and includes a rating and a directional trend for each. A majority of the indicators received a "Good" or "Very Good" rating, while trends are predominantly "Improving" or "Stable." Lower ratings or declining trends for some indicators show us where additional study and stewardship are required.

This 2019 evaluation reflects the collective effort of organizations and individuals throughout the Basin to improve the invaluable water resources we share. It also highlights water resource challenges for the Basin associated with climate change and includes recommendations and directions for addressing future challenges.

The preamble to the Delaware River Basin Compact begins with recognition by the four Basin states and the Federal government that:

> *the water and related resources of the Delaware River Basin [are] regional assets vested with local, State and National interests, for which [the Commission's members] have joint responsibility.*

The Basin's water resources provide drinking water for over 13.3 million people in four states – approximately 4 percent of the total population of the United States. These shared water resources also: underpin a regional economy that relies upon our water and waterways; provide a diverse habitat for living resources; afford abundant opportunities for water-based recreation; and support a high quality of life for residents throughout our region.

In addition to highlighting the work of the Delaware River Basin Commission (DRBC) to manage, protect and improve our irreplaceable waters and waterways, this report also recognizes the important contributions made by other agencies and organizations. Managing a river basin is a complex charge that requires dedication, commitment and stewardship, not only by government at all levels, but also by businesses, industries, philanthropic and academic institutions, and by each and every one of us who depend on this resource. In the Delaware River Basin, we are fortunate to be among a diverse and energized community of stewards – valued partners who are committed to shared local and regional goals.

Because water resource management is a community-wide endeavor, DRBC's 2019 State of the Basin enterprise is not limited to this report. For the first time, we are reaching out to organizations in all corners of the Basin to gather diverse perspectives about Our Shared Waters. I encourage you to take advantage of this new opportunity and provide your input on the conditions – whether good or not so good, seemingly improving or declining – in your or your organization's unique experience of the Delaware River Basin.

Steve Tambini, PE

ACKNOWLEDGEMENTS

The Delaware River Basin Commission staff are grateful to the following organizations that assisted in various ways throughout the development of this report.

- Partnership for the Delaware Estuary (PDE)
- Delaware Department of Natural Resources and Environmental Control (DNREC), Department of Fish and Wildlife (DE DFW)
- United States Fish and Wildlife Service (USFWS)
- Delaware Water Resources Center, Institute for Public Administration, University of Delaware
- United States Geological Survey (USGS), NJ Water Science Center - Jonathan Kennen, PhD and Pam Reilly

In addition to DRBC publications and in-house data, major sources of information in this report were obtained from the US Census Bureau, Shippensburg University, USEPA Storet, USGS NWIS, NatureServe Explorer and an array of environmental quality information from NJDEP, PADEP, DNREC, NYDEC, USFWS, US Forest Service, USGS, The Nature Conservancy (TNC), and the Academy of Natural Science of Drexel University (ANS).

The portion of this report focused on Living Resources (Section 4), relies significantly on the 2017 Technical Report for the Delaware Estuary and Basin prepared by the Partnership for the Delaware Estuary . Numerous sections were updated with recent data provided by DE DFW, referenced throughout the text as appropriate. Additional resources used are cited at the end of the section.

In addition to identifying desired environmental end states, the *Water Resources Plan for the Delaware River Basin* includes goals for the development of partnerships; the exchange of data, information and technology; and the improvement of coordination and cooperation among Basin institutions, agencies and organizations. The *State of the Basin Report 2019* fulfills those goals.

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Delaware River Sojourn. Photo credit: DRBC.
Blue spotted sunfish. Photo credit: Evan Kwityn, DRBC.

Fall into the Gap.
Photo credit: Kevin Haines.

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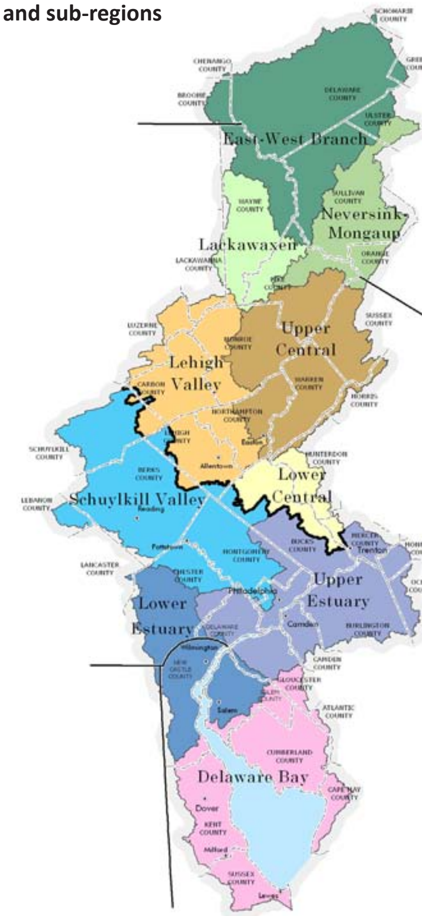


Figure I-1: An overview of the Delaware River Basin's setting in the United States with the 42 counties overlapping the basin.

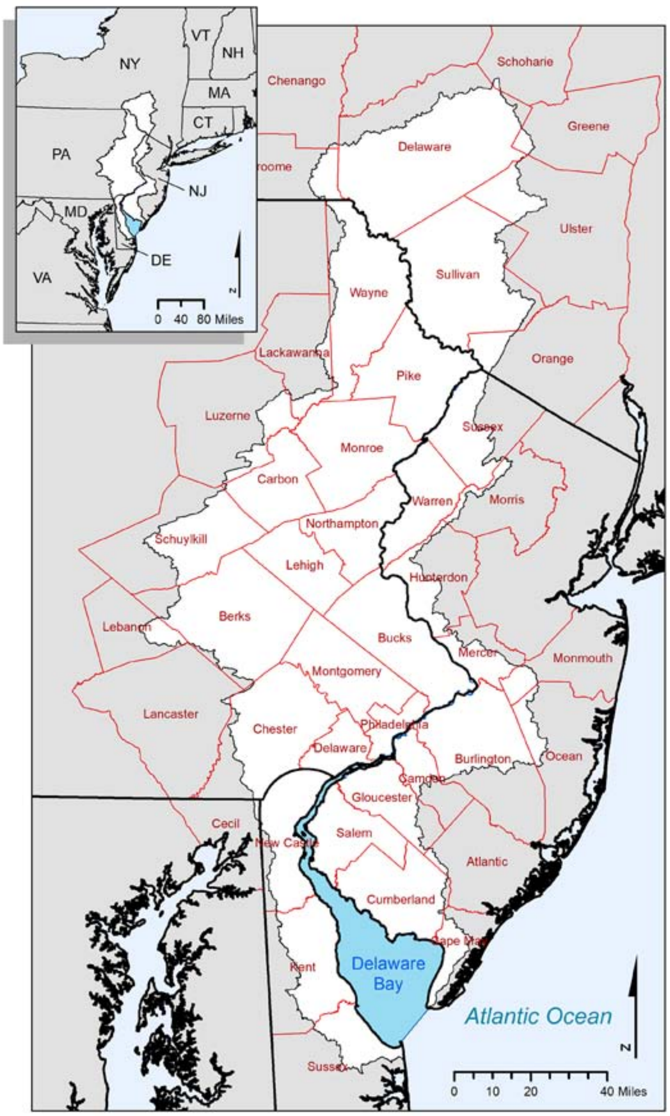


Figure I-3: The Physiographic Regions and Provinces of the Delaware River Basin.

INTRODUCTION

The Delaware River Basin Commission (DRBC) plays a unique role as the agency charged since 1961 with managing the Basin's water resources. Through the DRBC, the states of Delaware, New Jersey, New York, Pennsylvania, and the federal government have built an exceptional record of results to improve water quality and to provide a sustainable water supply.

On September 29, 1999, the Governors of the four Delaware River Basin states signed a resolution challenging the Basin community to develop a unifying vision: a comprehensive Water Resources Plan for the Delaware River Basin. In response to the Governors' challenge, the DRBC convened the Watershed Advisory Council (WAC). The WAC successfully forged a unifying vision for the Basin, which was a goal-based plan to guide policy and action. In 2004, the DRBC published the *Water Resource Plan for the Delaware River Basin* (The Basin Plan). The Basin Plan serves as a non-binding guide to the signatory parties and the Basin community on water resource issues. It acts as a guide for policy setting, decision-making and prioritizing actions originating from governmental units, private entities, organizations, and individuals.

The Commissioner's resolution (2004-BP) supporting the implementation of the Basin Plan directed staff, in coordination with state and federal agencies, to compile an environmental goals and indicators report every five years to define the state of the Basin and to describe progress towards achieving the desired results of the Basin Plan. This report follows previous iterations (performed in 2008 and 2013) and satisfies the directive in Resolution No. 2004-BP.

BASIN OVERVIEW

Lying in the densely populated corridor of the northeastern US, the 13,600 square mile Delaware River Basin stretches approximately 330 miles from headwaters in New York State to its confluence with the Atlantic Ocean. The basin includes approximately 12,800 square miles of land area, nearly 800 square miles of Bay and over 2,000 tributaries, including many that are rivers in their own right. The northernmost tributaries to the Delaware River originate in the forested western slopes of the Catskill Mountains, which reach elevations of up to 4,000 feet. The East and West Branches meet at Hancock, NY where the Delaware River officially begins. The River descends about 800 feet on its journey to the Atlantic Ocean.

POLITICAL SETTING

As shown in Figure I-1, the drainage area encompasses extensive landscapes in New York, New Jersey, Pennsylvania and Delaware and 8 square miles in Maryland, which are not included in this Report. All or portions of 42 counties and 838 municipalities within the four Basin states contribute to and benefit from the resources of the Delaware River Basin. Water resources are also exported to cities in NJ and NY outside of the Basin boundary. While the states retain autonomy, the Delaware River Basin is unique in governance. It is the only river basin with both an interstate-federal Commission and a national estuary program in place. The 1961 Compact establishing the Delaware River Basin Commission (DRBC) was the first federal-interstate agreement for basin-scale water resources management. The DRBC pre-dates the first Earth Day, the establishment of the Environmental Protection Agency and the passage of the Clean Water Act. The national significance of the Delaware Estuary was acknowledged in 1988 when it became part of the National Estuary Program.

BASIN PERSPECTIVE

The Delaware River's condition is a product of the cumulative flows from its many tributaries, which in turn take their character from the underlying geology, topography, microclimates and land uses of their watersheds. Therefore, this report is largely an assessment of the Delaware River basin as a whole system of functioning parts. While some analyses are presented as basin-wide averages, others are or can be broken down into smaller regional scales to refine conclusions.

Regional Watersheds

A watershed can be simply described as the area of land draining to a particular stream. As the Delaware River Basin is equal to the sum of its parts--regions and sub-regions are defined by watershed boundaries rather than state or political boundaries. There are four main regions, and ten sub-regions as indicated on Figure I-2. These are created by grouping watersheds together based on the segment of the Delaware River to which they drain.

Physiographic Provinces

The Delaware River Basin lies in two significantly different hydrologic regions which correspond to the two major physiographic divisions in the northeastern US: 1) the Appalachian Highlands 2) the Atlantic Coastal Plain. These regions are shown on Figure I-3, separated by a natural division called the "fall line".

1. The Appalachian Highlands consist predominantly of consolidated sedimentary rock. This area includes four provinces - each of which has distinctive geology, landforms, and hydrologic characteristics.
   - **Appalachian Plateau**. This is the 1,000- to 4,000-foot-high uplands that form the Catskill and Pocono Mountains - where rivers have carved deep and narrow valleys through folded shales and sandstone.
   - **Ridge and Valley**. The northern portion contains a series of long forested mountain ridges, while the southern portion is a broad lowland with rolling hills called the Great Valley.
   - **New England**. This is characterized by extensive forested hills and ridges drained by a network of steep,

rocky streams.

- **Piedmont**. Widespread branching streams, rolling hills and good agricultural soils cover low yielding sedimentary and crystalline rock.

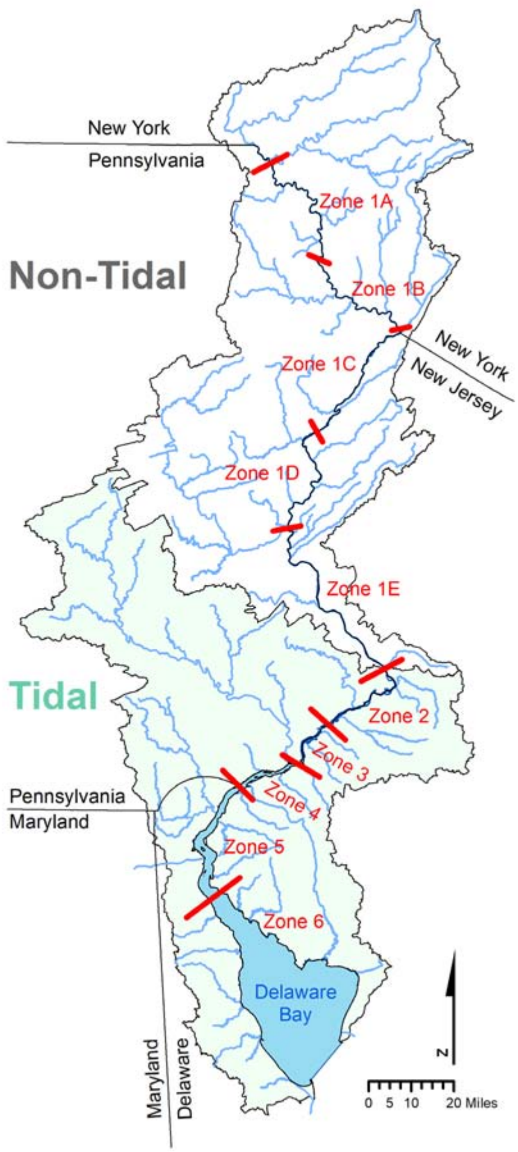
2. The Atlantic Coastal Plain is a large wedge of unconsolidated sediment, such as alternating layers of sand, clay and gravel.

Tidal Regions

Above the fall line freshwater riverine conditions exist. Below the fall line the Delaware River is subject to tidal influences and, with increased proximity to the Bay, estuarine conditions exist. This has created what is referred to as the "Non-Tidal" and "Tidal" regions of the Delaware River Basin, as indicated on Figure I-4.

- **Non-Tidal Region**: Upper and Central Regions
- **Tidal Region**: Lower and Bay Regions. This can also collectively be referred to as the Estuary Region, as it is the same area which is included in the National Estuary Program.

Figure I-4: The water quality zones are specific to the mainstem of the Delaware River.



Water Quality Zones

Much like the basin itself is divided into smaller regions to help analyze data and trends, the mainstem of the River has been divided into portions termed Water Quality Zones. These zones are defined along the Delaware River mainstem in the non-tidal (Zones 1A, 1B, 1C, 1D, and 1E) and tidal (Zones 2, 3, 4, 5, and 6) portions of the basin, in accordance with the DRBC Water Code 18 CFR Part 410 and as shown in Figure I-4.

How to Use the *State of the Basin* Report

A "thermometer" is used to provide the current status of each indicator in this report. For most of the indicators, an arrow appears with the "thermometer," pointing up, if the indicator shows an improving trend or pointing down, if the indicator is worsening. If there is no arrow, no trend is observed.

1

WATERSHEDS AND LANDSCAPES

POPULATION

DESCRIPTION

The population quantifies the number of people living in the Delaware River Basin. The data for this indicator are from the U.S. Census, Decennial Census and American Community Survey (ACS) estimates. An accurate estimate of the number of people is important to understand the needs for water supply and impacts to water resources in the Basin. Changes in population directly affect the existing land cover and land uses in the region. Communities need to accommodate population growth with added infrastructure and development, which often comes from conversion of open space, forests, and agricultural land. Population changes may result in stresses on the water resources available in the Basin.

PRESENT STATUS

According to the U.S. Census ACS data for 2016, the population in the Delaware River Basin is estimated to be 8.3 million people. Figure 1-1 shows the population breakdown by state in the Basin. Pennsylvania accounts for the highest population in Basin (67% of the total in-Basin population), followed by New Jersey (23% of the total in-Basin population). These two states also account for the largest land area in the Basin—PA 49.2% and NJ 23.2%.

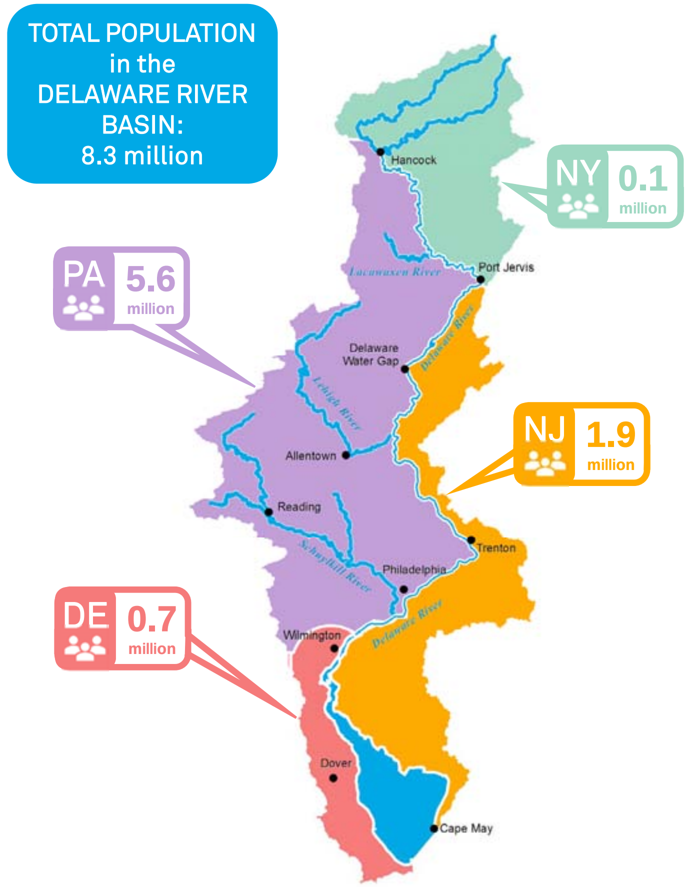


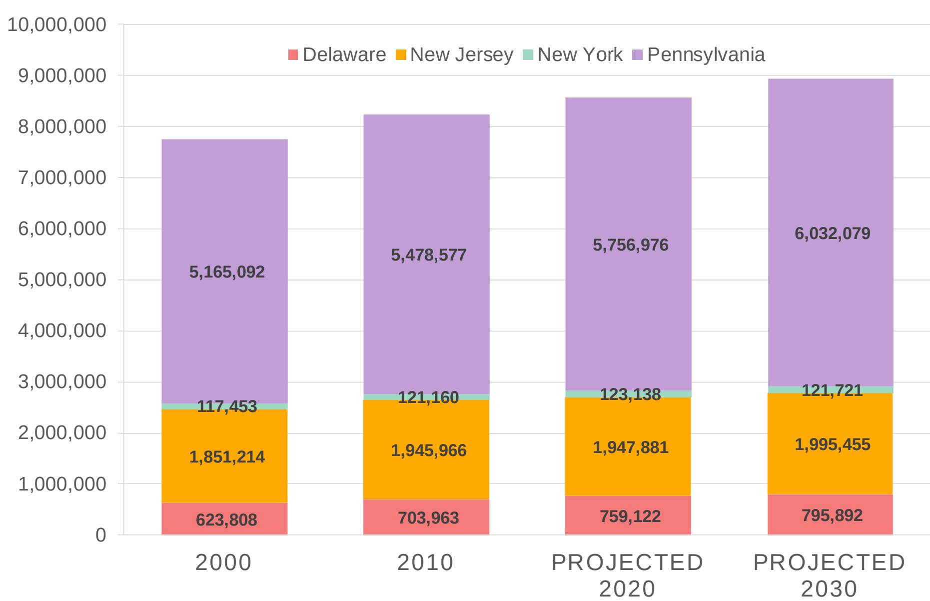
FIGURE 1-1: Total Population in the Delaware River Basin by State, 2016.

TRENDS

Understanding the changes in population over time is essential in order to plan for future water resource needs. From 2000 to 2016, the population in the basin increased by more than 93,500 people, or 7%.

The population in the Basin is projected to increase from 2010 to 2030 by nearly 700,000 people (Figure 1-2). The greatest growth is expected in Kent and Sussex Counties, DE; and Chester, Monroe, and Montgomery Counties, PA. However, Cape May and Salem County, NJ and Philadelphia County, PA are projected to experience a loss in population by 2030.

FIGURE 1-2: Population Projections for the Delaware River Basin by State from 2000 to 2030 *(Data Source: US Census Bureau, 2000 and 2010 Census and American Community Survey)***.**



ACTIONS/NEEDS

As populations change, communities need to plan for land development and its impact to natural resources. Additional development results in higher demand for clean water and the potential for negative impacts to overall water quality and watershed health. One of the challenges is balancing the increased need for development and infrastructure with the additional stresses on water resources.

SUMMARY

There are currently 8.3 million people living in the Basin. The population is expected to grow to almost 9 million people by 2030. The highest areas of expected growth are the counties in and around Philadelphia, as well as the Central and Bay regions.

LAND COVER

DESCRIPTION

Land use and land cover are important indicators of the health of the Basin and its water resources. Changes in land use and land cover reflect human impacts to natural ecosystems on a Basin-wide and local scale. Developed lands have been linked to negative effects on water quality and quantity compared with natural land cover categories (e.g. forests and wetlands). Forests and wetlands serve several ecosystem functions and provide natural habitat for wildlife and aquatic species. Farmland without conservation practices in place, such as cover crops or conservation tillage, may adversely impact the health of a watershed. Alteration in land use and landscapes directly impact the health of the Basin's watersheds.

PRESENT STATUS

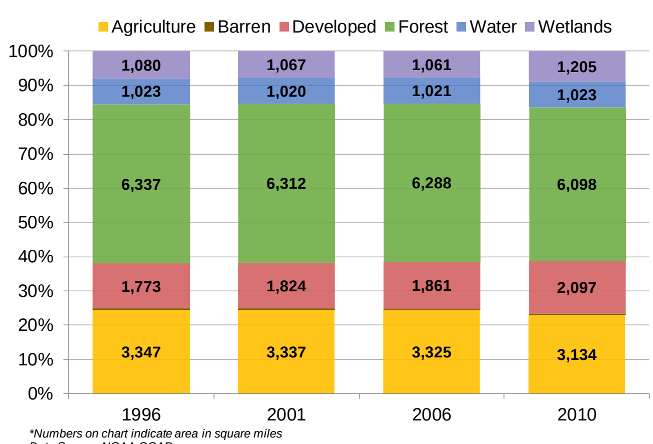
The most up-to-date land cover data was published in 2016 by Shippensburg University's Center for Land Use and Sustainability. The high-resolution land cover dataset is 1-meter resolution, LiDAR-based, and includes 12 land cover classes. This dataset focuses on land cover and incorporates information about roads, buildings, and other impervious surfaces. Figure 1-3 displays the Shippensburg high-resolution dataset for the Delaware River Basin. As with population, the geographic distribution of land cover is not uniform across the Basin. The Upper and Central Regions are primarily Tree Canopy with some Low Vegetation, while the Lower Region has the highest concentration of developed categories, such as Structures and Tree Canopy over developed areas.

The most recent NOAA Coastal Change Analysis Program (CCAP) dataset for 2010 shows broader land cover categories for the Basin (see Figure 1-4). Similar to the Shippensburg high-resolution data, the NOAA CCAP data indicates that the Basin is predominately forested (48%), followed by farmland (24%), and developed lands (16%). Similar to the 2016 Shippensburg data, the Upper Region is primarily forested, while urbanized areas and farmland increases southward in the Basin. The Lower Region, which includes the City of Philadelphia, has the greatest amount of developed land of all the regions.

TRENDS

As land cover changes, it is possible to identify areas under development pressure. The change in land cover from 1996 to 2010 is shown in Figure 1-4 using the NOAA CCAP data. During this time, urbanization has resulted in a loss of forested and agricultural lands. The greatest loss of forests and farmland is in the Lower Region, hence the largest increase in developed area. Following the Lower Region, the Central Region saw a large amount of development with the loss of forested land. Most of the Basin regions have also experienced a loss in wetlands from 1996 to 2010.

FIGURE 1-4: Land Cover in the Delaware River Basin 1996 to 2010.*



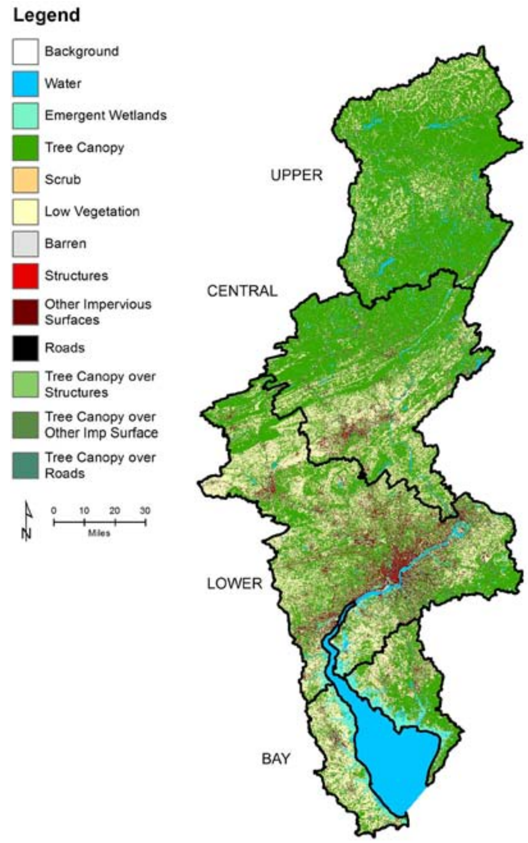


FIGURE 1-3: Land Cover in the Delaware River Basin, 2016.

ACTIONS/NEEDS

New development occurs with conversion of forested and agricultural land. As the trends indicate increased urbanization in parts of the Basin, state and local agencies will need to work together to manage the effects to water resources associated with development. The loss of forests to development may result in negative impacts to watershed health, water resources, and aquatic habitat. Conservation efforts by public and private entities to protect and restore lands impacted by development can mitigate some of the harmful effects associated with urbanization.

In addition, Basin-wide, high-resolution land cover data for multiple years is important to identify changes in land cover over time. Tracking these land cover changes will be useful in prioritizing areas for protection and restoration of water resources.

SUMMARY

Urbanization and development occur with the loss of forested and agricultural lands. Many of these forests protect critical water resources and aquatic habitat in the Basin. Management of growth and development will help mitigate the negative impacts to source waters, water quality, and aquatic life.

IMPERVIOUS COVER

DESCRIPTION

Impervious surfaces, such as roads, parking lots, and rooftops, prevent rainfall from infiltrating and recharging groundwater resources. This results in water running off impervious areas, which can carry pollutants to streams and rivers and contribute to local flooding. Impervious cover measures the percentage of impervious surfaces within a given area. Research has shown that when impervious cover reaches 10%, the health of streams and aquatic life are "impacted," while greater than 25% impervious cover, stream habitat are potentially "non-supporting." Areas with more development typically have higher percentages of impervious cover.

PRESENT STATUS

Figure 1-5 shows the impervious cover percentages for the 147 subwatersheds in the Delaware River Basin for the Shippensburg 2016 land cover dataset. Subwatersheds in the Lower Region along the Delaware River near Philadelphia have the greatest concentration of development, hence higher impervious cover of 30% and greater. In contrast, the primarily forested areas in the Upper Region of the Basin (East-West Branch, Lackawaxen, and Neversink-Mongaup) have the lowest percent imperviousness.

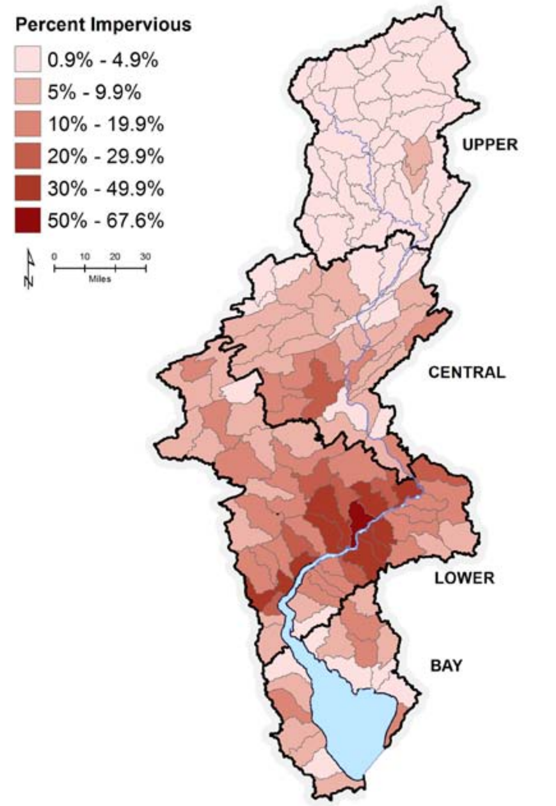
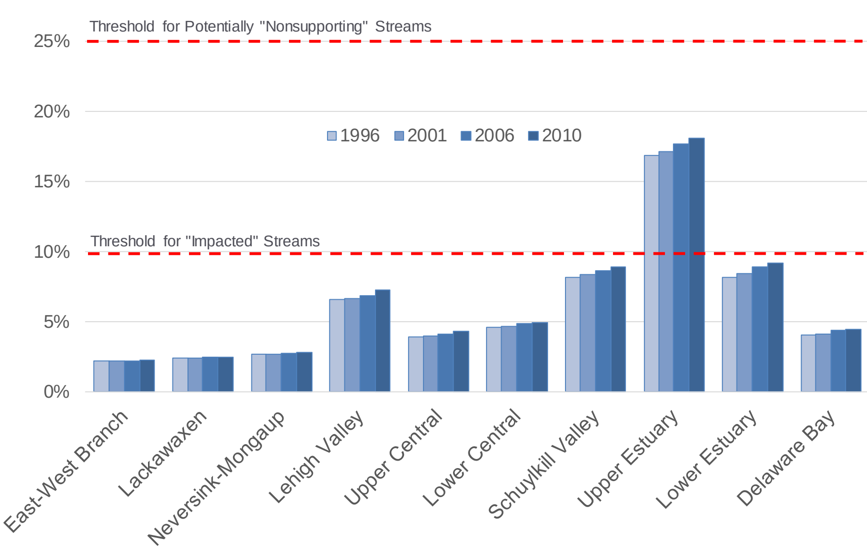


FIGURE 1-5: Percent Impervious in the Delaware River Basin, 2016.

TRENDS

Increases in impervious cover is an indication of growing development in a region. Figure 1-6 shows the levels of impervious cover for subregions in the Basin from 1996 to 2010. Consistent with the urbanizing areas in the Basin, the Lower Region of the Basin (Schuylkill Valley, Upper Estuary, and Lower Estuary) experienced the greatest increase of impervious surfaces from 1996 to 2010. In addition, the Lehigh Valley in the Central Region saw more development from 2006 to 2010.

FIGURE 1-6: Percent Impervious in the Delaware River Basin by Subbasin, 1996-2010.



ACTIONS/NEEDS

The current available land cover data and related impervious cover are NOAA CSC C-CAP for 1996, 2001, 2006, and 2010. Shippensburg University has an updated, higher-resolution (1-meter) land cover dataset for 2013; however, applying impervious cover percentages to these land cover categories is a challenge. Moreover, comparing between the NOAA and Shippensburg datasets poses an additional obstacle because of the difference in land cover categories. A crosswalk across the datasets would be very helpful.

Stormwater management strategies to reduce the impact from impervious surfaces vary in states and municipalities in the Basin. Coordinated stormwater management efforts across federal, state, and local entities is needed across the Basin for protection and restoration of water resources.

SUMMARY

Impervious cover is a good indicator of urbanization and consequently stream health in the Delaware River Basin. Identifying trends where impervious surfaces are increasing over time may be useful for managing urban sprawl and the potential negative impacts on stream health and aquatic life. Implementation of stormwater best management practices to reduce and limit impervious cover will help maintain healthy streams, provide aquatic habitat, and decrease flooding and groundwater recharge issues.

Good

2

WATER QUANTITY

2 WATER QUANTITY

WATER WITHDRAWALS

DESCRIPTION

Water withdrawals are tracked throughout the Basin to identify key water-using sectors and trends in use. Accurate and comprehensive water use information enables the proper assessment, planning and management of water resources. The 2016 water withdrawal data were compiled to generate a Basin-wide assessment by water use sector. All data are based on withdrawals reported to state agencies except for data for the Self-Supplied Domestic (individual homeowner wells) sector, which are based on the population from Census 2010 data for populations that reside outside of public water system (PWS) service areas. An estimated use of 75 gallons/capita/day, based on United States Geological Survey (USGS) values, was applied to calculate water use by this sector.

PRESENT STATUS

Total Delaware River Basin (DRB) water withdrawals (total withdrawn) and consumptive use (water withdrawn from but not returned to the Basin) are displayed in Figure 2-1. Based on 2016 data, an estimated 13.3 million people rely on water from the Basin for their daily water needs. Approximately 8.3 million people live in the Basin and the volume of water exports to New York City and northeastern New Jersey is sufficient to supply water to an additional 5 million people. Total ground and surface water withdrawals from the Basin amount to 6.6 billion gallons per day (bgd). In 2016, major exports from the Basin amount to 607 mgd and consumptive use within the Basin is estimated at 362 mgd . While nearly 6.6 bgd are withdrawn from the Basin, approximately 1 billion gallons are removed from the DRB each day and not directly returned. Approximately 95% of all water used in the Basin is obtained from surface waters and the three dominant use sectors account for over 80% of total water withdrawals: power generation ("Thermoelectric," 58%), public water supply ("PWS," 15%), and industrial use ("Industrial," 9%).

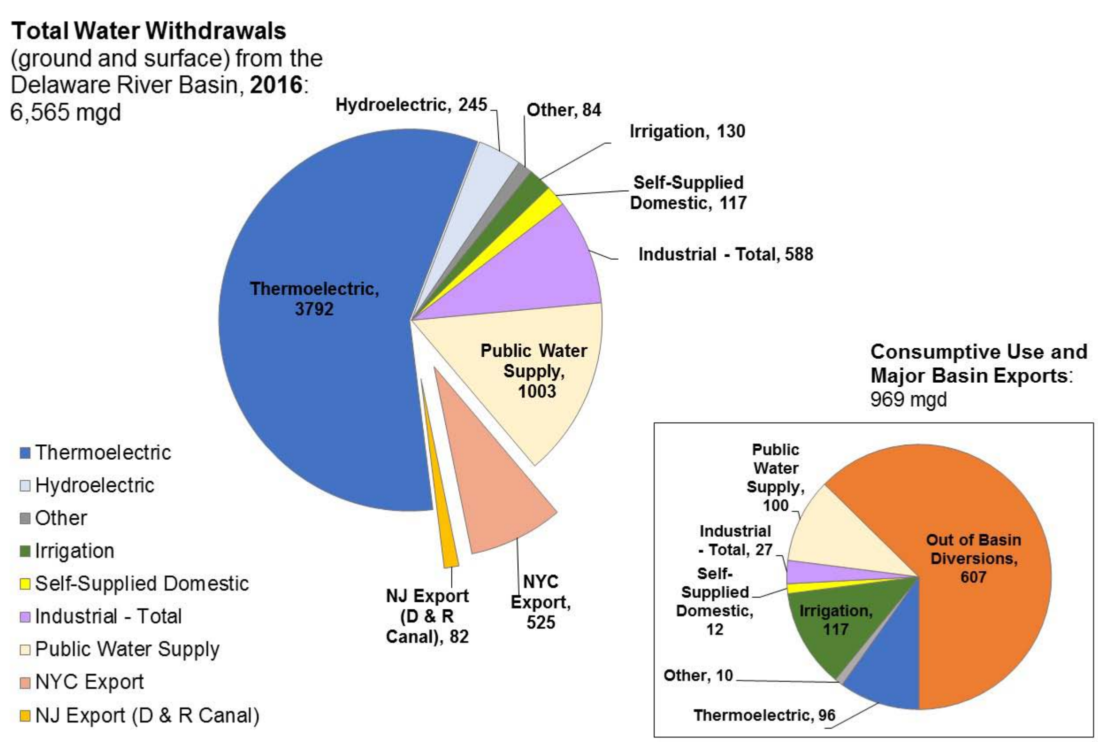
TRENDS

DRBC tracks withdrawals in these three sectors closely. Long-term data for these key sectors extend through calendar year 2016 and provide a monthly time series spanning a period of over 20 years. The results are summarized in Figure 2-2, which displays neutral trends in total water withdrawn. The public water supply sector's neutral trends are primarily attributed to the influence of conservation practices neutralizing population increases, while industrial use trends are more likely the result of facilities entering or exiting the industrial sector. The thermoelectric sector displays an overall decreasing trend in total water withdrawals.

The public water supply sector has maintained a relatively stable rate of withdrawals and consumptive use despite increasing population in the DRB (Figure 2-3). This pattern is primarily attributed to the influence of raised public awareness of conservation practices and changes in plumbing codes enacted in the early 1990s. Historic data for industrial withdrawals show a decline from levels in the early 1990s (Figure 2-4). The closing of the Bethlehem Steel plant in Bethlehem PA in 1995 contributed significantly to the overall decline in water use for this sector, as it was the Basin's largest industrial water user. Over the past decade, industrial water use has declined

Good

FIGURE 2-1: Total water withdrawals from the Delaware River Basin, 2016 in mgd (million gallons per day).



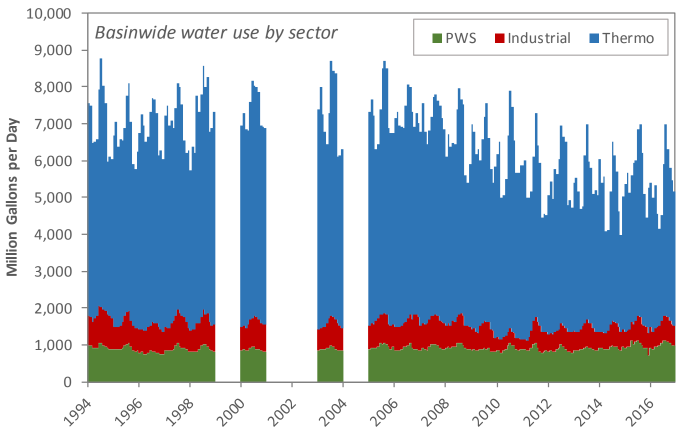


FIGURE 2-2: Long-term, monthly water withdrawal trends for PWS, Industrial, and Thermoelectric sectors.

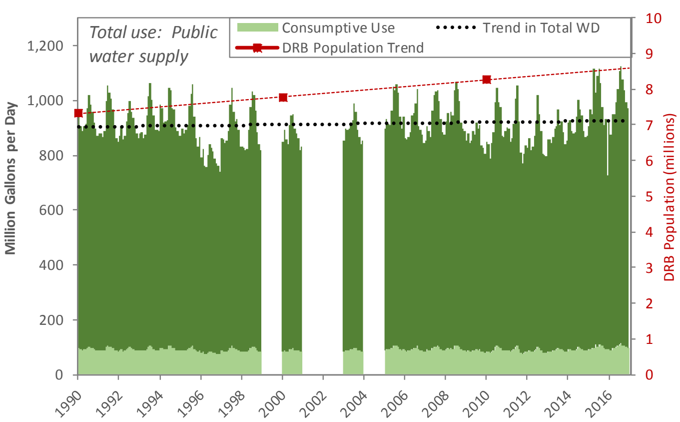


FIGURE 2-3: Historic monthly water withdrawal trends for PWS sector.

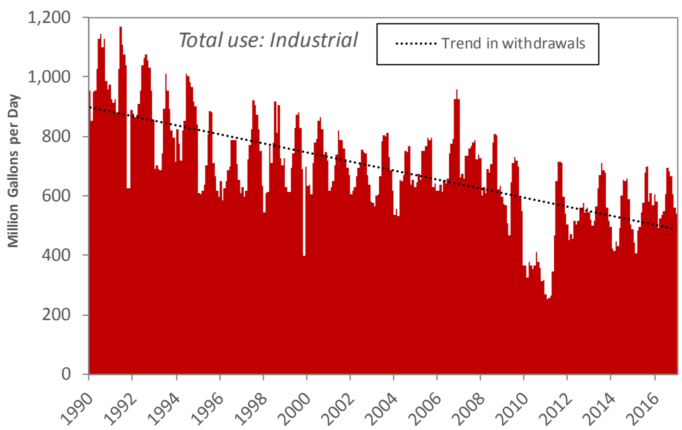


FIGURE 2-4: Historic monthly water withdrawal trends for Industrial sector.

slightly despite numerous facilities changing hands. Several large refineries in the Basin have seen considerable turnover in recent years. Refineries that were idle are once again in operation and water withdrawal use is returning to previous levels.

Understanding water withdrawals is integral to the management of water resources. In recent years, understanding the ways in which water is withdrawn and used has improved greatly, as have the underlying systems in place to manage the data. This has led to more timely and comprehensive assessments. It is likely that public water supply withdrawals and consumptive use will continue to decline relative to population growth as conservation initiatives result in more efficient use of water for public supply. Further improvements in efficiency in water withdrawn by water purveyors could be attained by improving the condition and operation of aging water distribution infrastructure. Water auditing required for the public water supply sector by DRBC may reduce water losses as stakeholders more effectively target their capital investments to improve water supply efficiency, further reducing overall withdrawal volumes and consumptive use. Likewise, only small changes in water use is expected for the industrial and thermoelectric sectors.

ACTIONS/NEEDS

Reporting of water withdrawals has improved in recent years due to electronic, web-based reporting; however, state agencies are adopting this approach at different speeds so data improvements should continue. Continued implementation of the water auditing program should bear strong results as public water suppliers target areas for administrative and capital improvement. Additional studies of the potential growth in water demand for the thermoelectric sector is required due to the impact that large power generating facilities can have on water resources.

SUMMARY

Recent advances in the collection and reporting of water withdrawals, primarily by state agencies, have improved our understanding of water use in the Delaware River Basin and its watersheds. The public water supply and industrial sectors display slightly decreasing trends in total water withdrawn. The thermoelectric sector displays an overall decreasing trend in total water withdrawals.

CONSUMPTIVE USE

DESCRIPTION

Consumptive use is the portion of water withdrawn from the watershed that is not immediately returned to the watershed. In some ways, it is a more important management consideration than total water withdrawals. Different types of water use have different consumptive withdrawals. For example, irrigation is highly consumptive (an estimate of 90% or greater is often used) as the water is absorbed by the plant or soil or lost to evaporation, while withdrawals for the public water supply sector are typically considered to have a low consumptive use (~10%), as only a small portion of water used in homes and cities is not returned to the hydrologic system via sewer or septic systems.

PRESENT STATUS

As noted in the water withdrawal section, over 6 billion gallons per day (bgd) of Delaware River Basin water are used. This includes an average of approximately 525 million gallons per day (mgd) for populations in New York City and 82 mgd for northeastern New Jersey. When combined, these two exports account for approximately 10% of total water withdrawals from the Basin. However, these exports account for nearly two-thirds of the total consumptive use, which is about 1 bgd. In-basin consumptive use of 362 mgd account for the remainder.

In addition to the two major exports, DRBC tracks consumptive use for the three dominant water using sectors within the basin: public water supply, industrial and thermoelectric. The public water supply and industrial sectors display neutral and decreasing trends, respectively, while the thermoelectric sector displays an increasing trend in consumptive use. Figure 2-5 shows that the consumptive use in the Basin for the thermoelectric and public water supply sectors account for approximately 35% and 30%, respectively. Agriculture and other irrigation-related uses (not shown) account for another 20% of in-basin consumptive use.


Good

TRENDS

As shown in Figure 2-5, consumptive use for public water supply systems has remained relatively flat, most likely due to water conservation efforts, while consumptive use for thermoelectric power generation has increased over the past twenty years. Water withdrawals for thermoelectric are primarily used for cooling purposes, which in recent years has transitioned from low evaporative once-through to highly evaporative cooling towers. The monthly data shown in Figures 2-5 and 2-6 highlight the extent to which water withdrawals and consumptive use vary seasonally.

Upward consumptive use trends of the past two decades are expected to continue with respect to the thermoelectric power sector. Most new thermoelectric facilities will rely on cooling towers, which will result in greater levels of consumptive use for the sector overall. The DRBC recently made advances in standardizing its policies regarding the use of replacement water during critical hydrologic conditions for thermoelectric users in the the Basin via Resolution 2018-05. The policy ensures energy security and economic resilience in the Basin during times of low freshwater flow conditions while safeguarding against salinization in the estuary via unifying provisions applied to power generating facilities to provide makeup water (primarily from the Merrill Creek Reservoir in New Jersey) in lieu of curtailing power production.

Withdrawals for public water supply and corresponding consumptive use will likely continue to decline slightly as conservation initiatives continue to result in more efficient use of water for public supply. Additionally, required water auditing by public water suppliers in the Basin will likely reduce overall withdrawal volumes and, thus, overall consumptive use for public water supply. The purpose of the water audit is to track how effectively water is moved from its source to customers' taps and to ensure that public water supply systems quantify and address water losses. Based on the CY2016 reported data,

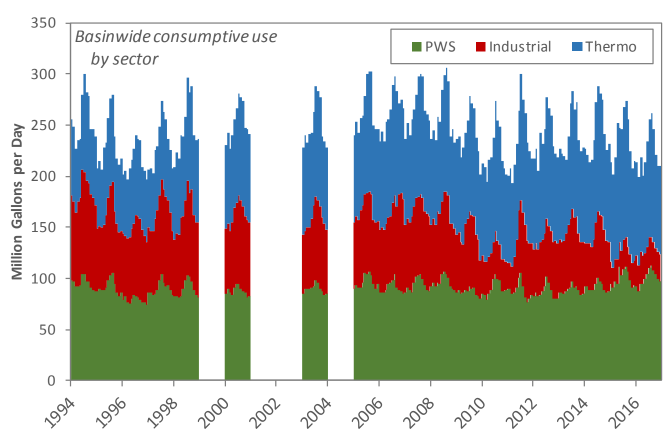


FIGURE 2-5: Long-term monthly consumptive use trends for PWS, Industrial, and Thermoelectric sectors.

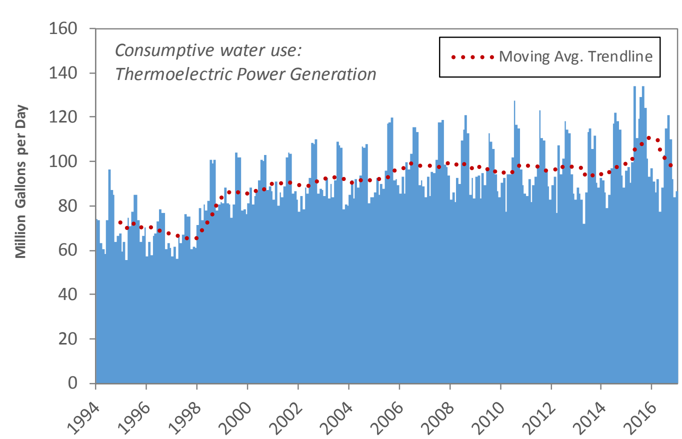
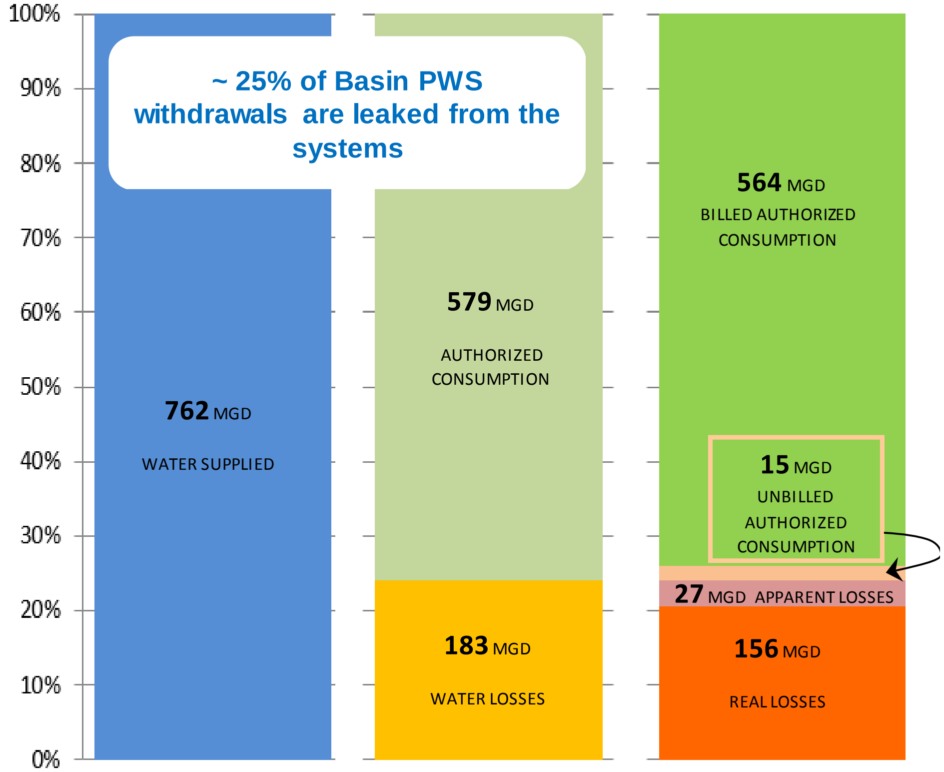


FIGURE 2-6: Historic monthly consumptive use trends for the Thermoelectric sector.

FIGURE 2-7: DRBC water audit program summary (CY2016); aggregate of 283 individual water system audits.



Billed authorized: All consumption that is billed to customers of the utility; this includes metered and unmetered connections.

Unbilled Authorized: All consumption that is unbilled but is still authorized by the utility. This is likely to include water used in activities such as firefighting, flushing of mains and sewers, street cleaning and fire flow tests. It may also include water consumed by the utility itself in treatment or distribution operations, or metered water provided to civic or institutions free of charge.

an estimated 156 mgd was reported as physically lost from distribution systems in the Basin along with an estimated 27 mgd reported as apparent losses, and 15 mgd of unbilled authorized consumption for a total of 198 mgd of non-revenue water reported. This non-revenue water has an estimated annual value of $132 million to water utilities in the DRB and represents a significant opportunity to improve the efficiency of public water supply in the Basin. Figure 2-7 shows a summary of the 2016 results of data collection under the DRBC Water Audit Program.

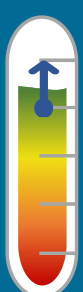
ACTIONS/NEEDS

Review and improvement of consumptive use factors would provide better estimates of consumptive loss. Thus, factors for major and minor sectors should be updated. In addition, water loss accountability should be extended beyond the water audit to the development of normalized indicators, such as gallons lost per mile or per connection, so that regulations may be put in place to reduce losses to industry standards. The system of reservoirs in the Upper Basin, which store water for export to New York City also make compensating releases to maintain downstream water temperatures and flows. Flow management under the Supreme Court Decree can impact consumptive uses during critical periods of water resource needs.

SUMMARY

An understanding of consumptive water use provides additional insight into water use patterns and is an important indicator in the management of water resources. Within the Basin, the largest consumptive uses are from the thermoelectric, public water supply and agricultural water use sectors, accounting for approximately 85% of in-basin consumptive use. Slightly downward consumptive use trends are expected to continue in the public water supply sector, while slightly upward trends may continue in the thermoelectric sector. In addition, there are two significant exports (to New York City and northern New Jersey) from the Basin, which are also considered consumptive uses. These exports are expected to be relatively constant over time and are subject to the U.S. Supreme Court Decree.

GROUNDWATER AVAILABILITY



Very Good

DESCRIPTION

Stress on groundwater resource systems can occur when withdrawals exceed natural recharge. The withdrawal of groundwater by wells is a stress superimposed on a previously balanced groundwater system. The response of an aquifer to pumping stress may result in an increase in recharge to the aquifer, a decrease in the natural discharge to streams, a loss of storage within the aquifer, or a combination of these effects, and impacts may extend beyond the limits of the aquifer being monitored.

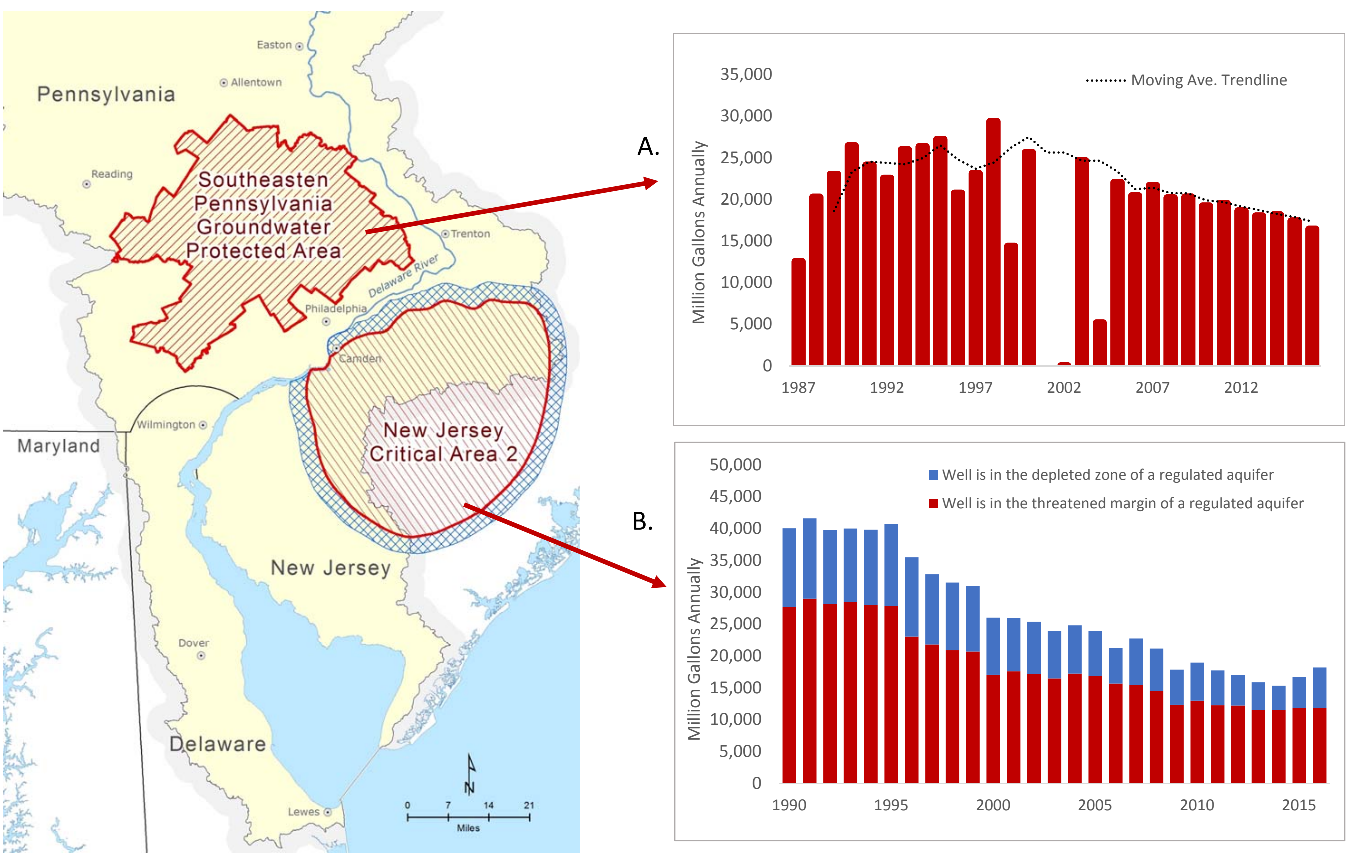
Two major areas, primarily within the watersheds of the Upper Estuary and Schuylkill Valley, have shown signs of stress and are recognized as critical or protected areas: the Southeastern Pennsylvania Ground Water Protected Area (SEPA-GWPA) and Critical Area #2 in south-central New Jersey, which overlays the Potomac-Raritan-Magothy (PRM) aquifer (Figure 2-8). New and/or expanded withdrawals in both critical areas are limited and managed by specific regulations which serve to allocate the resource based on a sustainable long-term yield.

PRESENT STATUS

A shift to surface water sources and regional alternatives to the local supplies are easing the stress in these two areas. In the SEPA-GWPA, reductions in total annual groundwater withdrawals have been observed over the past two decades (Figure 2-8A). The DRBC and the Commonwealth of Pennsylvania created a management program for this area in 1980. In 1999 numerical withdrawal limits were established for each of the area's 76 sub-basins. Between 1990 and 2013, total annual groundwater withdrawals within the SEPA-GWPA were reduced by approximately 8.5 billion gallons (23.4 mgd). A significant component of this reduction is the diversion of surface water from the Point Pleasant, PA intake on the Delaware River in the mid-1990s. The diversion alleviated the need for groundwater withdrawals for two major public water supply systems, as well as provided additional supply to Exelon's nuclear power station at Limerick, PA on the Schuylkill River.

The New Jersey Water Supply Critical Area #2 (see Figure 2-8B) was established by the State of New Jersey in 1993 to stabilize aquifer water levels, prevent saltwater intrusion, and prevent merging with Critical Area #1 in northeastern NJ by prohibiting increases in allocations (New Jersey Water Supply Plan, 2017-2022). Many of the municipalities in this region are now served by surface water diverted from the Delaware River near Delran, NJ. Because of the use of both ground and surface water, aquifer levels have risen and appear to be stabilizing in most parts of Critical Area #2 despite increasing demands in the area. The NJDEP has stated that while the regional aquifers are recovering, concerns exist over some unused portions of allocations (and resultant capacity to increase withdrawals) and does not plan to either increase or decrease allocations in

FIGURE 2-8: Trends in groundwater withdrawal in critical and protected areas of the Delaware River Basin



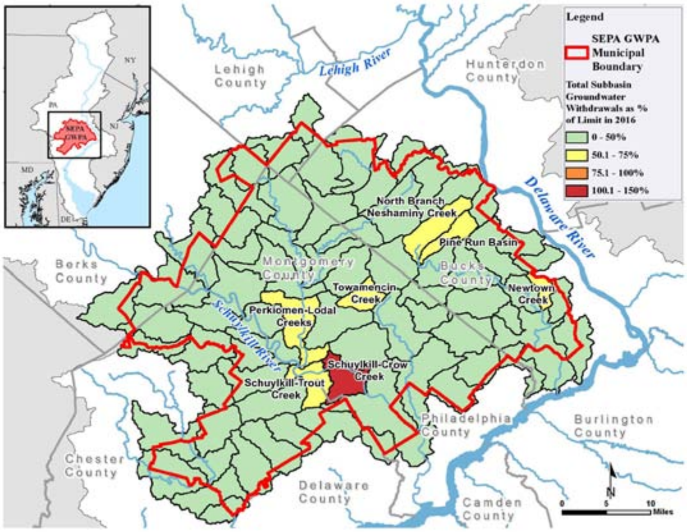


FIGURE 2-9: Areas of groundwater stress in the SEPA-GWPA for 2016.

the immediate future.

The results of a recent analyses within the SEPA-GWPA and Basinwide analysis completed with 2016 withdrawal data are summarized in Figures 2-9 and 2-10, respectively. The 25-year return interval baseflow was used for this analysis. Most of the Basin outside of the GWPA and Critical Area #2 appears to be under little to no stress pertaining to groundwater availability. However, the Little Lehigh Creek tributary system is pumped at a rate of approximately 50% of the 25-year flow. This region is underlain by limestone, which may reduce the reliability of this methodology. Groundwater withdrawals in the Red Lion Creek in Delaware represent 54% of the 25-year baseflow, but this is mostly due to a single industrial user and the watershed is largely tidally-influenced.

TRENDS

Reduction in groundwater withdrawals in the SEPA-GWPA are largely due to the adoption of sub-basin withdrawal limits by DRBC in 1999. Groundwater pumping in several sub-basins has been reduced due to the Point Pleasant diversion, which supplies surface water from the Delaware River to the public water supply systems operating within the GWPA. Other aspects of the management program administered by the DRBC in this area include a more aggressive water conservation program and a lower threshold of 10,000 gallons/month triggering regulatory review (as compared to 100,000 gallons/month elsewhere in the Delaware River Basin).

Figure 2-8A highlights the importance of sub-basin withdrawal limits established by DRBC in 1999 in the observed reductions in groundwater withdrawals in the SEPA-GWPA. Similarly, Figure 2-8B exemplifies the reduced stress in NJ Critical Area #2. This is corroborated by USGS observations from a deep (approximately 700 ft below land surface) well in the Middle PRM aquifer in Camden, NJ. These success stories are largely attributable to adopted management strategies and groundwater conditions in these regions are expected to continue to improve due to management strategies of the DRBC, Pennsylvania, and New Jersey.

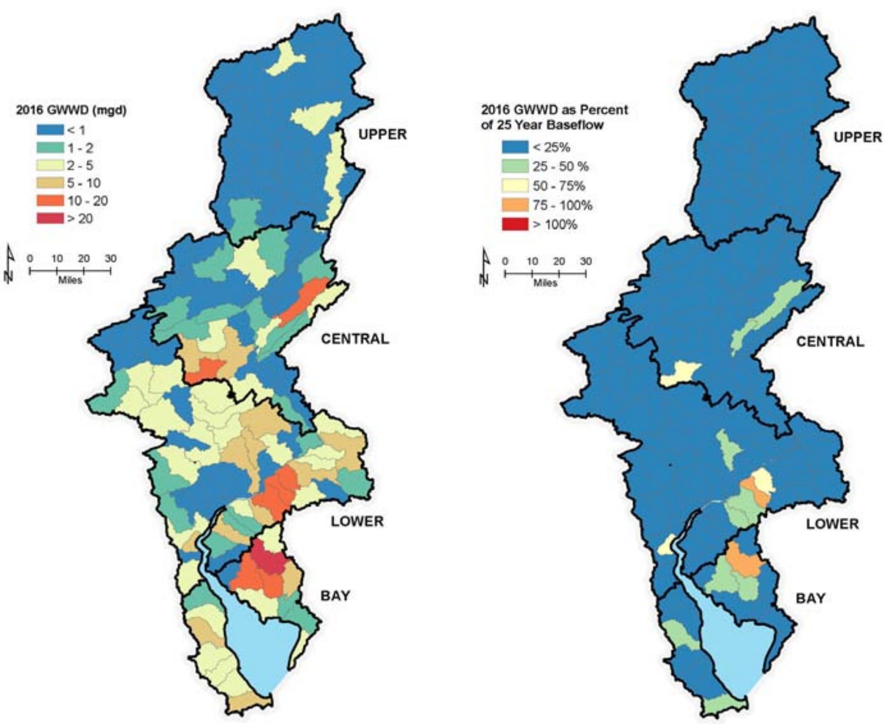
ACTIONS/NEEDS

The progress made in recent years to improve water use reporting needs to be continued to provide the necessary data to monitor conditions in sensitive areas such as the SEPA-GWPA and the NJ Critical Area #2. The metrics used to quantify groundwater availability in the GWPA could be applied to other areas of the Basin for assessment purposes.

SUMMARY

The two groundwater areas described in this section are examples of successful, proactive management strategies that could be applied to other areas undergoing stress because of groundwater pumping. Limits on groundwater withdrawals in conjunction with surface water diversions should allow continual recovery of those aquifers.

FIGURE 2-10: Basin-wide groundwater withdrawals in 2016.



CURRENT AND FUTURE HYDROLOGY

Flow

DESCRIPTION

The Delaware River and its tributaries provide water for many different purposes including: drinking and industrial water supply, power generation, water quality maintenance, ecosystem services, fishing, boating and recreation. Prior to 1927, there were no major reservoirs in the basin that affected flow on the main stem river. Since then, three reservoirs were built by New York City (NYC) to divert water from the Delaware River Basin to meet the needs of the growing city. In 1954, a Supreme Court Decree, resolving the Delaware Diversion Case, resulted in the establishment of the Montague Flow Objective, which required NYC to make releases to maintain a flow rate at Montague, NJ, providing water for downstream uses to compensate for water diverted from the Basin. In 1983, the Commission adopted a drought management program and established the Trenton Flow Objective. The Trenton Flow Objective is intended to assure that enough freshwater flows into the estuary to "repel" salinity (see SALINITY in Section 3). Releases from several basin reservoirs are used to manage freshwater inflows to the estuary. The main stem river is also susceptible to flooding, another issue of concern for the Basin.

PRESENT STATUS

During the 1960s drought of record, the lowest average monthly flow recorded at Trenton was 1,548 cubic feet per second (cfs) in July of 1965. Due to the construction of reservoirs, the implementation of the drought management plans and reductions in consumptive water use, the River is unlikely to see flows as low as those of the 1960s. Water is stored in reservoirs during periods of high flows and later released during periods of low flow providing some assurance of flow

FIGURE 2-11: Difference between Five-Year Average Annual Flow and Annual Average Flow

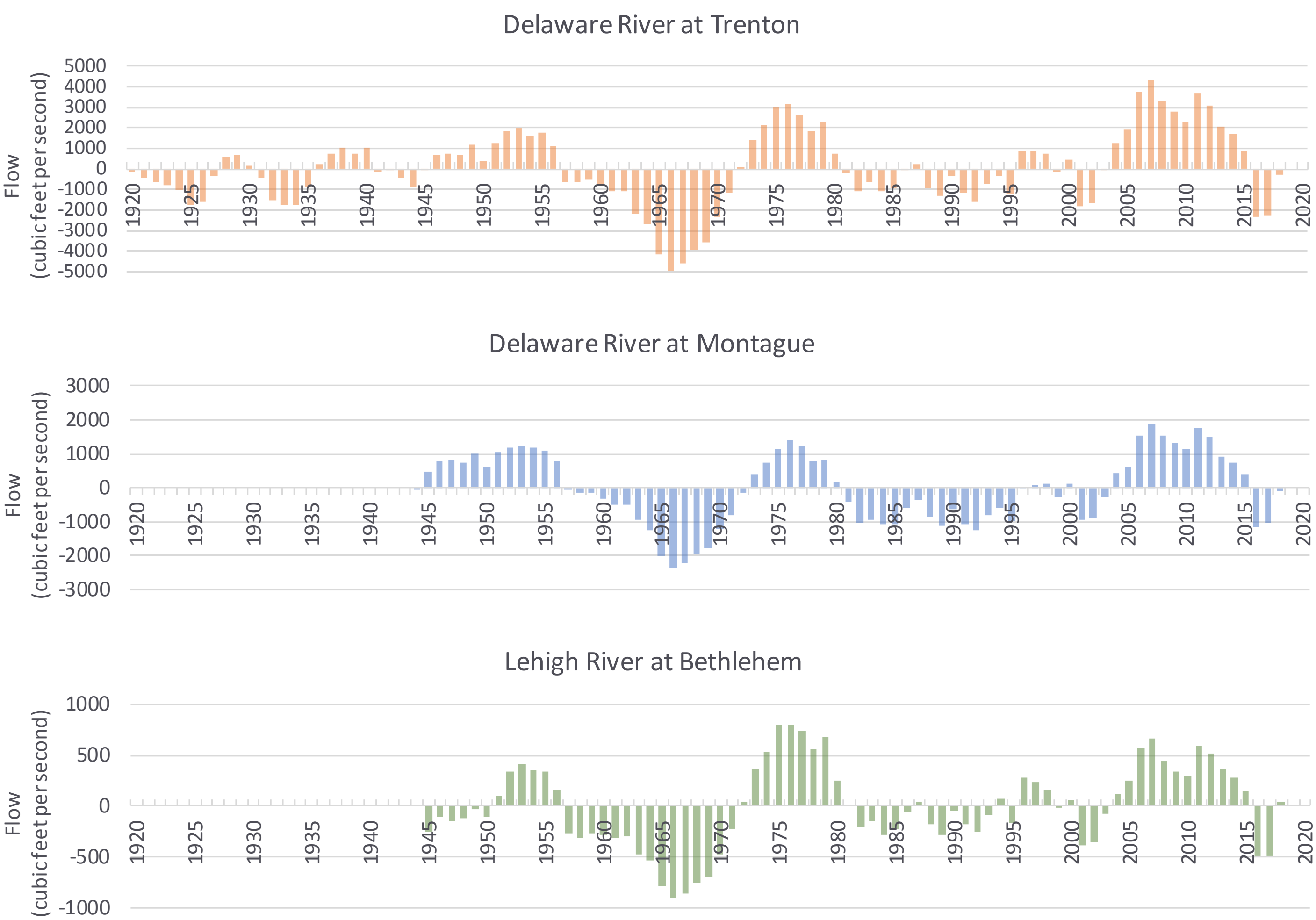


Figure 2-12: Washington's Crossing Bridge area in the June 2006 flood.

Figure 2-13: Washington's Crossing during a drought watch in late 2016. *Photo credit Elaine Panuccio, DRBC.*

levels in the River. Often, during dry periods, the minimum releases from the reservoirs are larger than the inflows, thus the River downstream will experience somewhat higher flows than it would have otherwise received in the absence of the reservoir releases. Since the 1960s, the lowest monthly flow at Trenton was 2,535 cfs in January 1981 during a winter drought.

In addition to droughts, flooding has also been a recent issue in the Basin. The flood of record for the main stem Delaware River was caused by a large rain and snow melt event in 1904. The second worst flood was caused by Hurricane Diane. Both the 1904 and 1955 flood occurred prior to the construction of most major basin reservoirs. Recently, in 2004, 2005, 2006 and 2011, main stem flooding also occurred on the Delaware River. All four floods in this century were in the top ten worst floods and after a period of 49 years without major main stem flooding.

TRENDS

The annual variability in precipitation and temperature make it difficult to discern trends in flow (see Climate Change). However, wet and dry periods are evident when longer-term averages are examined. Figure 2-11 presents the difference between the five-year running average annual flow and the average annual flow at three locations in the basin: the Delaware River at Montague and Trenton, NJ and the Lehigh River at Bethlehem PA, for the period with available data at each site. For Trenton, data show the dry periods experienced in the 1920s, 1930s, and 1960s. In evidence is the long dry period beginning in the late 1950s leading into the severe drought of the 1960s. Also apparent are the wetter decades of the 1970s and 2000s. Similar patterns are evident for the Delaware River at Montague and the Lehigh River at Bethlehem.

Figures 2-12 and 2-13 show the flow extremes experienced in the Basin in recent years near Washington's Crossing. The first photo shows the Washington Crossing Bridge area during the June 2006 flood. The second photo shows the same area during a Drought Watch in late 2016.

ACTIONS/NEEDS

To better understand potential future issues related to river flows, modeling and other analyses being conducted under the Commission's Water Resources Program and by others, are needed to develop an understanding of how climate change may affect river flows (hydrology) and how sea level rise may affect salinity. Preliminary results indicate that changes in precipitation and temperature will affect the timing and amount of water reaching the main stem. The shift in the seasonality of high flows is predicted to change along with a slight overall increase in flow. Sea level rise is anticipated to affect the mixing of fresh and salt water in the estuary. Modeling and analyses will help to determine the adequacy of flow management programs, drought management plans, and water availability to repel the salt front and meet other demands for water in the Basin. In addition, to the responsibilities of the Commission for water resources planning and management, flow management for the Basin is influenced by the 1954 US Supreme Court Decree. Planning for future water needs will be coordinated with the parties and other interested stakeholders, as applicable. More information about Climate Change and Sea Level Rise is located in the next Section.

SUMMARY

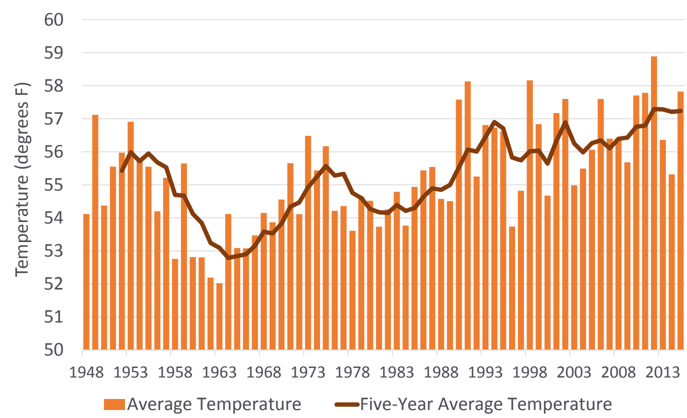
The Basin has experienced periods when flows persist above or below the long-term average, such as the dry period of the 1960s and the wet periods of the 1970s and mid-2000s. Freshwater inflows impact salinity in the estuary, which affects the availability of estuary water for drinking water and industrial uses. The flow objective at Trenton appears to be keeping the salt front below river mile (RM) 98, the salinity management goal. However, sea level rise may require new management measures, operations plans and/or additional water to maintain control of salinity.

Climate Change

DESCRIPTION

Climate change has the potential to impact water availability and the ability to meet water management goals in the Basin. Predicted increases in precipitation and temperature, as well as shifts in seasonality, may affect the water cycle and thus the amount of groundwater, streamflow, and snowpack. Warmer temperatures in the winter will mean less water stored as snow and greater evaporation rates. Although more precipitation is predicted for the region, increases in temperature may offset that due to the increase in evaporation rates. Sea level rise (SLR) is also a result of climate change that may change the salinity in the estuary and impact habitat, water availability and flow management goals.

FIGURE 2-14: Average Annual Temperature at Philadelphia



PRESENT STATUS

Figure 2-14 presents the average annual temperature (orange bars) at Philadelphia since 1948. The average temperature varies year to year, but the five-year average annual temperature (dark red line) indicates an increasing trend. Figure 2-15 presents the annual precipitation (blue bars) at Philadelphia for the same period. As with temperature, the precipitation varies year to year. The five-year average annual precipitation (dark blue line) indicates an increasing trend in precipitation since the year 2000. However, a review of the five-year averages over the period of record does not indicate a clear trend.

Figure 2-16 presents the mean sea level at Philadelphia over the last century. Since the early 1900s, sea level has risen at an average rate of 2.93 mm/year or 0.96 ft/100 year. A change in sea level affects the overall volume of water in the Bay and Estuary which may also affect the dynamics and persistence of salty water in the upper reaches of the Estuary (see section on SALINITY).

FIGURE 2-15: Annual Precipation at Philadelphia

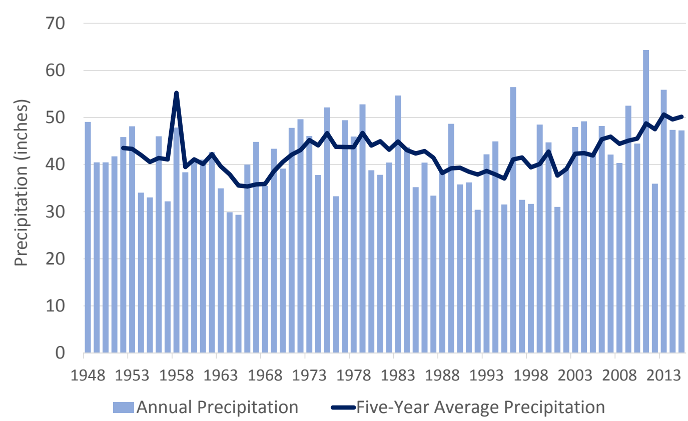
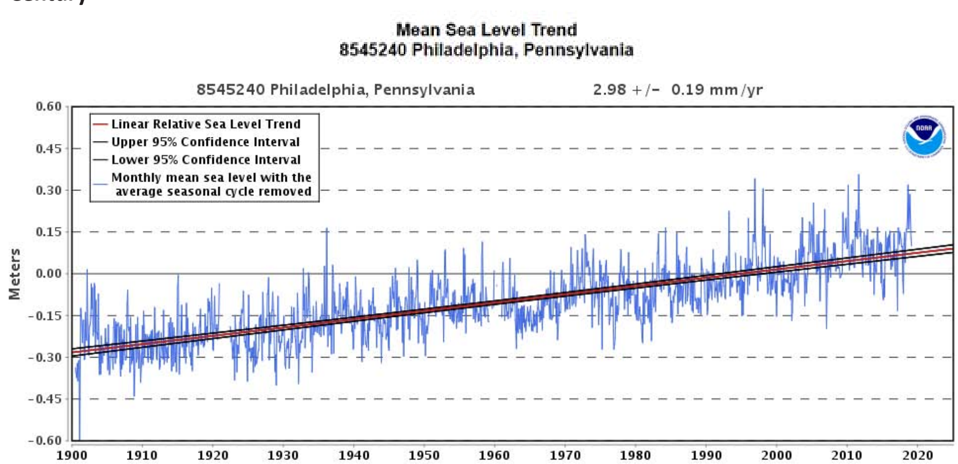


FIGURE 2-16: Observed Sea Level at Philadelphia over the last Century



TRENDS

Studies of the anticipated changes to temperature and precipitation indicate that the trend is for the Basin to be warmer and wetter in the future. In addition, weather events are predicted to be more extreme with a more active Atlantic hurricane seasons, higher intensity storm events and short-duration, but severe, dry periods. The changes to flow resulting from the increased precipitation and evaporation, combined with the impact of sea level rise to salinity, new drought and flow management programs may be needed.

Due to the concerns about how increases in precipitation and temperature may affect flows and flow management, the DRBC has employed the USGS Water Availability Tool for Environmental Resources (WATER) and the DRB Planning Support Tool (PST) to determine

FIGURE 2-17: Potential Differences in Average Monthly Precipation in 2060 Based on High Emission Scenario

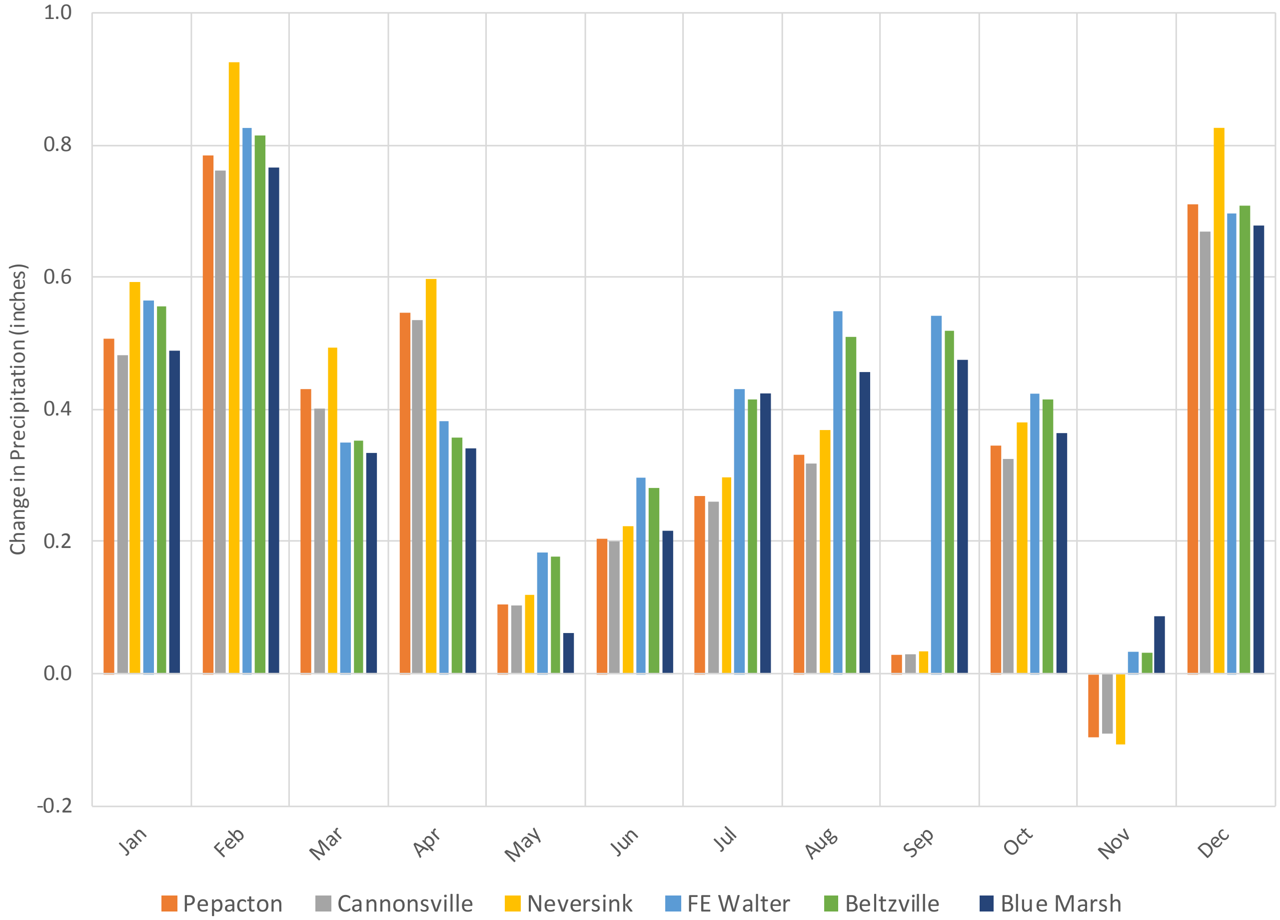
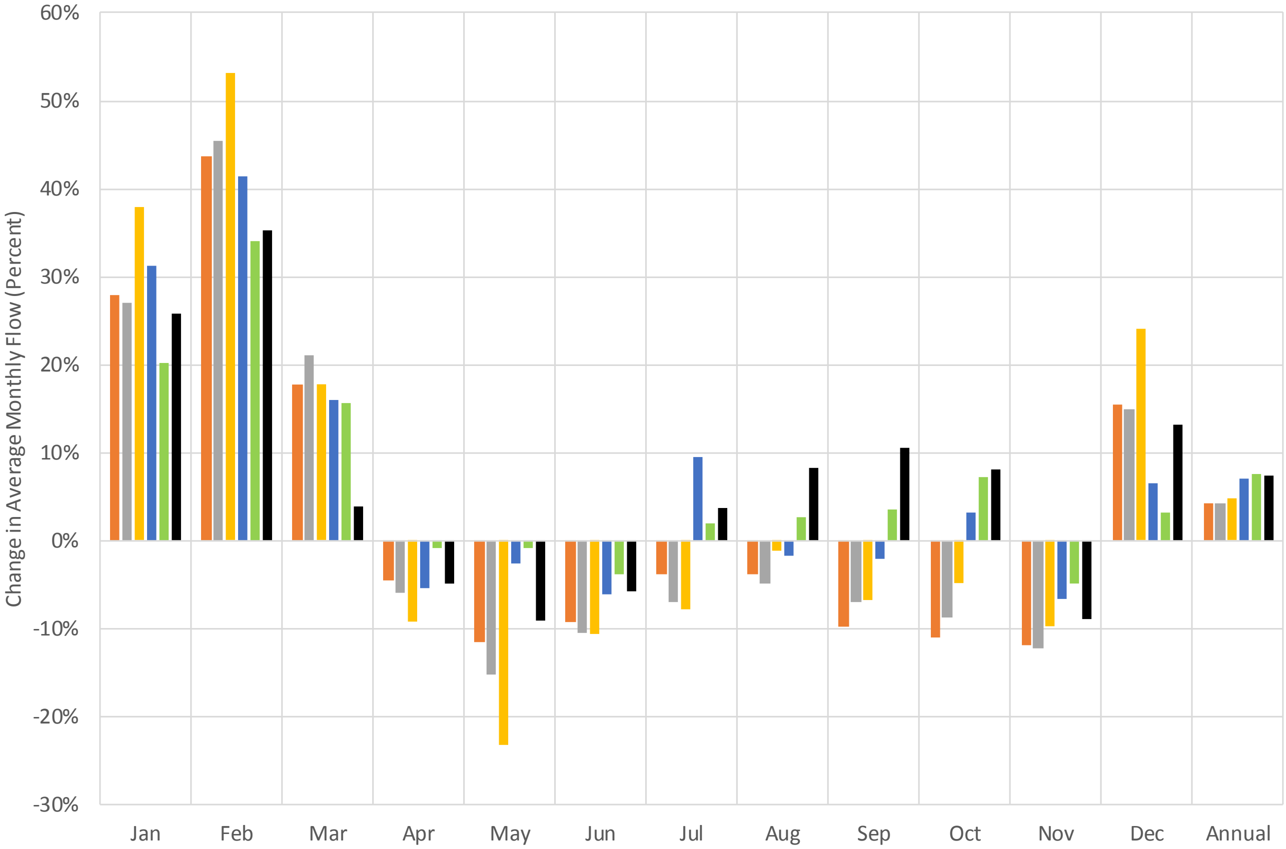


FIGURE 2-18: Potential Differences in Average Monthly Reservoir Inflows in 2060 Based on High Emission Scenario



how water availability may change in the future. WATER is a hydrologic model of the Delaware River Basin which can be used to simulate the inflows with changes in temperature and precipitation predicted by different climate models and emission scenarios. Those inflows are then used in PST to simulate different flow management plans for the Basin.

Figure 2-17 presents the simulated monthly change in precipitation at six major reservoir locations in the basin. In almost all months, the precipitation increases, with the larger increases occurring in the winter and early spring. Temperature and evapotranspiration (evaporation plus the removal of water by vegetation) also increases in all months (not shown). The overall result to the water cycle is mixed. Figure 2-18 presents the differences in simulated monthly inflows to the same six reservoirs. Winter inflows are higher, spring inflows are lower, and summer inflows appear to increase in the lower basin and decrease in upper basin. With higher temperatures, the increased precipitation in the winter occurs more often as rain rather than snow, reducing the snowpack. In the spring, because there is less snowpack and higher evaporation rates, less water is available to become streamflow. Because the evaporation is changing at different rates compared with the increase in precipitation, the changes in flow differ by location based on land use.

Figure 2-19 shows the predicted sea level rise in the Delaware Bay by 2100, which ranges from approximately 0.5 m (1.6 ft) to 1.5 m (5 ft). Previous modeling of salinity under different sea level rise scenarios indicated that a sea level rise of 3 feet would likely result in salinity concentrations that create corrosive conditions in surface water intakes and adversely affect drinking water treatment facilities in the Upper Estuary.

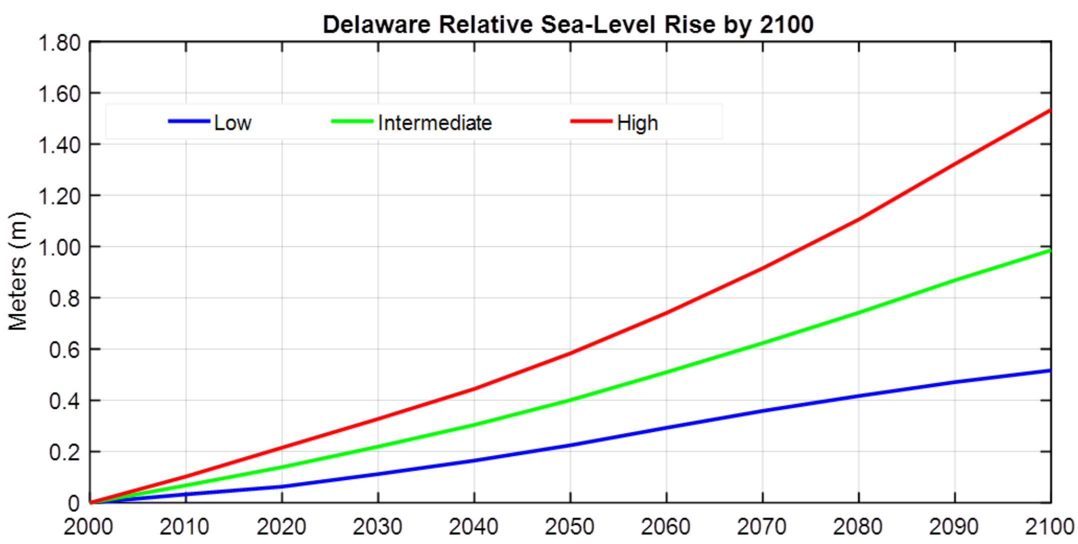
ACTIONS/NEEDS

The potential changes to reservoir inflows from climate change may impact the availability of water for all of its desired uses. Modeling and other analyses are already underway to further define the range of risks due to climate change, during both dry and wet periods, as well as evaluate future water demands for different purposes. Once this work has been completed, different approaches and mitigation measures will be needed to develop robust plans and resources to address the risks posed by climate change.

SUMMARY

Temperatures and precipitation in the Basin appear to be increasing. Predictions for increased temperatures and precipitation that may result from climate change were simulated and are likely to result in changes to the seasonality of flow, amount of snowpack, and the availability of water for different uses. Moreover, sea level rise will impact salinity, as well as, the associated flow and drought management in the Basin. More extreme weather events are anticipated including tropical storms, flooding and short-duration dry periods. With the likelihood of more hurricanes and high intensity storms, flood mitigation opportunities, new and previously identified, may need to be re-evaluated and implemented.

FIGURE 2-19: Predicted Sea Level Rise through the 21st Century
(Source: Delaware Geological Survey, https://www.dgs.udel.edu/projects/determination-future-sea-level-rise-planning-scenarios-delaware)

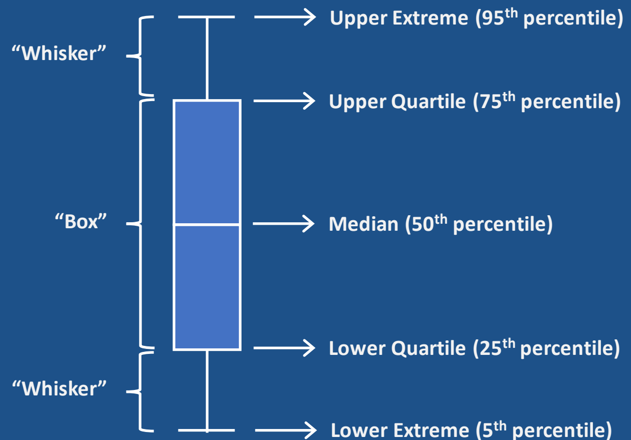


3

WATER QUALITY

How to Read a "Box and Whisker" Plot

Several indicators in this section use a box and whisker plot to visually display water quality data. Below explains the "anatomy" of the plot:



DISSOLVED OXYGEN

DESCRIPTION

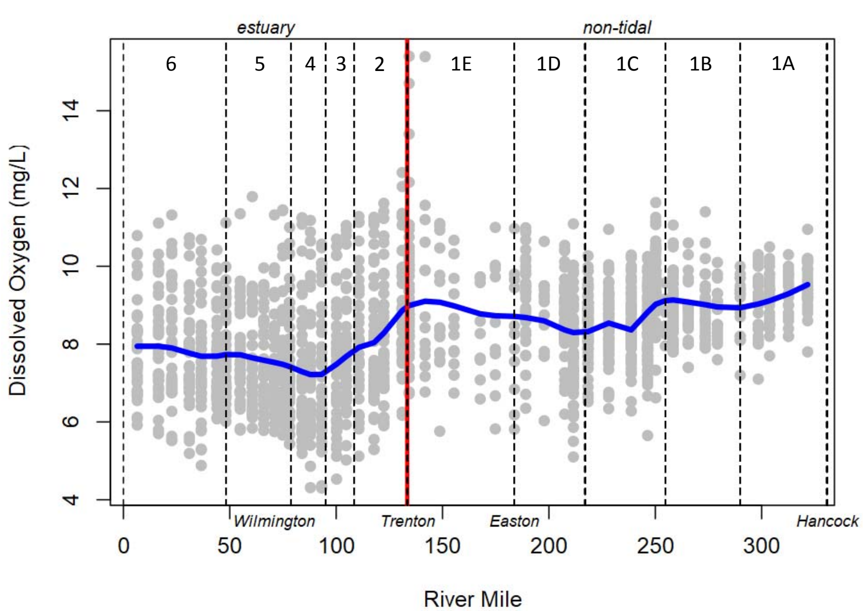
Dissolved oxygen (DO) refers to the concentration of oxygen gas dissolved in water. Oxygen enters water both by direct absorption from the atmosphere, which can be enhanced by turbulence, and as a by-product of photosynthesis from algae and aquatic plants. Sufficient DO is essential to growth and reproduction of aerobic aquatic organisms as well as an important factor for good water quality. Oxygen levels in water bodies can be depressed by the discharge or eutrophication of oxygen-depleting materials (often measured in aggregate as biochemical oxygen demand (BOD), from: wastewater treatment facilities and stormwater runoff); the decomposition of organic matter including algae generated during nutrient-induced blooms; the utilization of oxygen by aquatic organisms such as fish, reptiles, macroinvertebrates and bacteria; the oxidation of ammonia and organic carbon; abiotic factors such as temperature; and lastly, the amount of movement and volume of water.

PRESENT STATUS

Good

In the summer, when the temperature is generally high, DO levels are low. Because DO concentrations during this time are typically characterized by a daily peak in late afternoon and a pre-dawn daily low due to photosynthetic processes, continuous monitors are preferable to daytime spot measurements, which miss the daily low concentrations. DO is measured routinely by DRBC, continuously by the USGS at Reedy Island, and April through November at Chester and the Ben Franklin Bridge. DRBC's water quality standard for DO in the Estuary is a 24-hour average concentration not less than 5.0 mg/L in Zone 2, 3.5 mg/L in Zones 3, 4, and the upper portion of Zone 5, 4.5 mg/L in the middle portion of Zone 5, and 6 mg/L in the lower portion of Zone 5. In the 2016 Delaware River and Bay Water Quality Assessment (DRBC, 2016; https://www.state.nj.us/drbc/library/documents/WQAssessmentReport2016.pdf), greater than 98.5% of observations met criteria in Zones 2 through 5, and greater than 90% of observations met criteria in Zone 6. Figure 3-1 illustrates that DO concentrations are greatest at Reedy Island (River Mile 54.1), less at Chester (River Mile 83.1) and least at the Ben Franklin Bridge (River Mile 100.05).

FIGURE 3-1: DO by river mile along the mainstem Delaware River, 2008 through 2016.



In the non-tidal sections of the Delaware River, USGS continuous monitoring data provides a complete DO distribution for 2011-2016, but at fewer locations, including: Brandywine Creek at Chadds Ford; Christina River at Newport DE; Delaware River at Trenton; Schuylkill River at Vincent Dam; and Lehigh River at Glendon. Summer measurements of DO at various non-tidal locations in the Delaware River Basin from 2011 through 2016 are illustrated in Figure 3-2. Although the distributions are different at each location, the majority of values are greater than 5 mg/L.

DRBC has developed a daily near real-time assessment of DO comparing the 24-hour mean concentrations at USGS monitors to the DRBC surface water quality standard available at: http://drbc.net/Sky/waterq.htm. In addition, DRBC has developed a web app for exploring the Estuary Water Quality Monitoring data at: https://johnyagecic.shinyapps.io/BoatRunExplorer.

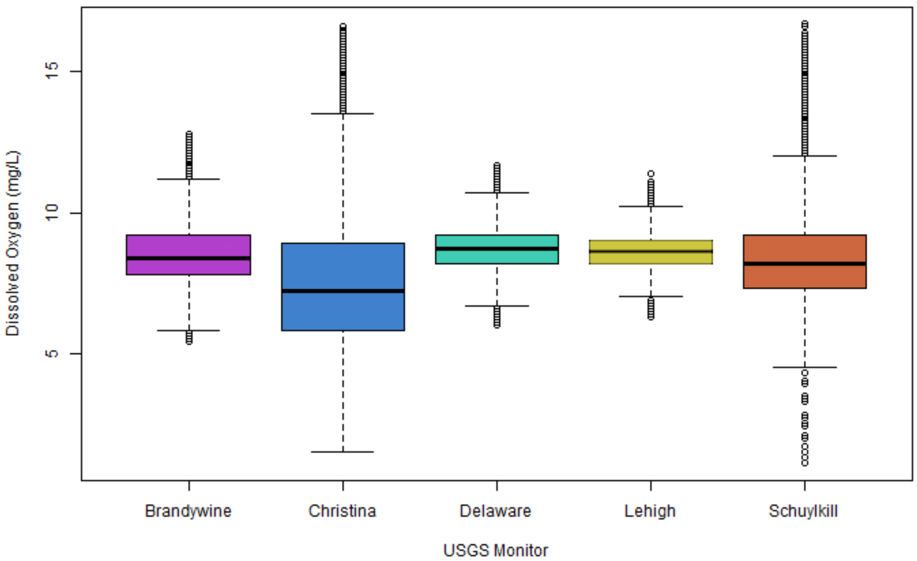
TRENDS

Historically, the limited treatment of human and industrial wastes through the mid-1900s caused severe water pollution problems in many areas of the Delaware Basin. The urban Delaware Estuary corridor surrounding Philadelphia was the most notorious of the problem areas. In fact, these water pollution problems were key to motivating the DRBC's formation, further leading to the development of the Clean Water Act and other state and federal laws to control water pollution in the 1960s and 1970s.

The pollution in the Delaware Estuary was so severe that, among many symptoms, there was essentially no DO in the Delaware River on a typical day from May through November of every year in the areas around Philadelphia. This zone of "anoxia" (a lack of DO) and the surrounding zones of "hypoxia" (severe depression of DO) eliminated the fish and other aquatic organisms and prevented migratory fishes such as American shad from completing their runs to the upstream spawning grounds.

After the DRBC was created in 1961, the first significant accomplishment was the adoption and implementation of water quality standards in 1967 and a waste load allocation in 1968 for one form of oxygen-consuming pollution known as CBOD (carbonaceous biochemical oxygen demand). As a result of these DRBC regulations, and with the help in subsequent decades from

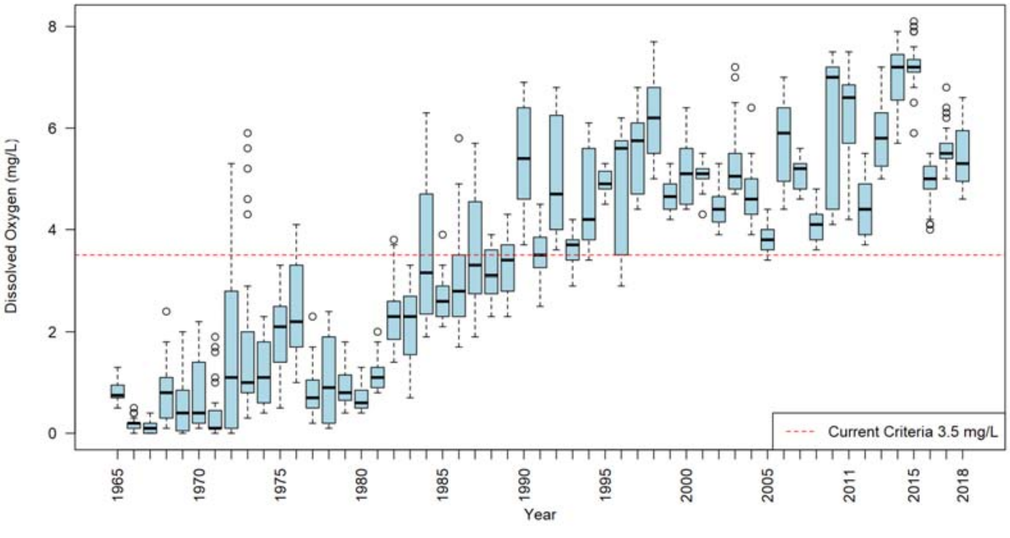
FIGURE 3-2: Summer DO measured by USGS continuous monitors on Delaware River tributaries, 2011 through 2016.



Clean Water Act grants and the diligent work of state and federal agencies, the DO levels in the Estuary steadily improved through the 1970s, 1980s, and into the 1990s (Figure 3-3). After the 1990s water quality got to the point where oxygen levels now meet the targeted goals (such as 3.5 mg/L average DO concentration around the Ben Franklin Bridge) and the fish populations in this region of the estuary have been partially restored.

Overall, DO concentrations are lowest in mid-summer. As shown in Figure 3-3, the July dissolved oxygen concentrations were historically below the current Zone 3 standard of 3.5 mg/L in the 1960s and 1970s. Improvements in DO became apparent through the 1980s as municipal waste water treatment facilities added secondary treatment. From the mid-1990s onward, criteria were mostly met, although DO concentrations exhibit a high level of variability from year to year. DO at the Ben Franklin Bridge for example was mostly above 6 mg/L in 2014 and 2015, but closer to 5 mg/L in 2016.

FIGURE 3-3: Delaware Estuary July daily mean dissolved oxygen concentrations by year at USGS gage at Ben Franklin Bridge, 1965 to 2016.



ACTIONS/NEEDS

The Commission is examining whether current criteria for DO may need revision to be better protective of fish reproduction. Looking ahead, temperature and salinity in the tidal portion of the river may increase due to sea level rise and global climate change. This increase could potentially lower the river's oxygen carrying capacity, therefore making other water quality improvements necessary.

Additionally, the current nation-wide focus on elevated nutrients, or eutrophication, and the depletion of DO in many aquatic environments subjected to high nutrient loading has re-focused efforts on the remaining DO issues in the Delaware Estuary. To address both nutrients and DO, the DRBC and its state and federal partners, the regulated community, and the environmental community, have initiated a program to measure the sources of nutrients and oxygen-depleting materials and to build a water quality model to integrate this information and forecast future scenarios for the Delaware Estuary.

SUMMARY

Available data indicates that DO levels support designated uses and aquatic life needs throughout the Delaware River Watershed, with only a few localized areas of low DO. The trend for the Delaware River at Trenton suggests that DO is stable at relatively high DO saturation. It is expected that good DO levels to persist under current regulations, with improvements at impaired sites over the long term.

The long-term trend of DO in the Delaware Estuary shows remarkable improvement from near anoxic (DO < 2 mg/L) conditions in the 1960s and 1970s to nearly always above criteria today. To capture and retain the recoveries in fish growth and spawning that have followed the recovery in DO, DRBC is conducting a study to determine the appropriate designated aquatic life uses of the Delaware River Estuary and the water quality criteria necessary to protect its uses.

NUTRIENTS

DESCRIPTION

The general category of "nutrients" is comprised of many different chemical compounds, including several species of nitrogen and phosphorus. These compounds help stimulate and sustain the growth and development of aquatic organisms, such as plants and algae. Indicators include the specific chemical substances nitrate and phosphate as being representative of nutrients. Specific concentrations of these two nutrient compounds are generally in a form that make them easy for biological uptake and under normal conditions should be a limiting component in relation to other essential elements. However, when these compounds become plentiful, plant and algal biomass increases as well. Under these constraints a surplus of dissolved oxygen is created. However, once these organism's die-off they take with them nearly all the dissolved oxygen, essentially creating a void or a Dead Zone. Nitrate and phosphorus have have the advantage of tracking productivity and the ability of being quantifiable in the Delaware Basin with use of long measurement records.

The DRBC Special Protection Waters (SPW) regulations has defined Existing Water Quality (EWQ) concentrations of several nutrients including total nitrogen, ammonia, nitrate, total Kjeldahl nitrogen, total phosphorus, and orthophosphate at multiple mainstem and tributary sampling locations. DRBC adopted SPW regulations for Upper and Middle Delaware in 1992, using existing data available at that time to define EWQ, and permanently designated the Lower Delaware as SPW waters in July 2008 (see Figure 3-5 for map of SPW). The SPW program is designed to prevent degradation where EWQ is better than the established water quality standards. This is achieved through management and control of wastewater discharges and reporting requirements.

The Delaware Estuary has both high loadings and high concentrations of nutrients relative to other large estuaries such as Narragansett Bay, Chesapeake Bay, and San Francisco Bay in the United States. The environmental effects from these high nutrient levels are not well understood but monitoring in the Estuary shows signs of suboptimal ecological health, including a persistent summer dissolved oxygen sag in the urban corridor of the Estuary. Although nutrient loading to the Estuary has not been demonstrated to be the cause of either suboptimal ecological conditions or the dissolved oxygen sag, high nutrient loading is one of the primary instruments for understanding the Estuary's ecological health and trophic level interactions (see DISSOLVED OXYGEN).

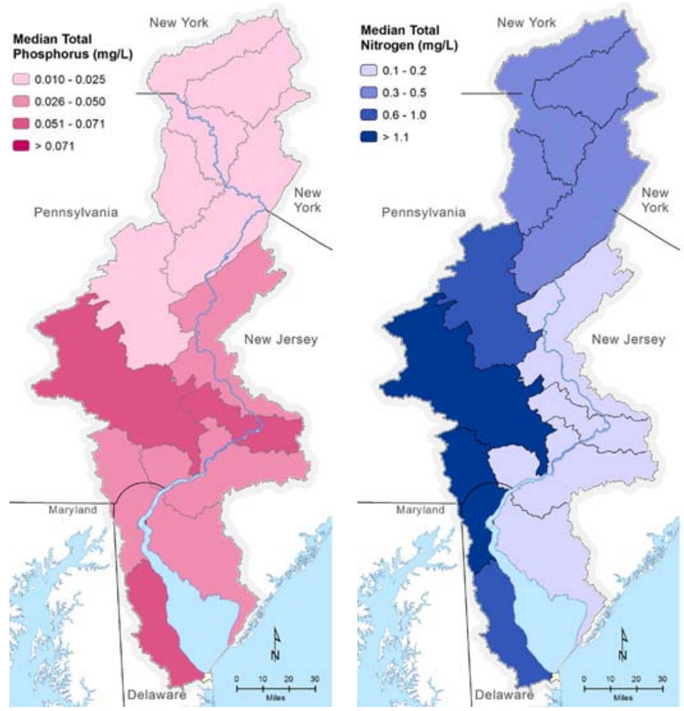
Very Good

PRESENT STATUS

Phosphorus

Phosphorus is often a limiting nutrient in freshwater ecosystems. It is important to note that total phosphorus concentrations account for all species of phosphorus, organic and inorganic, soluble and insoluble. Therefore, this measure accounts not only for those dissolved, inorganic species of phosphorus that are readily available for algal and plant assimilation, but also

FIGURE 3-4: Median nutrients concentrations for subwatersheds in the Delaware River Basin.



for those species of phosphorus that are tightly bound to soil particles or are contained as cellular constituents unavailable for algal assimilation.

Data compiled from the National Water Quality Portal for 2000 through 2016 suggest lower phosphorus concentrations in the headwaters with greater concentrations observed near the urbanized and Estuary portion of the Basin, from Easton, PA down to Wilmington, DE, as shown spatially in Figure 3-4 and graphically in Figure 3-6. Although greater concentrations are observed within the urban corridor, phosphorous concentrations during this time frame never exceeded 0.20 mg/L and held average concentrations at approximately 0.06 mg/L or less. As phosphorus concentrations approach the Atlantic Ocean they undergo a precipitously decrease to concentrations like those found in the headwaters. When observing available phosphorus concentrations from 2000 to 2016 throughout SPW illustrates that the Upper Delaware River watershed is generally low in rates of total phosphorus inputs (Figure 3-5). Notable areas of elevated median total phosphorus are occurring at Martins Creek, Bushkill Creek, Lehigh River, Lopatcong Creek, Pohatcong Creek, and the Musconetcong River.

Nitrogen

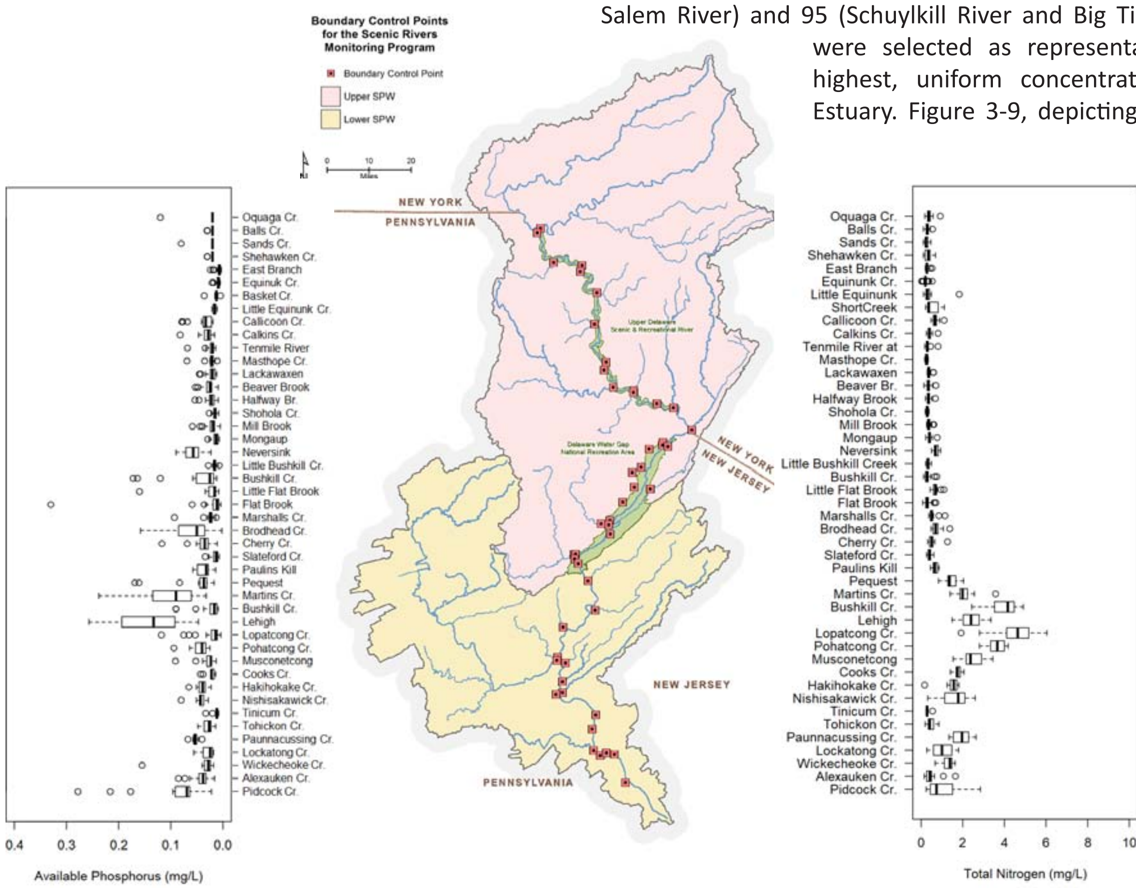
Nitrogen tends to be a limiting nutrient found within saltwater environments. Data compiled from the National Water Quality Portal for 2000 through 2015 suggest less concentrations of nitrate in the upper portion of the Basin, with greater concentrations seen towards the tidal portion of the basin and within the Schuylkill sub-watershed. Nitrate concentrations in the Estuary are presently less than 3 mg/L. The greatest concentrations are observed in the urbanized mid area of the Estuary, with somewhat less concentrations near the head of tide (reflecting lower concentrations in the non-tidal river) and substantially lower concentrations at the mouth of the Bay, as shown in Figures 3-4 and 3-8. This pattern suggests nitrogen loads might be originating in the Estuary, particularly in the urbanized area. Although nitrate concentrations are high, the worst eutrophication symptoms (such as anoxia, fish kills, and harmful algal blooms) are not currently present within the Delaware Estuary.

Total nitrogen concentrations were also observed throughout the SPW from 2010 to 2016 (Figure 3-5). In the SPW, total nitrogen concentrations appear to be the greatest from the Paulin's Kill down to the Pidcock Creek with concentrations greater than 1.0 mg/L occurring at each boundary control point (BCP) location.

TRENDS

In 2016, DRBC completed an assessment which demonstrated that the SPW program is effective at keeping clean water clean and has even allowed improvements corresponding to nutrient water quality. Additionally, DRBC compared historic baseline water quality data to the assessment period of 2009 - 2011 at 24 sites located on the Delaware River and tributaries. This analysis demonstrated that several water quality parameters did not observe measurable changes to existing water quality, and nutrient parameters showed meaningful improvements throughout the SPW area.

FIGURE 3-5: Nutrient concentrations in SPW from 2010 to 2016.



Phosphorus

All Estuary phosphorus measurements were used to generate the long-term trend, shown in Figure 3-7, with a considerable data gap between 1985 and 2000. Unlike nitrate, phosphorus data are sparse and show less spatial consistencies. Overall phosphorus concentrations were greater in the 1970s settling toward consistently lower concentrations, typically less than 0.25 mg/L in the 2000s, likely as a result of the elimination of phosphate by-products included in household detergents. These results show that there has been significant improvement in regulating overall phosphorus concentrations within the Delaware Bay Estuary.

Measurements of total phosphorus concentrations over the entire Basin from 2000 to 2018 observed the most notable concentrations from the Lehigh River down through the urban corridor and out to the Atlantic Ocean. Significant portions of the Upper Estuary observed some of the greatest concentrations of total phosphorus and continue to show signs of nutrient pollution throughout the estuary and its tidal reaches.

Nitrogen

Data from 1967 to 2016 were analyzed to assess long term trends in the Estuary. Nitrate is quantifiable throughout the data record and is expected to be the most prevalent form of nitrogen in the Delaware Estuary, thus providing a good approximation of nitrogen trends over time. Nitrate measurements between River Mile 65 (Brandywine Creek and Salem River) and 95 (Schuylkill River and Big Timber Creek) were selected as representative of the highest, uniform concentrations in the Estuary. Figure 3-9, depicting data points

FIGURE 3-6: Available phosphorus by river mile mainstem Delaware River, 2008 to 2016.

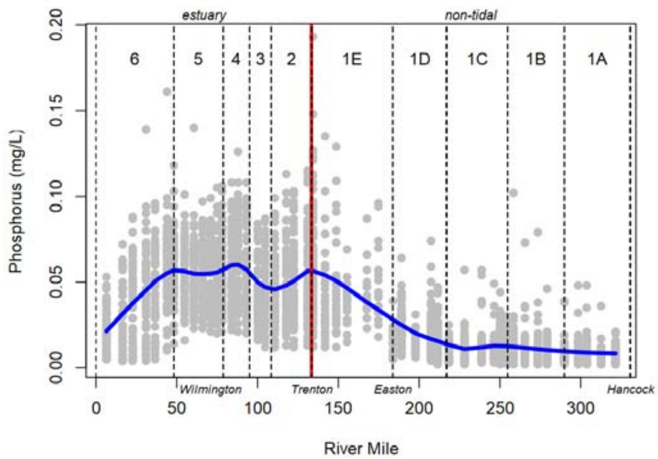


FIGURE 3-8: Total nitrogen by river mile in mainstem Delaware River, 2008 to 2016.

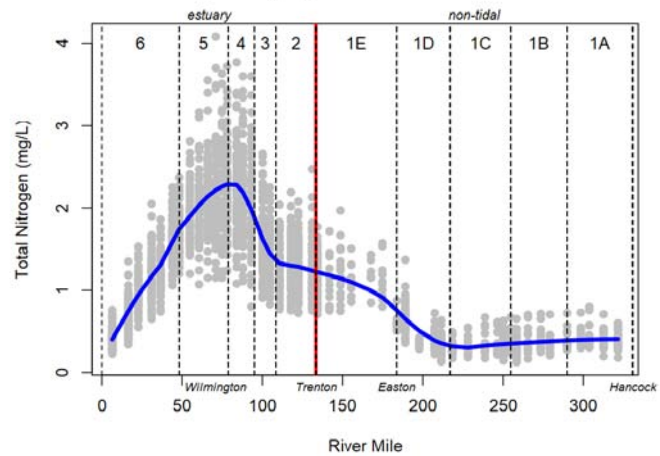


FIGURE 3-7: Historic available phosphorus in the Delaware Estuary from 1967 to 2016.

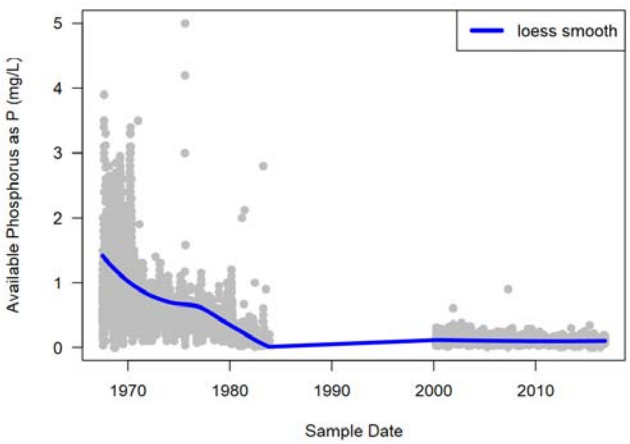
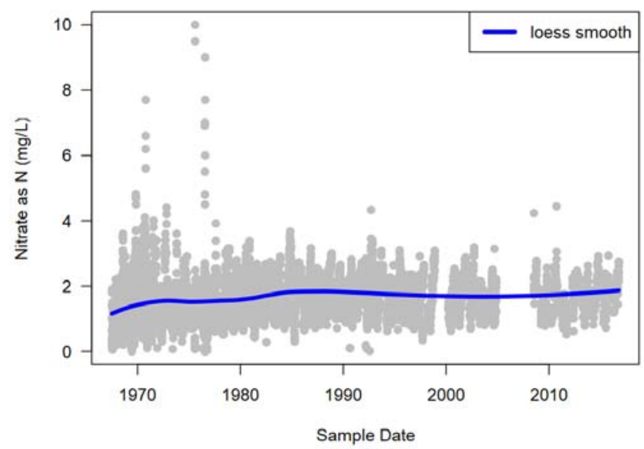


FIGURE 3-9: Historic Nitrate in the Delaware Estuary from 1967 to 2016.



and a smoothed curve, demonstrates relatively consistent concentrations of nitrate since the early 1990s, with variable and sometimes greater concentrations in the 1970s.

Similar to phosphorus, measurements of total nitrogen concentrations over the entire Basin for a period 2000 to 2018 observed the most notable concentrations at Schuylkill River and Brandywine Creek Watersheds. Significant portions of the Upper Delaware River have also been experiencing somewhat elevated total nitrogen concentrations throughout this same period and appear to have strong correlation with agricultural land uses.

ACTIONS/NEEDS

Presently, continued development and monitoring of Basin-wide nutrient criteria are needed to ensure ecological health of Basin waters. Additionally, due to the successful implementation of the DRBC SPW program, management should continue monitoring within the SPW area to determine that no measurable changes occur overtime.

Documentation of fish propagation in the Estuary and a proposal to designate the Estuary as essential fish habitat for Atlantic Sturgeon compel the identification and adoption of more protective dissolved oxygen criteria.

Conceptually, achievement of more protective dissolved oxygen standards will likely require tighter effluent limits on nutrients. The DRBC is in the process of developing a eutrophication model for the Delaware Estuary. This model will allow DRBC to determine what level of dissolved oxygen is achievable and what limitations on nutrient discharges will be needed to achieve these limits.

SUMMARY

The assessment of EWQ performed by the DRBC in the Lower Delaware in 2016 suggests that at most of the locations evaluated for most nutrient parameters, conditions are being maintained or improving. The Delaware Estuary nutrient concentrations are lower than historical levels. Presently, the DRBC will be producing a eutrophication model for the Delaware Estuary that will allow for the development of nutrient allocations needed to achieve greater dissolved oxygen concentrations.

pH

DESCRIPTION

pH is the mathematical notation for the negative log of the hydrogen ion concentration (-log[H+]) and indicates an acid, neutral, or base condition. The pH of surface waters can be an important indicator of ecological function and productivity, and pH impacts the bioavailability and toxicity of pollutants such as metals and ammonia. Currently, DRBC's criteria for the Delaware River and Estuary requires pH to be between 6.5 and 8.5.

PRESENT STATUS

In the Delaware Estuary, box and whisker plots of discrete pH values (Figure 3-10) measured at each of the USGS continuous monitoring stations are compared to the minimum and maximum pH criteria in DRBC's water quality standards. Although the distributions differ by location, all values are within the DRBC criteria. In non-tidal Basin waters, box plots of summer pH from USGS monitors at the Brandywine Creek at Chadds Ford, the Christina River at Newport DE, the Delaware River at Trenton, and the Lehigh River at Glendon from 2011 through 2016 show different distributions in pH by location (Figure 3-11), with all locations exceeding criteria. Summer was selected to capture this influence because pH can react to productivity. Exceedances of the criteria are permissible when due to natural conditions, but more work is needed to evaluate what proportion of these exceedances are attributable to natural conditions.

Figure 3-10: pH measurements at 3 USGS Delaware Estuary monitors, 2011 to 2016.

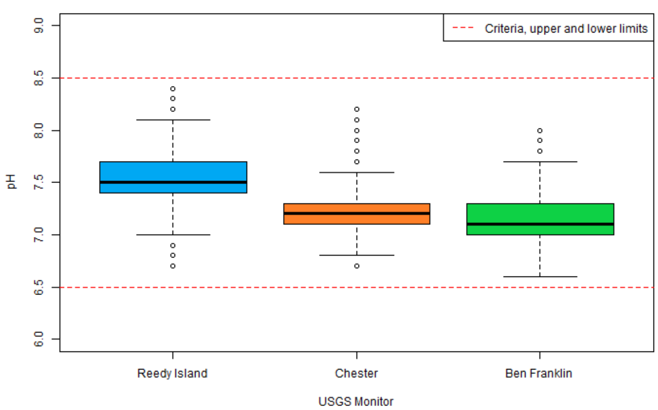
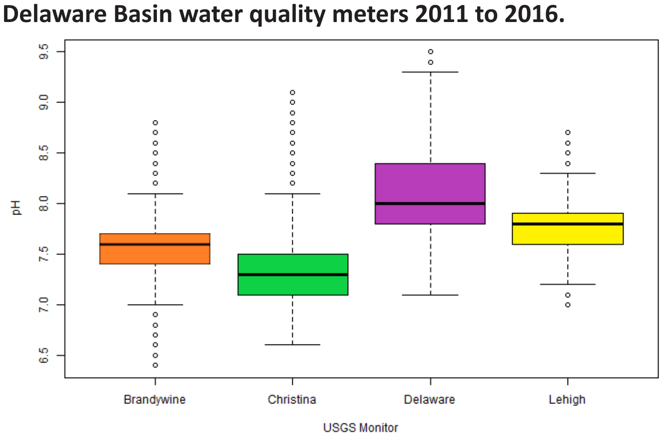


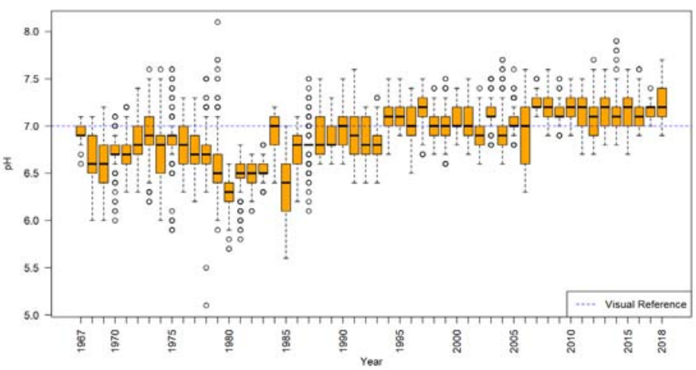
Figure 3-11: Summer pH observations at 4 USGS continuous Delaware Basin water quality meters 2011 to 2016.



TRENDS

No clear trend in pH has been determined at the Delaware River at Trenton for the period 2000 through 2016. Meanwhile in the Estuary, box plots continue to demonstrate an increase in pH over the period of record at the Ben Franklin (Figure 3-12). This phenomenon is likely linked to the gross pollution historically found in the urban corridor of the Delaware Estuary and the remarkable progress at eliminating some of this pollution over the past 40 years. In addition, this same period has seen the cessation of highly acidic industrial waste inputs to the Delaware Estuary, which may have also contributed to these temporal trends.

Figure 3-12: pH box and whisker plot by year at USGS 01467200, Ben Franklin Bridge, 1967 to 2016.



ACTIONS/NEEDS

A better understanding of the Estuary carbon cycle and its impact on pH is needed. While nutrients may play a role, we have also observed pH excursions above 8.5 in the upper portion of the River, where nutrient concentrations are substantially lower and considered to be oligotrophic.

SUMMARY

The pH of surface waters has long been recognized as both a natural and human-induced constraint to the aquatic life of fresh and salt water bodies, both through direct effects of pH and through indirect effects on the solubility, concentration, and ionic state of other important chemicals. Observations of pH at some locations, such as Trenton, show ranges frequently outside of criteria. A portion of this diel swing, however, is attributable to natural primary production.

Further improvements to waste treatment in the urban corridor could lead to further improvements in pH for those freshwater zones of the Estuary. Thus, with the processes driving pH in both directions, it is impossible to predict if pH values will continue to rise, level off, or if ocean acidification will pass a tipping point causing pH trends to reverse toward a more acidic Estuary.

SALINITY

DESCRIPTION

The Delaware Estuary provides drinking water for over one million people. Its suitability as a drinking water source is affected by salinity (saltiness of the water). Salt is not easily removed from water and may affect taste or cause health issues for those sensitive to sodium. Critical public water supply intakes that may be adversely affected are the Philadelphia Water Department's Baxter intake and the New Jersey American Water Company's Delran intake (near river mile (RM) 110), which serves four counties in south western New Jersey. Higher salinity and chlorides may also increase corrosion to the infrastructure of water purveyors and other surface water users, including industry and power producers.

The salt front represents the area where saltwater from the ocean meets freshwater from the river and reflects the extent of salinity intrusion into the estuary. The salt front is defined as the 7-day average 250 mg/l chloride concentration and was based on a recommendation from the U.S. Public Health Service for public water supplies. The location of salt front is not measured directly and is calculated daily from real-time data. The location fluctuates in the estuary based on tides and freshwater inflows, which result in seasonality of the location as well. Tides and ocean storms push the salt front farther upstream, while higher river flows push it downstream or slow its movement upstream.

During the 1960s drought, the maximum location of the salt front reached RM 102, approaching public water supply intakes. To reduce the chances of the salt front moving as far upstream, DRBC established the Trenton Flow Objective (see CURRENT AND FUTURE HYDROLOGY). During low flows, DRBC directs releases from reservoirs to increase the freshwater flows to the estuary. In addition to the flow objectives, DRBC established chloride water quality objectives in two zones between Trenton and Philadelphia. In Water Quality Zone 2 (Trenton to below the intakes) the chloride objective is a maximum 15-day average of 50 mg/L. The standards were developed based on previous modeling work and, if achieved, were predicted to maintain the location of the salt front below RM 98.

Good

PRESENT STATUS

Since the drought of the 1960s, the farthest upstream location of the salt front has been below RM 91 (Mantua Creek), due to the flow objective. In the 1960s, the lowest average monthly flow at Trenton was 1,548 cfs, whereas it has been greater than 2,500 cfs since 1966. The ranges of the salt front location by month, for the period of record, 1963-1969 (the drought-of-record period) and post–1968, are presented in Figure 3-13. The comparison of the different periods shows how the range of the salt front is further downstream than what was occurring during the drought-of-record. Figure 3-14 shows the chloride concentrations from the Delaware Estuary Water Quality Monitoring Program, at different RMs. Near RM 102, the chlorides have been below 100 mg/L from 2000-2016.

Figure 3-13: Salt front location by month for 1963-2019, 1963-1969 (drought of record), and post-1968.

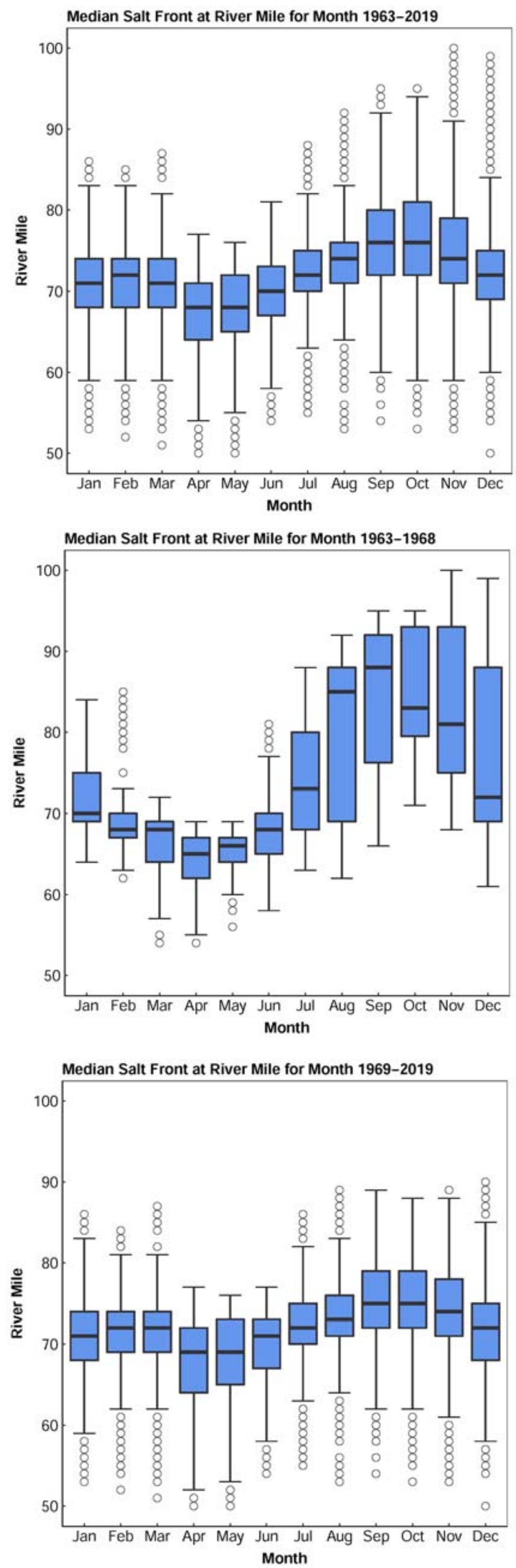
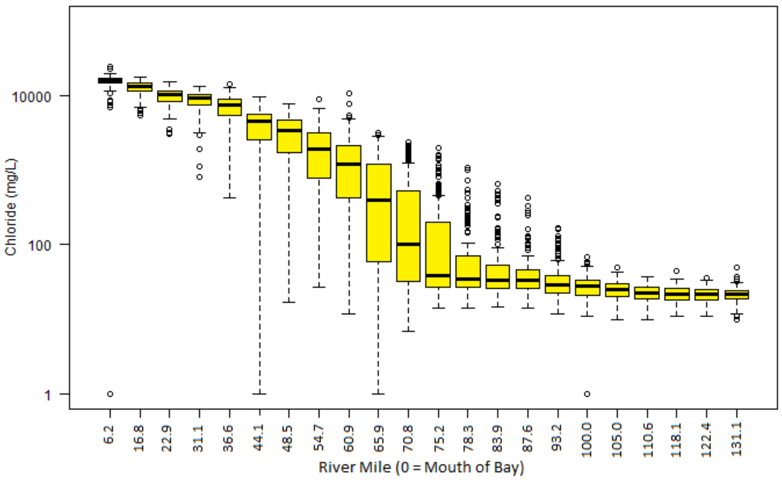


Figure 3-14: Chloride concentration ranges by river mile in the Delaware Estuary, 2000 to 2016.



TRENDS

Specific conductivity, also a surrogate for chlorides and salinity, was used to assess the long-term trends. Figure 3-15 shows the range of values observed during each year at the Ben Franklin Bridge at RM 100. An obvious trend is not discernable, although specific conductance has been increasing since 2010. Based on an assessment of trends in chlorides for the Lower Delaware, the likely causes of the increase are suspected to be caused by increased use of road deicing salts.

Tides and ocean storms tend to push the salt front upstream. Given the funnel shape of the Estuary, the increase in tidal elevations will be magnified in the upper reaches of the Estuary. With more salt water entering the bay and estuary, the range of the salt front will be pushed upstream along with its maximum extent of upstream intrusions. Older modeling studies support the theory that sea level rise will push the salt front further upstream.

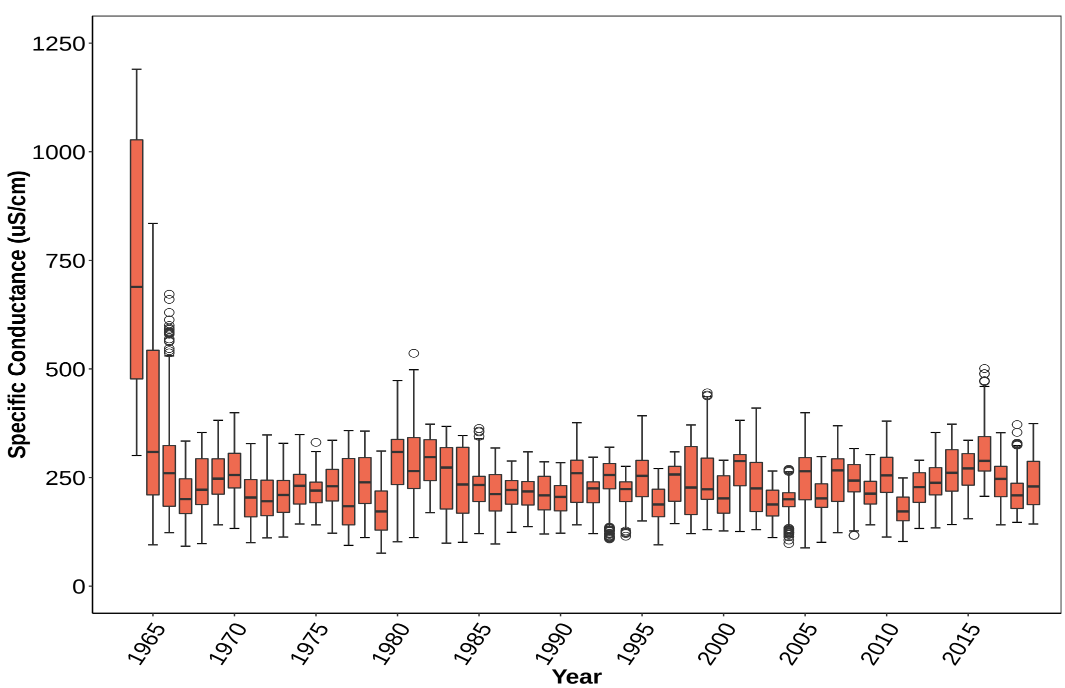
ACTIONS/NEEDS

More sophisticated modeling is needed to establish the relationship between sea level rise and salinity and develop a better understanding of the potential impacts. With the models, different adaptation options can be evaluated, including, but not limited to, new infrastructure, optimization of infrastructure, flow management (e.g. different flow objectives and the development of new sources of water). Research regarding the increasing trends in chlorides in freshwater is also necessary to assess the sources of chlorides and develop salinity management options.

SUMMARY

Salinity impacts the availability of Estuary water for drinking water and industrial uses. The flow objective and associated management operations appear to be keeping the salt front below RM 91, but sea level rise may require new management measures and additional reservoir storage. Although there are no definitive trends in Estuary salinity, the freshwater chlorides may be increasing and contributing to higher salinity in the Upper Estuary, where the impact of seawater is less pronounced.

Figure 3-15: Long-term specific conductivity box and whisker plots at USGS 01467200, Ben Franklin Bridge.



TEMPERATURE

DESCRIPTION

Water temperature is an important factor for the health and survival of native fish and aquatic communities. Temperature can affect embryonic development; juvenile growth; adult migration; competition with non-native species; and the relative risk and severity of disease. Temperature assessment in the non-tidal Delaware River is confounded by artificially lowered temperatures from reservoir releases in the upper portion of the River. Estuary temperature criteria are expressed in DRBC regulations by day of year.

PRESENT STATUS

In the non-tidal Delaware River, Figure 3-16 shows the summer temperature distributions at four USGS monitors: Lordville (River Mile (RM) 322), Callicoon (RM 303), above Lackawaxen near Barryville (RM 279) and Trenton (RM 134), from 2011 through 2016. The plot demonstrates the shift in temperature from the reservoir influenced cold water upstream to warmer temperatures downstream. In the tidal river, maximum daily water temperatures recorded at USGS continuous monitors at Ben Franklin and Chester from 2011 to 2016 were compared to DRBC's zone specific day-of-year temperature criteria (Figure 3-17). Comparing the continuous measurements at Trenton to the Pennsylvania criteria for warm water fisheries show that most observations meet criteria.

Figure 3-16: Summer water temperature box and whisker plot along the main stem of Delaware River, 2011 to 2016.

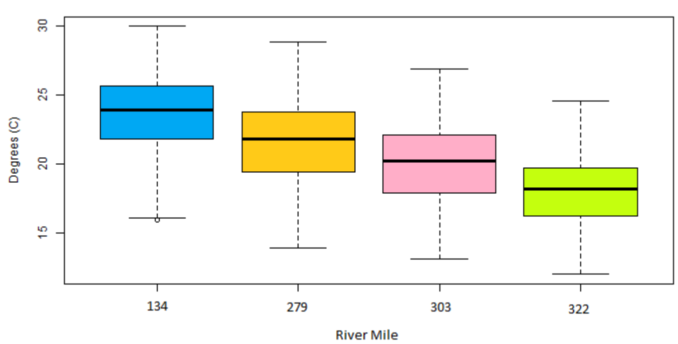
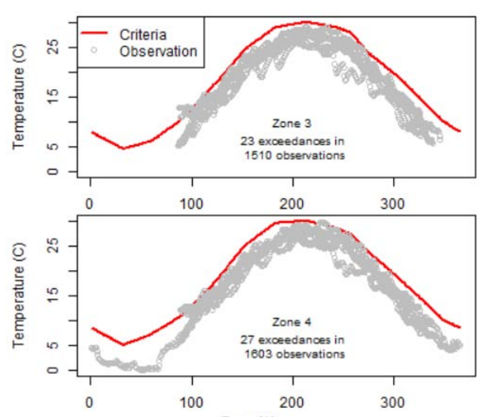


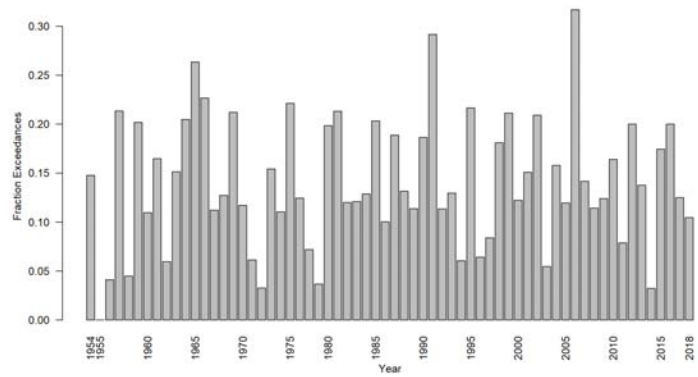
Figure 3-17: Temperature observations compared to DRBC day of year criteria, at Ben Franklin and Chester, 2011 to 2016.



TRENDS

Long term temperature records at Trenton (1954 through 2016) were evaluated to determine if the number of 'violations' would have increased over time (had those criteria been in place). As shown in Figure 3-18, no discernable trend in the number of exceedances per year is evident from the data. Temperature at Trenton appears to be stable over the continuous monitor period of record. Therefore, temperature at Trenton is expected to remain stable for the foreseeable future.

Figure 3-18: Water temperature exceedances over PA WWF criteria by year along Delaware River at USGS 01463500, Trenton.



ACTIONS/NEEDS

The development of temperature criteria in the non-tidal portion of the Delaware River should be continued to protect aquatic communities and allow meaningful interpretation of presently collected data. In addition, stronger linkages between meteorological drivers and resultant water temperatures are needed, so that assessors can distinguish between natural conditions and anthropogenic thermal loads.

SUMMARY

Temperature assessment in the non-tidal Delaware River is confounded by artificially lowered temperatures from reservoir releases in the upper portion of the river. A comparison with Pennsylvania's warm water criteria shows some exceedances at Trenton, mostly occurring in the spring. Delaware Estuary water temperatures are influenced by multiple drivers including meteorological forces, terrestrial and ocean water inputs, and municipal and industrial thermal loads. A review of the current status shows that 90% or more of daily observations are meeting temperature criteria. An analysis of historic trends suggests that the overlapping temperature drivers make it difficult to understand how water temperatures have changed over the last 5 decades. A more rigorous assessment, which explicitly accounts for overlapping temperature drivers, is desirable.

CONTAMINANTS

DESCRIPTION

"Contaminants" are specific elements and compounds with varying degrees of toxicity to aquatic life and human health. Water quality monitoring data from multiple organizations (DRBC, DNREC, NYSDEC, NJDEP, PADEP and USGS) are compared to stream quality objectives and a narrative standard to evaluate water quality impairments from contaminants. The narrative standard applicable to waters of the Basin requires that: "the waters shall be substantially free from…substances in concentrations or combinations which are toxic or harmful to human, animal, plant, or aquatic life."

PRESENT STATUS

For a recent report on the extent to which waters of the Delaware Estuary and Bay are attaining designated uses, see the "2018 Delaware River and Bay Water Quality Assessment" (https://www.state.nj.us/drbc/library/documents/WQAssessmentReport2018.pdf). Some contaminants that are identified in the report for additional monitoring and assessment efforts to assure water quality in the Estuary and Basin include metals, pesticides and polycyclic aromatic hydrocarbons (PAHs). The report also describes concerns for the support of human health due to polychlorinated biphenyls (PCB) and mercury concentrations and the need for further evaluation of aluminum, cadmium and copper in the River.

TRENDS

Data and detection insufficiencies make determination of past trends difficult. As monitoring and assessment procedures are refined, and criteria updated to reflect current research, appropriate endpoints can be defined along with contaminant concentrations relative to those endpoints. In the face of improving management, it is reasonable to expect improvements in water quality and declines in concentrations of priority pollutants; however, it is more likely that levels will remain relatively the same at their current levels.

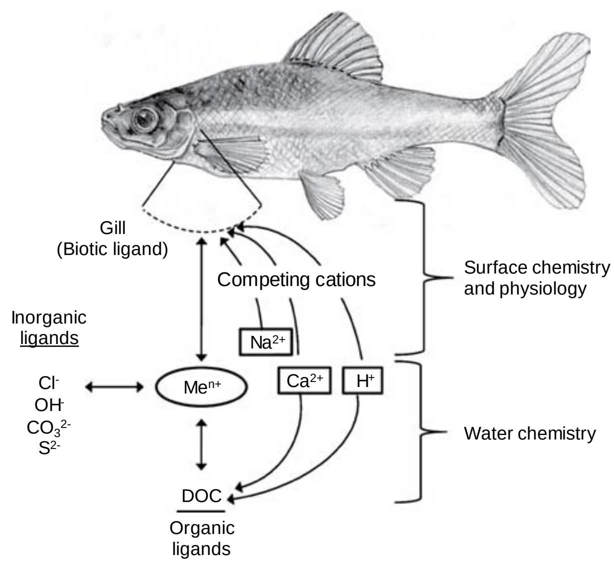


Figure 3-19: Conceptual model of the biotic ligand model (after Paquin, P.R. et al., Comp. Biochem. Physiol. C, 133, 3-35, 2002. Art credit Rob Harper, 2009)

ACTIONS/NEEDS

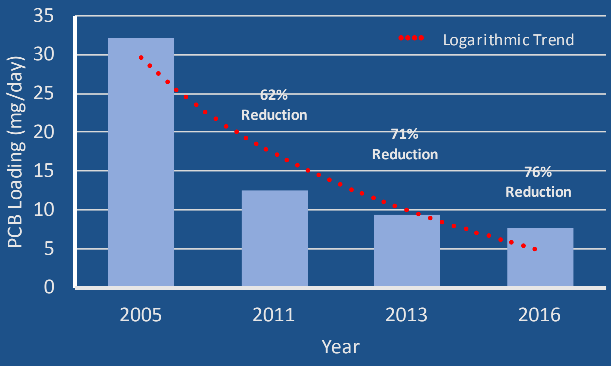
- Coordination should continue to ensure the use of appropriate analytical techniques and assessment methodologies to evaluate the effects of contaminants on water quality. With increasingly sensitive analytical methods in use to measure contaminants and more complex models to evaluate toxicity (e.g., Biotic Ligand Model in Figure 3-19), there will be an increasing need for coordination of water quality criteria and assessment methodologies in order to prioritize environmental management efforts.
- In the Estuary region, continuity in monitoring and assessment programs among Basin states and agencies and continued updates in criteria are all needed to maintain water quality and effectively decrease levels where they are elevated.
- Additional monitoring and assessment of toxic contaminants in the non-tidal portion of the Delaware River is recommended.
- Required PCB Pollution Minimization Plan (PMP) implementation should continue and regulatory agencies including DRBC should provide technical reviews and support to the regulated community.

SUMMARY

Trends for specific contaminants may result from regulatory restrictions on use, changes in loading rates, or degradation of the contaminant in the environment; however, effective management is needed to maintain water quality and efficiently decrease levels where contaminant levels are elevated.

Polychlorinated Biphenyls (PCBs)

PCBs are one of the main causes of fish consumption advisories issued by basin states. DRBC developed and EPA established PCB TMDLs for the Delaware River Estuary and Bay in 2003 and 2006. DRBC is currently revising the PCB TMDLs and is expected to finalize them in 2019. In May 2005, the DRBC adopted a Pollution Minimization Plan (PMP) approach to reduce or eliminate point source and non-point source discharges of PCBs in the Delaware Estuary. Recent findings demonstrate that the top ten dischargers have reduced their contributions by 76% from 2005-2016. This improvement will hopefully show a decrease in the amount of PCBs found in fish tissue in future years.



FISH CONTAMINANT LEVELS

DESCRIPTION

Certain chemicals tend to concentrate, or bioaccumulate, in fish to levels thousands of times greater than the levels in the water itself. The resulting concentrations in fish and the corresponding health risks to those individuals who consume the fish, such as recreational and subsistence anglers, are of concern to government agencies and the public. Bioaccumulative contaminants have been monitored over an extended period in fish fillet collected from the Delaware River. Bioaccumulation of contaminants in fish tissue is influenced by physical-chemical properties of the contaminant, fish species, age, migration and food habits as well as other environmental factors such as season of fish collection.

PRESENT STATUS

While programs are in place to reduce the concentrations of toxic pollutants that bioaccumulate, Delaware River Basin states issue "advisories" containing meal advice for consumers of recreationally-caught fish and shellfish to minimize the risk to human health. These advisories list the waterbodies, fish species, and number of meals recommended to minimize the risk. These advisories are typically revised yearly based upon recent fish tissue concentration data. In some cases, more stringent consumption guidelines for pregnant women and children or no consumption of any fish species from a waterbody is advised. The following websites present up-to-date fish consumption advisories:

New York: https://www.health.ny.gov/environmental/outdoors/fish/health_advisories/
Pennsylvania: https://www.dep.pa.gov/Business/Water/CleanWater/WaterQuality/FishConsumptionAdvisory/Pages/default.aspx
New Jersey: https://www.state.nj.us/dep/dsr/njmainfish.htm
Delaware: http://www.dnrec.delaware.gov/fw/Fisheries/Pages/Advisories.aspx

Good

TRENDS

There have been various instances in past years where fish consumption advisories changes have reflected a positive trend; however, these are regionally and species specific. One specific example was for the Delaware River from the Trenton, NJ-Morrisville, PA bridge to the PA/DE border, where PADEP fish consumption advisories of Carp increased from "Do Not Eat" (2015) to six 8-oz meals per year (2016).

While the DRBC does not establish fish advisories, the DRBC does monitor several bioaccumulative compounds measured in fish collected from the mainstem of the Delaware River. There are four mainstem sample locations within the non-tidal region, and five locations in the tidal region as indicated in Figure 3-20. Two species of fish are monitored in each region: White Sucker (*Catosomus commersonni*) and Smallmouth Bass (*Mictopterus dolomieu*) in the non-tidal region, and Channel Catfish (*Ictalurus punctatus*) and White Perch (*Morone Americana*) in the tidal region. Samples are collected at each location as a composite of five similarly sized fish. As an example, the data for total PCB concentrations (includes all 209 congeners) in fish tissue is presented in Figure 3-20, with the most recent results for the year 2018 highlighted in red. It is worth highlighting that the x-axis is a logarithmic scale. There is a clear trend of increasing concentration moving from the non-tidal to tidal regions. In general, the results from 2018 indicate non-tidal concentrations similar to the historic averages whereas the concentrations in the tidal region were often below the lower quartile (25th percentile).

DRBC Fish Tissue Monitoring

- Polychlorinated biphenyls (PCB)
- Dioxin/Furans
- Polybrominated diphenyl ethers (PBDE)
- Per- and polyfluoroalkyl substances (PFAS)
- Organochlorine pesticides
- Total and Methyl Mercury

Unit Perspective

1 picogram (ρg) = 0.000000000001 grams
1 grain of sugar ≈ 0.000625 grams
1 grain of sand ≈ 0.011 grams

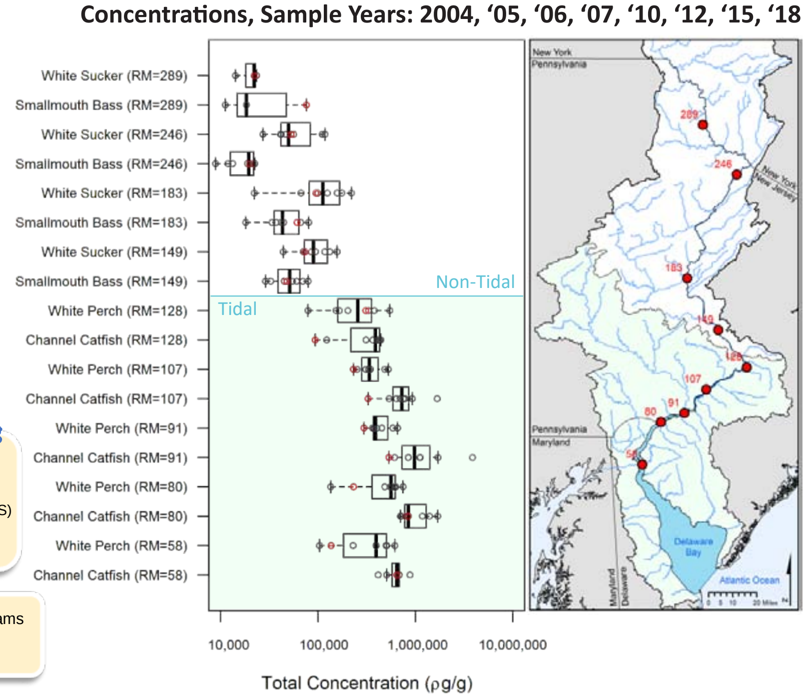
ACTIONS/NEEDS

Pollution minimization efforts are necessary to bring about the needed reductions in tissue concentrations. Cooperative efforts among state and federal agencies as well as other partners to reduce bioaccumulative contaminants in the Delaware River should continue and be expanded to address these persistent toxic pollutants.

SUMMARY

Trends for specific contaminants may result from regulatory restrictions on use, changes in loading rates or degradation of the contaminant in the environment. Trajectories for contaminant reduction in fish may be long depending on the contaminant of concern but can be shortened through effective management.

Figure 3-20: Mainstem Delaware River Fish Tissue PCB Concentrations, Sample Years: 2004, '05, '06, '07, '10, '12, '15, '18



EMERGING CONTAMINANTS

DESCRIPTION

Emerging contaminants are substances that have entered the environment through human activities, which may have environmental and ecological consequences. Current regulatory approaches are inadequate to address these contaminants and there is increasing public concern over their environmental and human health implications. Polybrominated diphenyl ethers (PBDEs) are among the emerging contaminants that have been monitored in the Delaware River. PBDEs are flame retardants used on several consumer products such as television and computer casings and the polyurethane foam inside furniture cushions. PBDE's are characterized as persistent, bioaccumulative, toxic compounds (PBTs). Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are also a diverse group of compounds that have varying degrees of persistence, toxicity and bioaccumulation in the environment. They are found in a variety of industrial and household products such as stain repellant textiles, fire-fighting foams and paper coatings. While there is still much to be learned about the effects of PFAS on human and ecological health, exposure from drinking water and fish consumption are of concern.

PRESENT STATUS

Environmental monitoring programs conducted worldwide during the past decade have shown increasing levels of PBDEs, which have been detected in the water, sediment, and fish of the Delaware Estuary. In November 2016, EPA issued a revised health advisory for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), the most extensively produced and studied of the PFAS. These substances have been detected in drinking water wells in Basin states. PFOS has also been detected in fish tissue in the Basin. Available data for surface water show PFOA and PFOS levels are below current EPA and basin state human health advisory levels in segments of the Delaware River designated as drinking water sources. The New Jersey Department of Environmental Protection (NJDEP) has issued a drinking water standard for perfluorononanoic acid (PFNA) of 0.013 parts per billion (ppb). In addition, the New Jersey Drinking Water Quality Institute has released recommended drinking water standards of 0.013 ppb for PFOS and 0.014 ppb for PFOA. In January 2019, NJDEP issued interim groundwater standards of 0.01 ppb for PFOA and PFOS. The Drinking Water Quality Council of New York has recommended an MCL of 0.010 ppb for PFOA and 0.010 ppb for PFOS. These levels, which would be the lowest in the nation, take into consideration the national adult population's "body burden," or the fact that all adults already have some level of exposure to these and other related chemicals. Pennsylvania has created an action team to address concerns about PFAS.

TRENDS

Emerging contaminants have not been routinely monitored, therefore, limited information is available on past trends. Previous studies by the USEPA, USGS, Basin states and private industry on emerging contaminants were identified in the DRBC report titled Emerging Contaminants of Concern in the Delaware River Basin (https://www.state.nj.us/drbc/library/documents/EmergingContaminantsFeb2007.pdf). However, insufficient data are available to track past trends. A collaborative project by the DRBC and West Chester University targeting populations that consume fish from the Delaware Estuary evaluated whether there is a declining trend of four PBDE congeners in fish tissue from the Estuary over the years of available data (2004-2012). Declining trends of PBDE 153, 99, and 47 in fish tissue were observed. Figure 3-21 displays the declining trend in channel catfish tissue for each of these congeners. BDE 209 levels also showed a moderate, inverse association with sampling year in both channel catfish and white perch (see Figure 3-22).

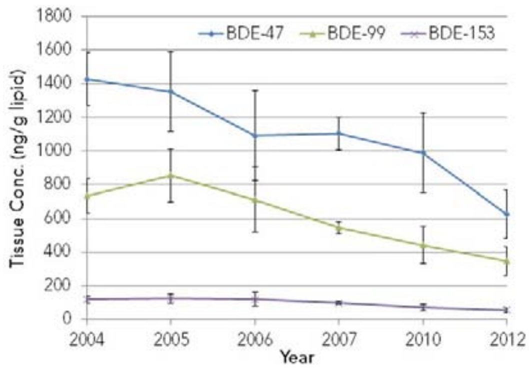


Figure 3-21: Lipid normalized tissue concentrations in Channel catfish of congeners BDE 47, 99, and 153 by year sampled in Zones 2-5.

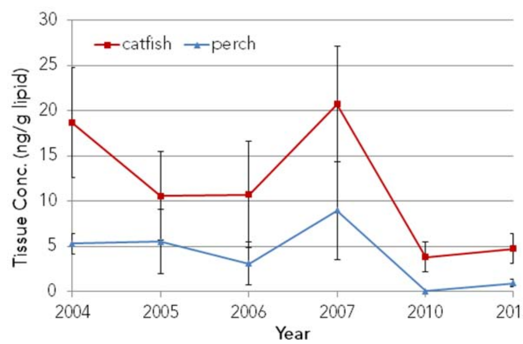


Figure 3-22: Lipid normalized tissue concentrations of BDE 209 in Channel catfish and white perch by year sampled in Zones 2-5.

ACTIONS/NEEDS

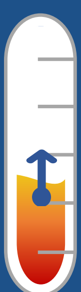
Due to variability of debromination end products by fish species, any future fish surveys should consider common PBDE debromination products to assess exposure levels. PFAS should continue to be monitored in drinking water and in the environment. Other emerging contaminants of concern that do not have established water quality criteria should be tracked and evaluated.

SUMMARY

Emerging contaminants are potentially harmful substances that have entered the environment through human activities and are not routinely monitored. Current regulatory approaches are inadequate to address these contaminants, thus additional study and creation of environmental policy are needed.

Fair

WHOLE EFFLUENT TOXICITY



DESCRIPTION

The tidal Delaware River contains numerous industrial and municipal discharge facilities (Figure 3-23). Whole Effluent Toxicity (WET) testing is a useful approach in the protection of aquatic life by measuring toxicity of effluents along with the chemical-specific measurements because WET tests evaluate the integrated effects of all chemicals in an aqueous sample. Chronic toxicity tests can detect effects at a much lower dose than acute toxicity tests providing a more direct estimate of the safe concentration of effluents in receiving waters. Therefore, chronic toxicity tests have a greater potential to produce more ecologically relevant data.

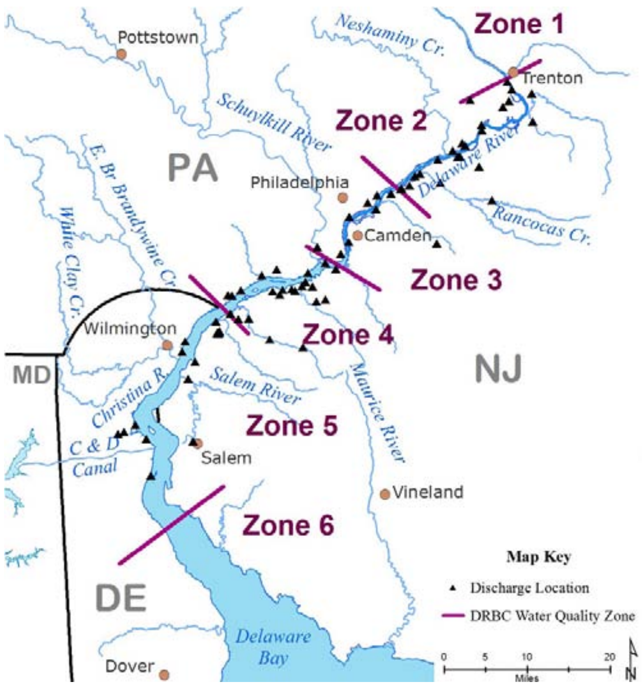


Figure 3-23: Delaware River water quality zones and NPDES Discharges.

PRESENT STATUS

In the 1990s, some dischargers reported toxicity which (estimated after dilution in the receiving water) exceeded the stream quality objective of 1.0 chronic toxicity unit (TUc). However, available data from recent years do not predict exceedances of stream quality objectives for chronic toxicity by individual dischargers.

TRENDS

A database was initiated in 1990 as part of the Commission established Toxics Management Program and updated to current WET methods in 2002, which most dischargers are now using. Data sets from individual discharges were evaluated by the Mann-Kendall test, a non-parametric statistical procedure. Of the twelve largest individual dischargers in the Estuary, two dischargers exhibited a decreasing trend for two WET test species. Four dischargers exhibited a decreasing trend for at least one test species. Six dischargers exhibited no trend. Effluent TUc versus sampling date for a representative municipal discharge and an industry discharge are shown in Figures 3-24 and 3-25, respectively. Possible causes of the observed reduction in chronic toxicity in effluent discharges to the Estuary are: improved efforts by industry to identify and reduce toxicity, pre-treatment and toxics reduction programs for municipal waste treatment facilities, and declining manufacturing in the region.

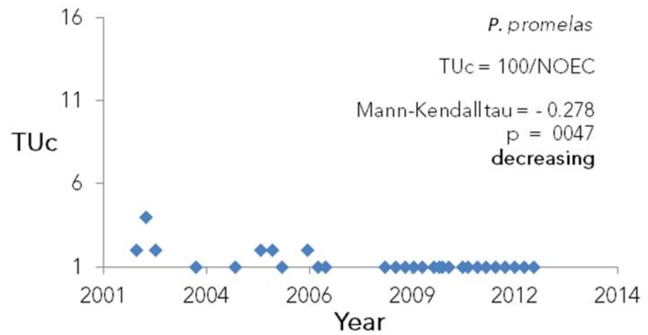


Figure 3-24: Municipal Discharge.

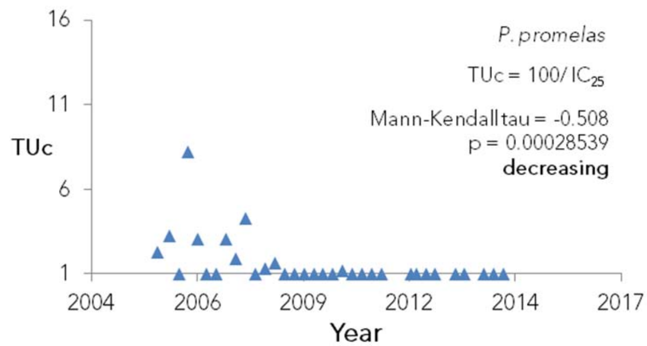


Figure 3-25: Industrial Discharge.

ACTIONS/NEEDS

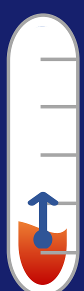
Recommendations for future WET monitoring in the Delaware Estuary include continued coordination among the basin states, DRBC, and USEPA to generate consistent WET testing and full compliance with WET monitoring by Estuary dischargers. Because the use of a numerical model to predict ambient toxicity from effluent data are complicated by possible additive effects of chronic toxicity, it is recommended that continued efforts be made to monitor not only effluent from discharges ,but also the ambient environment to ensure that the Delaware Estuary supports aquatic life.

SUMMARY

Most effluent discharges to the Delaware Estuary are currently monitored for chronic whole effluent toxicity. The twelve largest dischargers in the Estuary are exhibiting a decreasing trend or no trend in chronic WET data reported for 2002 to 2014. Limiting chronic toxicity in effluents decreases the impact of point source discharges on water quality in the Delaware Estuary.

4

LIVING RESOURCES



ATLANTIC STURGEON

A young-of-the-year Atlantic Sturgeon caught during a DE DFW survey. *Photo credit: Ian Park, DE DFW.*

DESCRIPTION

Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*, belong to a category of ancient bony fishes, which may live up to 60 years, reach lengths up to 14 feet, and weigh over 800 pounds. While mature Atlantic sturgeon are anadromous and return to spawn in fresh water with a hard bottom, both juvenile and mature individuals frequently visit other estuaries distant from their natal river. They are broadly distributed along the Atlantic Coast from Canada to Florida, and historically ranged into Europe before its regional extirpation (ASMFC, 2017). There are five distinct population segments (DPS) in U.S. waters, of which the “New York Bight” is considered native to the Delaware River Basin. In 2012, all population segments were listed as either endangered or threatened under the Endangered Species Act (ESA). In 2017, it was determined that the Critical Habitat Area within the Delaware River Basin as shown on Figure 4.1; however, habitat suitability within the range due to anthropogenic effects is currently unknown.

PRESENT STATUS

Historically, the Delaware River supported the largest Atlantic sturgeon population in the United States. Factors such as commercial demand for their meat and roe (caviar), degraded water quality and even ship vessel strikes have all contributed to a declining population. Specific to the Delaware River:

- As part of the Delaware Department of Natural Resources and Environmental Control (DNREC), the Delaware Division of Fish and Wildlife (DE DFW) currently monitors catch-rates from a sturgeon-specific gill net survey, as well as the Adult Finfish and Juvenile Finfish Research Trawl Surveys. Furthermore, DE DFW implements a robust tagging program which includes specialized sensors allowing acoustic tracking of the fish manually (e.g. scientists using a hydrophone) or with a passive network of receivers (e.g. Figure 4.1).
- A tag-recapture study in 2014 estimated an abundance of juvenile Atlantic sturgeon within the Delaware River to be 3,656 fish; although, wide confidence intervals indicate it is more likely between 2,000 and 33,000 fish.

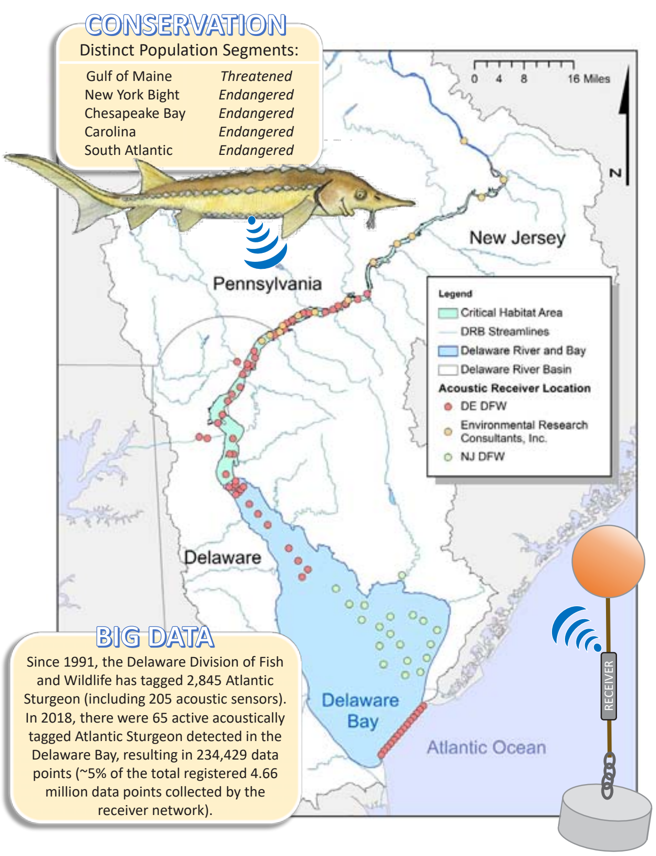


Figure 4-1: The current layout of passive acoustic receivers within the Delaware River Basin, maintained by three orginizations as indicated. Passive receivers are moveable, allowing adaptability to specific scientific needs. *Receiver data provided by DE DFW. Fish illustration by Laury Zicari, USFWS, Retired.*

TRENDS

- The Atlantic States Marine Fisheries Commission (ASMFC) assessed fifty fishery-independent data sets from the Atlantic Coast for viability in determining abundance; however, only six could be used in models. In general, population abundance showed no significant trends at the DPS level (ASMFC, 2017).
- Despite challenges in data availability for trend analysis, DE DFW has documented successful sturgeon reproduction in recent years which could result in stock growth in the Delaware River.
- There has been a recent increase of reported sturgeon carcasses attributed to vessel strikes; however, it is unclear if this is a result of increased reporting awareness, or increased mortality rates. Regardless, losing even a few adult individuals per year can have significant impacts on a recovering population.

ACTIONS/NEEDS

- Continue monitoring abundance to support model development (collect more data).
- Continue telemetry studies to better understand behavior and local habitat within the Critical Habitat Area.
- Expanded study of ship strikes and collaboration with the shipping industry to minimize population impacts.

SUMMARY

The Delaware River spawning stock, once the largest population on the Atlantic coast, was declared endangered in 2012. Mortality from shipping traffic strikes, impaired habitat and water quality all threaten current populations. While recent Basin-specific surveys have indicated recent spawning success, additional research is needed for future predictions on species recovery.

WHITE PERCH

DESCRIPTION

White perch, *Morone americana*, are one of the most abundant and likely widespread fish in the Delaware Estuary which makes them an important ecological indicator. The species is tolerant of a wide range of water temperatures, salinities, and low dissolved oxygen levels, thriving from landlocked headwater ponds to lower salinity reaches of tidal tributaries. In spring, white perch in the Delaware Estuary move to tidal tributaries to spawn and then out into the deeper waters of the Estuary to overwinter, rarely leaving the Estuary. Their diet consists of small invertebrates during their juvenile stages and includes fish as they begin to reach full maturity. White perch support local recreational and commercial fisheries, and have routinely been among the top five finfish species landed commercially in Delaware.

PRESENT STATUS

The young-of-the-year (YOY) index derived from the DE DFW Juvenile Finfish Research Trawl Survey is the primary indicator of year-class strength and may indirectly be an indicator of future spawning stock abundance. The survey is conducted using a 16’ trawl to sample 39 stations in the Delaware Bay and River from April to October. The index is calculated from 16 of these stations between June to October. From 2012 to 2017, the white perch YOY-index was below the time series median value of 0.81 YOY fish per tow (series 1990-2018) suggesting the Delaware Estuary spawning population had poor success during this period; however, the most recent data from 2018 showed a result slightly above the average. Commercial landings in the state of Delaware exceeded 100,000 lbs in 2009-2011, the highest three-year catch reported in a 60-year window. Landings have since declined and were well below the time series average in 2018.

White perch. *Photo credit: Evan Kwityn, DRBC.*

The species’ tolerance and wide range of habitat within the Delaware Estuary may buffer it from some of the extreme population fluctuations observed in other species. Past trends suggest that white perch will continue to support healthy fisheries in the Delaware Estuary for the foreseeable future.

ACTIONS/NEEDS

- Protection of instream habitat in the upper reaches of tidal tributary areas under human development pressure is important as these areas can be spawning habitats.
- All states in the Delaware Estuary should establish an 8-inch minimum (consistent with Delaware’s 1995 decision) size for white perch to ensure that most white perch may have a chance to spawn.

SUMMARY

White perch are tolerant of a variety of environmental conditions, and are widespread throughout the Delaware Estuary. While returning a relatively low YOY-index for multiple years before 2018, white perch have been historically abundant and the population within the Delaware Estuary seems to be maintaining itself. Basic management practices may help ensure the population continues to thrive.

TRENDS

Commercial landings are affected by factors other than population (e.g. fishing effort, market fluctuation). Figure 4-2 shows a decline in commercial landings since a historic peak in 2011. While it may be the result of changes in fishing success or market conditions, it may also reflect poor recruitment to the fishery during this time, as suggested by the recent low YOY-index. Together with the YOY-index, these findings suggest that white perch populations in the Delaware Estuary undergo cyclical expansions and declines.

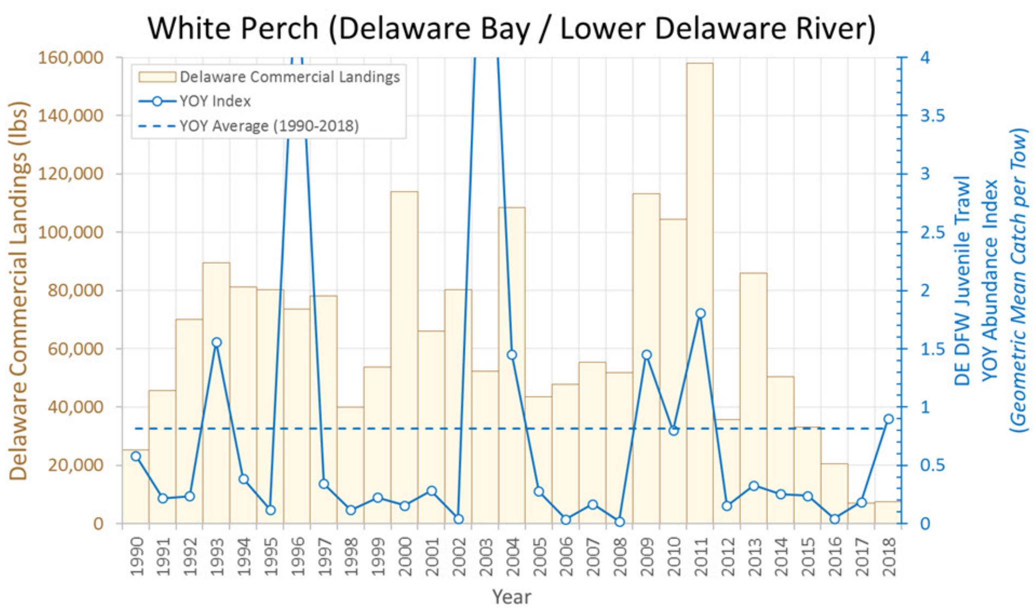
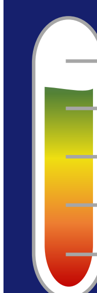


Figure 4-2: White Perch commercial landings in the State of Delaware, compared to a YOY abundance index. The YOY peaks in 1998 (4.84) and 2003 (6.35) are not shown. *Data provided by the DE DFW*.

4 LIVING RESOURCES



Very Good

STRIPED BASS

Striped bass. *Photo credit: Kurt Cheng, Partnership for the Delaware Estuary*.

DESCRIPTION

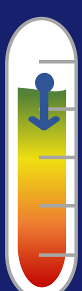
Striped bass, *Morone saxatilis*, are large, predatory fish with dark horizontal stripes extending along their flanks. Depending upon age and the time of year, striped bass will inhabit a wide variety of environments including tidal creeks/rivers, jetties, reefs and relatively open water in the Delaware Bay and River. Mature females spawn in the tidal freshwater portion of the Delaware River prior to migrating up the Atlantic Coast annually, while many males remain in the Estuary or nearby ocean waters year-round. Young bass feed primarily on small invertebrates (e.g. insects, worms). As they mature, they will eventually feed on small pelagic fish (e.g. anchovies, river herring) and larger invertebrates (e.g. blue crab). In addition to being important ecologically, striped bass provide a popular recreational fishery both Delaware and New Jersey. Economically, they support a commercial fishery in Delaware, while New Jersey has a moratorium in place on commercial harvest.

PRESENT STATUS

The striped bass population within the Delaware River was at one point thought to be extirpated by some biologists, prior to improvements of dissolved oxygen (DO) (see DISSOLVED OXYGEN in Section 3) in the 1980s. Today, the Delaware River population is one of the major spawning stocks on the Atlantic Coast, along with the Hudson River and Chesapeake Bay stocks. Two indicators from the Delaware Estuary serve to measure the relative health of the striped bass population:

1. The Delaware Spawning Stock Survey uses electrofishing to estimate the spawning population.
2. The New Jersey Recruitment Survey uses a seine haul to measure the annual average reproductive output of the stock. A large young-of-the-year (YOY) abundance often results in a greater number of recruits into the fishery several years later.

The most recent data in 2015 showed both indices under the long-term averages (Figure 4-3); however, it is noted that there is inter-annual variability present in each index.



Very Good

TRENDS

Low DO in the Estuary downstream of Philadelphia greatly impacted the Delaware River spawning stock in the mid-twentieth century. Improvements to water quality following the creation of the DRBC, Clean Water Act and a conservative fishery management regime improved the habitat. As a result, the population increased through the 1980s and the Delaware River stock was considered 'recovered' in 1998. Despite the Delaware spawning stock survey index results falling below the running average in recent years, the long-term recovery since the 1980s is still evident from the calculated New Jersey recruitment index (Figure 4-3). The most recent 2018 ASMFC stock assessment released in April 2019 provides a coast-wide status based on analysis of multiple fishery-independent surveys (of which both the NJ and DE surveys listed above are included). The status provided is based on a calculated female spawning stock biomass (SSB) and indicates that in 2017 the Atlantic striped bass stock was overfished and experiencing overfishing when compared to updated reference points. Despite these recent declines in female SSB, the levels are still above those observed in the mid to late 1980s (ASMFC, 2019).

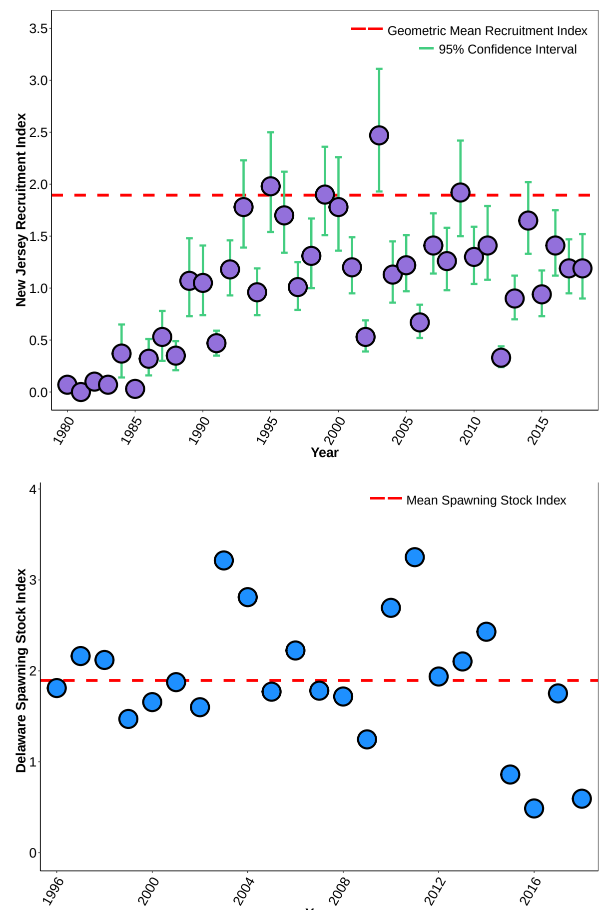
ACTIONS/NEEDS

Continued monitoring of long-term trends in biomass and recruitment, responding when necessary with management action.

SUMMARY

Striped bass are large, predatory fish which are ecologically, commercially and recreationally important to the Delaware River Basin. The population within the Basin has responded favorably to decades of management, improved habitat availability and water quality improvements to become one of the major striped bass populations on the Atlantic Coast.

Figure 4-3: Data showing trends for the *(top)* NJ-Recruitment Index and *(bottom)* DE-Spawning Stock Index. *Data provided by NJDEP and DE DFW, respectively.*



WEAKFISH

Weakfish caught in the Delaware Bay. *Photo credit: Evan Kwityn, DRBC.*

DESCRIPTION

Weakfish, *Cynoscion regalis*, are marine fish in the family *Sciaenidae*. While commonly referred to as “grey trout” or “sea trout”, they have no relation to actual trout, which are classified in the family *Salmonidae*. Weakfish occur along the Atlantic Coast but are most common from New York to North Carolina. At the beginning of spring, adult weakfish begin an inshore spawning migration to the Delaware Bay and other estuaries. Spawning in the Delaware Estuary occurs in the shallows and on shoals of the Bay. Larger weakfish leave the Bay for New England after spring spawning, while younger adult weakfish tend to stay in the Bay all summer. Younger fish feed on crustaceans and mollusks including shrimp species, while larger weakfish feed primarily on smaller fish.

PRESENT STATUS

There are two primary surveys of weakfish in the Delaware Estuary, both of which are performed by the DE DFW. These include:

1. An Adult Groundfish Research Trawl Survey, using a 30-foot otter trawl net at nine fixed locations in the Delaware Bay.
2. A Juvenile Finfish Research Trawl Survey to measure relative young-of-the-year abundance, using a 16-foot trawl to sample 39 stations in the Delaware Bay and River; the index is calculated from the 33 non-river stations.

Despite both indices being relatively close to historic averages for the Delaware Estuary (Figure 4-4), the most recent peer-reviewed stock assessment performed by the ASMFC in 2016 determined that the coastwide weakfish population is considered “depleted.” This threshold was defined as the coastwide estimated spawning stock biomass being below 30% of the estimated average biomass over the period 1982-2014 (ASMFC, 2016a).

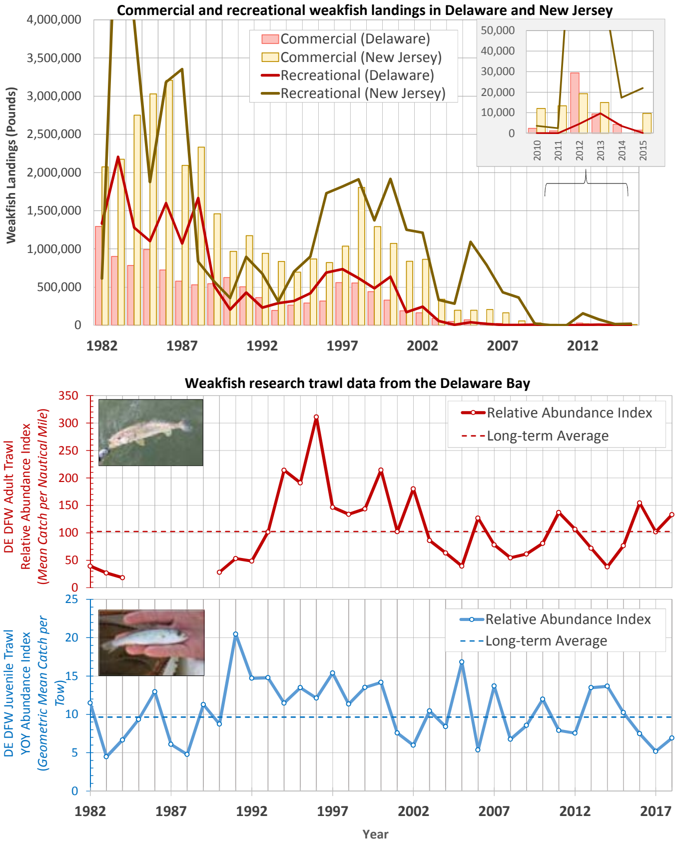
TRENDS

Within the Delaware Bay, weakfish were only moderately abundant prior to 1970; however, increasing fish size and population made the Delaware Bay famous for trophy-sized weakfish during the spring spawning run by the late 1970s. By the late-1980s, the coastal fishery started to decline in terms of total landings quantity (Figure 4-4). The ASMFC imposed coastwide restrictions throughout the early-1990s, coinciding with a slight rebound in abundance and landings through the late-1990s. Declines in estimated coastwide spawning abundance during the 2000s was mirrored by increasing natural mortality rates. In 2010, the ASMFC required states to implement revised commercial limits and a one fish recreational creel limit. While still considered depleted, the ASMFC 2016 stock assessment indicated a slight coastwide increase in the 2014 total abundance, spawning stock biomass, and recruitment of fish of age 1 have occurred (ASMFC, 2009; ASMFC, 2016a).

ACTIONS/NEEDS

- While some factors have been identified as contributing to recent weakfish decline, more investigation is warranted (e.g. high natural mortality rates).
- A reduction in fishing mortality from recreational and commercial fishing sectors resulting from discards. Recreational anglers should practice catch and release until the fishery is in healthy status.
- Continued use and creation of underwater artificial reefs programs by Delaware and New Jersey.

Figure 4-4: Commercial and recreational landings data adopted from ASMFC 2016 Stock Assessment. *Research trawl data provided by the Delaware Department of Fish and Wildlife. Adult weakfish photo credit: Evan Kwityn, DRBC. YOY weakfish photo adopted from ASMFC (2016b).*



SUMMARY

Delaware Bay weakfish abundance indices are near the historic averages; however, survivorship has declined to a point where catches of legal-size weakfish are uncommon in Delaware Bay. A recent coastwide stock assessment indicated a small increase in abundance; however, stock remains well below the recommended threshold and still faces threats due to natural mortality.

Poor

AMERICAN EEL

DESCRIPTION

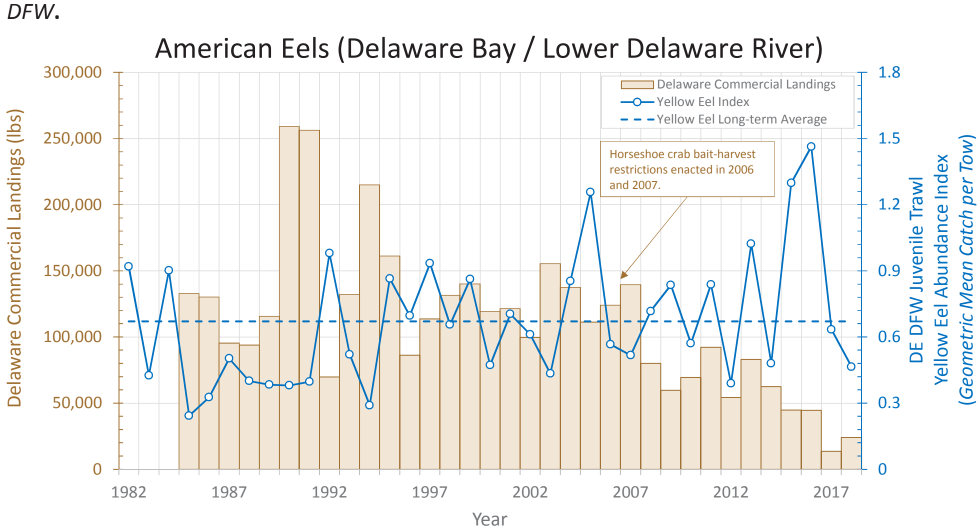
American eels (*Anguilla rostrata*) are catadromous, meaning they are born in the ocean, migrate into freshwater and the estuary where they spend most of their lives, and return to the ocean to spawn once before dying. Larval eels move inshore from the Gulf Stream in a randomized fashion. While some remain in brackish waters of the basin, others migrate far into the nontidal headwaters of the Delaware River tributaries where they can live for up to 20 years. Eels are valued commercially as bait for certain recreational fishing (e.g. Striped Bass) and within the food market. Ecologically, certain freshwater mussels (e.g. Eastern elliptio) are known to be highly dependent on eels for the transport of larvae, which helps sustain freshwater mussel populations integral to water quality (e.g. filtering nutrients and sediment) (Lellis et al., 2013).

PRESENT STATUS

The status of American eels has been reviewed by the United States Fish & Wildlife Service (USFWS) twice (2007 and 2015) and found no basis for listing the population as either threatened or endangered. While not having any legal implications, the International Union for Conservation of Nature (IUCN) assigned the species a Red List Category of "endangered" in 2014 (Jacoby et al, 2017).

The abundance of American yellow eels in the Delaware Estuary is represented by an index developed from 13 survey stations included in the DE DFW Juvenile Finfish Research Trawl Survey. The catch typically consists of eels from ages 0 to 7, the most common being 3 years of age. As indicated on Figure 4-5, the past two years have yielded results dropping below the long-term average, following the series record high results in 2016 and 2015.

Figure 4-5: American Eels commerical landings in the state of Delaware and yellow eel abundance index. *Data provided by the DE DFW*.



American eel. *Photo credit: USGS.*

TRENDS

Coast-wide populations have declined in recent years, thought to be a result of factors such as: slow rate of maturation, stage-specific mortality, fishing mortality, continued habitat loss (e.g. dams) and changes in oceanic conditions. Additionally, introduction of the Asian parasite *Anguillicola crassus*, is considered wide-spread in the American eel population; while relatively little is known about the population scale effects, it is known to negatively impact infected eels.

- Commercially, a sharp decline in American eel landings has been observed in the State of Delaware, since regulations enacted in 2007 stopped the harvest of female horseshoe crabs (the primary bait for American eel) in the Delaware Bay region (Figure 4-5).
- While the long-term series for the Delaware Estuary yellow eel index has a slightly positive trend, the slope has been largely neutral since the early 1990s, oscillating around an average value. There are currently no apparent bases for future predictions.
- Data from the non-tidal portion of the Delaware River Basin has not been collected consistently enough to draw conclusions of population trends.

ACTIONS/NEEDS

- Improved monitoring of species abundance in the non-tidal reaches of the Delaware River Basin and continued monitoring in the Estuary to support future predictions.
- Improved fish passage at dams to increase available habitat.

SUMMARY

Coast-wide American eel populations have declined in recent years. While the Delaware Estuary saw record high yellow eel index values in 2015 and 2016, the yellow eel index trend has remained largely neutral since the early 1990s. Continued and enhanced data collection is needed to support future population outlooks. When practical, initiatives which open quality habitat in the upper portions of Delaware River tributaries (e.g. dam removals) may help facilitate movement of other important species (e.g. freshwater mussels).

AMERICAN SHAD

American Shad caught in the Delaware River. *Photo credit Evan Kwityn, DRBC.*

DESCRIPTION

American shad, *Alosa sapidissima*, are the largest North American member of the herring family. They are an anadromous fish, spending the majority of their life at sea and only returning to freshwater tributaries to spawn. Beyond filling an important role in the food chain as both predator and prey, shad are a popular sport fish and have historically supported valuable commercial fisheries along the entire Atlantic Coast. In the late 1890s, the Delaware River had the largest annual commercial shad harvest of any river on the Atlantic Coast. However, factors such as overfishing, dammed spawning tributaries and degraded water quality (e.g. low dissolved oxygen) all contributed to population decline. Despite legislative action and artificial propagation, their numbers fell so low by 1920 that the shad industry collapsed. Based on historic shad abundance and the nature of factors attributed to the population's decline, trends in shad populations are a good indicator of restorative efforts within the Delaware River are effective.

PRESENT STATUS

In the non-tidal reach of the Delaware River, there are two major abundance indices:

1. The Lewis Fishery haul sein operation at Lambertville, NJ is indicative of the annual spawning run's relative abundance. The most recent data from 2017 and 2018 are both well above the recent average, and generally considered good shad runs. This is the first time in over two decades that two years in a row have an annual average of over 20 caught shad per seine haul.
2. The Pennsylvania Fish & Boat Commission (PFBC) gill-net survey at Smithfield Beach in the Delaware Water Gap National Recreational Area in Pennsylvania also measures the spawning run's relative abundance, approximately 68 miles upriver of Lambertville, NJ.

TRENDS

After the shad run decline in the 1920s, the return of populations observed in the mid-1970s corresponds with the timing of efforts to restore water quality (e.g. dissolved oxygen levels in the Delaware River). In recent years, the stock of American Shad in the Delaware River Basin was considered healthy and sustainable, but at moderate levels. Notably, both abundance indices have risen above historic averages in 2018, representing good spawning runs. Conservation efforts are continuing, such as the 2017 Sustainable Fishing Plan prepared by the Delaware River Basin Fish and Wildlife Management Cooperative, which establish precautionary low-level benchmarks designed to react to declining trends in abundance, triggering specific management actions (DRBFWMC, 2017).

ACTIONS/NEEDS

- Continued restoration of blocked habitat through dam removal and fish passage devices.
- Habitat conditions in spawning reaches must be maintained and monitored.
- Reintroduction of shad into newly opened bodies of water for spawning.
- Establishing sustainable harvest limitations after restoration.

SUMMARY

The American Shad population in the Delaware River Basin is healthy, has been at moderate-low levels for about two decades, and has just recently shown two consecutive years of strong spawning runs. Continued management, monitoring and research efforts play a key role in determining the causes behind trends of this indicator and identifying strategies to keep the basin healthy.

Good

Index of adult spawning American Shad in the Delaware River

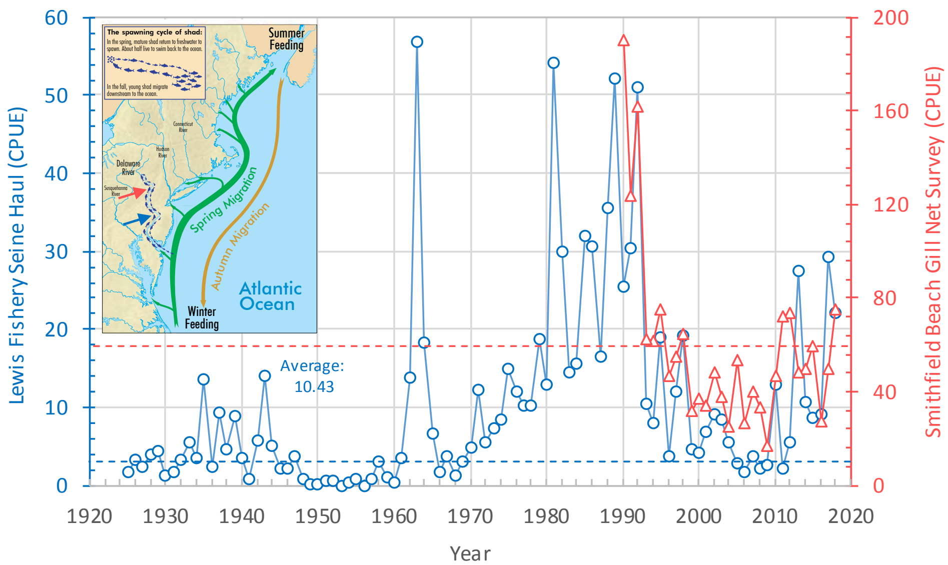


Figure 4-6: Spawning indices along the Delaware River Mainstem. *The Lewis Fishery seine haul data provided by Steve Meserve. Smithfield beach data obtained from The Delaware River Basin Fish & Wildlife Management Cooperative (DRB FWMC, 2017), and corresponding PFBC reports.*

BROOK TROUT

A brook trout caught in the Delaware River Basin (Jean's Run, Carbon County, PA). *Photo credit: Jake Bransky, DRBC.*

DESCRIPTION

Brook trout, *Salvelinus fontinalis*, are widely recognized for their recreational and cultural importance, as well as indicators of high water quality and good watershed health. They are the only native trout species to the Delaware River Basin, inhabiting high-quality freshwater streams with characteristics such as riffles, various stream beds, a vegetative canopy, and other forms of in-stream cover (e.g. large rocks, roots, submerged vegetation) (PADCNR, 2016). The optimal water temperature for brook trout has been reported as spanning between 11-16°C, ideally with a high dissolved oxygen concentration (optimally near saturation). A tolerance range for pH has been reported between 4.0-9.5, with an optimal pH range of 6.5-8.0 (Raleigh, 1982). Within the mid-Atlantic region (including the Delaware River Basin), brook trout populations are primarily located in headwater streams originating in mountains/ foothills, and spring-fed limestone creeks (EBTJV, 2008).

PRESENT STATUS

Fair

A recent 2008 study evaluating current brook trout populations against historical reports in the eastern United States has indicated that there have been widespread reductions in natural populations (Hudy et al., 2008). Continued population assessments have resulted in updated 2015 population maps indicating the presence/absence of eastern brook trout in sub-watersheds within the Delaware River Basin, as shown in Figure 4-7.

TRENDS

Research has indicated that the trend of brook trout population reduction is attributed to factors such as historical and current land use practices, changes in water quality, elevated water temperatures, spread of exotic and nonnative fishes, habitat fragmentation and destruction, and natural events (Hudy et al., 2008). Efforts to reverse this trend have increased over the last twenty years through the formation and action of partnerships such as the Eastern Brook Trout Join Venture (EBTJV), and the adoption of conservation and/or management plans by numerous agencies such as the PFBC, NJDFW, and NYDEC.

ACTIONS/NEEDS

- Continue overall conservation and management efforts.
- Implement conservation plans specific to brook trout habitats to ensure long-term survival.
- Determine if a special designation or current status reclassification is needed (i.e. Species of Special Concern, Threatened, Endangered, etc).
- Continued research and quantitative monitoring of brook trout population to assess population trend responses to conservation efforts.

SUMMARY

Eastern brook trout are native to the Delaware River Basin, and widely seen as indicators of high-quality water and good watershed health. While research has shown that native populations have been reduced over time, a recent push for conservation and management is seeking to restore populations to historic native levels.

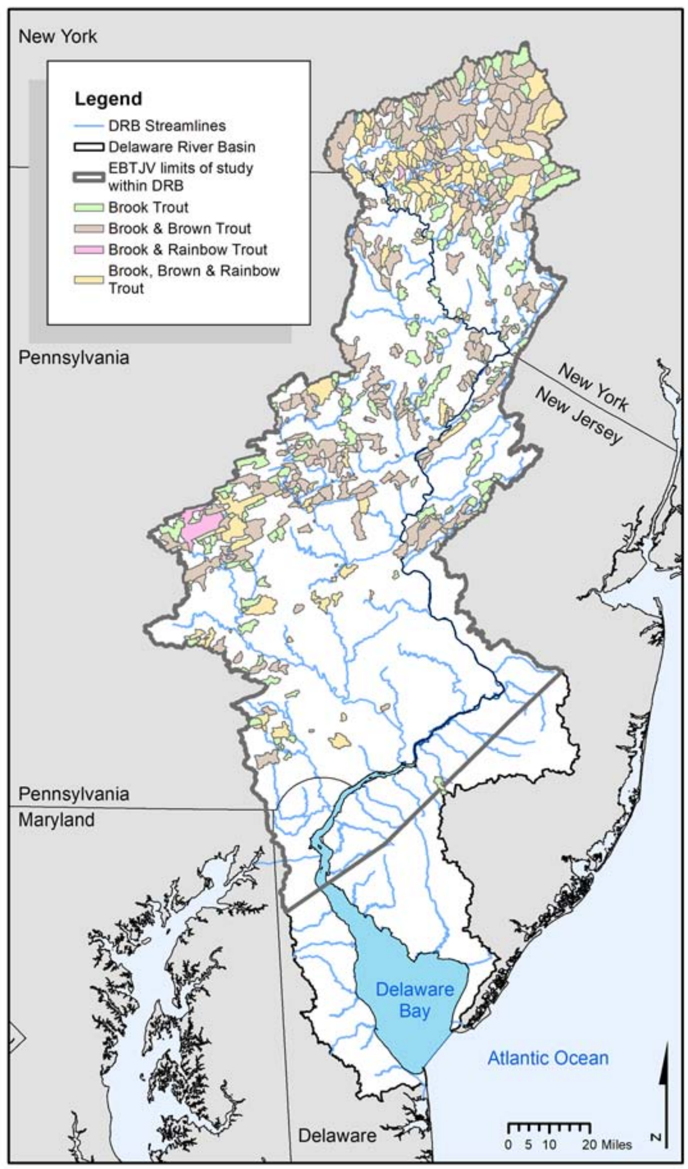


Figure 4-7: Distribution of brook trout catchment habitats across the Delaware River Basin, as determined by a 2015 analysis based on inputs such as salmonid species sample points and anthropogenic barriers. *Data retrieved from Coombs and Nislow, 2015.*

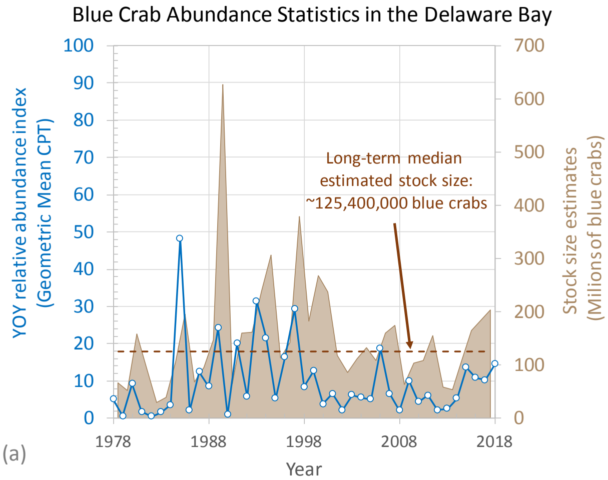
BLUE CRAB

DESCRIPTION

The blue crab, *Callinectes sapidus*, inhabits estuarine habitats throughout the western Atlantic. Blue crabs spawn primarily in the summer months in mid to lower Delaware Bay. The larvae from crabs are transported from the Delaware Estuary to the coastal ocean during zoeal development, and return to the Delaware Bay via wind-driven flows. Ecologically, blue crabs are important because they are opportunistic benthic omnivores. This means they feed on bivalves, fish, crustaceans, and are also at times cannibalistic, where adult blue crabs are predators of their juveniles. Additionally, there are more than 60 known fish species that prey on blue crabs.

The State of Delaware has monitored blue crab populations since 1978. Overfishing and stock sustainability concerns from the mid-1980s through the 1990s prompted Delaware to prepare a fishery management plan and perform stock assessments. The Delaware Division of Fish and Wildlife (DE DFW) collects biological information and year-round landings reports to assess annually the size and status of blue crab stock to make informed management decisions for both recreational and commercial fishing industries.

Blue crab. *Photo credit: Evan Kwityn, DRBC.*



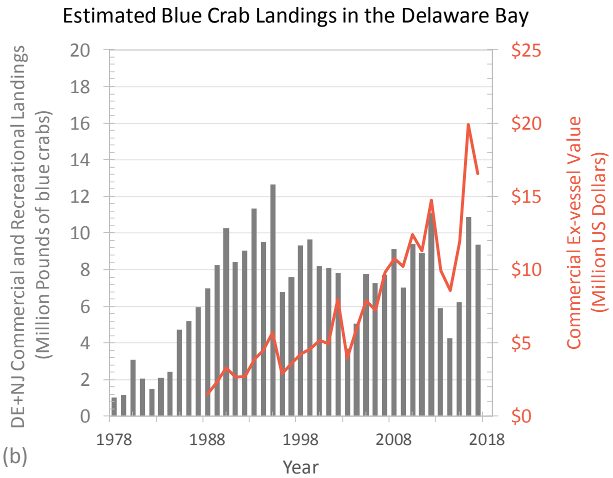


Figure 4-8: (a) Young-of-the-Year relative abundance index measured by the DE DFW Delaware Bay Trawl survey, and the estimated population abundance based on DE DWF annual modelling. (b) Commercial and recreational landings, plotted with commercial ex-vessel value. *Data provided by DE DFW.*

PRESENT STATUS

The current blue crab stock in the Delaware Bay is at healthy levels of abundance and at safe levels of fishing mortality. Population models for 2017 indicated that the blue crab stock in Delaware Bay increased to approximately 202 million crabs as shown in Figure 4-8a, well above the median value of 125.4 million. Presently, the blue crab fishery recruitment as indicated by the Young-of-the-Year (YOY) index calculated from the DE DFW Delaware Bay Trawl survey has remained above a geometric mean of 10 catch-per-trawl (CPT) since 2015.

In 2017, over 9.3 million pounds of blue crabs were landed in the Delaware-New Jersey fishery (commercial and recreational) which had a commercial ex-vessel value of $16.5 million dockside (Figure 4-8b). While the blue crab harvest from the Delaware Bay is generally split between the two states (51%:49%, DE:NJ), blue crab are the most important commercial fishery in the State of Delaware. Additionally, recreational blue crab harvest from the Delaware Bay comprises over 2 million crabs annually.

TRENDS

Blue crab productivity was high from 1985 to 1999, based on the DE DFW indices which were generally at or above median levels during this period. While the next 15-year period showed lower juvenile recruitment, 2015-2018 observations indicate a robust juvenile recruitment, possibly signaling an end to the low productivity period. The YOY recruitment numbers have shown a reasonable linear correlation with the ensuing year's commercial landings.

ACTIONS/NEEDS

- Continue performing long-term and fishery-independent management surveys and through monthly trawl surveys.
- Continue accurate reporting of fishery landings are needed to protect and manage the fishery stock.
- Habitat preservation and restoration (i.e. water quality) for critical life-history stages, particularly nursery grounds in seagrass beds.

SUMMARY

Recent levels of blue crab exploitation rates have been high; however, juvenile recruitment has rebounded and has increased adult stock abundance. Currently, the blue crab stock in the Delaware Bay is at healthy levels of abundance and fishing mortality rates are safely below overfishing thresholds. The near-term outlook for blue crabs in the Delaware Bay is promising.

Good

HORSESHOE CRAB

Horseshoe crabs at Egg Island, NJ. *Photo credit: PDE Staff.*

DESCRIPTION

Horseshoe crabs, *Limulus polyphemus*, are benthic arthropods that inhabit both estuarine and continental shelf habitats stretching from the Yucatan Peninsula to Maine; however, the largest spawning population in the world is within the Delaware Bay. Experiencing few physical changes over the last 350 million years, this "crab" is more closely related to spiders than other crustaceans. Horseshoe crabs may live up to 19 years, initially near intertidal breeding beaches before moving into deeper water up to a few miles offshore.

Horseshoe crabs are commercially important in the fishing industry as bait, and the biomedical industry which uses their blue blood to test medications and biomedical devices. Most importantly, horseshoe crabs play an essential role in the Delaware Bay ecosystem. An adult female may deposit up to an estimated 88,000 eggs annually on intertidal beaches. Eggs uncovered by wave action and other mechanisms are an essential food for several shorebird species in the Delaware Bay, which is the second largest migratory staging area for shorebirds in North America. Annual Delaware Bay volunteer spawning surveys are performed at 25 beaches, as shown on Figure 4-9. More information on the survey and how to volunteer is at the following link:

Delaware Bay Horseshoe Crab Survey:
https://www.delawarebayhscsurvey.org/.

PRESENT STATUS

A trawl survey conducted within the coastal region adjacent to the Delaware Bay has been conducted by the Virginia Polytechnic Institute and State University (VT) between 2002-2011 and 2016-2017 (Figure 4-9). Each tow was typically performed for 15-minutes (average 1.22 km), and a catch density (catch/km2) was calculated from the tow distance and net spread. Population totals were estimated by multiplying stratified mean density by survey area (Hata and Hallerman, 2018).

TRENDS

Historically, annual harvests between the 1850s-1920s ranged from 1.5-2 million horseshoe crabs; this rate dropped in the 1950s, ceased in the 1960s and varied until the 1990s. Increased need for bait in the American eel and whelk pot fisheries in the 1990s led to a peak harvest in 1998 of over six million pounds. The Atlantic States Marine Fisheries Commission has regulated the industry by establishing horseshoe crab bait landing quotas since 1998 (ASMFC, 2019). In 2001, the National Marine Fisheries Service established the Carl N. Shuster, Jr. Horseshoe Crab Reserve (HCR) to protect the large spawning population of horseshoe crabs in the Delaware Bay. Harvests within Delaware Bay States have been restricted to 'male-only' since 2006, and New Jersey has had a moratorium in place (no harvest allowed) since 2007 (ASMFC, 2018). Assessing data collected since 2002, the VT trawl survey (Hata and Hallerman, 2018) has presented notable findings:

- The estimated population of mature males and females within the Delaware Bay area appears to be increasing over time, but not within the HCR.
- On average, about 75% of immature or newly mature horseshoe crabs were outside the HCR; notably, spawning occurs outside the HCR in coastal embayments and juveniles stay close to these beaches for several years.

ACTIONS/NEEDS

- Continued data collection and monitoring to enhance scientific models of the relationship between horseshoe crab spawning and shorebird population trends.
- Continued monitoring and management efforts to protect horseshoe crab populations.
- Habitat enhancement efforts.

SUMMARY

Horseshoe crabs have historically supported a commercially important fishery, aided advancements in the biomedical industry, and are an essential element of the Delaware River Basin ecosystem. The combination of conservation approaches (conventional management actions and instituting a reserved area) appears to be achieving the objectives of protecting and maintaining horseshoe crab spawning stocks.

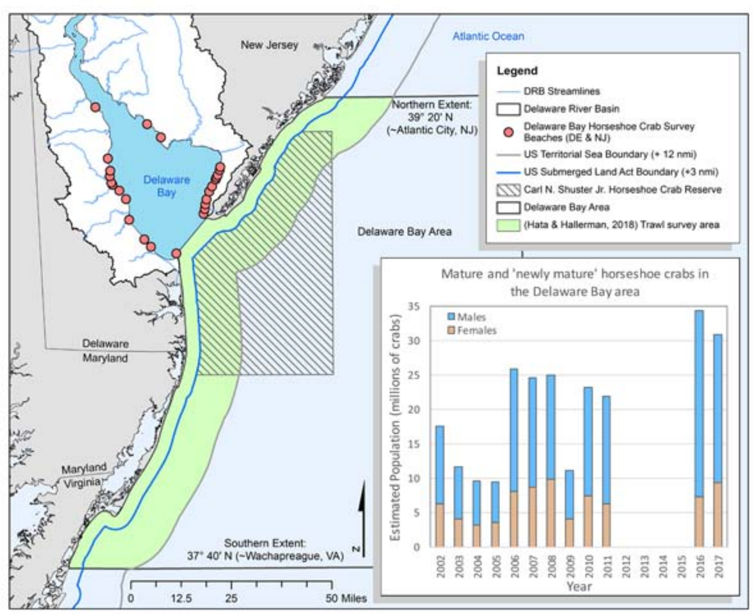
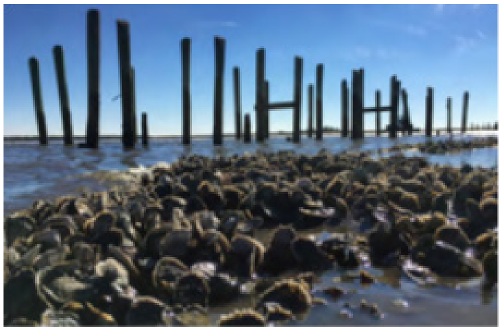


Figure 4-9: The survey points are the twenty-five beaches which are part of the annual Delaware Bay volunteer spawning surveys. The data presented are estimated populations of mature and 'newly mature' horseshoe crabs within the Delaware Bay area (including the Carl N. Shuster, Jr. Horseshoe Crab Reserve). *Data obtained from (Hata and Hallerman, 2018). Graphic base layers obtained from NOAA and the US Department of the Interior.*

EASTERN OYSTER



Oyster reef exposed at low tide in the Mispillion River, DE. *Photo credit: Spencer Roberts, Partnership for the Delaware Estuary.*

DESCRIPTION

The eastern or American oyster, *Crassostrea virginica*, is a critical native inhabitant Delaware Bay benthic environment. Initially spawning as a free-swimming larva, they will attach to a hard substrate within a few weeks (preferably a clean oyster shell) and grow over 3 to 6 years to reach a marketable size. They stabilize sediments and create habitats for other species by forming oyster beds (reefs) and enhance the water quality by filter feeding large quantities of water. Similar to other bivalve mollusks, oysters are sensitive to degraded water conditions and are generally recognized as a bioindicator of environmental conditions.

PRESENT STATUS

Between 2002-2016, the population of oysters on the New Jersey side of the Delaware Bay has been relatively steady between 1 and 2 billion oysters. The 2017 whole stock oyster abundance in New Jersey side of the Delaware Bay was estimated to be approximately 2.95 billion oysters, at an average density of 56 oysters/m^2; this is the highest estimate since 2001. Of this surveyed abundance, approximately 853 million (29%) are estimated to be market size. While the oyster resources in the Delaware Bay are distributed approximately 90:10 (NJ:DE) due to habitable area, population dynamic trends presented by the State of Delaware at the annual stock assessment workshop tend to mirror trends on the New Jersey side.

TRENDS

Surveys of commercial oyster beds on the New Jersey side of the Delaware Bay have been conducted since 1953 , as is shown in Figure 4-10. Two diseases lethal to oysters but not known to be harmful to humans ("MSX" and "Derma") have largely affected the population dynamics (Ewart and Ford, 1993). As the intensity of oyster diseases and recruitment success are not easily predicted, the only mechanism available to inform resource management (e.g. state harvesting quotas) is the annual survey.

- Harvesting has not had substantial effects on the oyster population dynamics in Delaware Bay since at least the 1960's. As identified in an annual stock assessment report prepared by the Haskin Shellfish Research Laboratory, the 2017 picture for the oyster population was determined to be positive.
- Oyster recruitment numbers suggest the population may be limited by habitat availability (e.g. available empty shells), rather than bound by natural recruitment dynamics.
- Increased salinity potentially linked to channel deepening, extraction of groundwater, consumptive water uses and even climate change may have implications for associated diseases on the oyster population.

ACTIONS/NEEDS

- Continue annual oyster population and oyster disease surveys to effectively manage the wild fishery.
- Shell planting efforts are between 100,000 and 200,000 bushels a year, whereas half a million or more would help to ensure better recruitment.
- Continued monitoring and enhanced modelling of Bay-wide temperature and salinity, related to external factors.

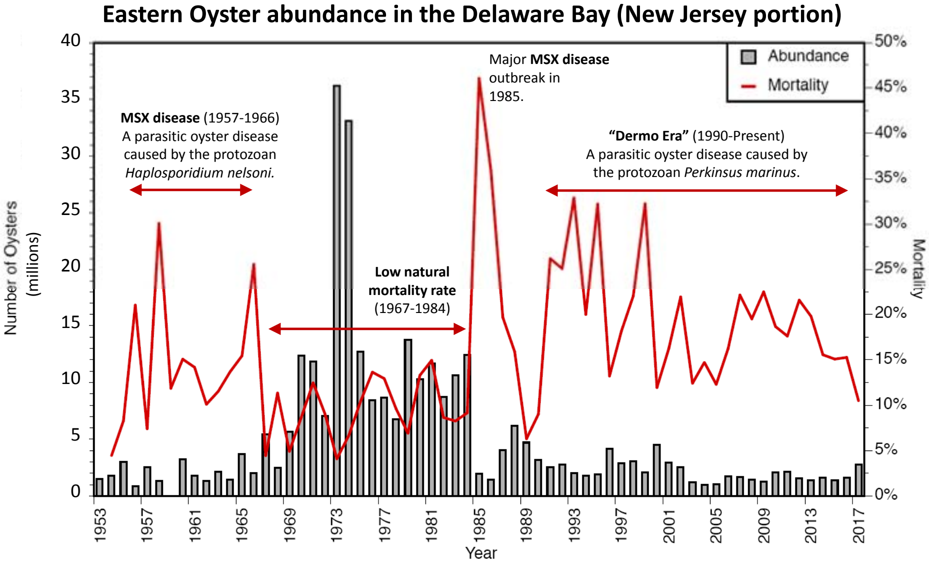


Figure 4-10: Time series of total oyster abundance (left axes) compared to natural mortality rate (right axis). *Figure adopted from HSRL, 2018; used with permission*.

SUMMARY

The oyster is an important living resource within the Delaware River Basin, which is largely controlled by a balance between recruitment and disease-related mortality. Successful settlement of young oysters in recent years suggest adult population will increase if sound monitoring and management practices are continued.

FRESHWATER MUSSELS

Creeper *(Strophitus undulatus)* **Freshwater Mussel.** *Photo Credit: Evan Kwityn, DRBC***.**

DESCRIPTION

Freshwater mussels are filter feeding bivalve mollusks that live in lakes, rivers, and streams. They provide valuable ecosystem services by increasing water clarity, enriching habitats, and stabilizing bed erosion. These species grow slower yet live longer (50 years or more) than their marine counterparts, and have complicated reproduction strategies dependent on fish hosts. Because of their long and complex lifecycle, freshwater mussels are recognized as sensitive, long-term indicators of water quality and habitat condition.

PRESENT STATUS

There are over a dozen species of freshwater mussel which are native to the Delaware River Basin. The conservation status of each as defined by NatureServe (global, national and sub-national levels) is provided in Table 4-1, accompanied by any associated US Federal or US State regulatory status. All four states within the Delaware River Basin have defined a subnational (state/province) status rank for native mussel species, which is based on the classification guidance provided by NatureServe. The reduced population of freshwater mussels in the Delaware River Basin is consistent with nationwide patterns of threatened biodiversity within this taxonomical order. The primary factors which have resulted in declining and imperiled mussel populations within in the Delaware River Basin are habitat and water quality degradation.

TRENDS

A recent focus on the importance of freshwater mussel populations within an ecosystem has driven many projects within the Delaware River Basin over the last decade. A few highlighted projects ongoing with the Delaware River Basin are presented on Figure 4-11.

As part of the Freshwater Mussels Recovery Program, additional studies of freshwater mussel populations in the Delaware Estuary have expanded on a comparison against a baseline survey performed between 1909-1919. In summary, the Piedmont streams in PA have a limited population abundance which may not be reproducing, the Coastal Plain streams in NJ and DE are less degraded than the Piedmont, and the Lower Delaware River mainstem revealed some large beds including species believed to be extirpated from the Basin. It is suggested that the decline appears to be continuing .

Additional assessments of the non-tidal reach of the Delaware River mainstem between Columbia, NJ and Trenton, NJ found declines in overall mussel biomass and shifts in community composition below the Lehigh River confluence.

Table 4-1: Native Delaware River Basin Freshwater Mussel Conservation Status.

Common Name	Species	Global	United States		New York		Pennsylvania		New Jersey		Delaware	
		G-Rank[1]	N-Rank[1]	Reg.[2]	S-Rank[1]	Reg.[3]	S-Rank[1]	Reg.[4]	S-Rank[1]	Reg.[5]	S-Rank[1]	Reg.[6]
Dwarf Wedgemussel	*Alasmidonta heterodon*	G1G2	N1N2	E	S1	E	S1	E	S1	E	SH	E
Triangle Floater	*Alasmidonta undulata*	G4	N4	--	S4	--	S3	--	S2	Th	SH	E
Brook Floater	*Alasmidonta varicosa*	G3	N3	--	S1	T	S1S2	--	S1	E	SX	E
Eastern Elliptio	*Elliptio complanata*	G5	N5	--	S5	--	S4	--	S4	--	S5	--
Yellow Lampmussel	*Lampsilis cariosa*	G3G4	N3N4	--	S3	--	S4	--	S2	Th	SH	E
Eastern Lampmussel	*Lampsilis radiata*	G5	N5	--	S4S5	--	S1	--	S2	Th	S1	E
Green Floater	*Lasmigona subviridis*	G3	N3	--	S1S2	T	S2S3	--	S1	E	Not in DE-DRB	
Tidewater Mucket	*Leptodea ochracea*	G3G4	N3N4	--	Not in NY-DRB		S1	--	S2	Th	S1	E
Eastern Pondmussel	*Ligumia nasuta*	G4	N4	--	Not in NY-DRB		S2S3	--	S2	Th	S1	E
Eastern Pearlshell	*Margaritifera margaritifera*	G4	N4	--	S2	--	S1	E	SX	--	--	--
Eastern Floater	*Pyganodon cataracta*	G5	N5	--	S4	--	S4	--	S4	--	S4	--
Creeper	*Strophitus undulatus*	G5	N5	--	S4	--	S5	--	S3	SC	S1	--
Alewife Floater	*Anodonta implicata*	G5	N5	--	S1S2		S3	--	S4	--	S1	--
Rayed Bean	*Villosa fabalis*	G2	N2	E	Not in NY-DRB		S1S2	T	--	--	--	--
Northern Lance	*Elliptio fisheriana*	G4	N4	--	Not in NY-DRB		Not in the PA-DRB		--	--	S2	--

Subnational Status Rank
SX: Presumed Extirpated
SH: Possibly Extirpated
S1: Critically Imperiled
S2: Imperiled
S3: Vulnerable
S4: Apparently Secure
S5: Secure
SU: Unrankable
SNR: Not Yet Ranked

Regulatory Status:
E: Endangered
T: Threatened
SC: Special Concern

Notes:

[1] Global (G-Rank), National (N-Rank) and Subnational (S-Rank) status ranks retrieved from NatureServe Explorer (accessed: January 7, 2019).

[2] US Federal Regulatory Status as indicated under the Endangered Species Act of 1973 (accessed: February 4, 2019).

[3] New York regulatory status as indicated in 6 CRR-NY Part 182.5 (current through September 15, 2018).

[4] Pennsylvania regulatory status as indicated in 58 Pa. Code § 75.2 (amended September 2, 2016).

[5] New Jersey regulatory status as indicated in N.J.A.C. 7:25-4 (last updated May, 2015).

[6] Delaware regulatory status as indicated in 7 Del. C. § 3900.16.2.3 (accessed: January 7, 2019).

ACTIONS/NEEDS

- Improve coordinated monitoring (e.g. mussels are not targeted in routine macroinvertebrate assessments), data sharing, and current models of mussel conservation/ restoration benefits on the ecosystem.
- Expanded studies to better understand specific causes of impairment (e.g. habitat suitability studies).
- Enhanced efforts to protect, conserve and restore mussel populations based on existing data and models (e.g. habitat restoration, mussel reintroduction).
- Expanded assessment surveys of tributaries in the Upper Region, and Central/Lower border.

Poor

SUMMARY

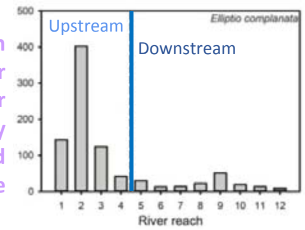
Freshwater mussels are valuable contributors to improving water quality. A robust community of freshwater mussels should be widespread with high biodiversity. Unfortunately, the present status of the native species is poor in most areas of the Delaware River Basin. Continued watershed development and climate change represent increasing threats, although these have the potential to be offset by enhanced watershed management combined with pro-active mussel conservation actions.

Figure 4-11: Project highlights for freshwater mussel programs in the Delaware River Basin.

Freshwater mussel surveys of the Upper Delaware River

Studies by the USGS in 2001 and 2002 focused on identifying species diversity in the Upper Delaware Scenic and Recreational River and the Delaware Water Gap National Recreation Area. This included identification of the endangered Dwarf Wedgemussel. Surveys continued through 2009. A recent analysis of studies published by the USGS in 2016 estimates a DWM population between 7,961–26,161 across following areas: Delaware River mainstem, Big Flat Brook, Little Flat Brook, Neversink River and Paulinskill. More long term monitoring, continued surveys and assessments are still needed within the Delaware River Basin (Gailbraith et al., 2016).

Photo Credit: Jeffrey Cole, USGS Leetown Science Center.



Non-tidal Mainstem Delaware River Assessments for Community Composition and Relative Abundance

The Delaware River Basin Commission (DRBC) in collaboration with the USGS has monitored freshwater mussels along the mainstem of the Delaware River. Findings at 12 "reaches" spanning between RM206.5 and RM137.4 showed a direct relationship between freshwater mussel (*Elliptio complanata*) abundance above and below the Lehigh River confluence.

Using Sidescan Sonar Imaging to map Freshwater Mussels in the Tidal Delaware River

Through PADEP's Coastal Resources Management Program (CRMP), staff are performing studies to assess the viability of using sonar to map freshwater mussel presence into four categories: None, Sporadic, Common/Bed, Unknown. Shown above is an example sonar output from a survey near Mud Island, with confirmation underwater video (PADEP CRMP, 2019).

Images adopted from PADEP CRMP, 2019; used with permission.

Fairmount Water Works Freshwater Mussel Hatchery & Large Scale Hatchery Expected at Bartram's Gardens

The nations first city-owned mussel hatchery has been formed with the help of numerous contributors, with the overall goal of propagating new mussels and boosting diminished populations in the Delaware River watershed. In 2017, the state of Pennsylvania granted funding to The Partnership for the Delaware Estuary to construct a commercial scale freshwater mussel hatchery. This will be the world's first freshwater mussel hatchery dedicated to restoring mussel beds to promote clean water.

Photo Credit: Michael Thompson, DRBC.

Freshwater Mussel Recovery Program (FMRP)

Launched in 2007 by the Partnership for the Delaware Estuary, this program has the main goal of conserving and restoring native freshwater mussels within the Delaware Estuary. There have been numerous studies in the Lower and Bay Regions including but not limited to surveys of mussel presence, conservation, assessments on stream suitability for restorative habitat, and even reintroduction! Mussels are often tagged with electronic passive integrated transponders, allowing them to be re-found and tracked using a portable antenna and electronic tag reader.

PDE Mussel News & Reports: http://www.delawareestuary.org/science-and-research/freshwater-mussels/.

Photographs obtained from PDE Report No. 12-02 (mussel with tags) and Report No. 14-01 (locating mussels); used with permission.

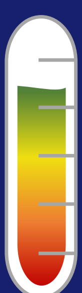
MACROINVERTEBRATES

DESCRIPTION

Benthic macroinvertebrates refer to a group fauna which live at the bottom of a waterbody such as the stream bed sediment, stones or debris ('benthic'), can be seen without magnification ('macro') and do not have backbones ('invertebrates'). While this group largely consists of insects, other examples are snails, clams, aquatic worms, and crayfish. It is widely acknowledged that macroinvertebrates are an essential biological indicator in freshwater ecosystems, for numerous reasons:

- **Localized results:** Most macroinvertebrates have limited movement, will inhabit a short segment of stream and therefore generally reflect the local habitat conditions.
- **Current picture:** Most species live in a stream for a year or more and can experience a full range of environmental conditions, but only typically have a lifespan which is indicative of the present and recent conditions.
- **Habitat sensitivity:** The group "macroinvertebrates" encompasses a diverse group of organisms with different niches, and varying degrees of tolerance to changes in water quality and watershed characteristics. This means that the presence or absence of a notable species can help indicate stream health.
- **Study feasibility:** Macroinvertebrates are relatively abundant, easy to sample for, and easy to analyze. A program of study usually entails sampling, identifying the organisms, applying a bioassessment metric (e.g. scoring system), and calculation of a single numerical index of biological integrity (IBI). An example photograph of sampling is presented in Figure 4-13.

PRESENT STATUS



Very Good

Data for assessing macroinvertebrates within the Delaware River Basin are primarily derived from the four states and the Delaware River Basin Commission (DRBC); however, there are many additional groups which perform essential monitoring throughout the Basin. A summary of sampling locations grouped by agency is presented as Figure 4-12. An important caveat which accompanies this extensive dataset is that most organizations currently use different bioassessment protocols for performing macroinvertebrate studies. This can be caused by different factors such as regional requirements, available resources, or even the specific sub-ecosystem being sampled.

A recent USGS study by Cuffney & Kennen (2018), which made use of data within the Basin demonstrated that while possible, it is not simple nor always feasible to compare data collected using different methods. Historically, this issue has resulted in generalized reports on status within the Basin based on qualitative comparisons. In general, while some level of impairment is found in almost all watershed regions the best conditions have been in the uppermost portion of the Basin where a higher percentage of land remains as natural landscapes. The lower portion of the basin has a higher percentage of impaired streams around urbanized areas, and in sub-watersheds with legacy mining activity.

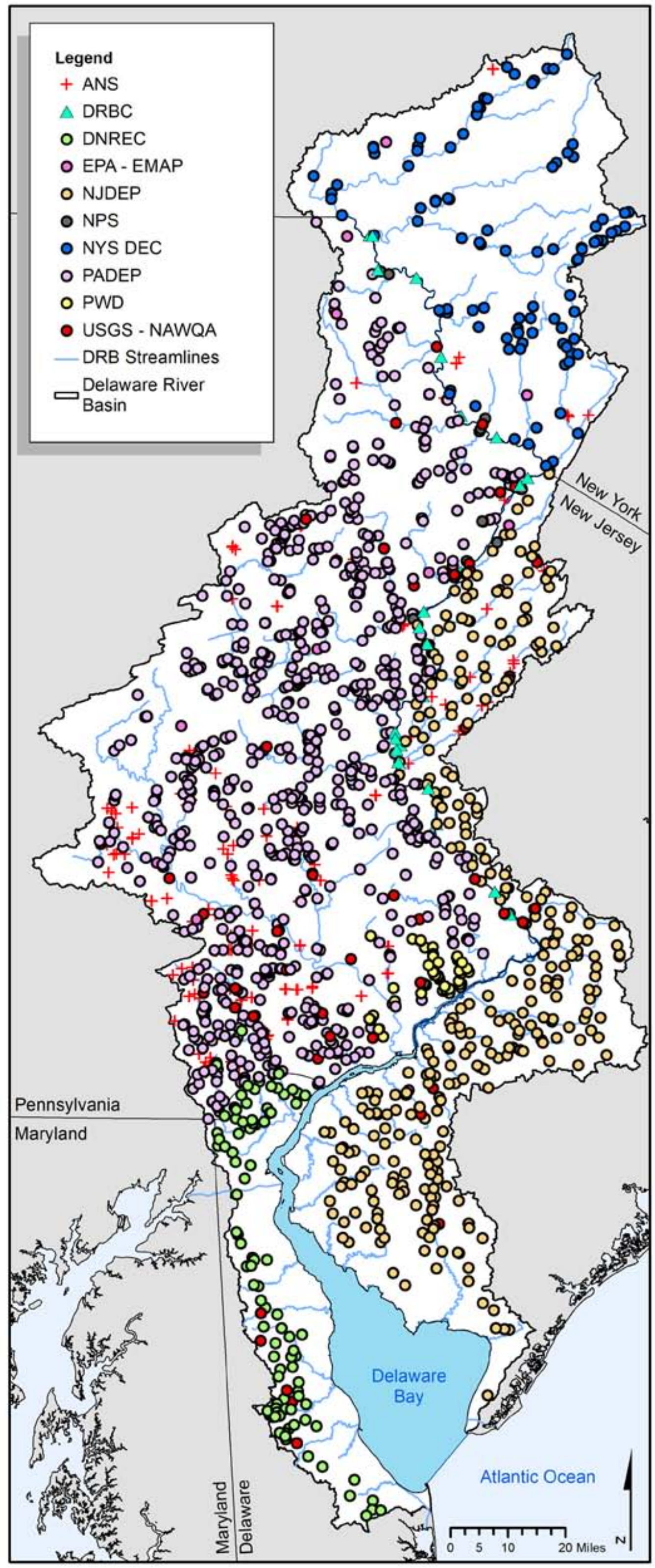


Figure 4-12: Aquatic invertebrate sample locations from ten major agencies within the Delaware River Basin (compiled by Cuffney & Kennen, 2018) and additional sample locations from the Academy of Natural Science (provided by Stefanie Kroll, ANS).

Figure 4-13: (Top) An example of using the "kick-net" technique to entrain macroinvertebrates in streamflow and collect/analyze those captured in the net. *Photo credit: R. Limbeck, DRBC.* **(Bottom Left) Mayfly nymphs live in the water for approximately 3-6 months. Nymphs are one of the most important species to the macroinvertebrate bottom-dwelling community and are commonly used indices of aquatic ecosystem health. Their presence is a strong indicator of clean water quality.** *Photo credit: G. Smith, DRBC.* **(Bottom Right) Adult Mayflies only live for approximately 1-3 days, and are highly sensitive to chemicals and pollutants found within freshwater environments. Their presence is often a great indicator of proper health and good water quality.** *Photo credit: Michael Thompson, DRBC.*

TRENDS

Although highly important, the quantitative monitoring of trends are challenging due to short or inconsistent datasets. Sampling frequencies may vary based on the size of the watershed, and ecoregional differences may warrant the application of one index inappropriate (e.g. New Jersey currently uses three different macroinvertebrate indexes for the Pinelands, Coastal Plains, and High Gradient zones). Scientific studies have suggested that general watershed characteristics correlate with macroinvertebrate conditions negatively (e.g. increased urban development, population and impervious surfaces) and positively (e.g. watershed with greater areas of forest and wetland, cobble substrates and consistent baseflows).

The DRBC performs biomonitoring at twenty-five fixed stations along the mainstem Delaware River. The samples are collected via a standardized kick-net method, and an IBI is calculated on a scale ranging from 0-100 based on the number macroinvertebrates and specific species collected. The DRBC has established a threshold such that when a sample location scores an IBI≥75.6, it suggests that "biological integrity" has been attained at that location. Sample locations were grouped by Water Quality (WQ) Zone, and the percentage of locations within each WQ-Zone scoring at or above the threshold is summarized in Figure 4-14. Historically, all sample locations within WQ-Zone 1A have returned values above the threshold. Typically, the percentage of sites meeting or exceeding the threshold decreases when moving downstream. There has not been significant variation between different sampling years.

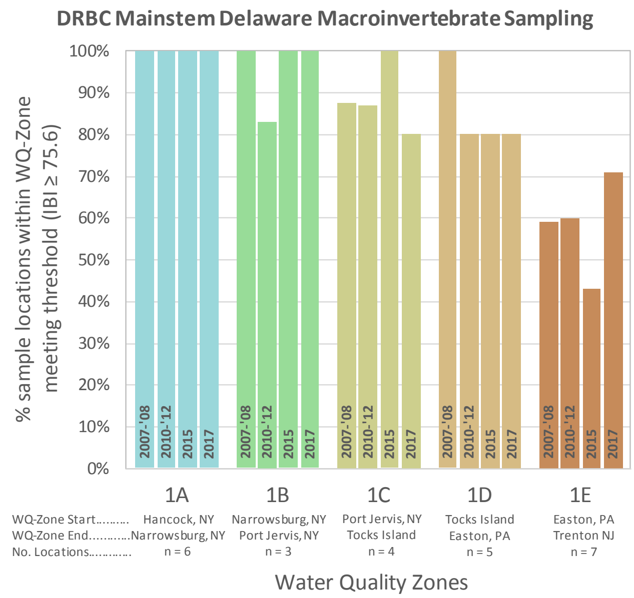


Figure 4-14. Biomonitoring data collected by the DRBC along the mainstem of the Delaware River, aggregated into WQ-Zones and presented by year. The data represents the percent of sample locations within a WQ-Zone which met or exceeded the DRBC IBI threshold. Meeting or exceeding the threshold indicates a location is attaining "biological integrity."

ACTIONS/NEEDS

- Continued use of bioassessment of macroinvertebrates for protecting water quality
- Encourage refinement of growing datasets as organizations gain experience with the interpretation of data.
- Foster development of methods for more meaningful interstate comparisons.
- Consistent monitoring stations from year to year or on a designated sampling frequency.

SUMMARY

Benthic macroinvertebrates are a diverse and important resource within the ecosystem. While they are well known to those involved with water quality and watershed health, their importance is often unrecognized or they are not considered for targeted management. It is expected that macroinvertebrates thrive best when preventing water pollution by protecting or restoring natural habitat conditions in waterways.

INVASIVE SPECIES

DESCRIPTION

Invasive species are animals, plants or other organisms introduced (intentionally or accidently) into habitats outside their natural environment. Their introduction into new habitats is currently one of the greatest impacts to biodiversity and species extirpation. This is often due to ecosystems weakened by pollution, climate change and habitat fragmentation. Invasive species often have the advantage of outcompeting or predating on native species that have naturally evolved to fill an environmental space such as sunlight, water and minerals. Their occupancy generally results in detrimental ecological, socioeconomical and even in more severe situations, human health impacts.

Presently, horticulture is one of the most common reasons for the introduction of a new species. Other species are generally introduced through means of farming, hunting, fishing or even as new exotic pets. Transportation of invasive species is not always intentional, and some species have been introduced merely by accident such as boaters inadvertently transporting them through bait buckets, live wells or in ballast water. In addition, climate change will enable some invasive species to continue to expand their non-native range as a result of increased average temperatures and changes to precipitation patterns. Taking advantage of drought-weakened plants, insect infestations will likely be more severe. Several plants species will increase their ability of secreting harmful chemicals into soils limiting growth of other plant species. Warmer oceans, rivers and lakes will reduce cold-water fisheries and increase the range of more tolerant species, such as carp and catfish, or non-native species may begin hybridizing with native species.

Fair

PRESENT STATUS

The Delaware River Basin offers a diverse number of habitats for invasive species to occupy. Table 4-2 shows only some of the many invasive species of concern currently found, and which may become introduced to the Basin in the coming years. Presently, many stewardship, restoration and management plans have been initiated throughout each state to: increase

Northern Snakehead found at the Fairmount Dam Fishway along the Schuylkill River in Philadelphia. *Photo Credit: J. Perillo, Philadelphia Water Department.*

Table 4-2: Commonly found invasive species and species of concern throughout the Delaware River Basin.

INVASIVE SPECIES OF CONCERN	
COMMON NAME	**SCIENTIFIC NAME**
AQUATIC VEGETATION	
Creeping Primrose	*Ludwigia peploides*
Brazilian Waterweed	*Egeria densa*
Didymo (Rock Snot)	*Didymosphenia geminata*
Eurasian Watermilfoil	*Myriophyllum spicatum*
Hydrilla	*Hydrilla verticillata*
Parrot-Feather	*Myriophyllum aquaticum*
Water Chestnut	*Trapa natans*
Water Hyacinth	*Eichhornia crassipes*
RIPARIAN AND UPLAND VEGETATION	
Autumn Olive	*Elaeagnus umbellata*
Common Reed	*Phragmites australis*
Garlic Mustard	*Alliaria petiolata*
Honeysuckle Spp	*Lonicera spp*
Japanese Barberry	*Berberis thunbergii*
Japanese Stiltgrass	*Mycrostegium vimineum*
Knotweed	*Polygonum spp*
Multiflora Rose	*Rosa multiflora*
Norway Maple	*Acer platanoides*
Oriental Bittersweet	*Celastrus orbiculatus*
Poison Hemlock	*Conium maculatum*
Purple Loosestrife	*Lythrum salicaria*
Tree of Heaven	*Ailanthus altissima*
Wineberry	*Robus phoenicolasius*
Yellow Flag Iris	*Iris pseudacorus*
INVERTEBRATES	
Asian Clam	*Corbicula fluminea*
Asian Longhorn Beetle	*Anoplophora glabripennis*
Asian Shore Crab	*Hemigrapsus sanguineus*
Asian Tiger Mosquito	*Aedes albopictus*
Chinese Mitten Crab	*Eriocheir sinensis*
European Periwinkle	*Littorina Littorea*
Green Crab	*Carcinus maenas*
Gypsy Moth	*Lymantria dispar dispar*
Hemlock Woolly Adelgid	*Adelges tsugae*
New Zealand Mud Snail	*Potamopyrgus antipodarum*
Red Swamp Crayfish	*Procambarus clarkii*
Rusty Crayfish	*Orconectes rusticus*
Spotted Laternfly	*Lycorma delicatula*
Virile Crayfish	*Orconectes virilis*
Zebra and Quagga Mussels	*Dreissena spp.*
FISH	
Asian Swamp Eel*	*Monopterus albus*
Common Carp	*Cyprinus carpio*
Bighead and Silver Carp*	*Hypophthalmichthys spp.*
Blue Catfish	*Ictalurus furcatus*
Flathead Catfish	*Pylodictis olivaris*
Grass Carp (Triploid)	*Ctenopharyngodon idella*
Northern Snakehead	*Channa argus*
Oriental Weatherfish	*Misgurnus anguillicaudatus*
Round Goby*	*Neogobius melanostomus*
REPTILES	
Red-Eared Slider	*Trachemys scripta elegans*
Yellow-Bellied Slider	*Trachemys scripta scripta*
TERRESTRIAL ANIMALS	
European Starling	*Sturnus vulgaris*
Feral Swine	*Sus scrofa*
Mute Swan	*Cygnus olor*
Nutria	*Myocastor coypus*

*Not yet reported in the Delaware River

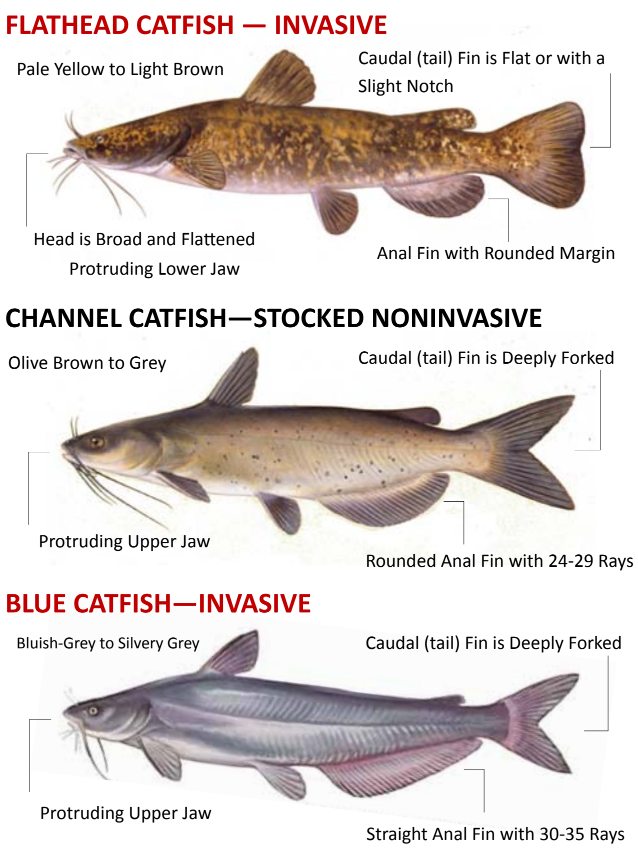
New Zealand mud snails. These species have recently been discovered in the Musconetcong River, NJ in 2018. *Photo Credit: USFWS.*

awareness of the risks posed by invasive species; identify new invasive species soon after their arrival; control established invasive species; and eliminate invasive species from key areas to prevent their spread.

TRENDS

It is likely that as climate change continues, greater numbers of new species will be introduced. However, government and non-profit organizations have begun working together to drive management and action plans. Presently, all Delaware River Basin states have their own invasive species councils, cooperate in rapid response initiatives, and utilize volunteers and the public to help identify and stop the spread of these species.

Fish identification of invasive and stocked noninvasive catfish species presently found in the Delaware River. *Photo Credit: USFWS and Iowa DNR.*



ACTIONS/NEEDS

- Implement management and eradication of exotic invasive plants and replacing them with species native to Delaware, New Jersey, Pennsylvania and New York.
- Increase the density and diversity of native plants in riparian zones, forests and other areas.
- Construct new and restored/expanded existing wetlands.
- Inform citizens of invasive species found within the Delaware River Basin and how to properly handle the spread of such species after recreation. If individuals find anything they might think is an invasive species throughout the Delaware River Basin they should contact the following State Agencies or submit pictures with latitudinal and longitudinal coordinates.

Flathead Catfish found at the Fairmount Dam Fishway along the Schuylkill River in Philadelphia. *Photo Credit: J. Perillo, Philadelphia Water Department.*

State and Government Invasive Species Contacts and Information

Delaware: Invasive Species Council
http://delawareinvasives.net

New York: Invasive Species Information
http://nyis.info/

New Jersey: Forest Service & Division of Fish & Wildlife
https://www.state.nj.us/dep/parksandforests/forest/invasive_species.html
https://www.state.nj.us/dep/fgw/aquatic_invasives.htm

Pennsylvania: Department of Agriculture & Fish & Boat Commission
https://www.agriculture.pa.gov/Plants_Land_Water/PlantIndustry/NIPPP/Pages/default.aspx
https://www.fishandboat.com/Resource/AquaticInvasiveSpecies/Pages/default.aspx

United States: Department of Agriculture & Geological Survey
https://www.invasivespeciesinfo.gov/resources-0
https://nas.er.usgs.gov/

OSPREY

Adult Osprey. *Photo credit: Barry Blust.*

DESCRIPTION

Osprey, *Pandion haliaetus*, are one of the largest birds of prey in North America with an average wingspan of five to six feet. They arrive in the Delaware Bay in early March, and by mid-March, typically begin nesting near large bodies of water as they almost exclusively eat fish. They are known to use a variety of nesting sites, including live or dead trees, man-made platforms, utility poles or even channel markers. Osprey are good indicators of the health in an aquatic ecosystem because they are widely-distributed and at the top of the food web, exposing them to high concentrations of contaminants. Monitoring programs in Delaware and New Jersey include osprey nest checks between the end of April and mid-July. These programs observe the number of eggs and fledglings in the nests.

PRESENT STATUS

The results from New Jersey and Delaware state monitoring programs indicate that ospreys are thriving in the Delaware Bay. The most recent nesting survey data from New Jersey and Delaware are indicated in Figure 4-15 and Table 4-3, respectively. The data shows that osprey may currently be close to historic populations, before the widespread use of Dichlorodiphenyltrichloroethane (DDT) to control mosquitos during the 1950s to 1970s. Although the rates of osprey nesting and productivity have reached sustainable levels in the Delaware Bay, recovery has been slower along the Delaware River (Rattner et al, 2018).

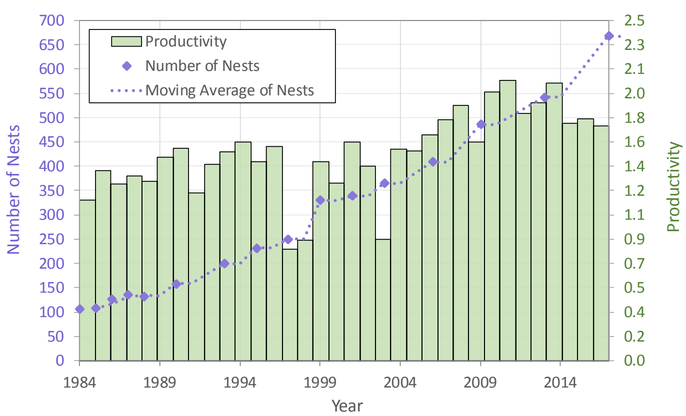


Figure 4-15: Osprey nesting population (points) and productivity (bar) in terms of young fledged per nest 1984-2017 in New Jersey. *Data obtained from the 2017 Osprey Project Report prepared by the Conserve Wildlife Foundation of NJ and the NJDFW (Wurst and Clark, 2018).*

TRENDS

The osprey populations decreased during the 1950s to 1970s, largely attributed to bioaccumulation of chemicals such as DDE (a degraded form of DDT), which results in eggshell thinning and depressed reproductive success. Following the ban of DDT and other organochloride pesticides in the late 1960s, many populations of ospreys and other large fish-eating bird populations started to rebound (Bierregaard et al., 2016). A recent study by the USGS in 2015, focusing on osprey nesting in the Delaware River Basin, found no evidence of eggshell thinning and indicated that contamination levels are not impairing egg hatching (Rattner et al., 2018). Aside from contamination, osprey are generally adaptable to living near human activity, but are still at the risk of activities such as: being electrocuted while landing on power lines; vehicular or aircraft collision; and entanglement in fishing line or twine (Bierregaard et al., 2016). Overall, osprey populations within the Delaware Bay have continued to increase under current management practices, offering a positive trajectory for future osprey success.

Table 4-3: Osprey nesting success in Delaware.

	2003	2007	2014
Active Nests in DE	119	173	197
Successful Nests in DE	77	136	103
Nestlings	135	293	424

Active Nest = eggs or chicks seen in nest during at least one survey
Successful Nest= at least one chick reach banding age
Data obtained from DE DFW report on the Citizen Osprey Monitoring Program (DE DFW, 2017)

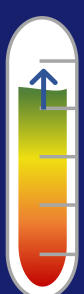
ACTIONS/NEEDS

The state programs rely on volunteers to monitor nests and productivity. Since osprey often use a variety of artificial or man-made materials for nest sites, volunteers can help to establish nesting structures.

- **NJ: Conserve Wildlife NJ** (http://www.conservewildlifenj.org/)
- **DE: Delaware Division of Fish and Wildlife** (https://dnrec.alpha.delaware.gov/fish-wildlife/)

SUMMARY

Osprey populations within the Delaware Bay appear to be doing well and the population status has a good outlook for the future. The success of osprey conservation is reflective of both sound environmental management practices, and volunteer support.



Very Good

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Neshaminy Creek, Tyler state Park.
Photo credit: Paul MIchael Bergeron.

SUMMARY OF INDICATORS

Indicator	2019 Status	Present Condition/Trend	Recommendations
○ = Poor ◔ = Fair ◑ = Good ◕ = Very Good ● = Excellent ◍ = Not Rated			
↑ Improving ↓ Worsening ↔ Stable/No Trend			
Watersheds/Landscapes			
Population	Not Rated	*No Rating* The population is expected to increase in the Basin from 2010 to 2030 by 700,000 people.	• Plan for land development and its impacts on natural resources • Balance increased need for development with stresses on water resources
Land Cover	Not Rated	*No Rating* Urbanization has resulted in a loss of forested and agricultural lands, especially in the Lower Region.	• Manage effects of water resources associated with development • Partake in conservation efforts • Continue tracking land cover changes
Impervious Cover	Good ↓	*Good* The lower region of the Basin had increased impervious surfaces due to urbanization.	• Apply impervious cover percentages to land cover categories • Reduce impact from impervious surfaces through stormwater management strategies
Water Quantity			
Water Withdrawals	Good ↔	*Good* The public water sector has maintained a stable rate of withdrawals despite increasing population in the DRB.	• Continue reporting water withdrawals • Continue implementing water auditing program • Study potential growth in water demand for the thermoelectric sector
Consumptive Use	Good ↔	*Good* Consumptive use for public water supply stayed flat; for thermoelectric power generation has increased; and industrial has decreased.	• Update comsumptive use factors • Extend water loss accountability beyond water audit to develop normalized indicators • Create regulations to reduce industry standard losses
Groundwater Availability	Very Good ↑	*Very Good* Groundwater conditions are exptected to continue to improve over time.	• Continue improving water use reporting
Flow	Good ↔	*Good* The variability in precipitation and temperature makes it difficult to discern trends in flow.	• Continue developing models and analyses to understand how climate change affects hydrology • Evaluate flow and drought management plans
Climate Change	Not Rated ↓	*No Rating* There is an increasing trend in average temperature and annual rainfall.	• Continue developing models and analyses to understand risks of climate change during dry and wet periods • Evaluate future water demands • Develop plans to address risks
Water Quality			
Dissolved Oxygen	Good ↑	*Good* From the mid-1990s onward, criteria has mostly been met, although DO concentrations exhibit high variability from year to year.	• Examine whether DO criteria needs revision • Measure sources of nutrient and oxygen-depleting materials • Build water quality model
Nutrients	Very Good ↑	*Very Good* Total nitrogen and phosphorus concentrations were highest towards the Upper Delaware River.	• Continue developing and monitoring nutrient criteria • Develop eutrophication model
pH	Not Rated ↔	*No Rating* All pH values from each monitoring station are within DRBC's criteria.	• Develop a better understanding of the Estuary carbon cycle and its impact on pH
Salinity	Good ↓	*Good* It is estimated that the range of the salt front will be pushed upstream along with its maximum extent of upstream intrusions.	• Create better models to establish relationship between sea level rise and salinity • Evaluate different adaptation options • Research increasing trends in chlorides
Temperature	Good ↔	*Good* Temperature at Trenton is expected to remain stable for the forseeable future.	• Continue developing temperature criteria in non-tidal portion of Delaware River • Create stronger linkages between meteorological drivers and resultant water temperatures
Contaminants	Fair ↑	*Fair* It is likely that levels will remain relatively the same at their current levels.	• Continue evaluating and monitoring effects of contaminants on water quality • Continue implementing PCB PMPs • Provide techical reviews and support to the community
Fish Contaminants	Good ↑	*Good* There is a trend of increasing concentration moving from non-tidal to tidal regions.	• Partake in pollution minimization efforts • Cooperate between state and federal agencies to reduce bioaccumulation contaminants and expand to address persistent toxic pollutants
Emerging Contaminants	Fair ↑	*Fair* PFOA and PFOS levels are below current EPA and basin state human health advisory levels in parts of the Delaware River.	• Continue monitoring PFAS in drinking water and the environment • Track and evaluate other emerging contaminants of concern
Whole Effluent Toxicity	Fair ↑	*Fair* Recent data do not predict exceedances of stream quality objectives for chronic toxicity by individual discharges.	• Continue coordinating between the basin states, DRBC, and USEPA to generate consistent WET testing • Monitor both effluent from discharges as well as ambient environment

Indicator	2019 Status	Present Condition/Trend	Recommendations
○ = Poor ◔ = Fair ◑ = Good ◕ = Very Good ● = Excellent ◍ = Not Rated ↑ Improving ↓ Worsening ↔ Stable/No Trend			
Living Resources			
Atlantic Sturgeon	○ ↑	*Poor* Commercial demand for their meat and degraded water quality contributed to their declining population.	• Continue monitoring abundance • Continue telemetry studies to better understand behavior • Expand study of ship strikes • Collaborate with shipping industry
White Perch	◕ ↔	*Very Good* The species' tolerance and wide range of habitat will help it continue to support healthy fisheries.	• Protect upper reaches of tidal tributary areas under developmental pressure • Establish an 8-inch minimum size for white perch to ensure they have a chance to spawn
Striped Bass	◕ ↓	*Very Good* The overall status of the Delaware River spawning stock is positive.	• Continue monitoring long-term trends in biomass and recruitment
Weakfish	○ ↑	*Poor* Coastwide, weakfish population is considered depleted.	• Investigate factors contributing to recent weakfish decline • Recreational and commercial fishing sectors should practice catch and release • Continue artifical reef use and creation
American Eel	◑ ↓	*Good* Coast-wide populations have declined in recent years, but there is no apparent bases for future predictions.	• Improve monitoring of species abundance in non-tidal reaches • Continue monitoring in the Estuary • Improve fish passage at dams
American Shad	◑ ↑	*Good* 2017 and 2018 data show abundance well above the recent average.	• Continue restoring blocked habitat • Maintain and monitor habitat conditions in spawning reaches • Establish sustainable harvest limitations after restoration
Brook Trout	◔ ↑	*Fair* There have been widespread reductions in populations due to many factors. Efforts to reverse this trend have increased.	• Continue conservation/management efforts • Determine if special designation or current status reclassification is needed • Continue researching and monitoring population
Blue Crab	◑ ↑	*Good* They are at healthy levels of abundance and safe levels of fishing mortality.	• Continue long-term ad fishery-independent management surveys • Report fishery landings accurately • Preserve and restore habitat needed for critical life stages
Horseshoe Crab	◑ ↑	*Good* Popuation within the Deleware Bay Area is increasing over time, but not within the HCR.	• Continue collecting and monitoring data • Continue protection efforts • Enhance habitats and reduce harvesting
Eastern Oyster	◔ ↑	*Fair* Population has been steady between 2002-2016. Population may be limited by habitat availability.	• Continue annual oyster population and disease surveys • Improve shell planting • Continue monitoring/enhancing temperature and salinity
Freshwater Mussels	○ ↔	Poor As biodiversity is threatened, the population of freshwater mussels reduces.	• Improve coordinated monitoring/data sharing • Improve model of mussel conservation • Continue advacing survey technology for mapping mussel beds and habitats
Macroinvertebrates	◕ ↔	*Very Good* All sample locations are above the biological integrity threshold.	• Continue using bioassessment of macroinvertebrates • Encourage refinement of growing datasets • Consistently monitor from year to year
Invasive Species	◔ ↓	*Fair* As climate change continues, it is likely that more invasive species will be introduced.	• Replace invasive species with native species • Increase density/diversity of native plants • Inform citizens of invasive species and how to properly handle it
Osprey	◕ ↑	*Very Good* Populations are increasing and the rates of nesting have reached sustainable levels.	• Encourage volunteers to monitor nests and productivity

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